DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Advancing the Development of Biofuels for the Marine Sector

April 3-7, 2023

Systems Development and Integration Session A

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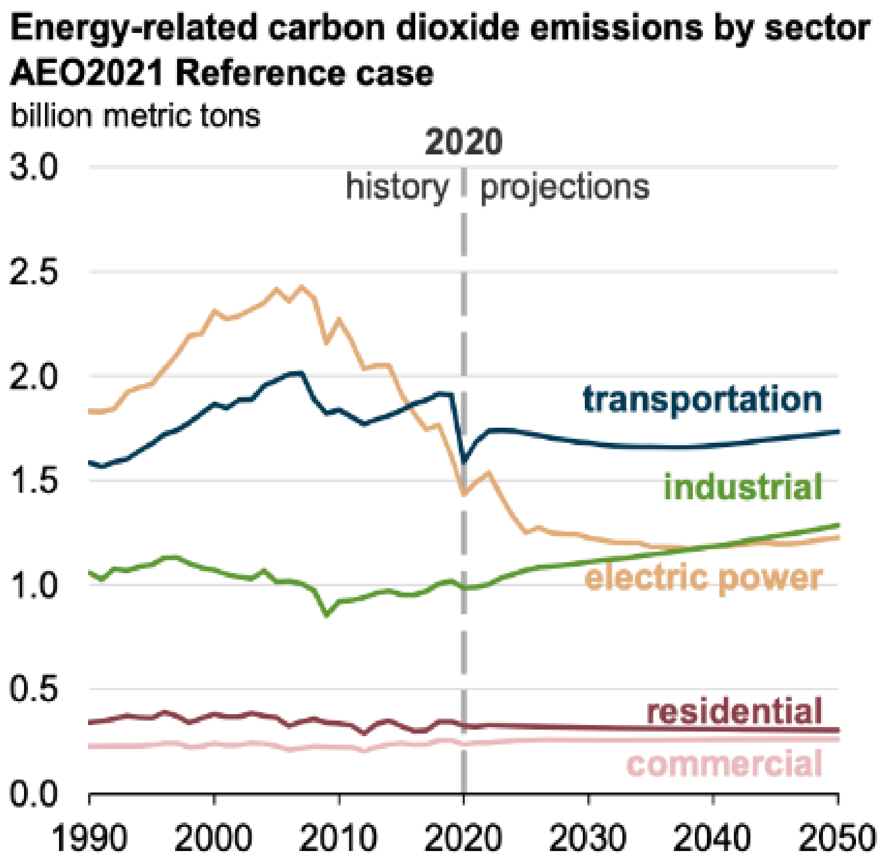
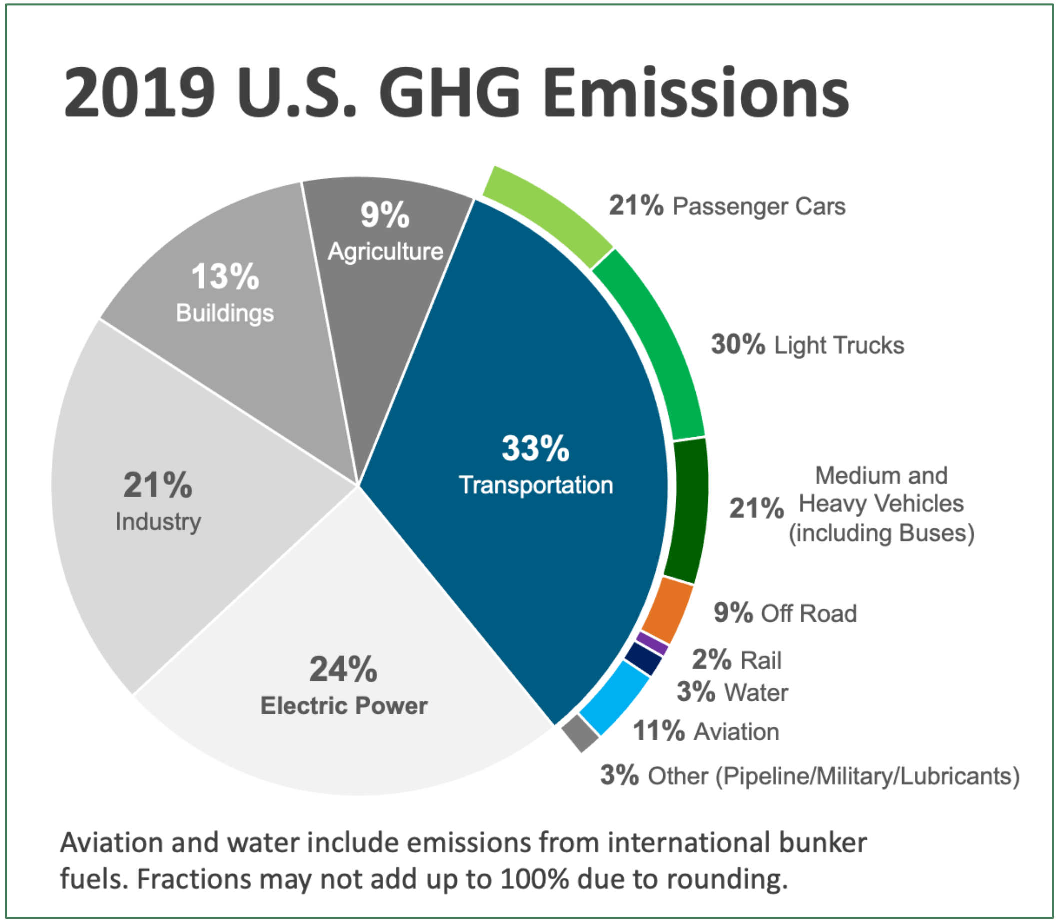
We are in the 2nd year of a three year effort to examine the feasibility of biomass-derived fuels for the marine sector

- Goal: to provide information to determine if biofuels have potential for the maritime sector. This information is to be used in:
  - ***Techno-economic analyses (TEA)***
  - ***Life-cycle analyses (LCA)***
  - ***Technical feasibility analyses***
- Budget is around $2M/year
- Emphasis on ocean-going vessels
- External advisory board was formed to provide necessary stakeholder input to national labs

Transportation sector is now the largest contributor of CO_2 emissions





Transportation, especially marine is considered the most difficult sector to decarbonize

Domestic shipping emissions are comparable to rail, but global CO_2 emissions are 2-3% of total inventory

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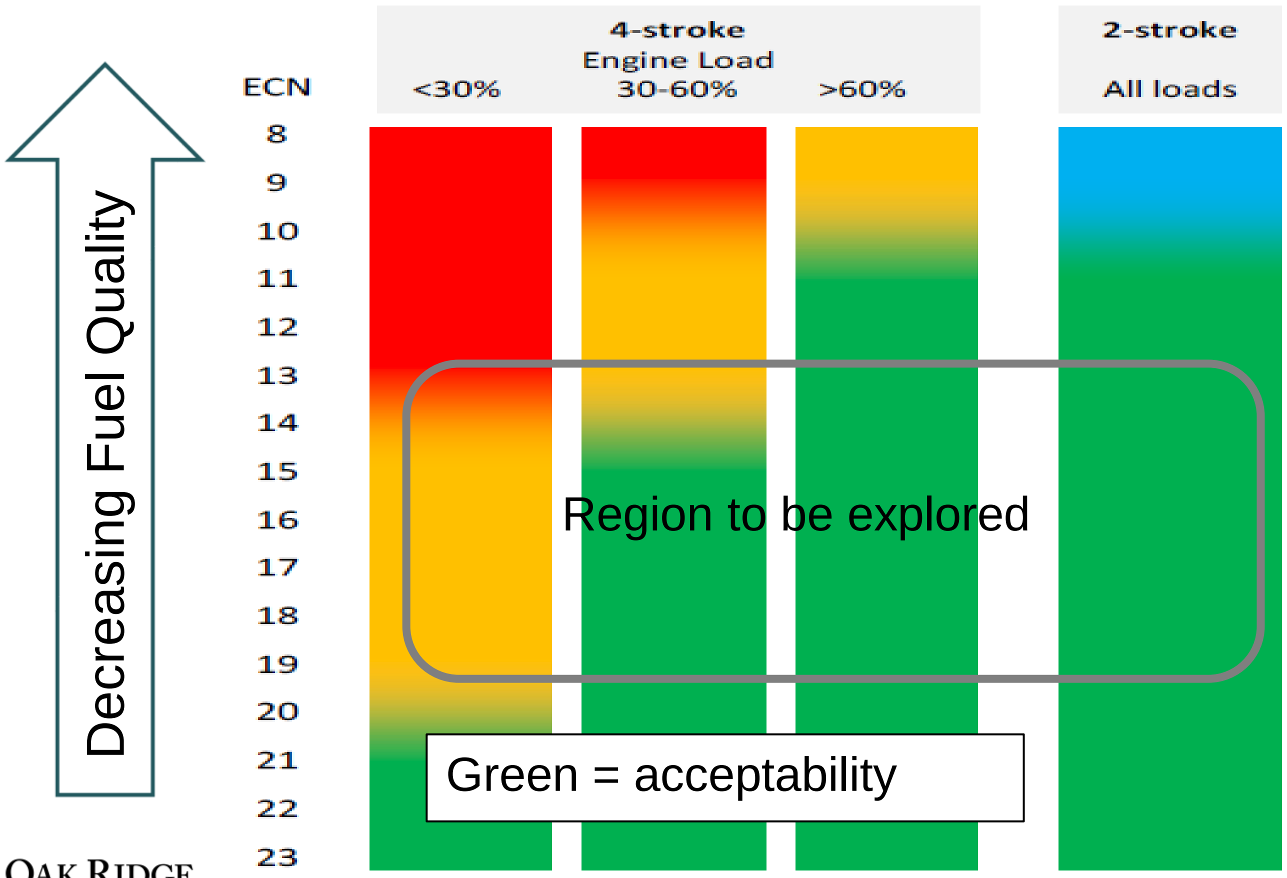
Large 2-stroke engines can operate on lower combustion quality fuels than other internal (reciprocating) combustion engines

Biofuels are attractive due to their capacity to leverage existing fuel and bunkering infrastructure, high energy density, and potential climate benefits.



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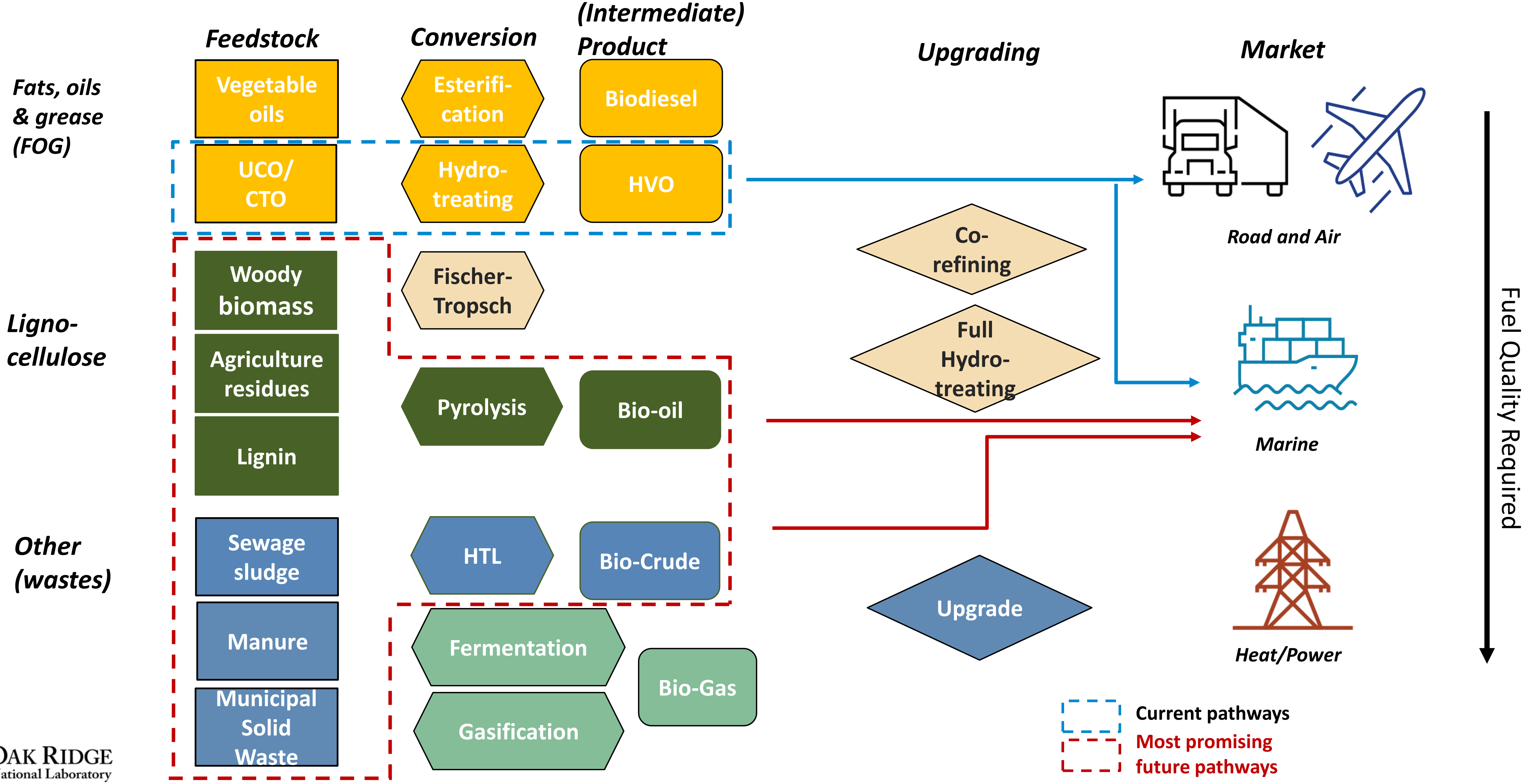
Use of lower quality fuels allows different feedstocks and pathways to be considered



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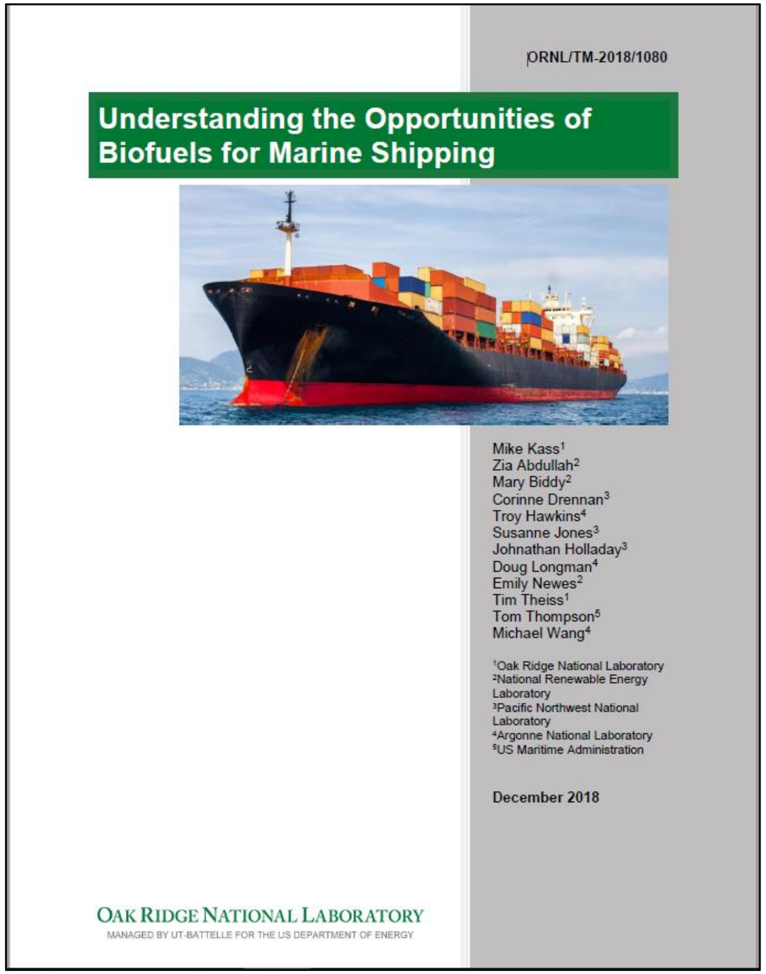
Multi-lab team formed to examine marine biofuel potential opportunities

- Initial motivation driven by potential of bio-intermediates to reduce sulfur emissions from 2-stroke marine engines
- Outcome: Publication describing the opportunities for biofuels for marine shipping was distributed to DOT Maritime Administration (MARAD) and industry
  - *This served as the basis for the current project*
- DOE Bioenergy Technologies Office (BETO) initiated a project to evaluate the viability of biofuels in the maritime sector
- Lab Roles:
  - **ORNL**: project lead & engine/emissions expertise
  - **NREL**: Catalytic fast pyrolysis (CFP) oil production & technoeconomic analysis
  - **PNNL**: Hydrothermal liquefaction oil production & technoeconomic analysis
  - **ANL**: life-cycle, scale-up analysis & engine expertise


ORNL/TM-2018/1080

Understanding the Opportunities of Biofuels for Marine Shipping

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December 2018

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MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

Project Goals: This effort addresses BETO goals of developing and advancing bioenergy production technologies and establish the use of domestic biofuels as a sustainable and cleaner marine fuel

BETO SDI Goals

- **Develop and test bioenergy production technologies through verified proof of performance in pre-pilot, pilot systems**
- **Demonstration of scale systems in relevant environments**
- **To enable commercial deployment**
- **Identify innovative end uses**

Project Goals (FY22 & FY23):

- **Provide the foundational information and demonstrations leading to a ship engine demonstration of an advanced biofuel**
  - Techno-economic Analysis (TEA) to ensure cost competitive pathways (including assessing bioresources for sustainable aviation fuel, SAF)
  - Life cycle analysis (LCA) support
  - Technical Feasibility

Additional Goals for FY23:

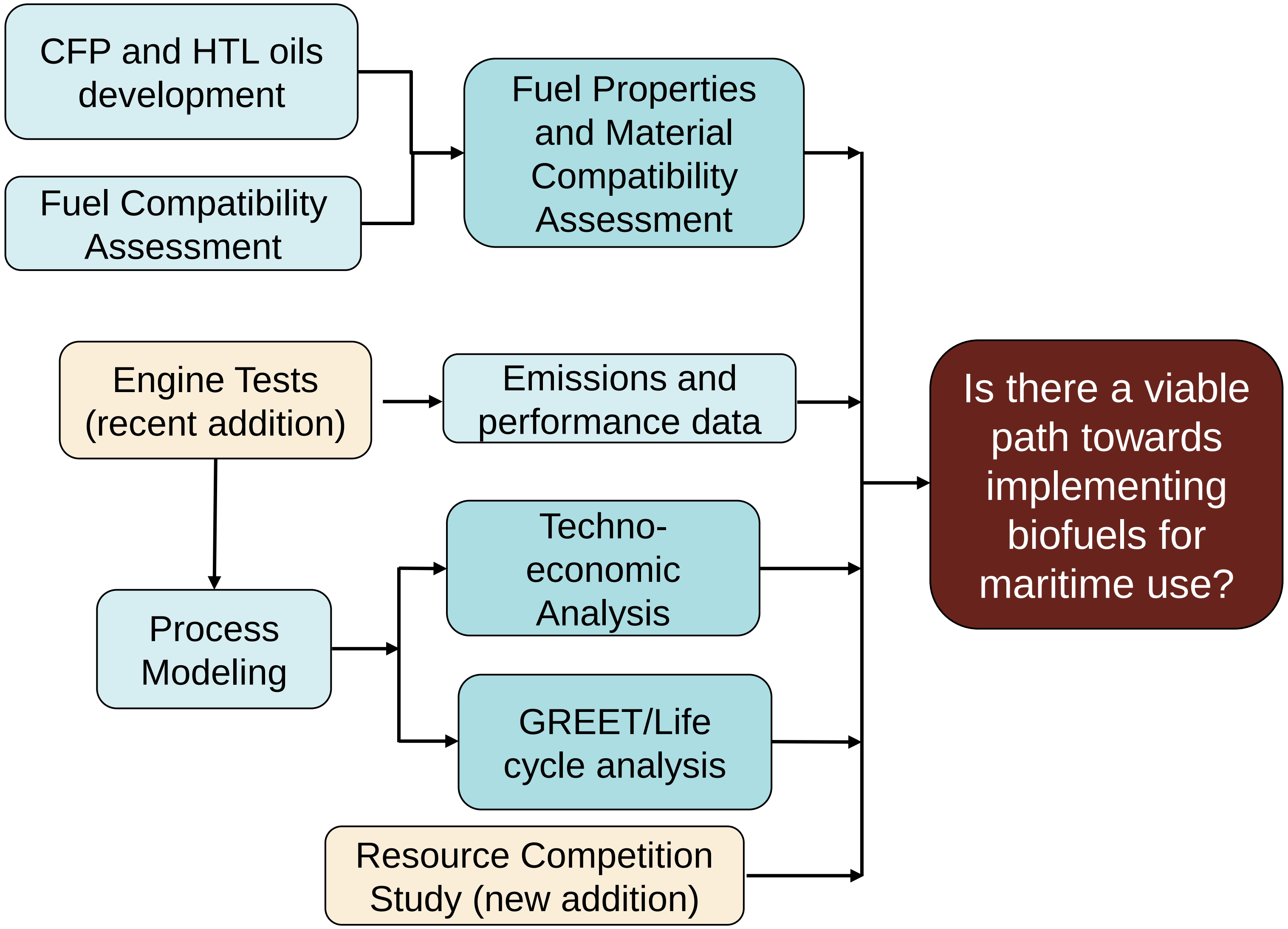
- **Determine minimal upgrading of bio-intermediates for use with heavy fuel oils**
- **Engine studies to characterize engine performance & emissions**

Specific question that project addresses: Can biofuels provide an economically-viable pathway towards reducing carbon intensity in a hard-to-electrify sector?

Approach

Integrated Framework for Evaluating Marine Biofuels

- Interdisciplinary analysis that considers economic, environmental, and technical metrics
- Emphasis on feedstock agnostic bio-intermediates and minimal hydrotreatment
- Evaluating fuel performance criteria (ISO 8217)
- Leveraging with other DOE offices, industry, biofuel producers, DOT Maritime Administration
- Down-select promising marine biofuel pathways, and engage with maritime stakeholders



Stakeholders and External Advisory Board provide direction and feedback on all tasks and progress

Approach

Research team identified the following fuels & properties

Biofuels

CFP oil (bio-oil)
HTL oil (bio-crude)
Lignin ethanol oil
Fischer-Tropsch (F-T) diesel
Renewable diesel

Baseline Fuels

HFO/VLSFO
Marine gas oil (MGO)
LNG
Biodiesel, methanol & ethanol

Category	Property	Baseline Fuels			Pyrolysis Oil/Blendstocks					HTL Bio-crude							
		HFO	MGO	LNG	FP Bio-oil	FP Bio-oil blend with HFO	FP Bio-oil (2% O2)	Ex situ CFP oil (2019 SOT)	Ex situ CFP oil (Target)	Algal HTL raw	Algal HTL hydrotreated	Wet waste HTL raw	Wet Waste HTL hydrogenated	HTL distillate	Biodiesel	Methanol	Ethanol
Engine/Fuel System/Bunkering Infrastructure	Material compatibility (corrosivity and wear)	Suitable	Suitable	Suitable	Poor	Suitable	Moderate	Poor	Poor	Moderate	TBD	TBD	TBD	TBD	Moderate	Moderate	Moderate
	Fuel-fuel compatibility & stability	Suitable	Suitable	Suitable	Moderate	Suitable	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Moderate	Suitable	Moderate
	Component compatibility (viscosity at 50 & 100C)	Suitable	Suitable	Suitable	Poor	Suitable	Moderate	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Moderate	TBD	TBD
	Blend limits with HFO or MGO	N/A	N/A	N/A	N/A	TBD	High	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Suitable	N/A	N/A
	Waste generation/disposal	High	None	None	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	None	None	None
Fuel Characteristics	Production maturity	Suitable	Suitable	Moderate	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Moderate	Moderate	Moderate
	Scalability	Suitable	Suitable	Moderate	TBD	TBD	Good	Good	Good	Moderate	Good	Good	Good	Good	Good	Good	Good
	Transport	Suitable	Suitable	Moderate	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Moderate	Moderate	Moderate
	Engine use maturity	Suitable	Suitable	Suitable	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	High	High	High
Fuel Properties	Composition/impurities	Suitable	Suitable	Suitable	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Low	Suitable	Suitable
	Stability	Suitable	Suitable	Suitable	Moderate	Suitable	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Moderate	Suitable	Suitable
	Density	Suitable	Suitable	Suitable	Poor	Suitable	Suitable	TBD	TBD	Poor	TBD	Poor	TBD	Poor	Suitable	Suitable	Suitable
	Volumetric energy density	Suitable	Suitable	Low	Suitable	Suitable	Suitable	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Suitable	Suitable	Suitable
	Estimated Cetane Number	Suitable	Suitable	Suitable	Poor	Suitable	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Suitable	N/A	N/A
	Cold filter plugging point	Suitable	Moderate	Suitable	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Poor	N/A	N/A
	Viscosity	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Suitable	N/A	N/A
	Lubricity	Suitable	Suitable	Poor	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Suitable	Moderate	Moderate
Economic	MFSP ($/gge)	2.00	4.00	TBD	1.95	TBD	3.29	3.33	2.48	4.82-11.35	TBD	2.11	3.46	3.71	TBD	2.29	3.57
	5% blend @ $2.62/GGE; HVO @ $2.00/GGE	N/A	N/A	N/A		N/A					TBD				TBD		
	20% blend @ $2.52/GGE; HVO @ $2.00/GGE	N/A	N/A	N/A		N/A					TBD				TBD		
	5% blend @ $3.12/GGE; HVO @ $2.50/GGE	N/A	N/A	N/A		N/A					TBD				TBD		
	20% blend @ $3.02/GGE; HVO @ $2.00/GGE	N/A	N/A	N/A		N/A					TBD				TBD		
	Price uncertainty	N/A	N/A	N/A	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	N/A	N/A	N/A
	Current fuel reliability	Suitable	Suitable	Suitable	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	N/A	N/A
	Retrofit cost	None	None	None	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	N/A	N/A
	Retrofit schedule	None	None	None	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	N/A	N/A
	Fuel Standards	Suitable	Suitable	Suitable	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Suitable	N/A	N/A
Safety	Human health (toxity, carcinogenic, etc.)	Suitable	Suitable	Suitable	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Suitable		
	Flammability	Suitable	Suitable	High	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable		
	Suffocation potential	Suitable	Suitable	High	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable		
	Explosion risk	Suitable	Suitable	High	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable		
Environmental Health	Life cycle GHG	High	High	Favorable	Favorable	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	Sulfur emissions	Moderate	Suitable	Favorable	Favorable	Favorable	Favorable	Favorable	Favorable	TBD	TBD	TBD	TBD	TBD	Favorable	Favorable	Favorable
	Nox, CO2, CO, CH4	TBD	TBD	Moderate	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Moderate	TBD	TBD
	PM	High	Moderate	low	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Moderate	Favorable	Favorable
	Large spill/release impact	High	high	High	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Moderate	Moderate

Note that there are multiple feedstock and production pathways

Approach

Identified 6 major tasks for FY 23

FY 22	FY 23
• Supply/demand curve and TEA (NREL & PNNL) • Life cycle analyses (ANL) • Pathway assessments and analyses (PNNL & NREL) • Compatibility analysis (ORNL & ANL) • Fuel production and testing (PNNL & NREL) • Logistics (NREL) • Project management (ORNL)	• Determine minimal treatment for forming stable blends with VLSFO (NREL & PNNL) • TEA and LCA informed pathways (NREL, PNNL & ANL) • Compatibility assessment (ORNL & ANL) • Project coordination and stakeholder engagement (ORNL, PNNL, NREL & ANL) • Opportunity assessment (ORNL, ANL, PNNL & NREL) • Engine testing (ORNL)

Key Challenges

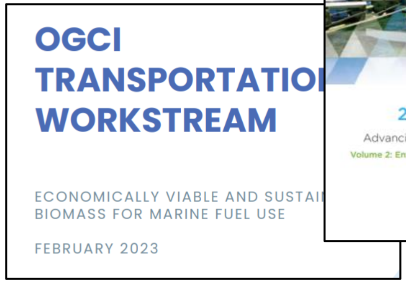
Biomass production
- **Feedstock availability**
- **Resource competition – sustainable aviation fuel (SAF)**
- **Scalability/logistics/maturity**

Technical challenges
- **Fuel blend compatibility with existing petroleum fuels**
- **Properties & specifications (ISO 8217)**
- **Engine testing is needed**
  - **Requires suitable test fuel quantities**
  - **Limited test facilities**

The Go/No-Go decision will be made based on economic costs associated with biofuel production relative to potential GHG and efficiency benefits

Criteria is based on:
- Near-term assessments of biofuel costs versus the predicted fuel costs for baseline fuels
- Mid-term/transitional efficacy of bio-oil and bio-crude as HFO substitutes. Can serve both aviation and marine markets.
- Long-term potential for carbon reduction
- Industry willing to pay premium
- GHG reduction

Goal is 100% biofuel or zero carbon fuel implementation. Blends provide a near-term drop-in benefit.



Approach Stakeholder engagement has been crucial to our success

- External advisory board formed at start of project (Lee Kindberg of Maersk is the committee chair)
- Provided virtual-based meeting and webinars. In person meeting held on March 21 (CMA Shipping Conference)
- Members are represented by 20 companies/organizations

Shipping/port Terminals
- Metro Vancouver

Energy companies
- ExxonMobil
- BP
- SunCor
- AramcoAmericas

Shipping/Engine Companies
- Maersk
- MAN Diesel & Turbo
- Carnival Cruise lines

Govt/Professional/Trade/Nonprofit
- IBIA
- DNV
- DOT MARAD
- ICCT

Industry Experts
- BlueInsight
- DNV
- Flexport

When the lab partnership was first formed in 2017, we were unable to get stakeholder interest, now we have companies asking for lab contributions and to join the external advisory board!!!

Biofuel Companies
- GoodFuels
- LanzaTech
- Ensyn
- Alder Fuels
- Circla Nordic

Risk Analysis and Mitigation Strategies

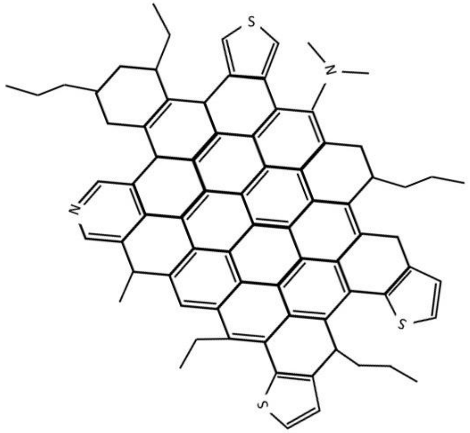
Risk	Mitigation Strategy
Lack of Information (especially engine data)	• ExxonMobil marine research engine at ORNL is approved and commissioned • Formed external advisory board and other partnerships • Mission Innovation (MI) data sharing • Oil and Gas Climate Institute (OCGI) interaction
Insufficient quantities of biofuels for engine & spray studies	• Utilize blends with low sulfur fuel oil as a drop-in option • Working with commercial suppliers to obtain suitable quantities
Blend stability	• Hydrotreating/upgrading to improve miscibility
Stakeholder input	• Formed external advisory board • Hosted several webinars & numerous presentations/publications • Involved with MI and OCGI

Progress toward meeting project goals

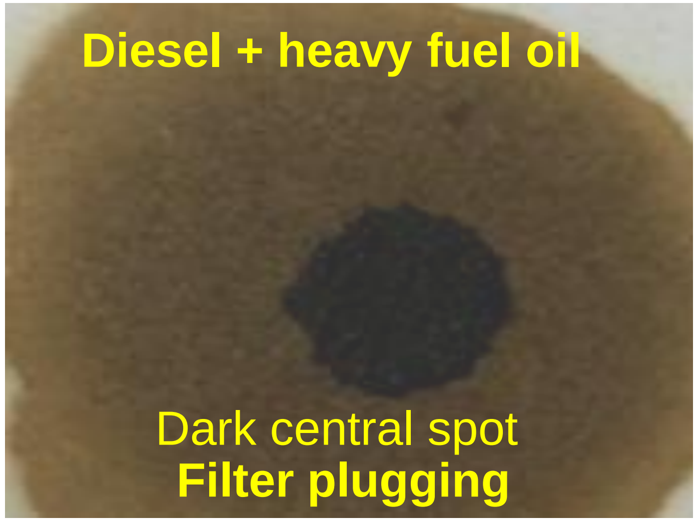
Goal	Progress
Identifying economic pathways	• Established framework and methodology for TEA studies • Determined and downselected TEAs based on feedstock and pathways • Model is still being tuned as we learn
LCA analyses	• Completed for many biofuels • Combined with TEAs to compute marginal abatement cost • Empirical validation and tuning as needed
Developing and production of miscible bio-intermediates	• Met for some bio-intermediates, but results limited to <20%
Engine Testing	• Commissioned on VLSFO, biodiesel. Trying to procure larger quantities of biofuels

Key Technical Challenge: Bio-intermediates are not readily miscible with heavy fuel oils. This is being addressed though minimum hydrotreating to remove water and other oxygenates.

- Marine fuel oils contain a highly colloidal dispersion of high molecular-weight compounds that have complex polyaromatic structures known as **asphaltenes**
- Asphaltenes exist in chemical equilibrium with the surrounding fuel oil
- The asphaltene dispersion is highly sensitive to changes in fuel chemistry and will readily precipitate (fall out of solution) if the solubility is highly altered
- Before a fuel is bunkered onboard a vessel, the fuel is evaluated for blend stability (ASTM 4740) to determine if asphaltene precipitation will occur

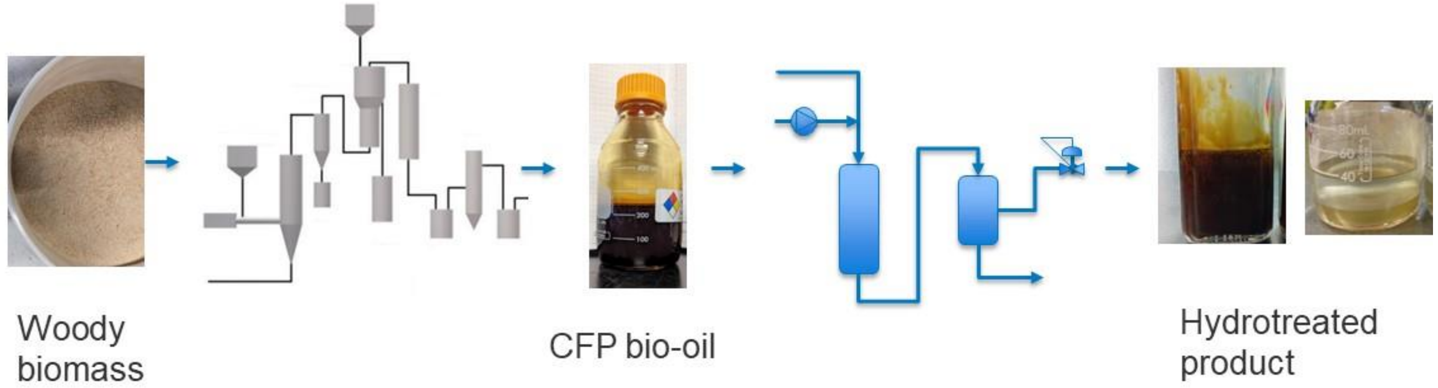


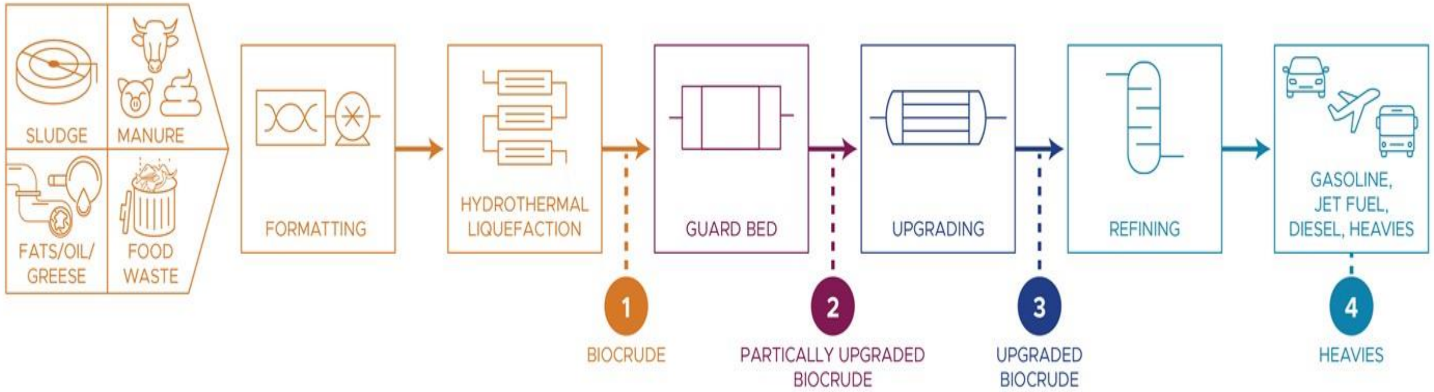
Asphaltenes contain paraffinic side chains of acids, carbonyls, and phenols capable weak bonding interactions with the surrounding fluid



Approach: Determine minimum upgrading/hydro-processing of CFP and HTL oils required to enable blending with very-low sulfur fuel oil (VLSFO)

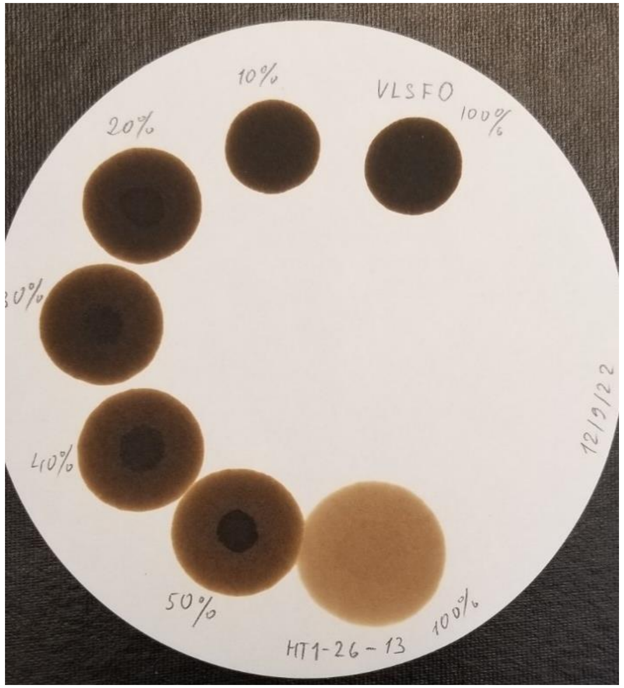
- Evaluating trade-off between hydrotreating level (cost) and compatibility
- CFP samples selected based on hydro-processing conditions
- Analyzed HTL biocrude samples generated from different feedstock composition consisting sludge; manure; food waste (FW); fats, oil and grease (FOG) and tested for marine fuel compatibility





Blend stability was achieved for HTL oils with mild upgrading

- Tasks 1 and 3-focused on hydrotreating and additives
  - Blend stability up to 40% HTL oil addition
  - HTL oils have inherently less water and acidity than CFP oils
  - Hot water wash was used to remove inorganics to improve mild hydrotreating process and meet ISO 8217 specifications
- Prior efforts have demonstrated that HTL oils are:
  - compatible with fuel system infrastructure metals
  - Exhibit suitable combustion quality results for blend levels up to 10%



Property	RMG 380 Specs	HTL Biocrude	Partially Upgraded Fuel
Viscosity at 50 °C, cSt	380	10,000	3.5
Density at 15 °C, kg/m^3	991	950	830
Flash Point °C	60	High	74.6
TAN, mg KOH/g	2.5	121-125	0
Pour Point °C	30	-	15-18
Water, Vol %	0.5	2.35-4.44	<0.22
Ash, Mass%	0.1	~0.5	0
Vanadium, mg/kg	350	0	0
Sodium, mg/kg	100	2926	0
Al plus Si, mg/kg	50	530	0

Catalytic Fast Pyrolysis (CFP) Oils: Tasks 1 & 3

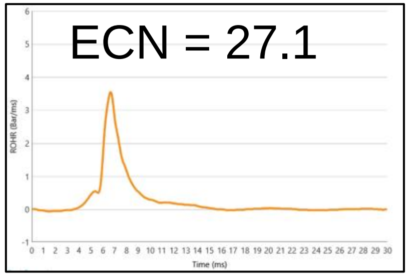
- Hydrotreating screening studies led to CFP oils meeting many key ISO 8217 criteria
- Identified suitable hydro-treatment process of 1500 psi and 300°C
- Blends up to 50% pass the ASTM D4740 spot test
- TEA updated to reflect hydrotreatment process
- Flash point specifications were subsequently met via distillation

Property	ISO 8217	CFP oil	Hydrotreating Severity Decreases →				
Pressure, psi			1500	1500	1500	1500	1000
Temperature			350	300	300	300	200
H_2: oil, L/L			4200	4200	4200	3000	3000
WHSV, g/(g h)			0.12	0.12	0.17	0.24	0.78
Oil O, wt% db		22%	<0.01	0.02	3	5	17
Acid number, mg KOH/g	≤2.5	28	0	0	0	0	25
Density, kg/m³	<1010	1130	845	884	968	988	1060
H_2O, wt%	≤0.5	4.5	0.3	<0.01	≤0.5	≤0.5	9
Flash point, °C	≥60	48	<7	<7	<7	<7	
Blend stability 50% with VLSFO		No	Yes	Yes	Yes	Yes	Yes

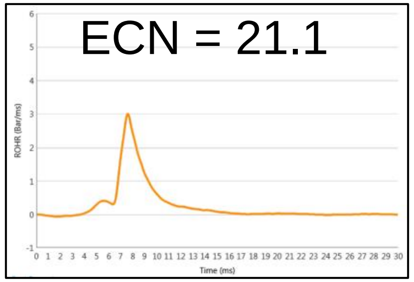
- Partial hydrotreating appears to be an option

Prior compatibility & combustion studies have demonstrated that blending with heavy fuel oils (HFOs) mitigates corrosivity

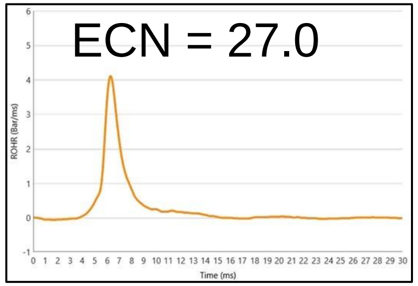
- Raw CFP oil was blended with HFO to evaluate corrosivity & other properties
- Dilution effect mitigates polymerization & acidity
- Combustion quality (Estimated Cetane Number) is acceptable for CFP and HTL oils up to 15% blend levels. Also, suitable for biodiesel blends (recent publication)
- Viscosity and lubricity were benefited



5% Upgraded HTL oil



10% CFP oil



20% Biodiesel

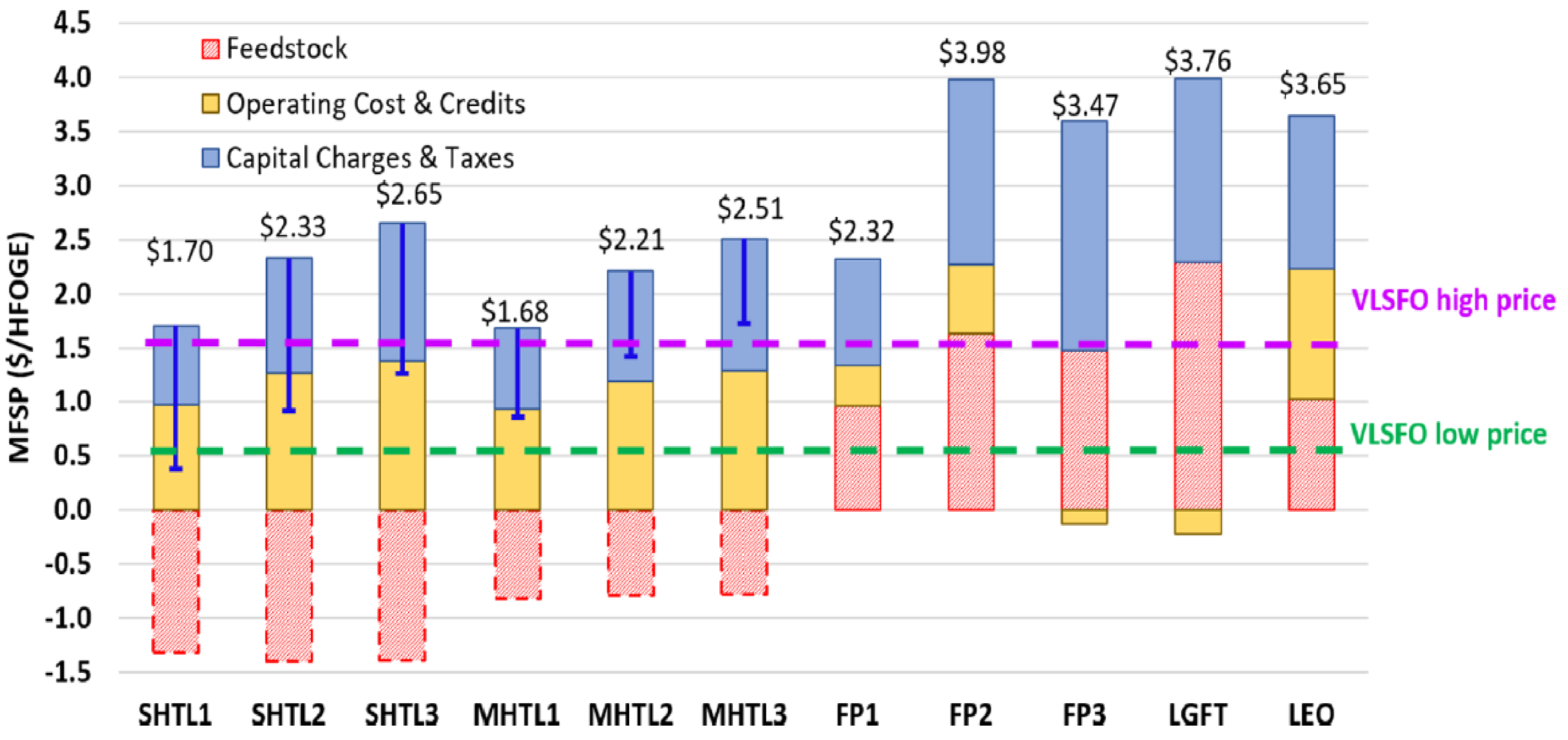
Estimated cetane number (ECN) values greater than 20 are considered highly suitable for use in marine engines

Table showing corrosion rates (mils per year) for each metal and blend level

Bio-oil content (mass%)	Carbon Steel		2.25Cr– 1Mo Steel		409 Stainless Steel		304L Stainless Steel		316L Stainless Steel	
	250h	500h	250h	500h	250h	500h	250h	500h	250h	500h
8	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
19	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
25	0.02	0.03	<0.01	0.07	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
50	0.05	0.04	0.09	0.05	0.05	0.04	<0.01	<0.01	<0.01	<0.01
100	1.97	1.69	4.82	2.83	1.32	0.94	<0.01	<0.01	<0.01	<0.01

Progress & Outcomes

Techno-economic analysis (TEA) shows that costs are highly dependent on feedstock and capital costs. Operating costs are not primary drivers.



SHTL -Sludge HTL
MHTL - Manure HTL
FP Fast Pyrolysis
FP1- no catalysis
FP2/FP3 – catalyst FP
LGFT – landfill gas
Fischer-Tropsch diesel
LEO – lignin ethanol oil

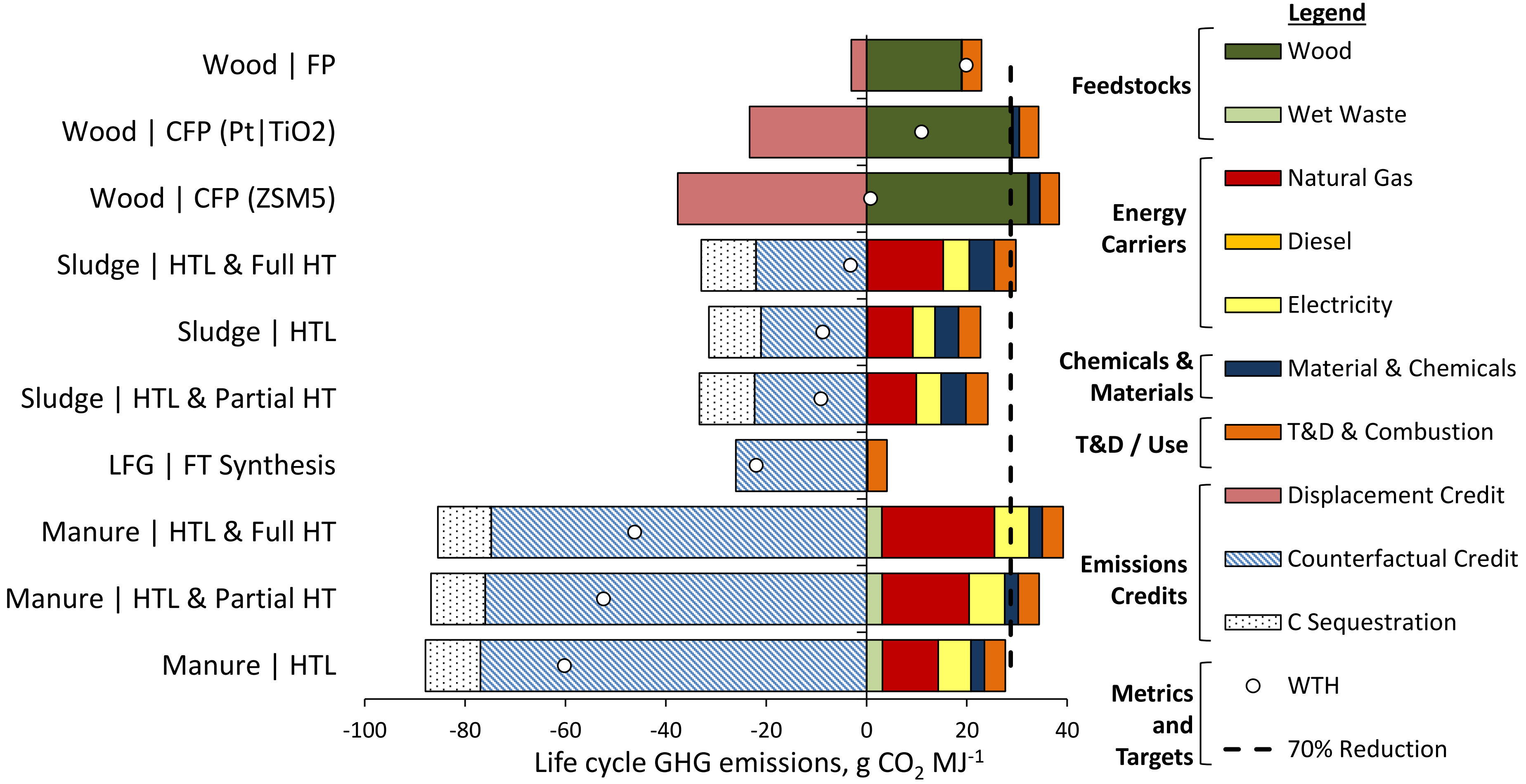
Comparative TEA result summary (the dash feedstock costs for HTL cases represent the sensitivity cases with the potential wet waste avoided disposal fee, while the blue error bars indicate the potential decrease of MFSP for HTL pathways; high and low VLSFO prices are the last 2 years' historical price range from the main ports of North America

https://doi.org/10.1021/acs.est.2c03960
Environ. Sci. Technol. 2022, 56, 17206−17214

Oak Ridge National Laboratory

Life cycle analysis identifies multiple biofuel pathways offering acceptable GHG reductions (Task 2)

- CFP and HTL oils are less GHG intensive compare to heavy fuel oil (HFO).
- They provide >70% reduction compared to HFO.
- Waste-based fuels have negative emissions as they divert waste form the business-as-usual cases

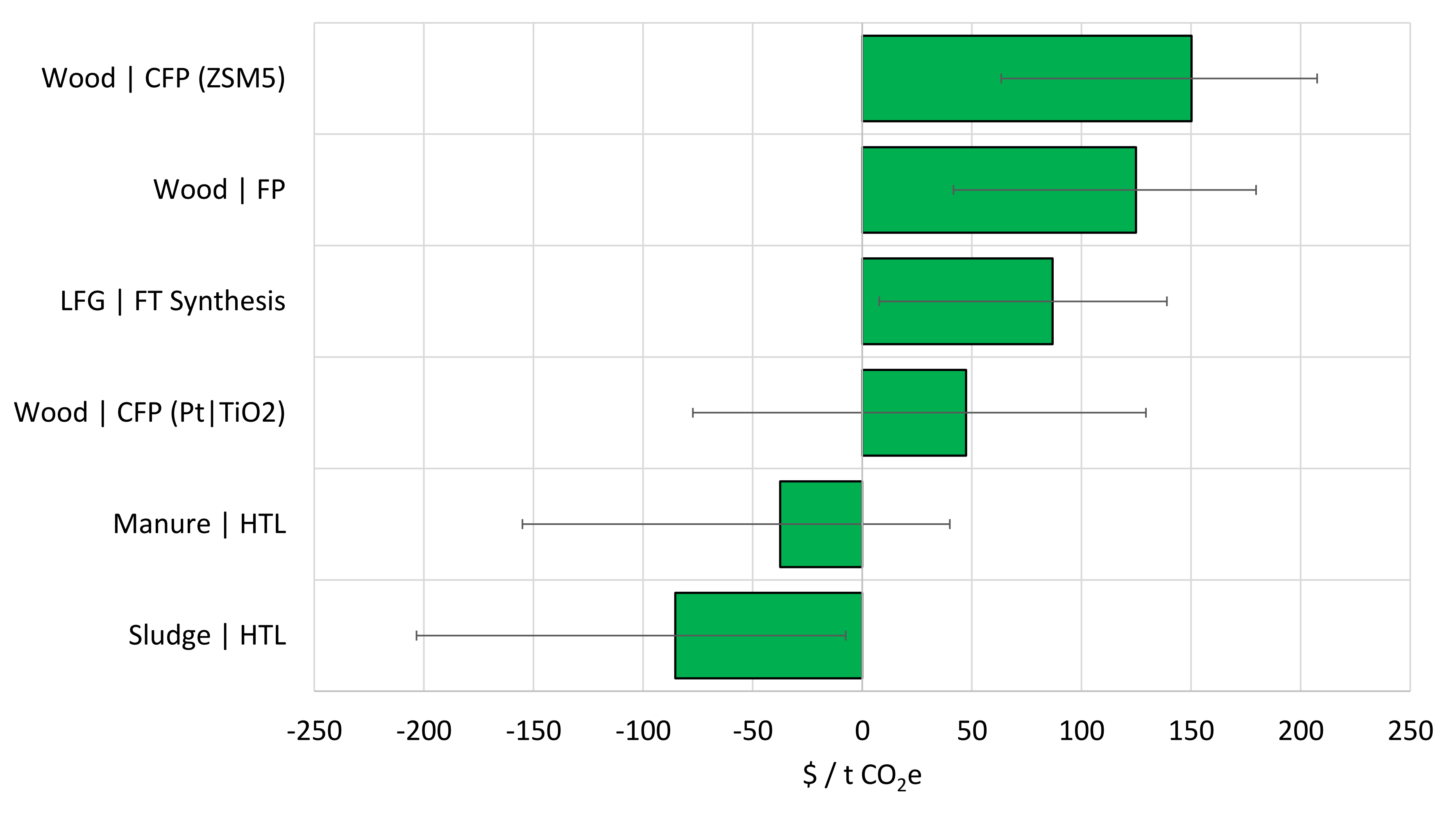


CFP: Catalytic Fast Pyrolysis; **FP:** Fast Pyrolysis; **HTL**: Hydrothermal Liquefaction; **LEO:** Lignin Ethanol Oil; **LFG:** Landfill gas; **WTH**: Well-to-Hull

Fossil Baseline (HFO 0.5% S) = 95.4 gCO_2e/MJ, 50% GHG Reduction = 47.7 gCO_2e/MJ, 70% GHG Reduction = 28.6 gCO_2e/MJ

Marginal GHG avoidance costs are encouraging

- Pathways with negative results may be already competitive with conventional VLSFO
- Biomass based fuels, except from poplar, can be made competitive with existing LCFS credit
- California Low Carbon Fuel Standard credits have ranged around $100-200 /tonne CO_2-eq. in recent years



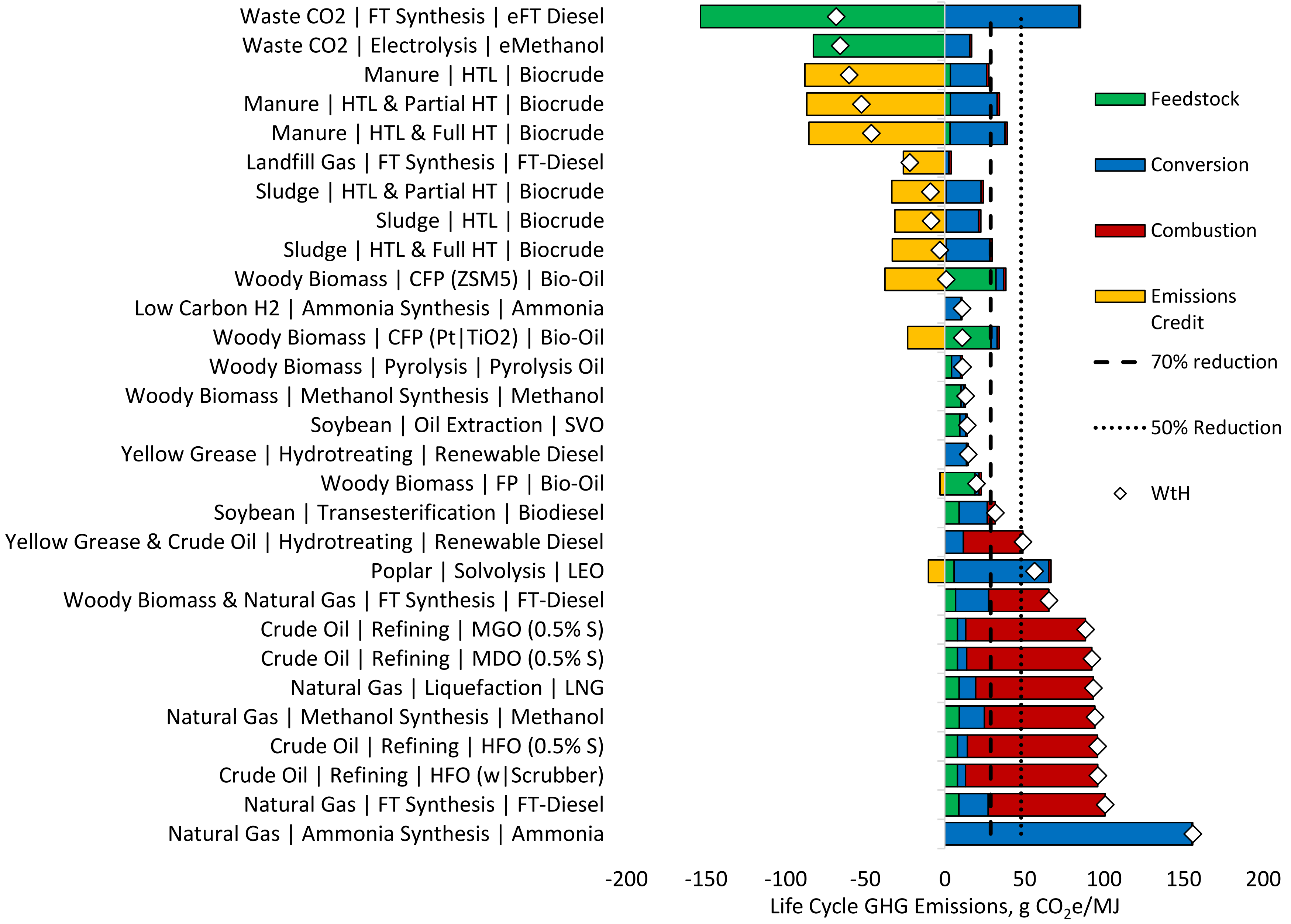
LCFS – low carbon fuel standard

LCA highlights benefits of multiple low carbon fuels (not just biofuels) in context of marine fuel options

- Larger panel of fuel options is available in GREET database, also in the new, interactive GREET Marine Module

- Fuels produced from biomass and waste feedstocks offer promising carbon intensities

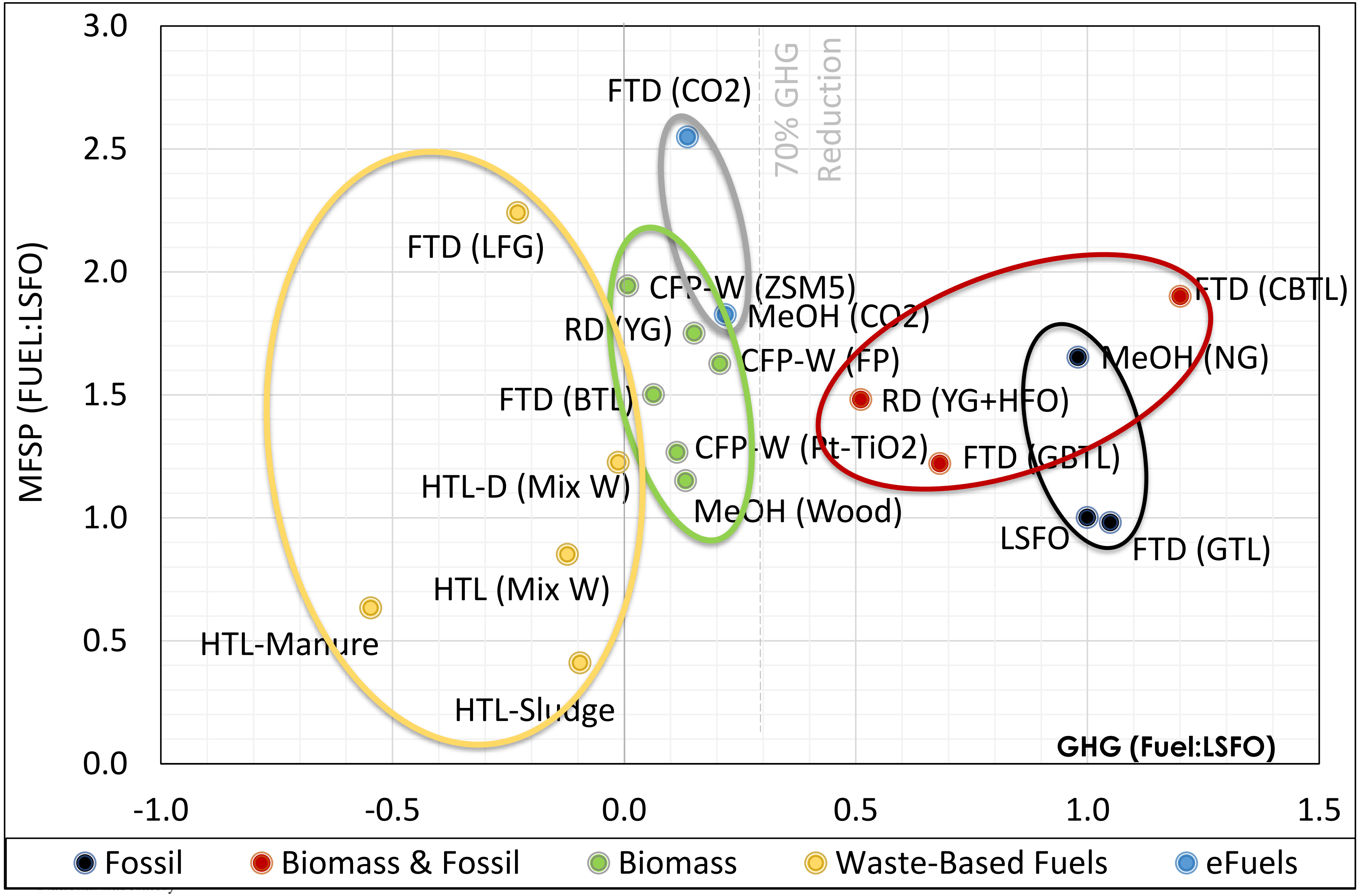
- Life cycle perspective is critical for understanding impacts of "carbon free" fuels such as ammonia



CFP: Catalytic Fast Pyrolysis; ZSM5: Zeolite Socony Mobil-5; TiO2: Titanium Dioxide; FP: Fast Pyrolysis; HTL: Hydrothermal Liquefaction; HT: Hydrotreating; LFG: Landfill Gas; SVO: Straight Vegetable Oil; LEO: Lignin-Ethanol Oil; MGO: Marine Gas Oil; MDO: Marine Distillate Oil; HFO: Heavy Fuel Oil; LNG: Liquefied Natural Gas; FT: Fischer-Tropsch; S: Sulfur; T&D: Transportation and Distribution; WtH: Well-to-Hull

Progress & Outcomes

Examining LCA and TEA results yields multiple promising pathways



Acronyms
CFP – catalytic fast pyrolysis
FTD – Fischer Tropsch diesel
HFO – heavy fuel oil
HTL – hydrothermal liquefaction
LSFO – low sulfur fuel oil
MeOH - methanol
RD – renewable diesel

Impact

Efforts have led to collaborations with key international and domestic initiatives

- Actively contributing to the International Maritime Organization’s guidance for life cycle analysis of marine energy systems.
- Supporting the inter-governmental Mission Innovation: Zero Emission Shipping Mission
- Partnerships with DOT Maritime Administration
- Partnering with Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping.
- Leveraging interactions with the External Advisory Board to fill key data gaps and incorporate stakeholder perspectives
- Engaging with the Methanol Institute around LCA of methanol pathways

Methanol Institute

Industry participation is driven by the recognition that there is no clear path to decarbonization

This effort advances a new market for biofuels and furthers the decarbonization of the maritime sector

Immediate Impacts

- TEA & LCA work being used by MI and others to improve their own models and predictions
- Effort has directly led to new agreements & projects with:
  - DOE Vehicle Technologies and Fossil Energy & Carbon Management Offices
  - U. S. Department of Transportation
  - U. S. State Department
  - At least 2 new commercial partnerships

Dissemination of results

- High-impact publications (Fuel, Journal of Environmental Science & Technology, others)
- Invited presentations/panels (IBIA, CMA Shipping, ABLC, MI, OGCI, etc.)
- Webinars (CMA and DOE-sponsored)
- Biannual stakeholder meetings

FY24 to emphasize engine testing, SAF co-production, zero-carbon fuels

Engine Studies

- Engine tests to confirm performance, define boundaries, and obtain accurate emission profiles are needed to address new rule changes.
- Lack of engine studies and test facilities has been a key concern of the maritime industry

SAF Co-production Options and Opportunities

- Research team to further explore opportunities with co-production of SAF and “bio-residuals” (for maritime use)
- This approach is also being examined by industry

Zero-carbon Fuels

- Bio-methanol
- Green ammonia
- Hydrogen

Summary

1. This effort directly supports BETO's overarching commercial viability mission while providing a unique solution to addressing the limited energy options of the marine sector
2. Stakeholder community is strongly supportive of a federal program focused on biofuels for marine sector
3. Biofuels offer a pathway toward GHG reduction
4. Studies to-date have shown that biofuels have good compatibility and combustion characteristics
5. Blend stability (preventing asphaltene precipitation) is improved by upgrading/hydrotreating

Publications

1. “Stability, rheological and combustion properties of biodiesel blends with a very-low sulfur fuel oil (VLSFO),” Fuel, 316 123365 (2022)
2. “Biofuels for Marine Applications: Techno-Economic Analysis and Life-Cycle Assessment,” Environmental Science & Technology, 55(11), 7561-7570 (2021).
3. “Techno-economic Analysis of Sustainable Biofuels for Marine Transportation,” Environmental Science & Technology, 56, 17206−17214 (2022).
4. “Comparing Life Cycle Emissions of Novel Sustainable Biofuels for Marine Applications,” Environmental Science & Technology,” submitted.

Presentations

1. “Decarbonizing the Marine Sector: Opportunities and Challenges,” ASABE 2021 Annual International Meeting, July 13, 2021.
2. “Displacing Heavy Fuel Oil Use in Marine Shipping Through Biofuels: Opportunities and Feasibility,” IBIA Annual Convention, November 2-4, 2021.
3. “Environmental Assessment of Alternative Fuels for Maritime Shipping,” The International Symposium on Sustainable Systems and Technology (ISSST), Virtual, June 22-24, 2021.
4. “Comparing Lifecycle Emissions of Novel Biofuels for Marine Applications,” 2022 International Symposium on Sustainable Systems and Technology (ISSST), Pittsburgh, PA, June 21-23, 2022.
5. “Sustainable Biofuels for Low-Carbon Maritime Transportation,” 2022 AIChE Annual Meeting, Phoenix, AZ, November 13-18, 2022.

Quad Chart Overview

Timeline

- *Project start date: Oct 1, 2021*
- *Project end date: Sept 30, 2024*

	FY23 Costed	Total Award
DOE Funding	*(10/01/2022 – 9/30/2023)*	*FY22: $1.9M* *FY23: $2.1M* *FY24: $2.0M*
Project Cost Share *		

TRL at Project Start: 2

TRL at Project End: 4

Project Goal

- To provide information to DOE and the stakeholder community on biofuel cost and performance as a marine fuel.
- To be achieved by conducting TEA, LCA and technical feasibility analyses on biofuels and pathways within the BETO portfolio.
- Fuels to be evaluated for near- and longer-term scenarios and whether the economic and carbon reduction targets can be met with biofuels.

End of Project Milestone

Deliver final report and recommendations to DOE and stakeholder community. The report will provide a final listing of biofuel types most suitable for near- and long-term targets. A minimum of 3 promising pathways for biofuel production and infrastructure upgrades will be reviewed along with a priority list of research needs.

Funding Mechanism: AOP

Project Partners

- DOT Maritime Administration
- Mission Innovation
- ExxonMobil

Additional Slides

Responses to Previous Reviewers’ Comments

Comments: "Interesting project looking at the feasible use of biofuels for marine applications. Well managed project with a coherent and clear approach. Seems like the cost of logistics and establishment of a supply chain, as well as preferred feedstocks per targeted location should be emphasized and prioritized. Some of the commercial targets being pointed out (slide #16) look to be high for what currently is a commercially marginal fuel (HFO). Seeking advice from the commercial side of fuel/refining companies should be very helpful here. Connections and differentiation between this project and project 3.2.1.001 should be clarified.“

Response: We had a late start on the logistics task, but it is now progressing at full speed. Our team has had discussions with US and international port authorities and are currently collecting data. The logistics and feedstock supply teams are the same ones that have successfully evaluated these factors for aviation biofuels. This is important since the BETO program seeks to evaluate the use of separating the light MW hydrocarbons for aviation from the heavier MW cuts suitable for marine use. Agree that connections and differentiation from this effort with 3.2.1.001 should have been clearer. There is considerable overlap and the work that was done in 3.2.1.001 is being folded into the current multilab effort.

Responses to Previous Reviewers' Comments

Comments: Impact could be significant, but the path to commercialization is not totally clear. The stakeholder feedback slide struck was indicative to this as the feedback was just a bulleted list without any apparent organization or identification of key take-aways. It was also not apparent how this feedback was helping to guide the project. It appeared that the project needed stakeholder input and so it checked the box.

Response: Pathway to commercialization is providing information to the maritime sector. We did not provide a complete listing of all our stakeholder interactions and, in hindsight, should have included the full non-abbreviated listing as a backup slide. We have had a number of discussions with the stakeholder community, and they have been important in directing us towards biofuels of interest and those which are not, including baseline fuels such as natural gas. The feedback slide was, in fact, a listing of key take-aways. We should have made this more clear.

Lab Roles

National Renewable Energy Laboratory (NREL)

- Conduct preliminary conversion/cost/supply-demand assessment to inform the techno-economic characteristics of candidate biofuels
- Develop/produce catalytic fast pyrolysis (CFP) oils for improved blend stability and testing.

Pacific Northwest National Laboratory (PNNL)

- Conduct conversion and cost assessment for biofuels/bio-crudes from appropriate feedstocks
- Develop/produce hydrothermal liquefaction (HTL) oils for improved blend stability and testing

Argonne National Laboratory (ANL)

- Conduct LCA to assess potential energy and environmental benefits of marine biofuels
- Conduct fuel spray characterization tests on fuel blend candidates to evaluate the effects of the physical properties on spray combustion

Oak Ridge National Laboratory (ORNL)

- Serve as project coordinator and assess technical feasibility (including engine tests) of biofuels
- Responsible for leading engagement with the stakeholder community