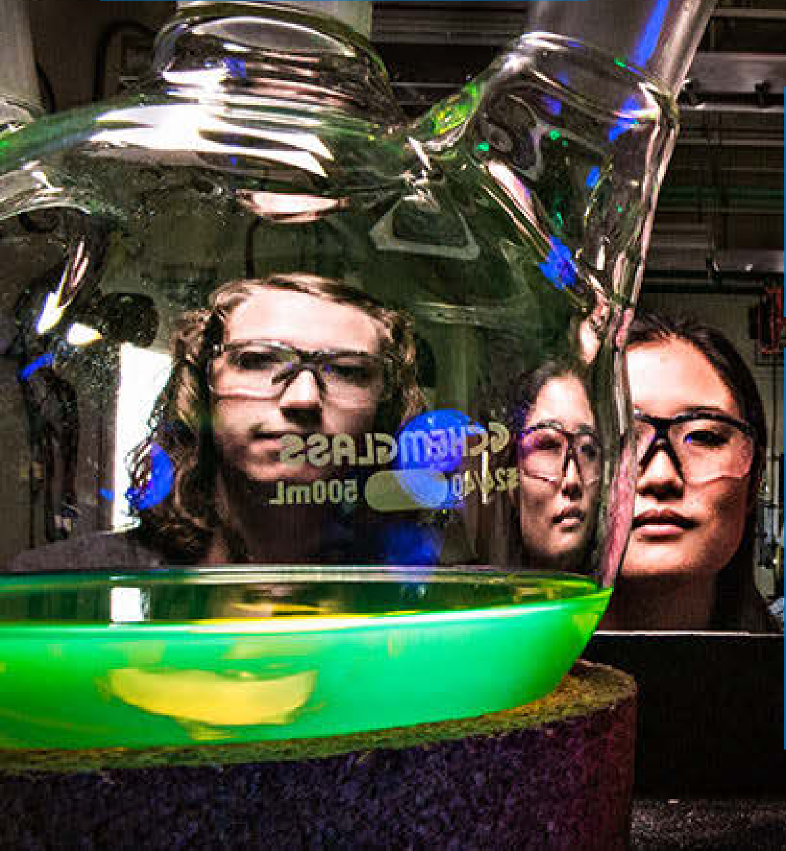

Adoption of Biofuels for Marine Shipping

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2020 AIChE Annual Meeting, Virtual

Session: Biofuels Production: Design, Simulation, and Economic Analysis

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Marine shipping

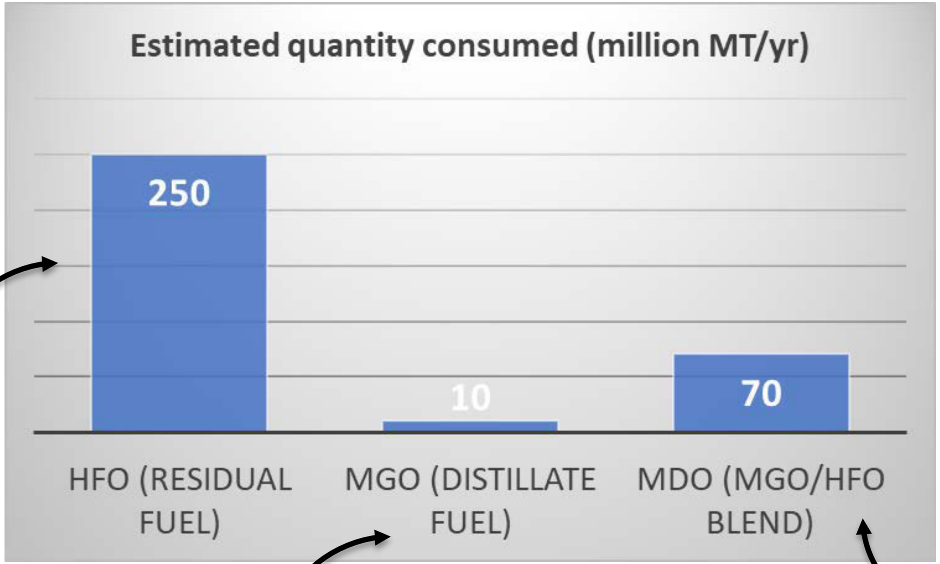
- One of the largest consumers of petroleum fuels, i.e., = one of the largest emitters of air pollutants

- Annual consumption: ~330 million metric tons (87 billion gal), 2x US cars + trucks

- > 90% world's shipped goods by marine vessels

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

Current marine fuels



- 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

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

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

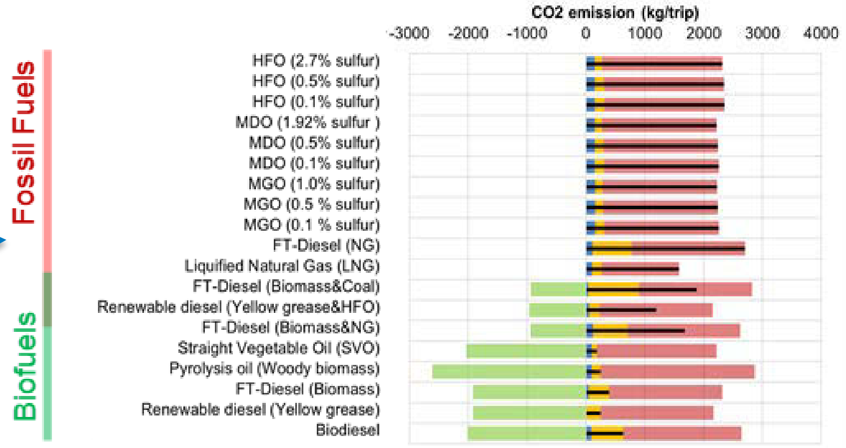
- Beyond 2025, IMO has established a framework for reducing CO_2 emissions per tonne-mile by 30%, and at least by 50% by 2050 compared with 2008 levels.

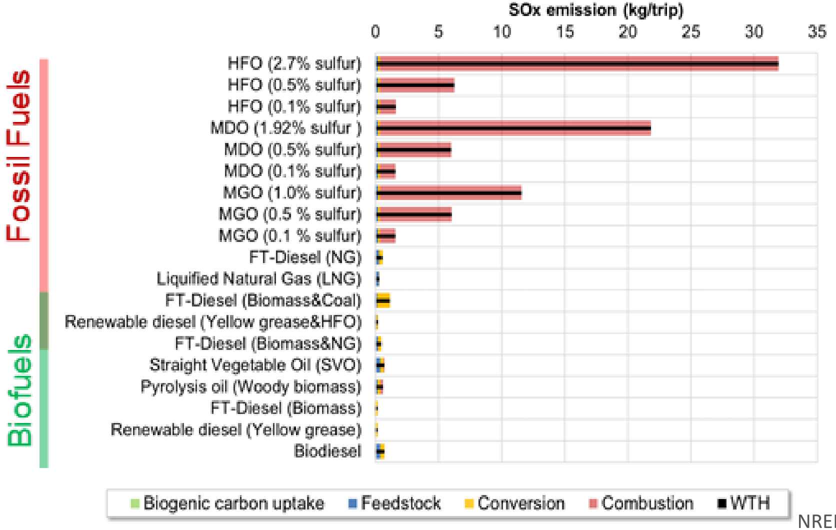
The reduced S content has required ship operators to shift their engines from lower cost bunker C heavy fuel oil to much costlier distillate fuels, such as diesel.

Adoption of Biofuels for Marine Shipping

Why biofuels?

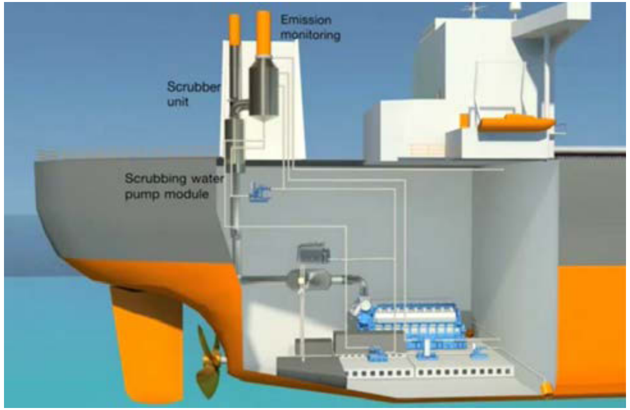
- ✓ Decarbonization
- ✓ Zero or low sulfur





Ref: Tan, et al., "Biofuels for Marine Applications: Techno-Economic Analysis and Life-Cycle Assessment," Environmental Science & Technology, submitted.

Options to comply with low-S regulations



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

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

1. Install **sulfur scrubber** on ships to reduce SOx emissions

2. Switch to **low-sulfur content fuels**
   - ***a) Low-S HFO***
     - ✓ Low-S price increase,
     - ✓ High-S price decrease due to lower demand --> favor the adoption of sulfur scrubbers
   - ***b) 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

Options to comply with low-S regulations

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

1. Install **sulfur scrubber** on ships to reduce SOx emissions

2. Switch to **low-sulfur content fuels**
   c) ***LNG – bridging fuel***
   - ✓ 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

   d) ***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://info.ornl.gov/sites/publications/Files/pub120597.pdf

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

Biofuels being tested for marine shipping

Alcohols
- Ethanol
- Isobutanol
- Methanol

Bio-oils / Biocrudes
- Fast Pyrolysis Oil
- Catalytic Fast Pyrolysis Oil
- Algae HTL Biocrude
- Wet Waste HTL Biocrude

Renewable LPG

Renewable Diesel
via Hydroprocessed esters and fatty acids (HEFA)

Fischer-Tropsch Diesel
- Biomass only (BTL)
- Coal-Biomass Co-feed (CBTL)
- NG-Biomass Co-feed (GBTL)

Objectives, Scope, Approach

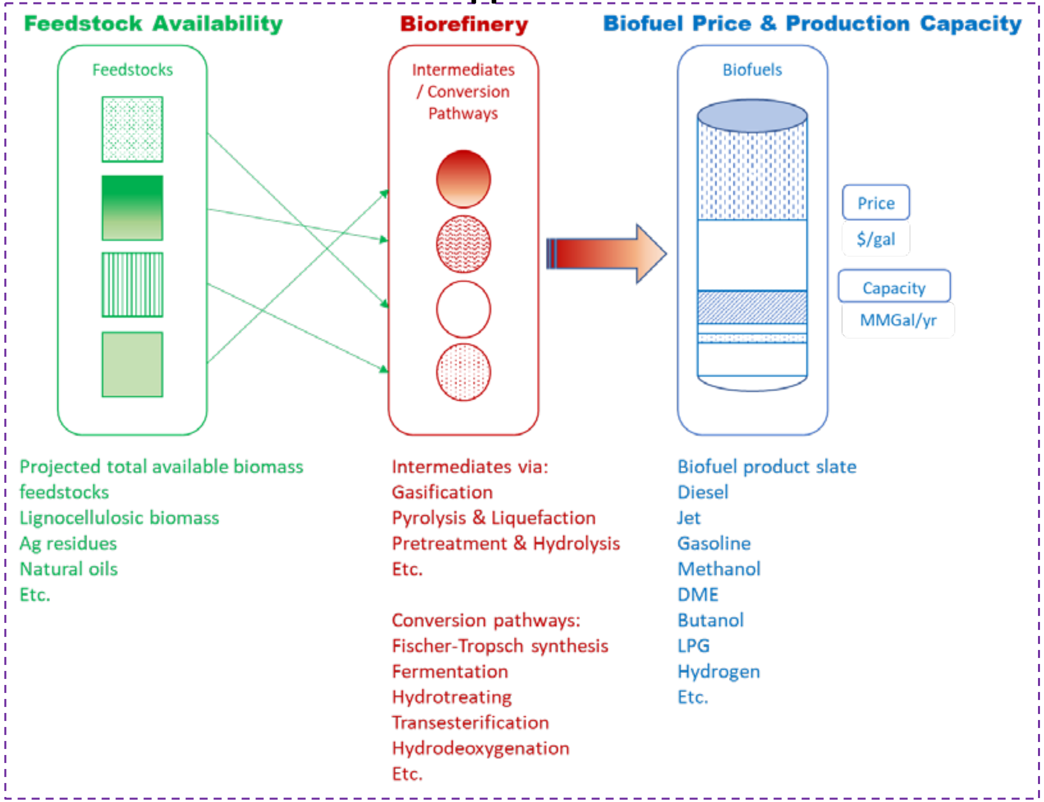
Objective

- ✓ Project the <u>potential</u> long-term price and annual production capacity of biofuel in the US

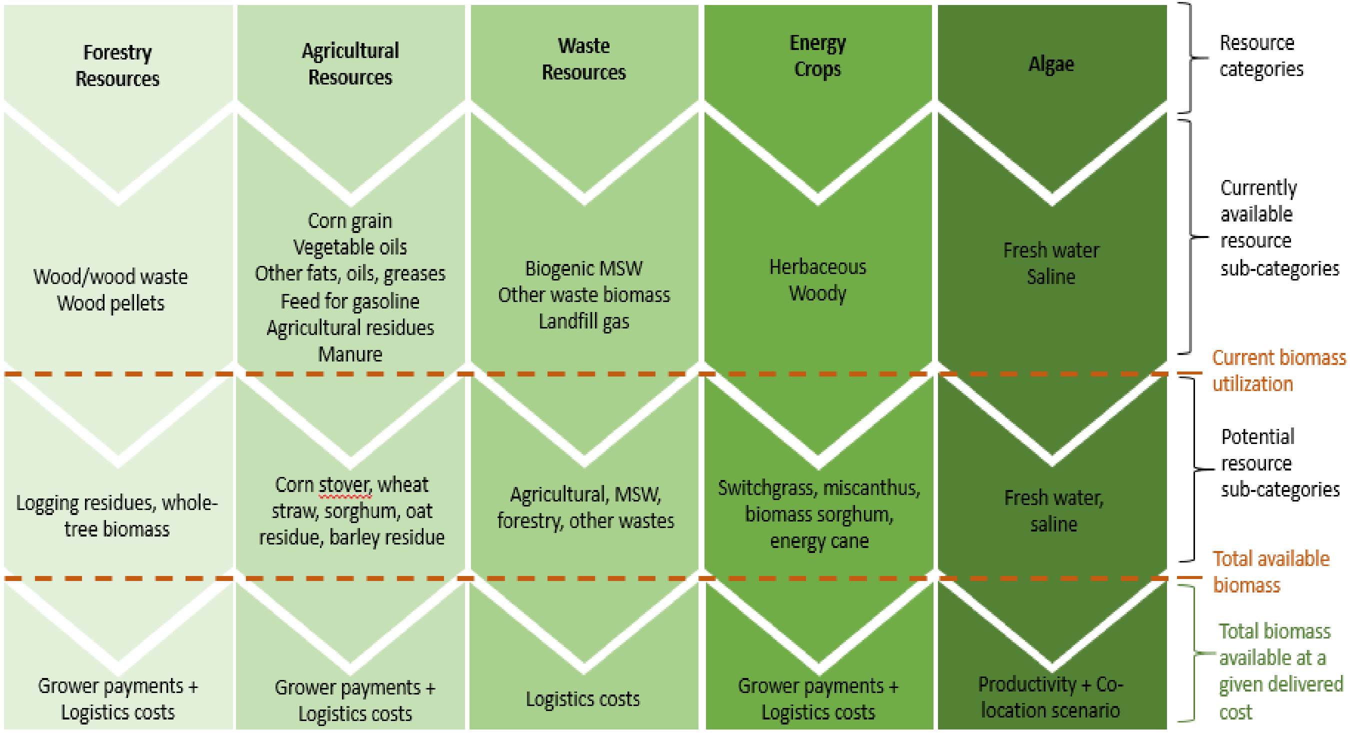
Scope

- ✓ US domestic resources
- ✓ Will not consider spatial distribution
- ✓ Long-term 2040
- ✓ Feedstock types and prices derived from BETO's 2016 Billion Ton study (BT16)
- ✓ Base case: assume all available feedstock go to marine biofuels; ignore the market force, i.e., feedstocks will not be used for other industries (e.g., power, biochemicals, and bioplastics)

Approach



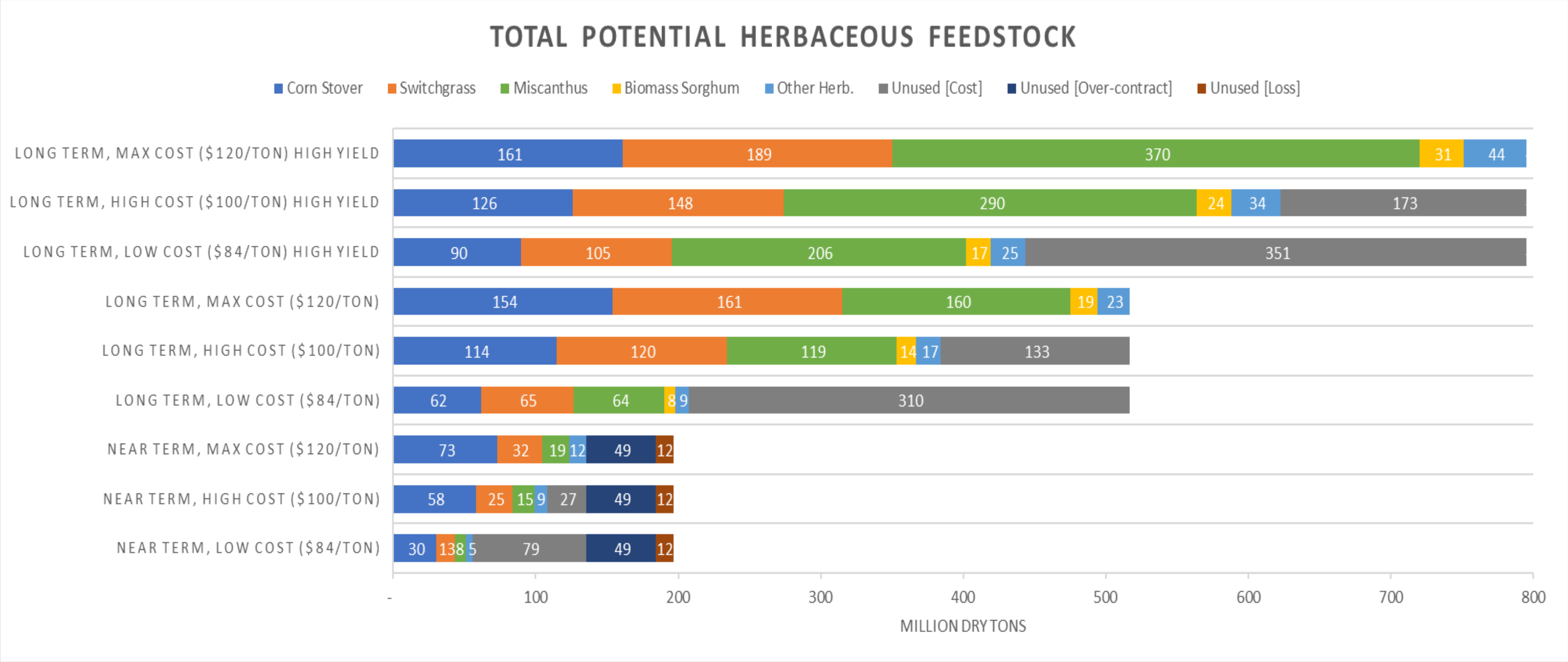
Feedstock Analysis Summary



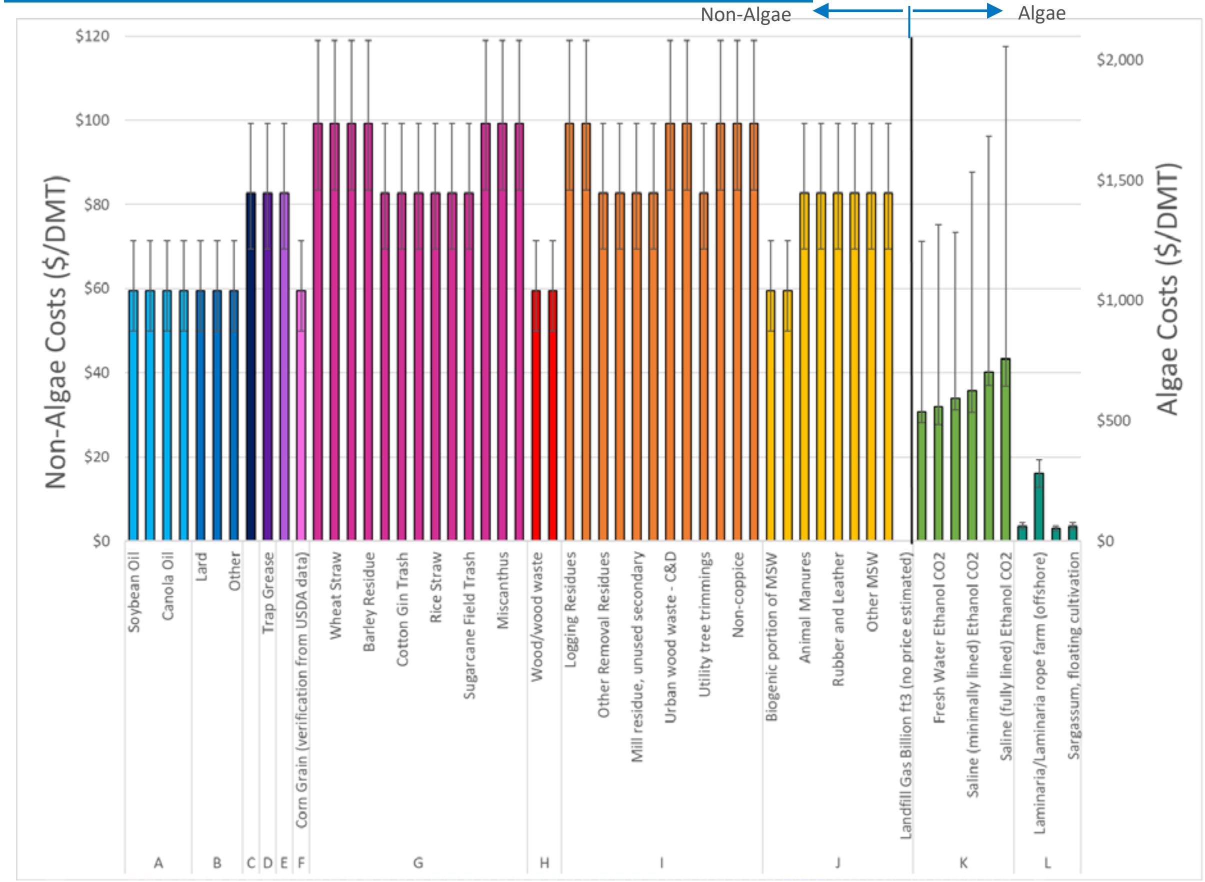
- A feedstock survey was performed to quantify the current and future biomass resource potential for (marine) biofuel utilization.
- The BETO's 2016 Billion-Ton Report (BT16) served as the key source of the data analyzed.
- Available feedstocks were identified by the five categories.

Potential Feedstock Availability

- The unused portions: unused due to cost limitations, unused due to over-contracting, and unused due to supply chain losses.

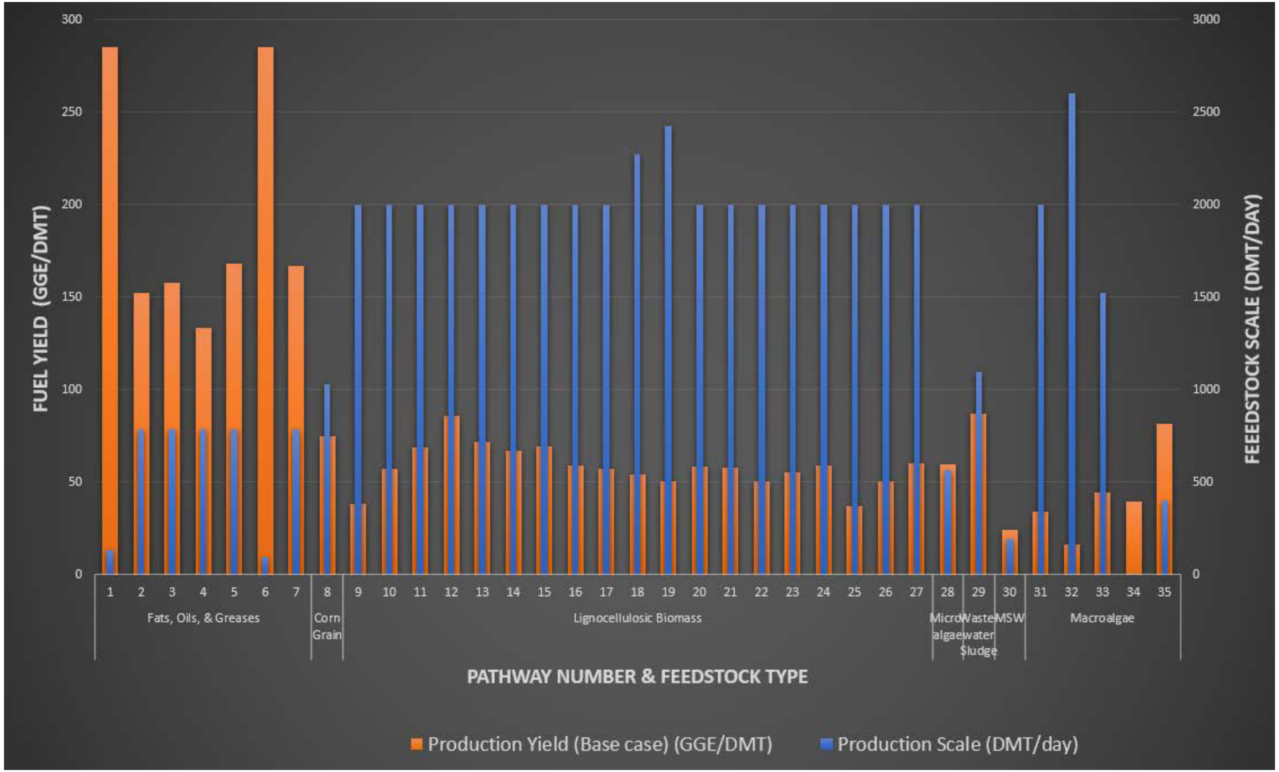


Feedstock costs (2040)

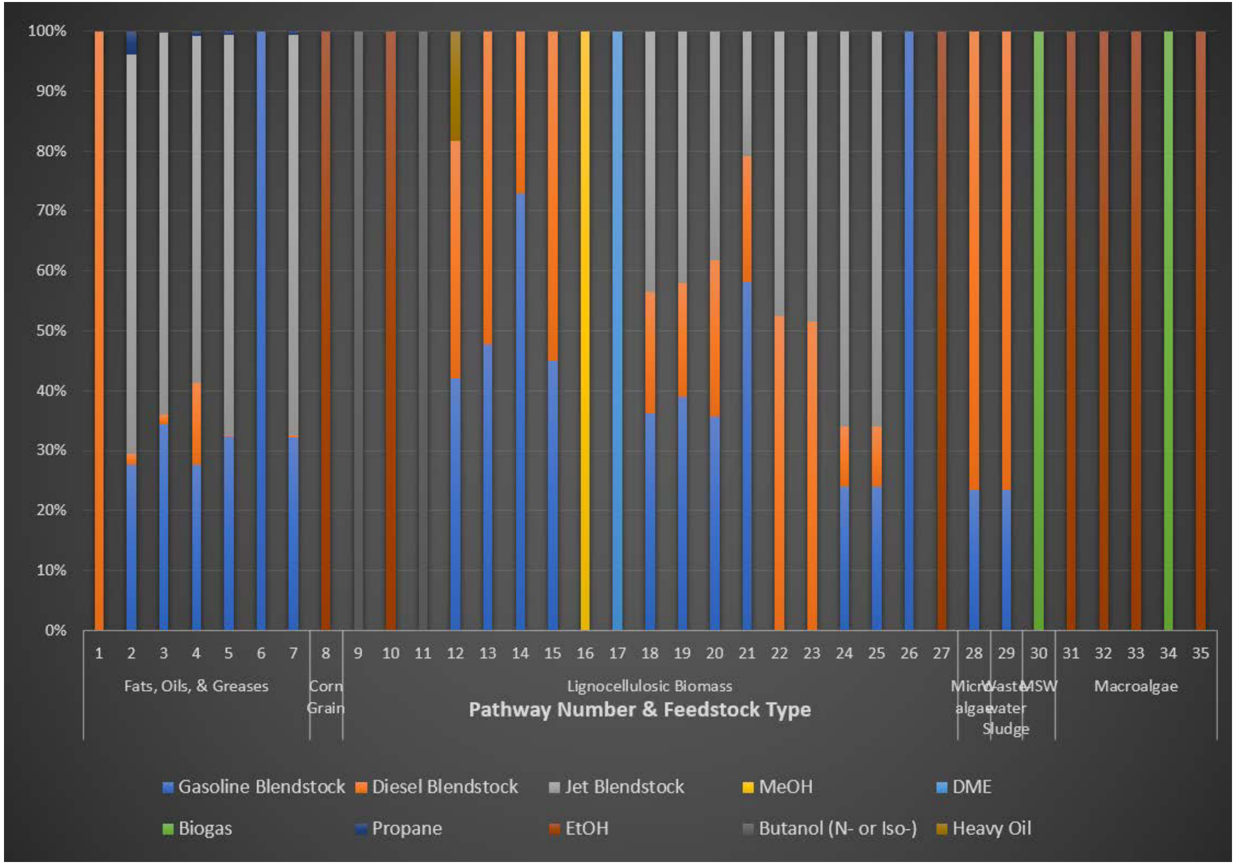


A - Vegetable Oils
B - Other Fats, Oils & Greases
C - Biosolids
D - Trap Grease
E - Food Processing Waste
F - Corn Grain
G - Agricultural Residues
H - Wood/Woodwaste
I - Wood Pellets
J - Municipal Solid Waste (MSW)
K - Microalgae
L - Macroalgae

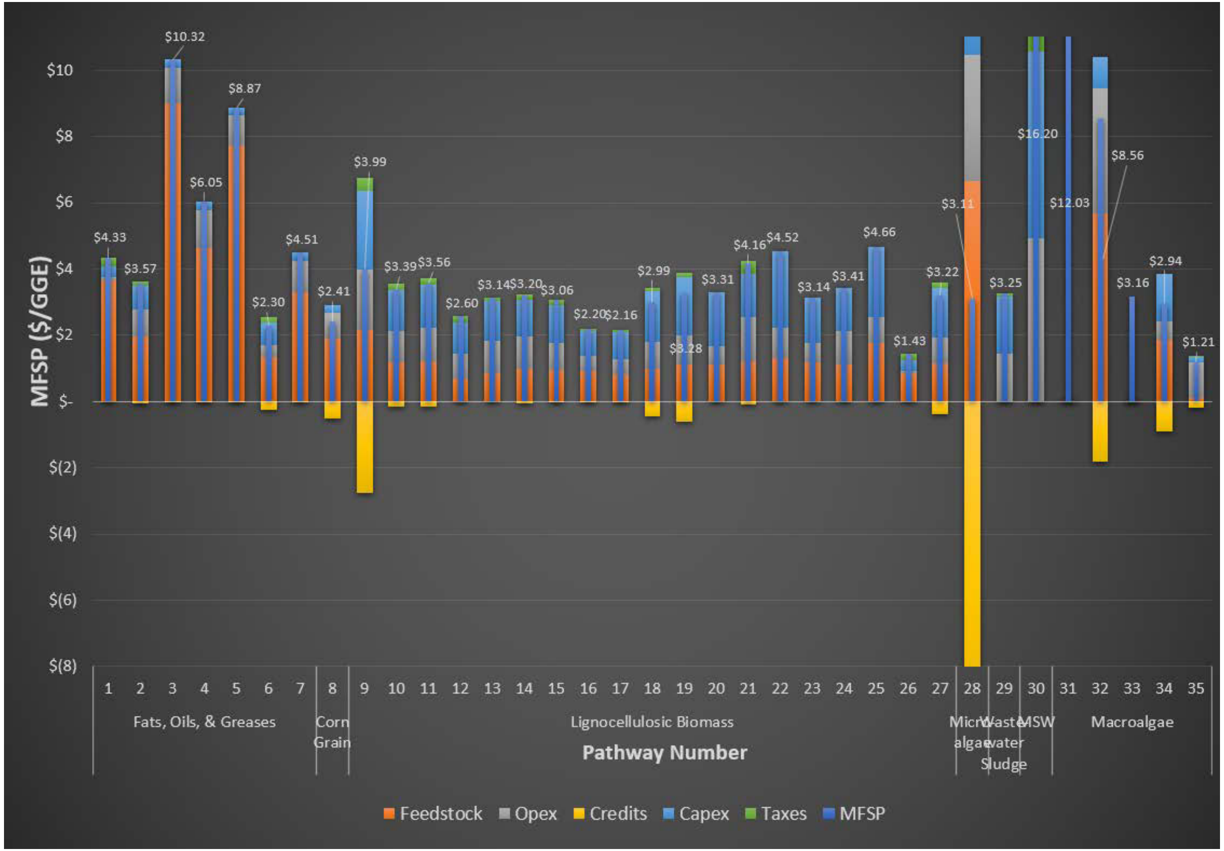
Selected biofuel production pathways



Fuel product distribution (wt%)

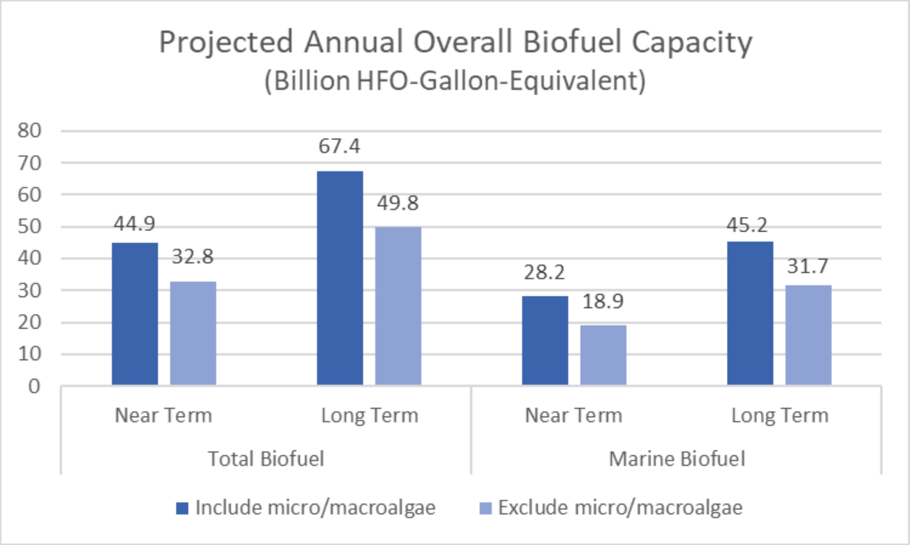


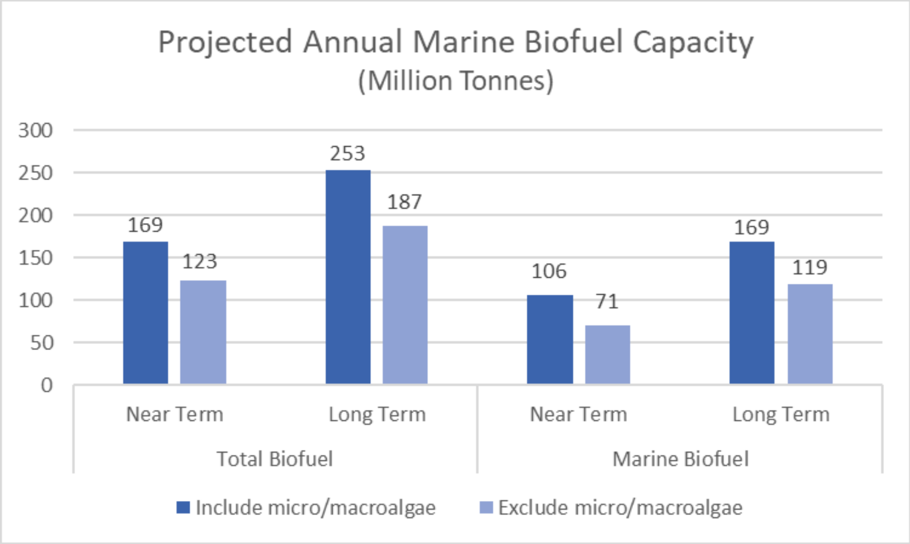
Minimum fuel selling prices



Projected Biofuel and Marine Biofuel Capacity

- Scenario 1 – Maximize the overall biofuel production capacity
- Scenario 2 – Maximize marine biofuel, i.e., jet/diesel range (C12+) blendstocks for MGO/MDO
- Based on projected median feedstock availability



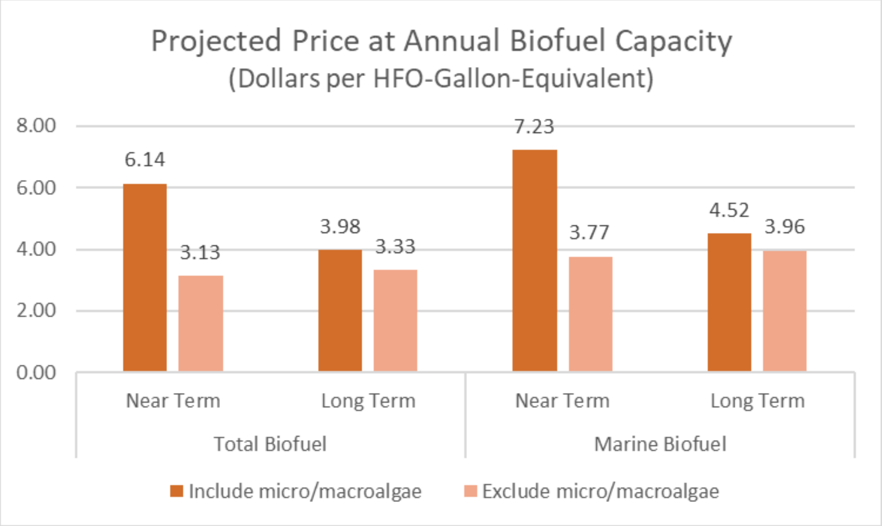


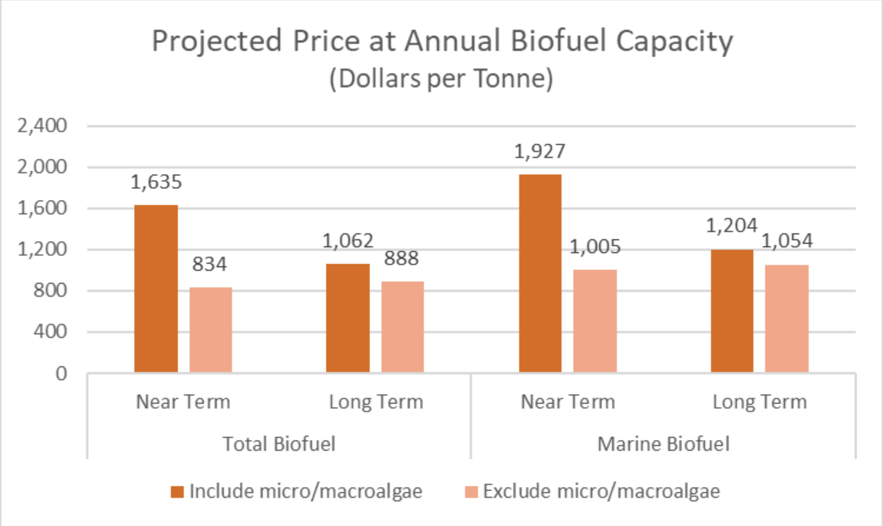
- 1 HFO-gallon-equivalent (HFOGE) = 140,353 Btu
- 1 metric ton = 267 HFOGE
- To put into perspective, annual global marine fuel consumption is estimated to be around 330 million metric tons (87 billion gallons).

		MM MT/yr	% of 330 MM MT/yr
Long-term	Total Biofuel	253	77%
	exlude algae	187	57%
	Marine Biofuel	169	51%
	exlude algae	119	36%

Projected Prices at Max Biofuel and Marine Biofuel Capacity

- Scenario 1 – Maximize the overall biofuel production capacity
- Scenario 2 – Maximize marine biofuel, i.e., jet/diesel range (C12+) blendstocks for MGO/MDO
- Based on projected feedstock median prices

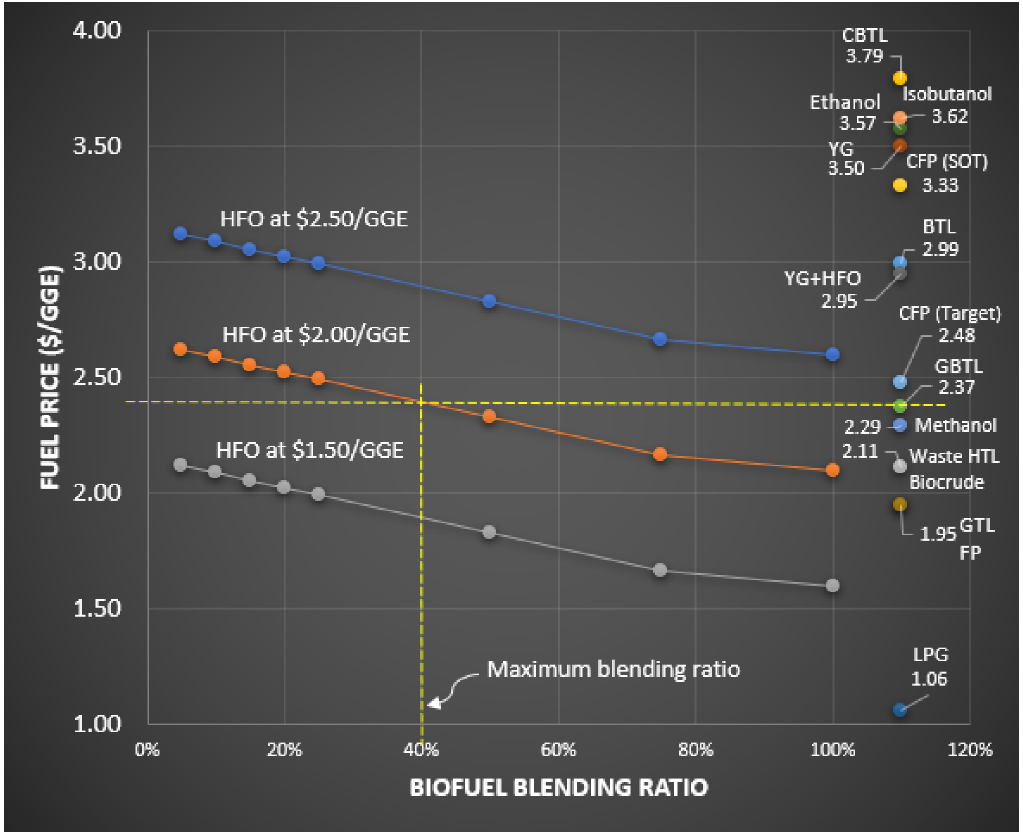




- 1 HFO-gallon-equivalent (HFOGE) = 140,353 Btu
- 1 metric ton = 267 HFOGE
- Pre-2020, 2019 average MGO $700/MT

Marine Biofuel Market Penetration Potential

1 HFOGE = 1.2 GGE
Biofuels potentially feasible for marine shipping even at price > fossil fuels



Max. biofuel price based on assumptions:

- Cost difference between 1% and 3.5% S fuel at $24.95/MT → $30/MT premium

Biofuel blending ratio at 5%

- 300 million MT/yr (global consumption)
- 15 million MT/yr or ~4.5 billion gal/yr

Summary

- Biofuels play an important role in accelerating the energy transition and enabling the marine shipping industry to achieve decarbonization and low-S targets.
- This study projected preliminary potential long-term marine biofuel production capacity and cost.
- The study's approach combined literature review (journal articles and grey literature), economic and linear program model development, and meta-analysis of the literature. The analysis adopted a bottom-up approach: feedstock availability → biorefinery (conversion technology) → biofuel production capacity and price.
- The basic assumptions of the study were predominantly based on 1) feedstock availability and prices reported in the 2016 Billion-Ton Report; and 2) existing biomass-to-fuel conversion technology in the public domain, including leveraging the portfolio of conversion pathways developed under the US Department of Energy's Bioenergy Technologies Office (BETO).
- Future study will address other challenges and opportunities for biofuel adoption for marine shipping, including infrastructure and fuel compatibility/blending.

Acknowledgements

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Thank You

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