U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Current State of Sustainable Marine Fuels

Presenters:

Josh Messner, Technical Manager, Bioenergy Technologies Office

Dr. Troy Hawkins, Fuels and Products Group Leader, Argonne National Laboratory

Dr. Lee Kindberg, Head of Environmental Sustainability–North America, Maersk

March 15, 2022

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About the Bioenergy Communicators (BioComms) Working Group

Sponsor:

- U.S. Department of Energy (DOE) Bioenergy Technologies Office (BETO)

BETO & DOE National Laboratory Members:

- Bioenergy communicators, laboratory relationship managers, BETO tech team, and education and workforce development professionals

Purpose:

- Communications strategy for BETO-funded bioenergy research and development

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Today's Agenda

I. Josh Messner: Alternative Marine Fuel R&D Support at BETO
II. Dr. Troy Hawkins: Life Cycle Analysis of Alternative Fuels for Maritime Shipping
III. Dr. Lee Kindberg: Marine Fuels for the Future

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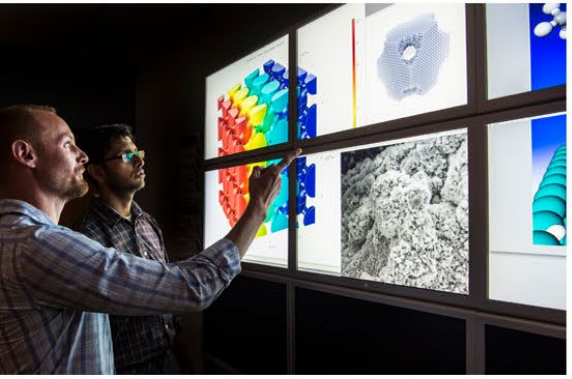
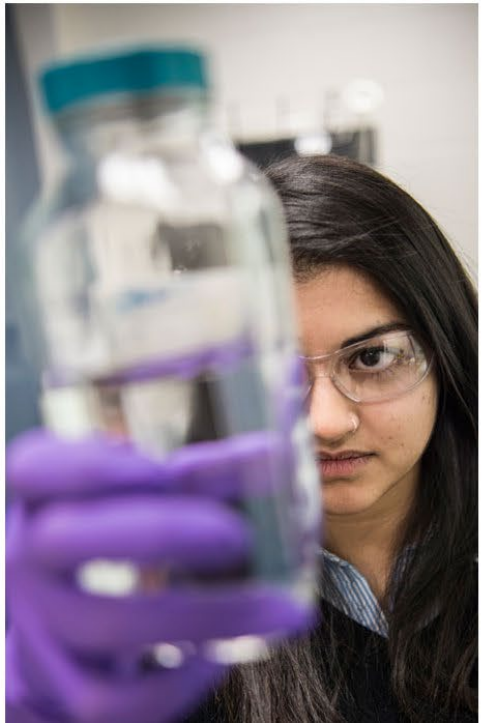
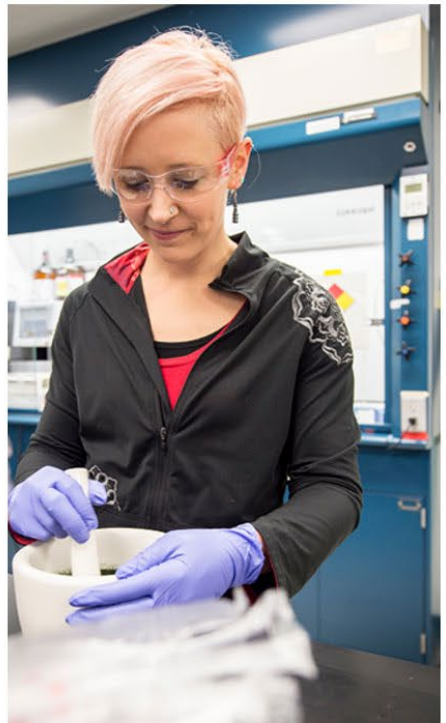
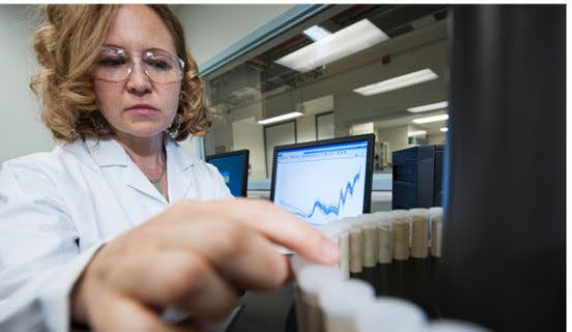
Alternative Marine Fuel R&D Support at BETO

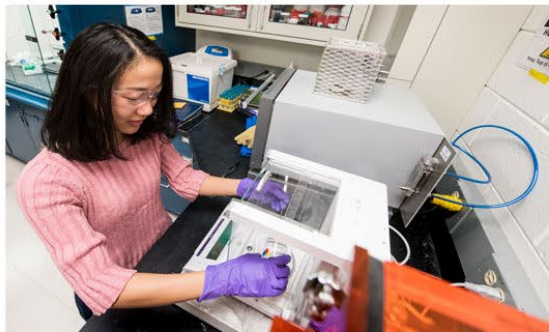
Josh Messner, Systems Development & Integration Technology Manager

3/15/2022





Outline

I. Bioenergy Technologies Office Overview

II. Biofuels for Marine Use Progress to Date

III. Collaborations

IV. Future Work

V. Questions

BETO Mission, Vision, and Strategic Goals

A thriving and sustainable bioeconomy fueled by innovative technologies

Developing transformative and revolutionary sustainable bioenergy and coproduct technologies for a prosperous nation

Develop industrially relevant technologies to enable domestically produced biofuels, biopower, and coproducts

BETO Program Areas

Feedstock Technologies

Advanced Algal Systems

Conversion Technologies

Systems Development and Integration

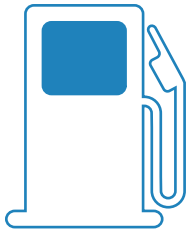
Data, Modeling, and Analysis

Impacts of a Billion Ton Bioeconomy – Maximized for Fuel Production

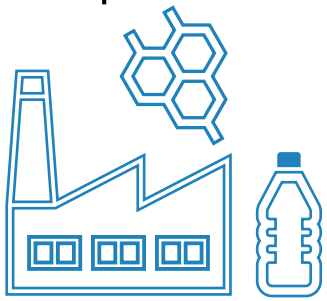
1 Billion

dry tons of sustainable biomass
has the potential to:

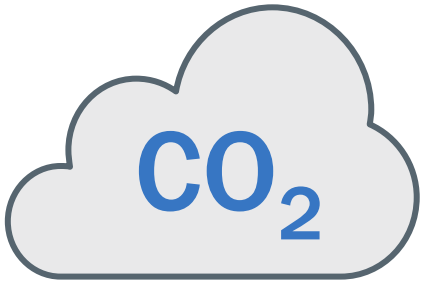
Produce
60 Billion
gallons of renewable, low-carbon fuels



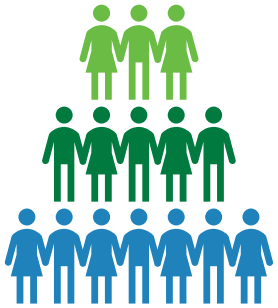
Produce
40 Billion
pounds of bio-based chemicals and bioproducts



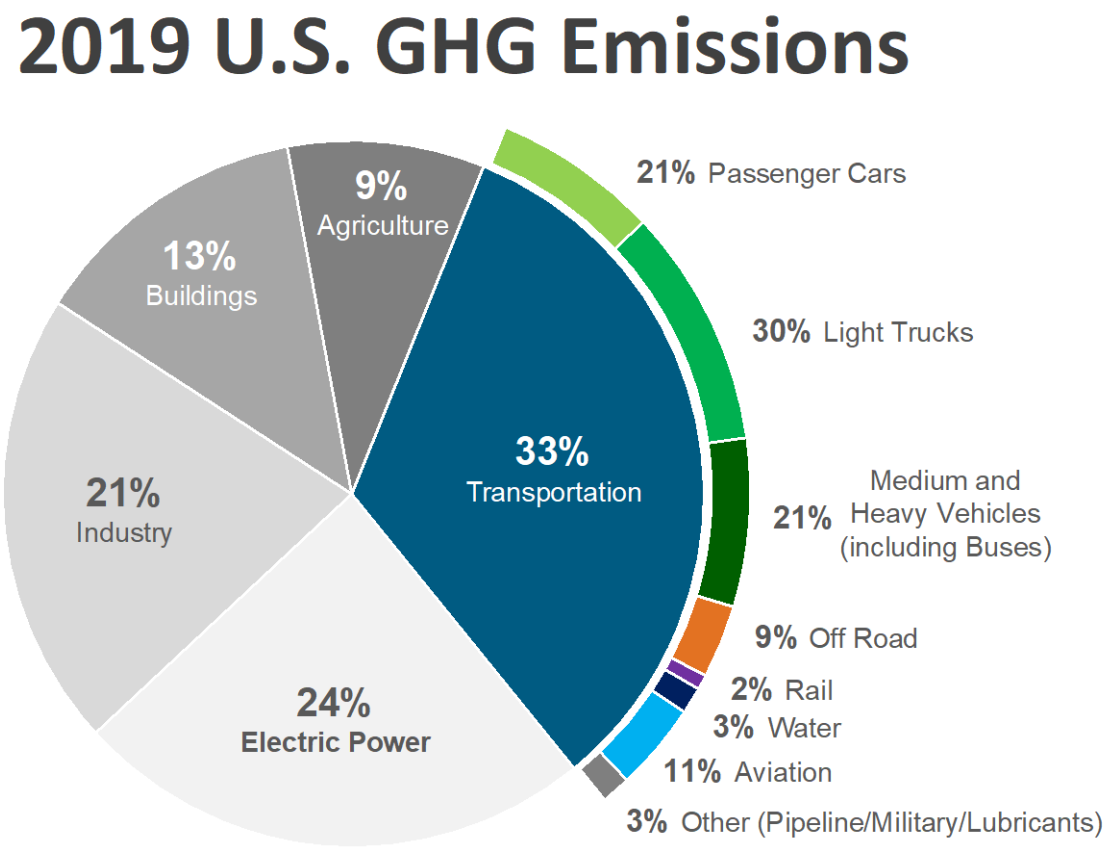
Reduce
450 million
metric tons of greenhouse gases per year



Produce
1 million
direct jobs



Bioenergy Can Support Decarbonization in Multiple Sectors of the Economy



Aviation and water include emissions from international bunker fuels. Fractions may not add up to 100% due to rounding.

1 Billion Tons of Biomass = 450-500 MMTons CO_2 reduced annually across multiple sectors

Marine Sector:

- 3% of U.S. transportation sector, totaling 1% of U.S. greenhouse gas (GHG) emission
- Does not include Particulate Matter ($PM_{2.5}$) emissions

Transportation Sector: Passenger Cars, Air, Marine, Rail
12.6% GHG emissions (37% of sector)

- Electrification of passenger cars, light, medium, and some heavy vehicles
- Hard to electrify: Aviation, marine, rail, off-road
  - Biofuels are a strong contender

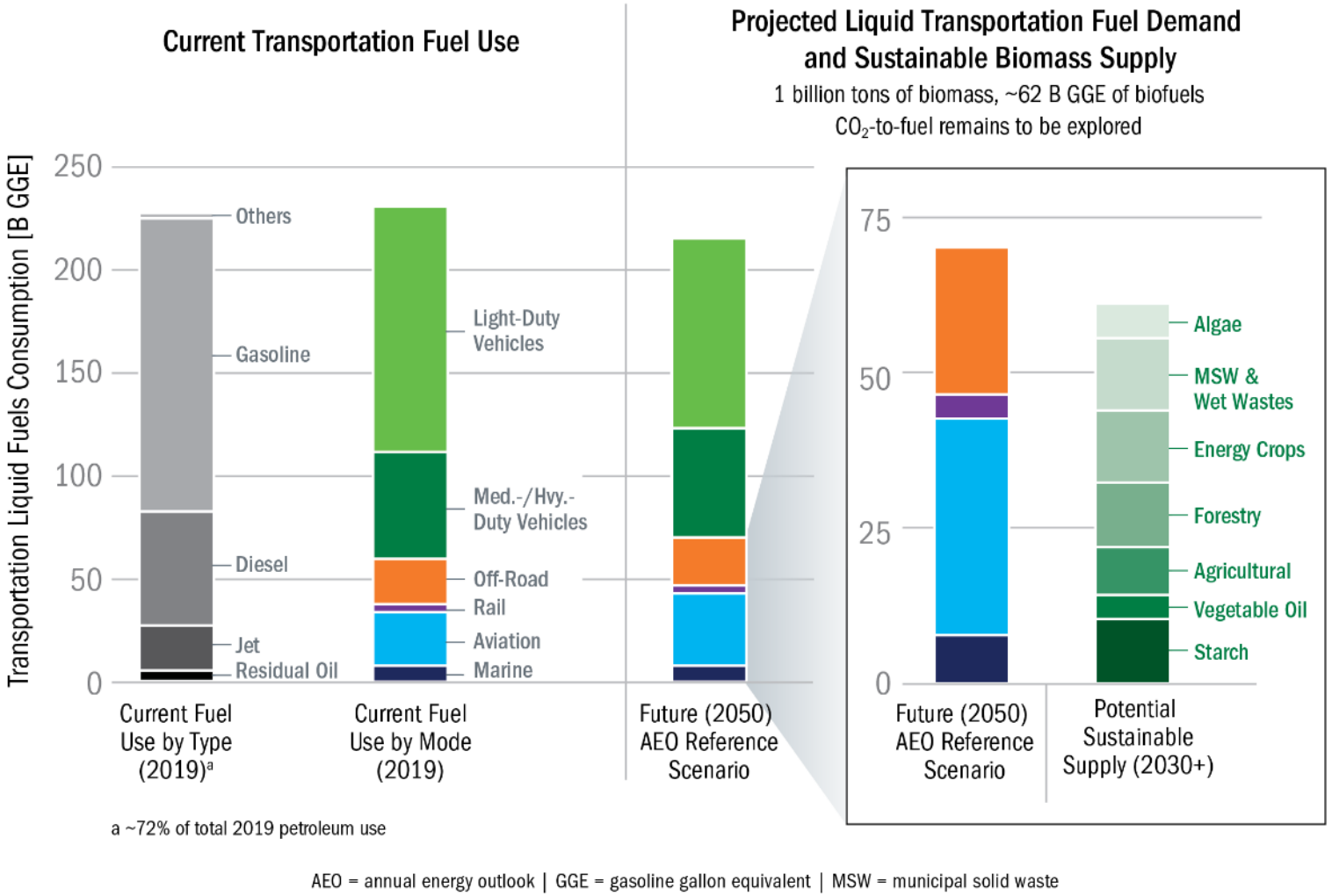
Industrial Sector: Chemicals 5.5% GHG emissions (19% of sector)

- Increased production of biobased direct displacement chemicals as well as performance-enhanced bio-based chemicals

Agricultural Sector: 9% GHG Emissions

- Healthy forests, sustainable agriculture, manure management

Biomass Budgeting



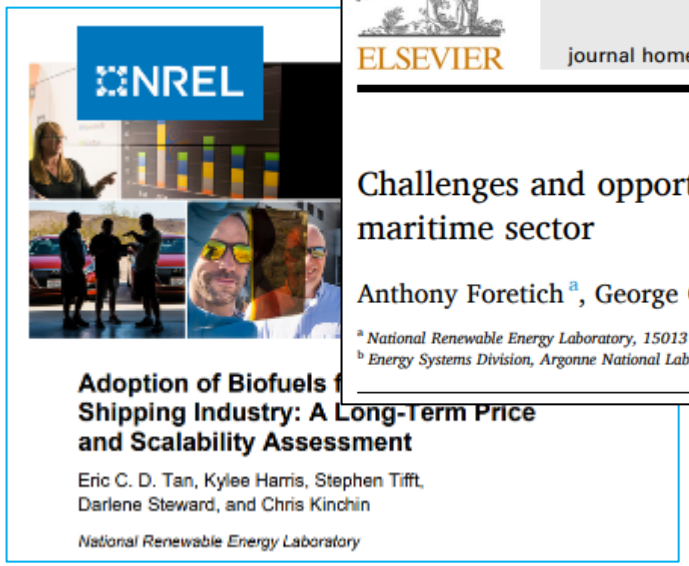
Develop and demonstrate technologies to cost-effectively decarbonize "hard-to-electrify" modes of transportation (aviation and marine industry)

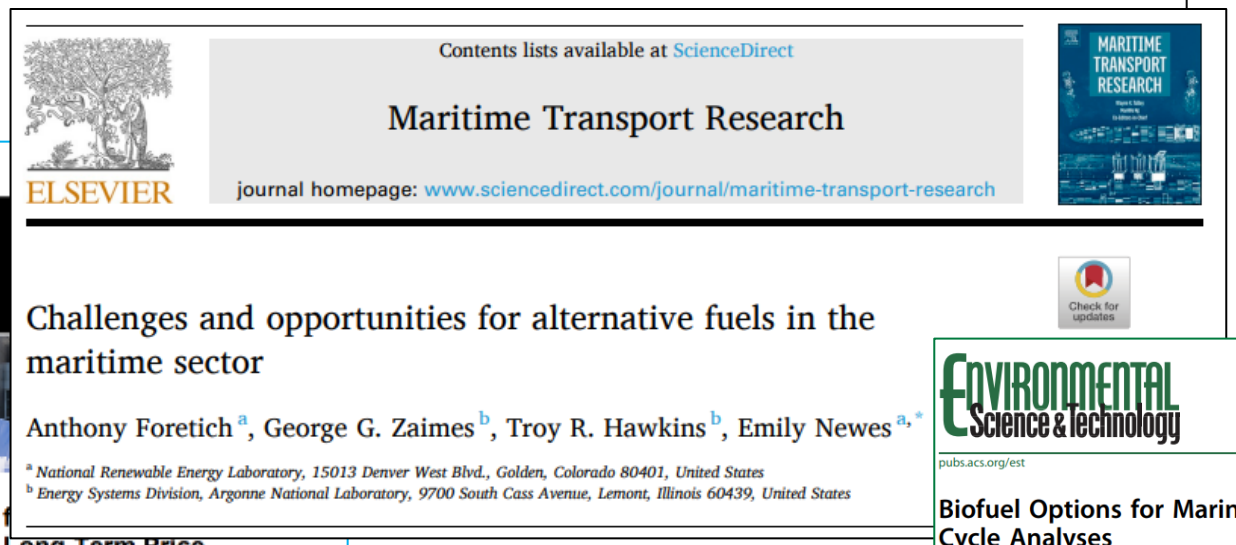
Goals:

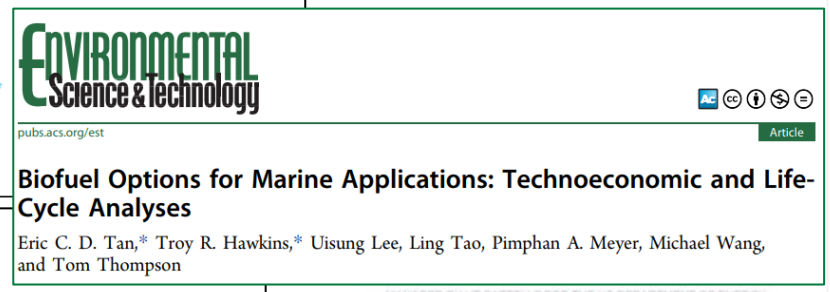
- Continue R&D to enable competitive fuel cost of multiple feedstock conversion paths with >70% CO_2 emission reduction
- Demonstrate technologies to improve life cycle GHG emissions of 17B gal/year corn-ethanol industry up to >70% reduction.

Marine Biofuels Accomplishments to Date

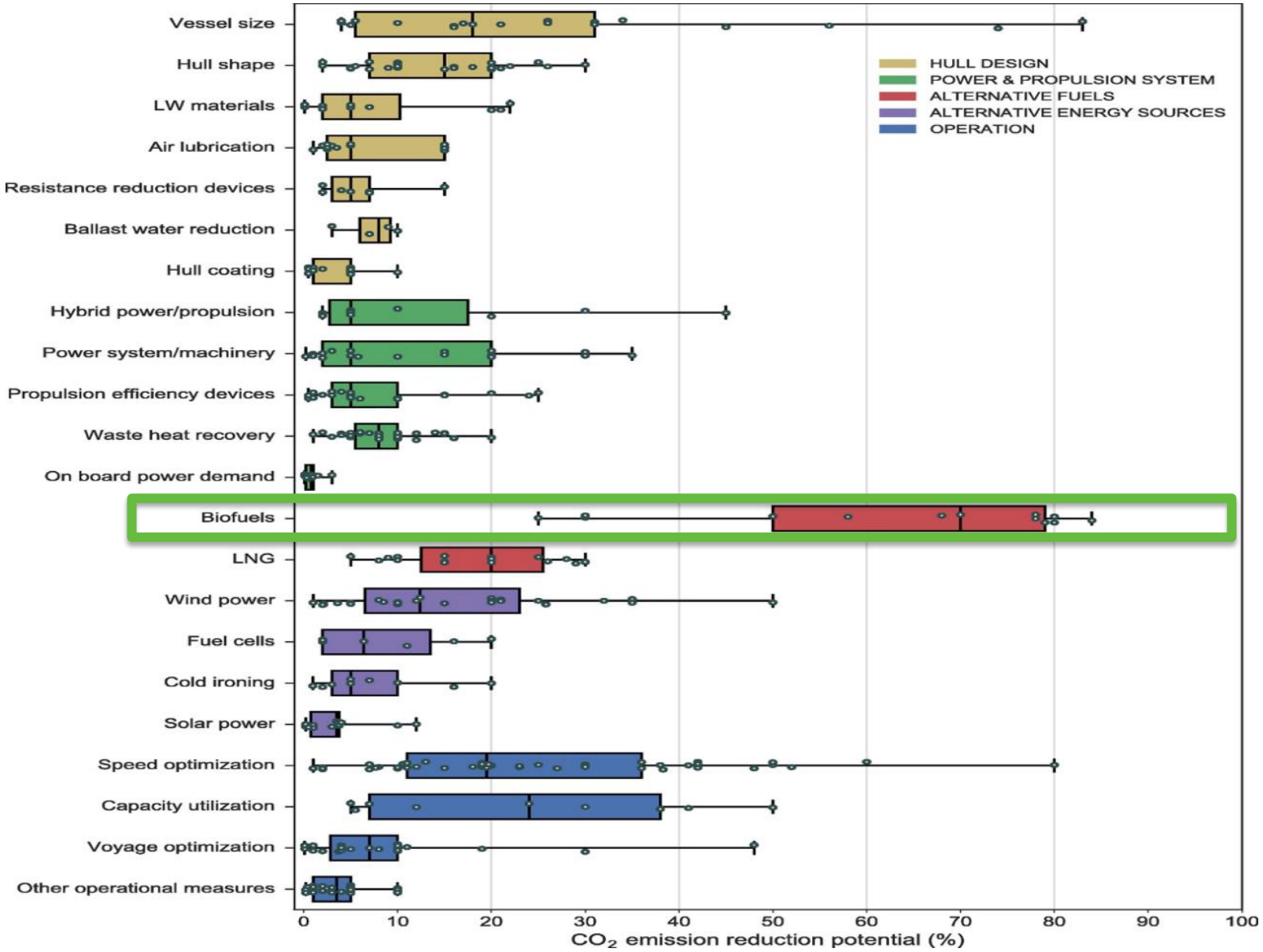
- Baseline fuels
- Fuel Options
- Life Cycle Analysis
- Economic Analysis
- Environmental Benefits
- R&D Challenges and Opportunities
- Port Logistics







Systems Thinking is Needed



Evert A. Bouman, et al., State-of-the-Art Technologies, Measures, and Potential for Reducing GHG Emissions from Shipping – A Review, https://doi.org/10.1016/j.trd.2017.03.022. http://www.sciencedirect.com/science/article/pii/S1361920916307015

Marine Biofuels Progress to Date

Many feedstocks

- Lignocellulosic (wood, grasses, ag residues)
- **Wet waste and bio-solids**
- Municipal solid waste (MSW)

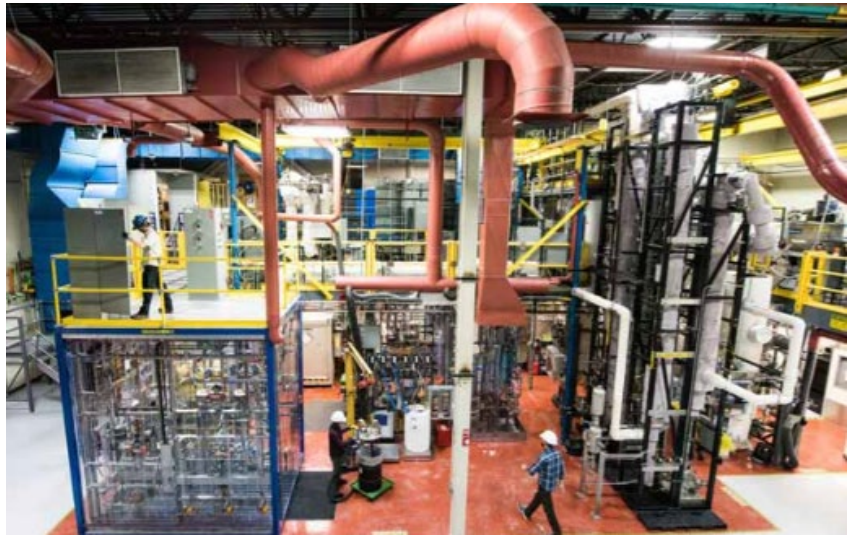
Many fuel

- Hydrocarbon distillates drop-ins
  - e.g., Renewable diesel
- Biogas
- Methanol
- **Bio-crudes**
- **Bio-oils**

Vary in cost, quality, volumes, and uses

- Direct diesel replacements
- Residual replace for ocean going vessels
- Potential for methanol pilot fuel

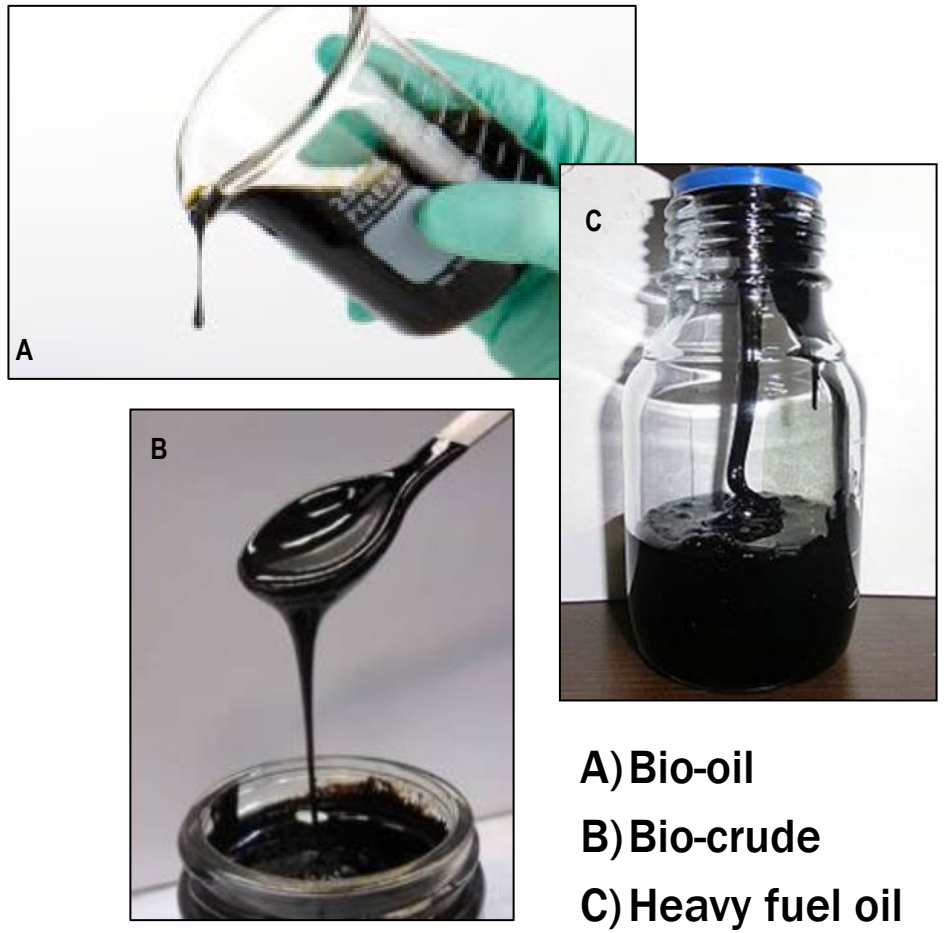
Hydrothermal Liquefaction Skid at PNNL



Thermochemical Process Development Unit at NREL

Marine Biofuels Progress to Date

- **Focus on large ocean-going vessels**
  - Smaller vessels can more easily utilizes other energy sources (electric/hydrogen, etc.)
- **Heavy fuel oil (HFO) replacing biofuels / blends**
  - Bio-oil
  - Bio-crudes
- **Biodiesels and renewable diesels are currently available**
  - Only part of the solution
  - Potentially have global LCA, TEA, and availability risks
- **Based on techno-economic analysis (TEA), life cycle analyses (LCAs), characterization data**

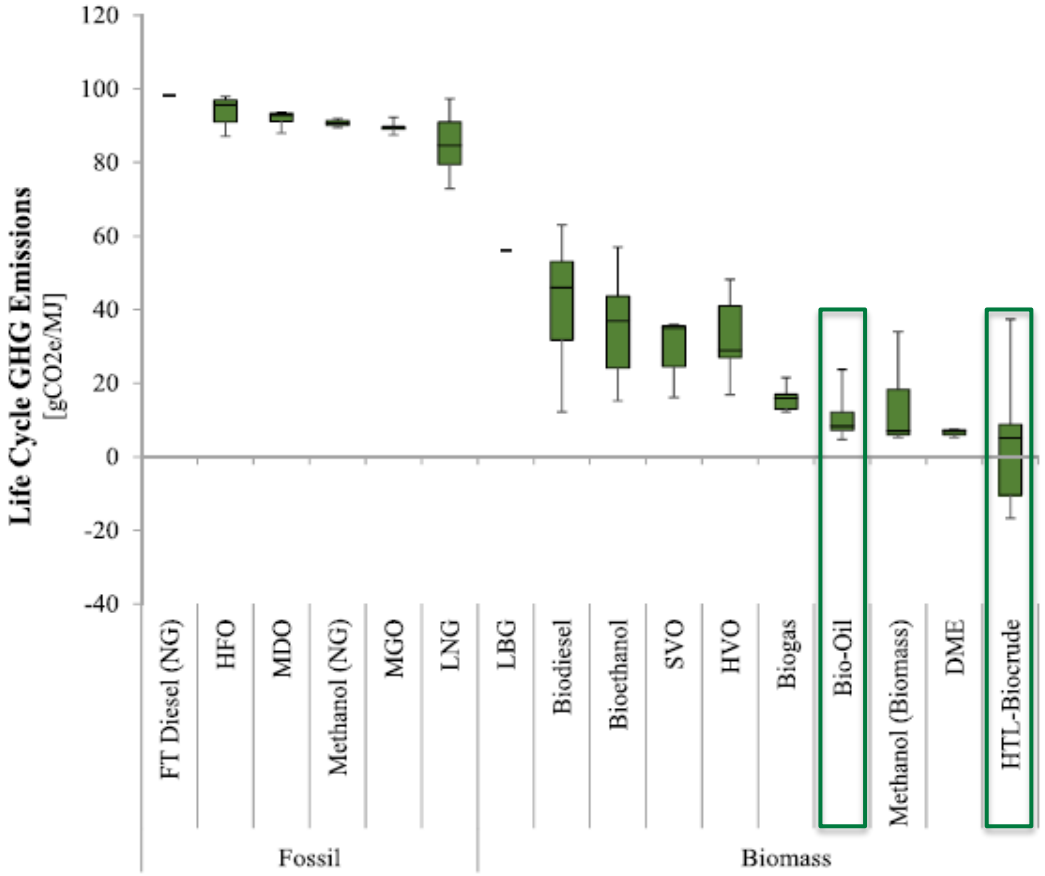


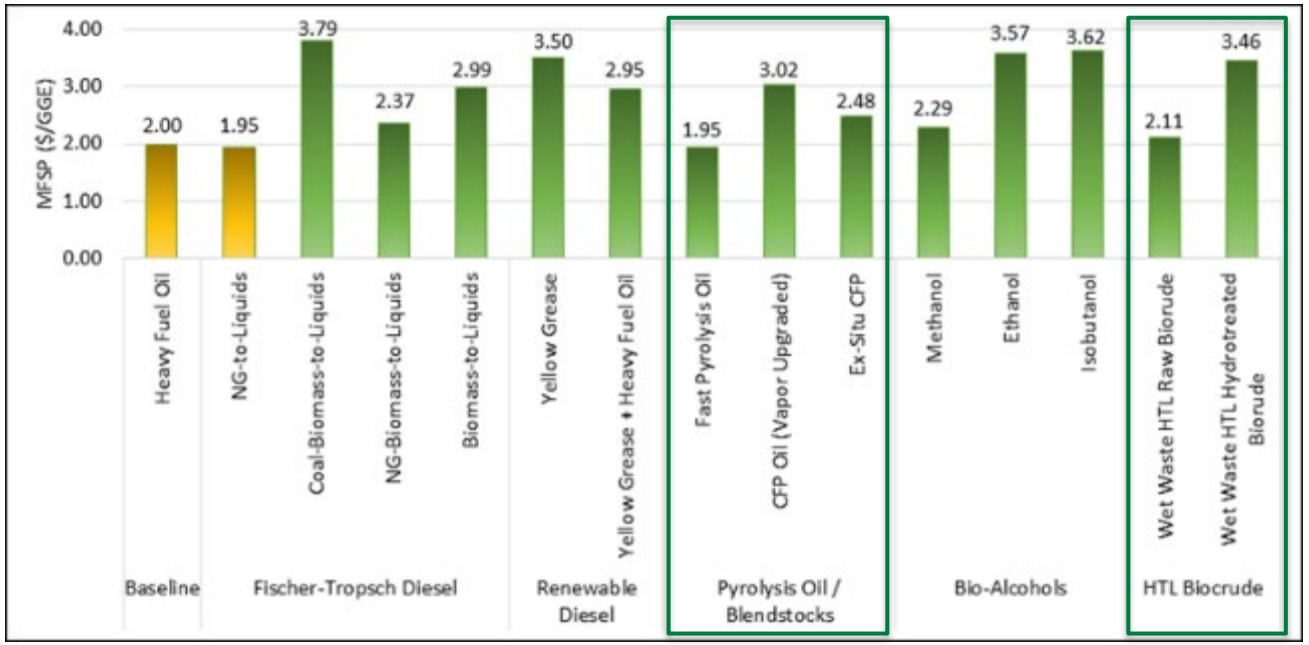
A) Bio-oil
B) Bio-crude
C) Heavy fuel oil

Images courtesy of IEA Bioenergy Task 34 and PNNL

Marine Biofuels Progress to Date

- GHG reduction potential is good
- Costs need to be reduced
- Drop-in/blending options





- **Environmental justice considerations**
  - Less pollutants near ports
  - Can be made from typical waste streams
- **Energy security**

Marine Biofuels Progress to Date

Biofuels for Marine Use Potential

- Have great potential for CO_2e reduction on a full well-to-wake basis
- Environmental justice contributions
- Drop-in fuel potential
- Better for near- and mid-term goals
- Ability to utilize existing infrastructure or relatively lost retrofit costs

Biofuels for Marine Use Barriers

- One piece of the maritime carbon reduction puzzle
- But are currently costly and have volume limitations
- Potential land-use change for feedstock production
- Need industry buy-in

Collaboration

Crosscutting EERE Office Effort

Hydrogen and Fuel Cell Technologies Office, Vehicles Technologies Office

- Developing hard to electrify strategies
  - Aviation, marine, rail, and heavy-duty fuel

Intra- and Inter-Agency Efforts

U.S. Department of Transportation (DOT) Maritime Administration, DOT Volpe Center, State Department, DOE Loan Programs Office, DOE Arctic Energy Office

- Aligning with a whole-of-government approach

International Efforts

Mission Innovation: Zero-Emissions Shipping

- The Goal: For ships capable of running on zero-emission fuels to make up at least 5% of the global deep-sea fleet by 2030

International Energy Agency (IEA): Task 39

- Biofuels for the marine shipping sector

Industry Engagement

Lab Led External Advisory Board

- Made up of over 16 industry members
- Helps give perspective to industry's thinking

Future Work

More detailed LCA and TEA

- Optimal biofuel production pathways and blend levels
- Further refine the GREET marine fuel module
- Conducting LCAs for apples-to-apples comparison
  - Green ammonia, green methanol, green hydrogen, and CO_2 derived fuels
- Temporal considerations

Global feedstock resource evaluation

- Resource assessments
- Green Corridor analyses

Evaluate pathways that can serve both aviation and marine sectors

Future Work

Further investigation of fuel properties

- Determine fuel upgrading needed for bio-oils/bio-crudes
- Determine the optimum blend levels
- Bunkering logistics

Process scale-up

- Produce meaningful quantities, evaluate at meaningful scale
- Eventual engine/vessel testing

Environmental justice

- Ensure equity

Mechanisms for continued work

- Continue to work with national laboratories
- Leverage interagency collaborations
- Leverage Mission Innovation work
- Scale-up funding opportunities announcements

Are You Interested in Becoming a BETO Reviewer?

Wanted:

Subject matter experts to review research funding applications.

Applying is as easy as 1-2-3.

Fact Sheet:
energy.gov/eere/bioenergy/interested-becoming-beto-project-reviewer

EERE Funding Opportunity Exchange:
eere-exchange.energy.gov/Registration.aspx

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Learn more about BETO: energy.gov/bioenergy

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BIOENERGY TECHNOLOGIES OFFICE

Resources

Understanding the Opportunities of Biofuels for Marine Shipping
- https://info.ornl.gov/sites/publications/Files/Pub120597.pdf

Adoption of Biofuels for the Marine Shipping Industry: A Long-Term Price and Scalability Assessment
- https://www.nrel.gov/docs/fy21osti/78237.pdf

Biofuel Options for Marine Applications: Techno-Economic and Life Cycle Analyses
- https://pubs.acs.org/doi/10.1021/acs.est.0c06141

Challenges and Opportunities for Alternative Fuels in the Maritime Sector
- https://www.nrel.gov/docs/fy21osti/78747.pdf

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Life Cycle Analysis of Alternative Fuels for Maritime Shipping

Troy R. Hawkins

Argonne National Laboratory

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  - Asanga Padmaperuma
  - Jalal Askander
  - John Holladay

Objective

Accelerate uptake of biofuels for maritime shipping with analysis and testing. Lay groundwork for biofuel demonstration.

Photo source: https://www.shutterstock.com/image-photo/large-container-ship-roaring-across-sea-1217473543

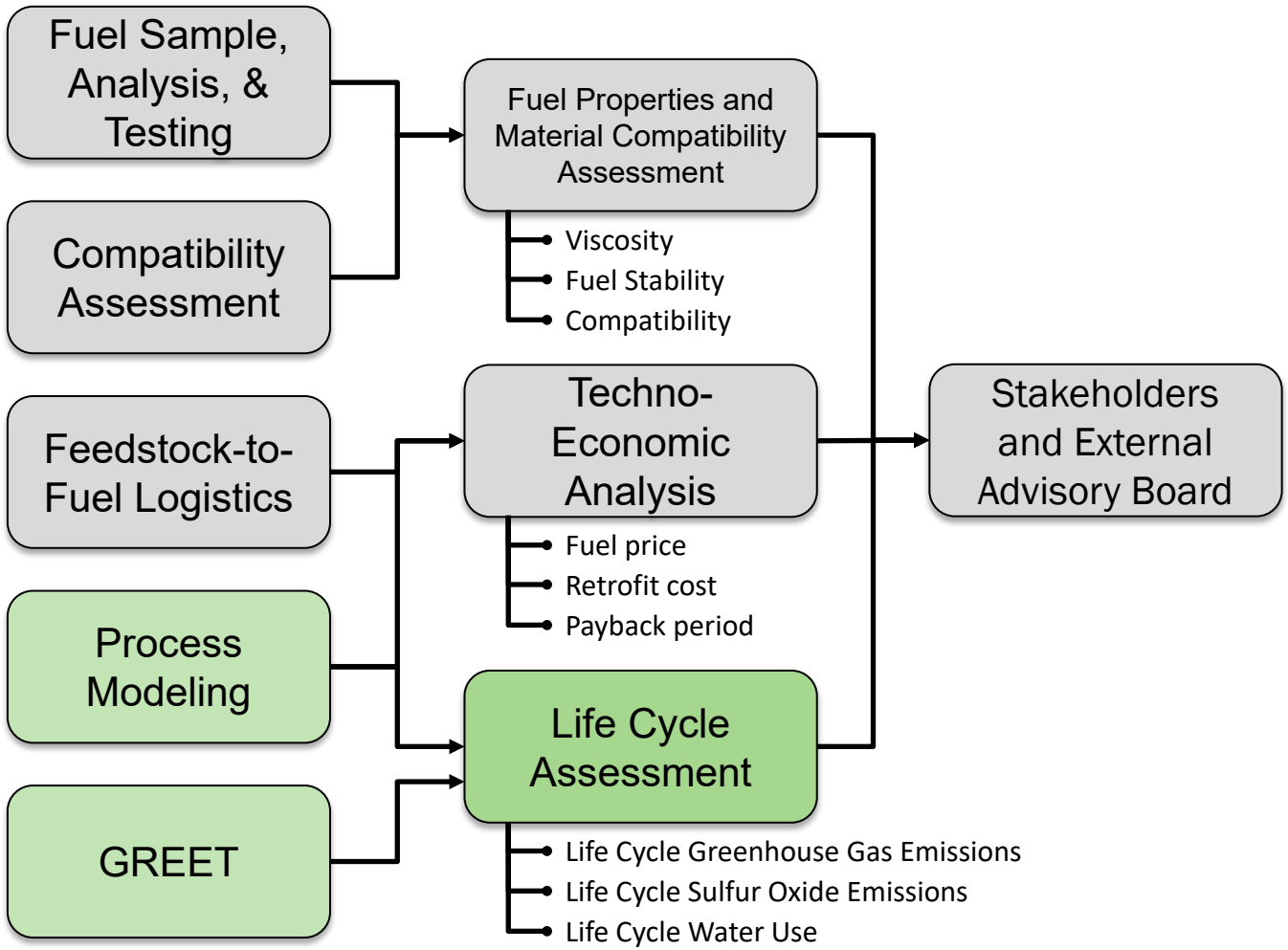
Bioenergy Technologies Office Multi-Laboratory Effort

OAK RIDGE National Laboratory

Argonne NATIONAL LABORATORY

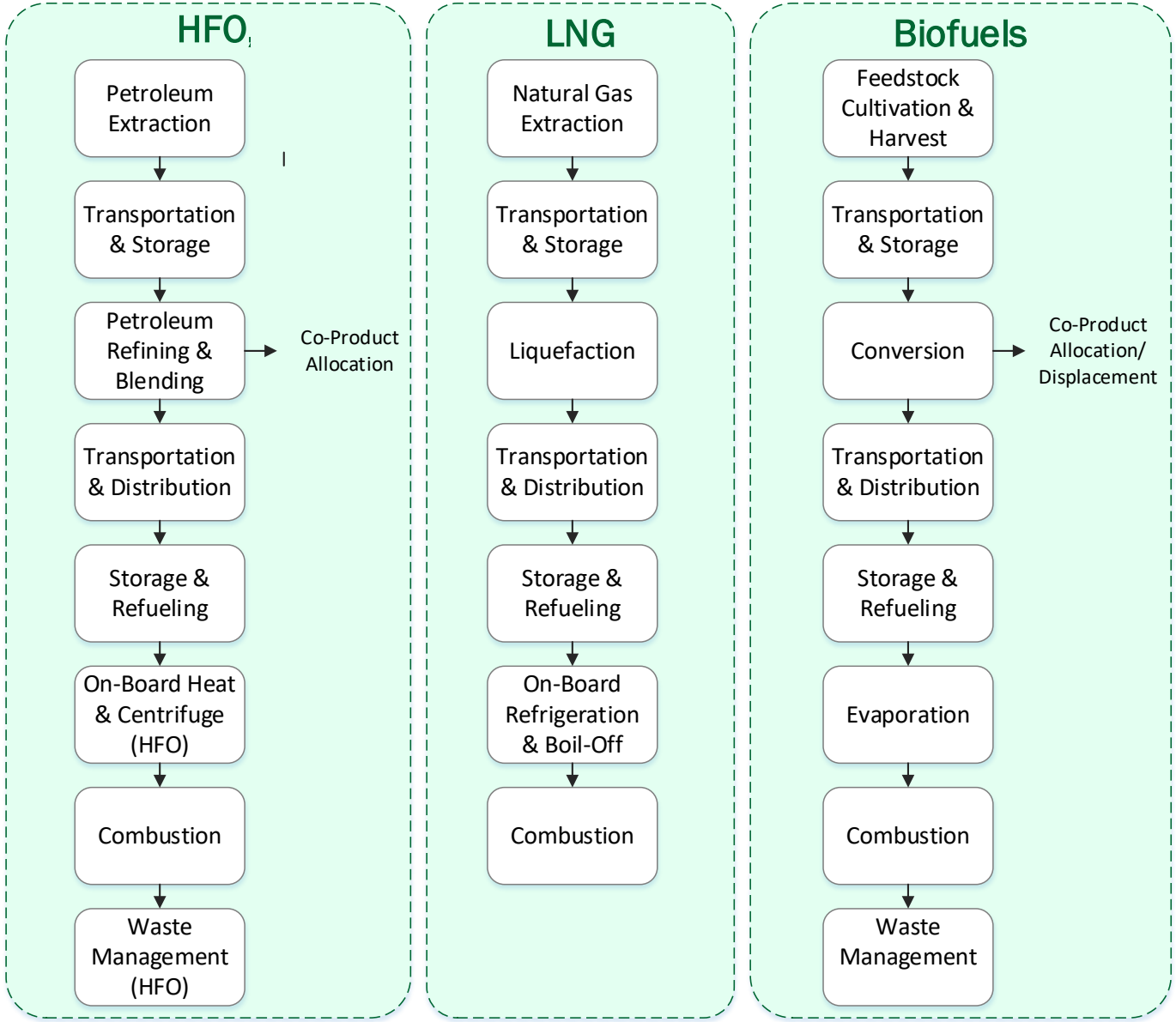
NREL Transforming ENERGY

Pacific Northwest NATIONAL LABORATORY



Life Cycle Analysis

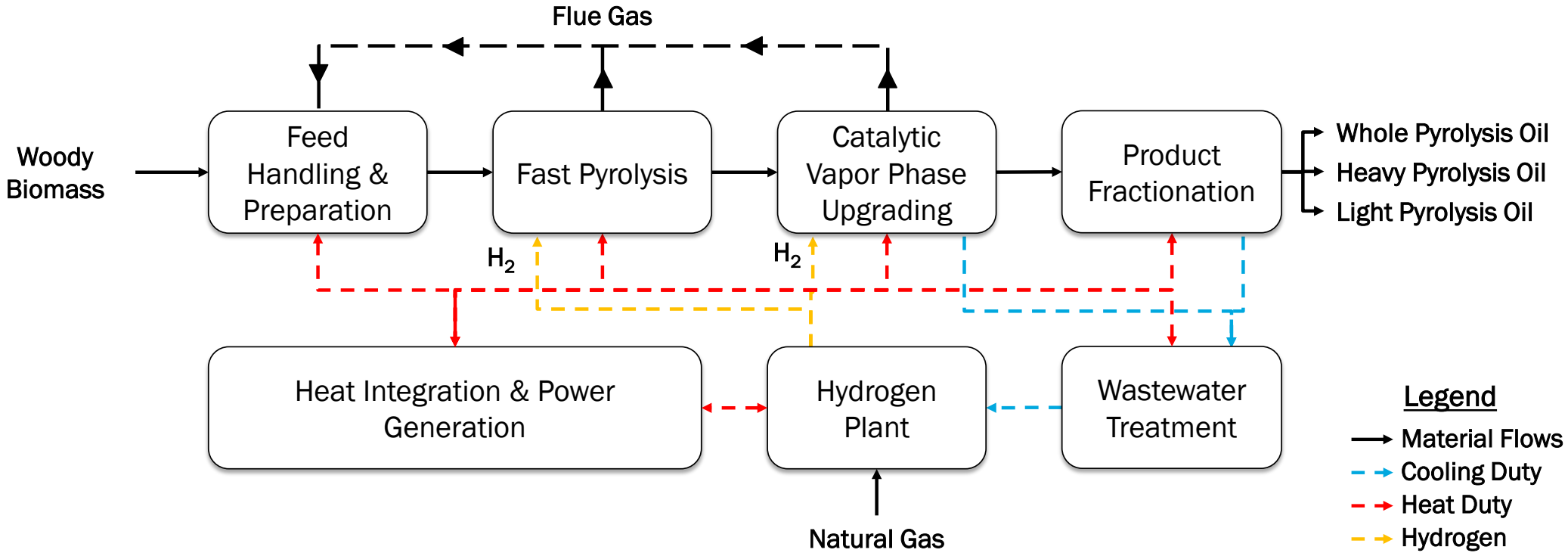
- Avoid burden shifting across supply chain segments
- Screen across potential environmental impacts
- Identify key drivers
- Compare on an apples-to-apples basis



HFO: heavy fuel oil; LNG: liquefied natural gas

Marine Bio-Oil Pathways

- Catalytic fast pyrolysis
- Hydrothermal liquefaction of sludge and manure
- Fischer-Tropsch synthesis of landfill gas
- Lignin-ethanol oil

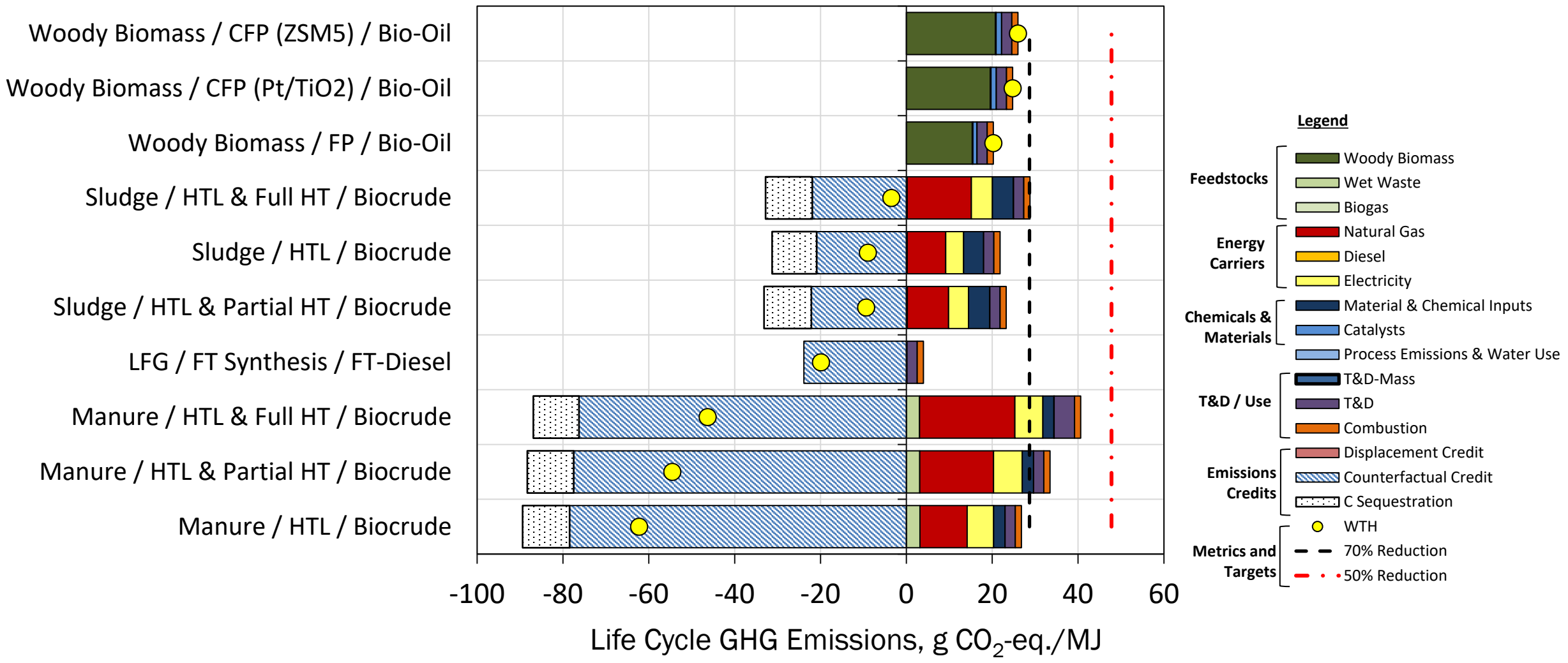


Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies

- **Tracks life cycle performance of fuels and transportation technologies**
- **Over 50,000 registered users**
  - Distributed globally and across industry and research organizations
- **Used to support regulatory measures**
  - U.S. Environmental Protection Agency Renewable Fuels Standard
  - California Low Carbon Fuel Standard
  - International Civil Aviation Organization (ICAO)
  - Oregon Clean Fuels Program
- **Developed since 1995 with annual updates and expansions**
- **Long-term support from DOE**
  - Bioenergy Technology Office
  - Vehicle Technologies Office
  - Hydrogen Fuel Cell Technologies Office

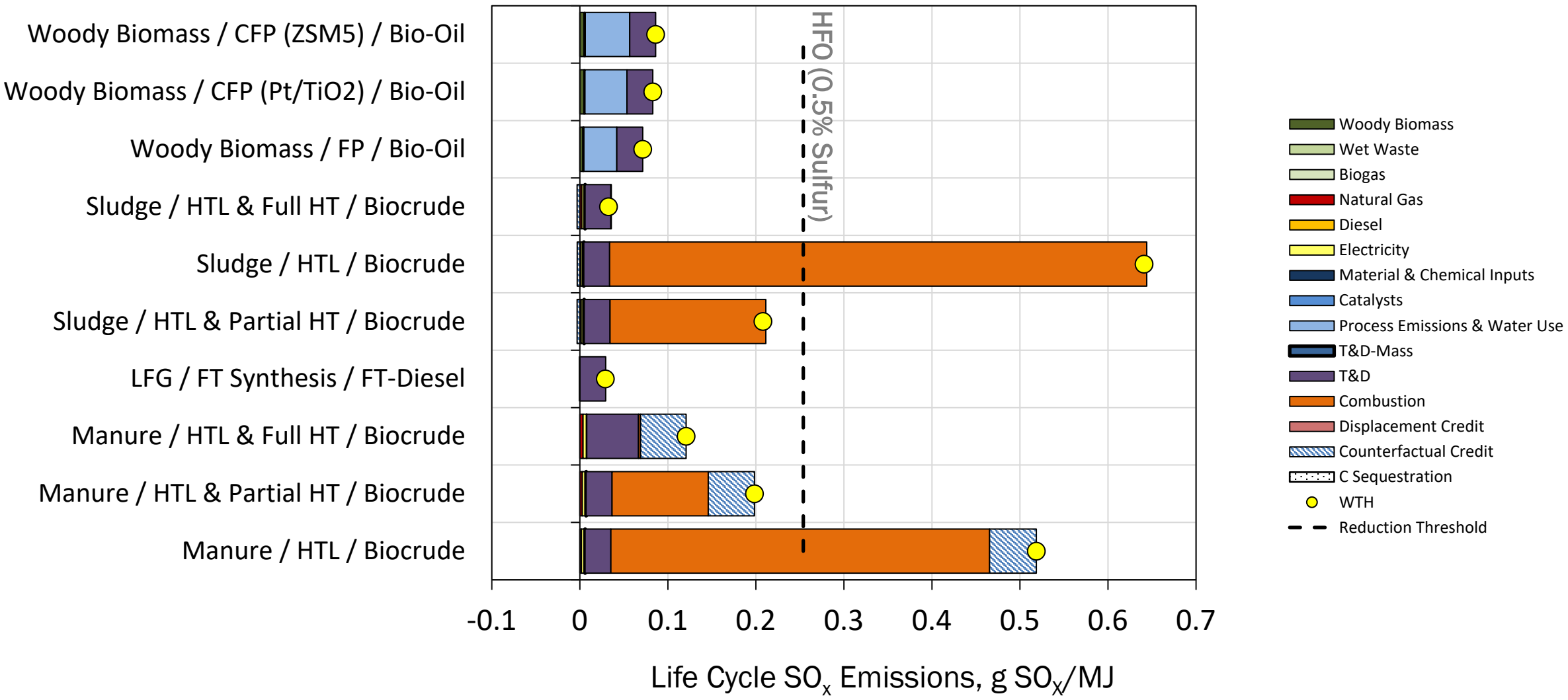
https://greet.es.anl.gov/

Marine Bio-Oils: Life Cycle Greenhouse Gas Emissions



CFP: Catalytic Fast Pyrolysis; **ZSM5**: Zeolite Socony Mobil-5; **TiO2**: Titanium Dioxide; **FP**: Fast Pyrolysis; **HTL**: Hydrothermal Liquefaction; **HT:** Hydrotreating; **LFG**: Landfill Gas; **T&D**: Transportation and Distribution; **WTH**: Well-to-Hull

Marine Bio-Oils: Life Cycle Sulfur Oxide Emissions



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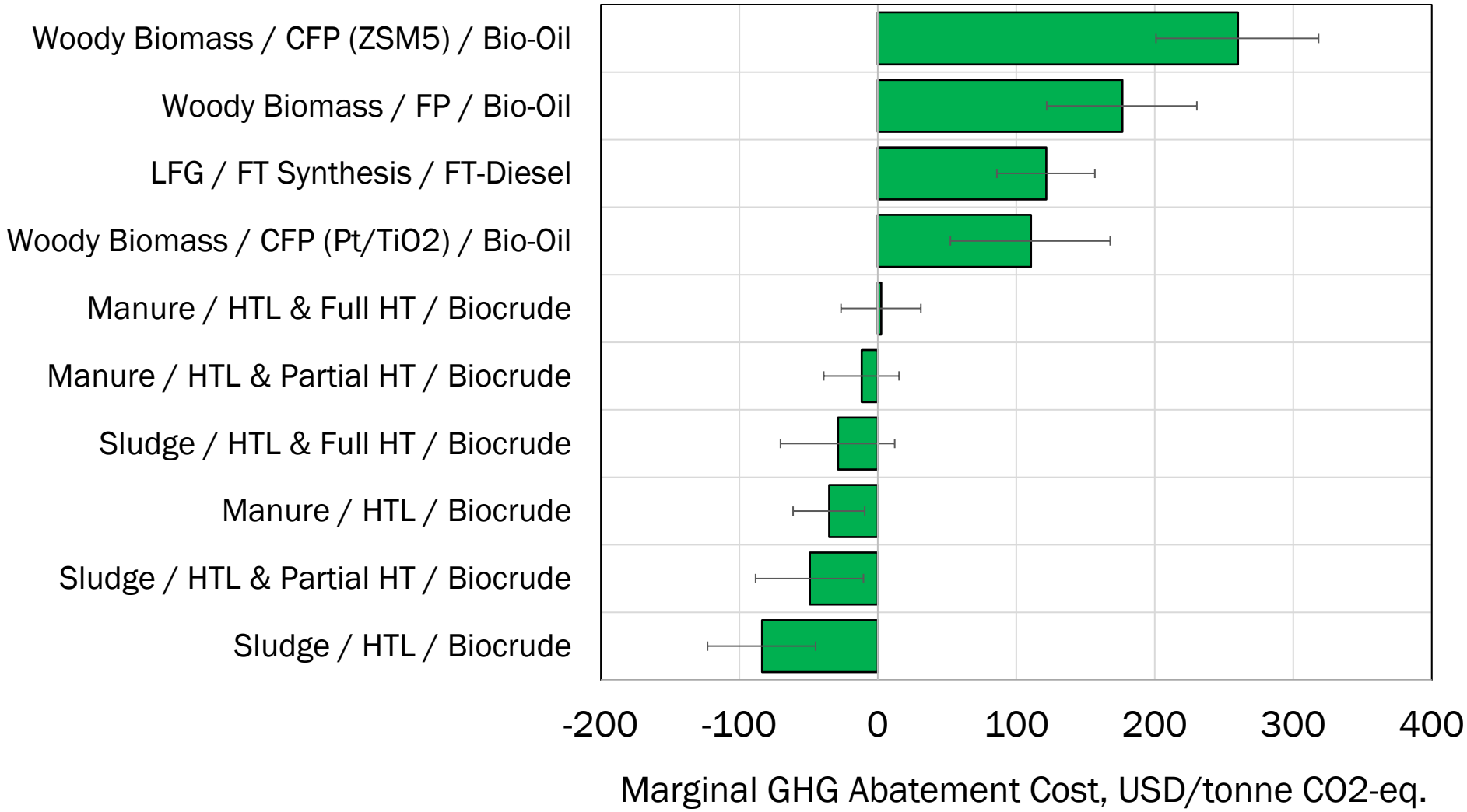
Marine Bio-Oils: Marginal GHG Abatement Cost



- -90 to 400 USD/tonne CO_2-eq.
- Waste HTL achieve negative MAC due to low prices
- California Low Carbon Fuel Standard credits recently ~150-200 USD/tonne CO_2-eq.

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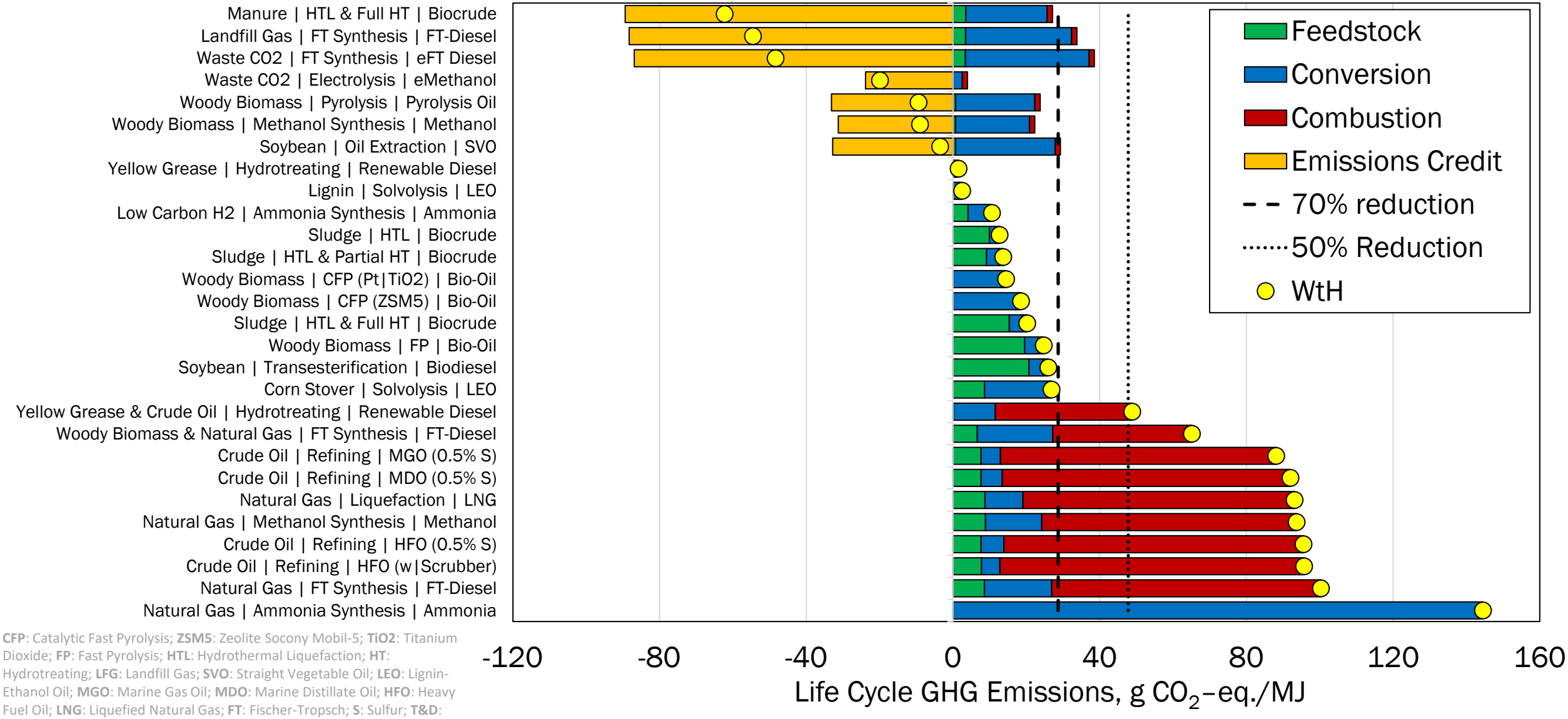
Marine Fuel Alternatives: Life Cycle GHG Emissions



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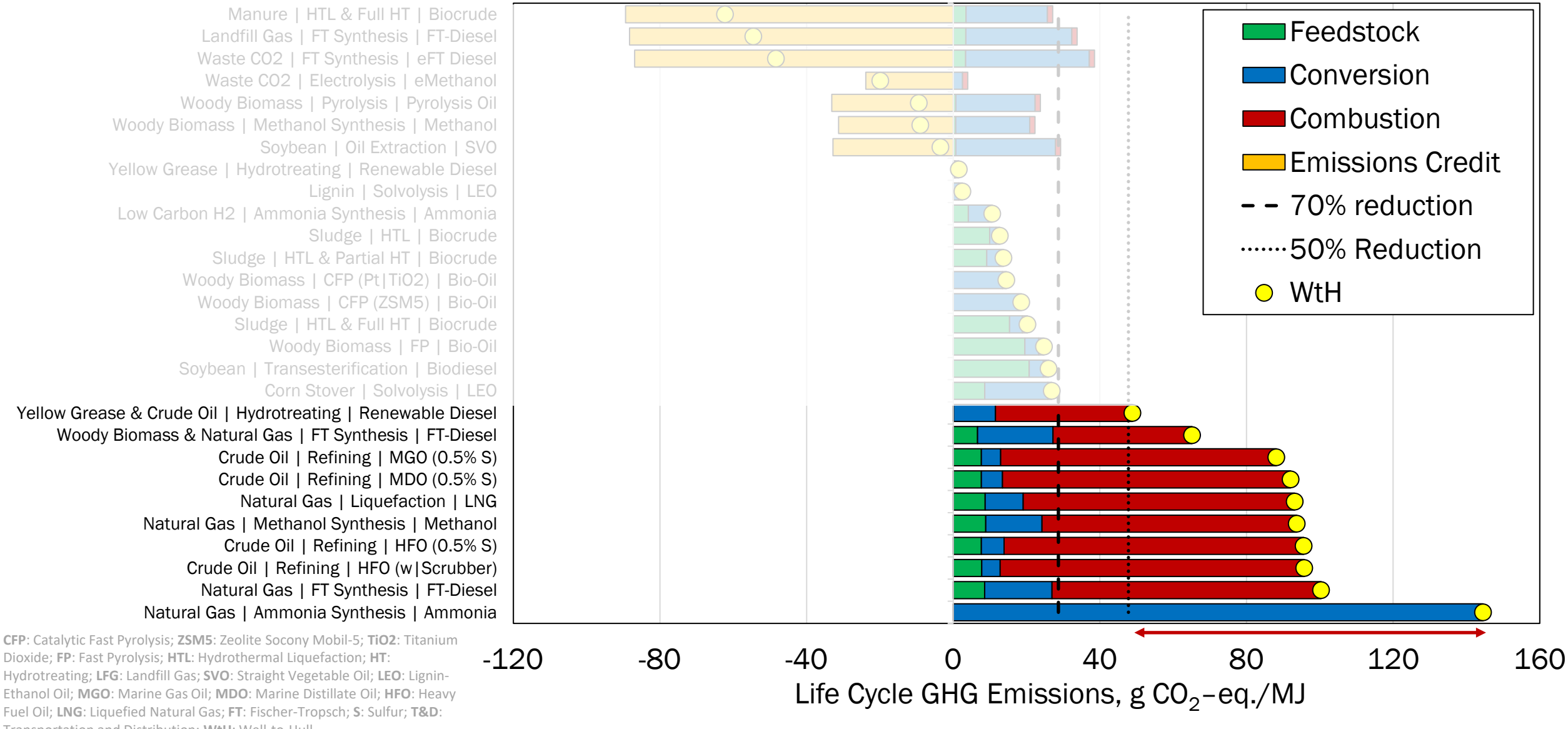
Fossil Fuels: Life Cycle GHG Emissions



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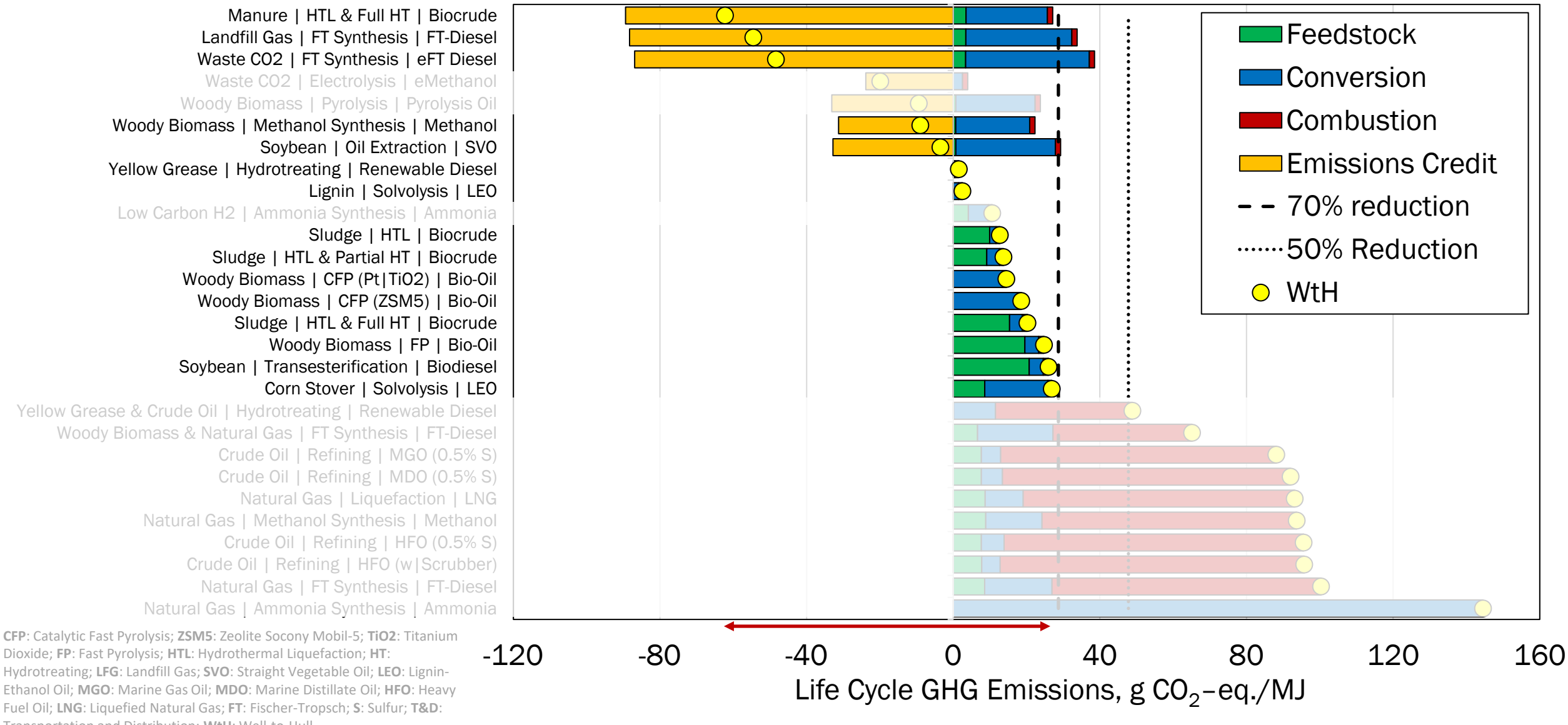
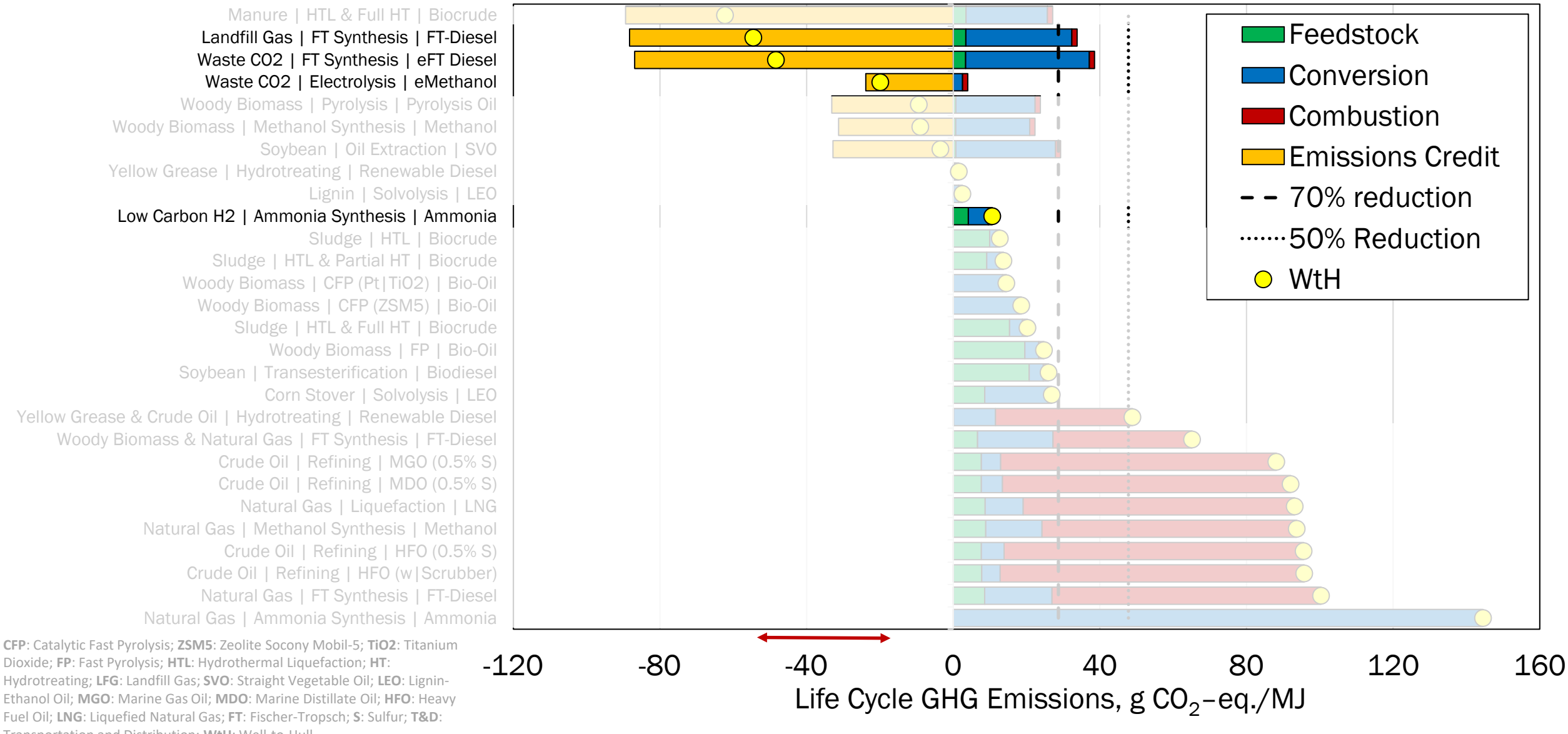
Biofuels: Life Cycle GHG Emissions



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

E-Fuels and Green Ammonia: Life Cycle GHG Emissions



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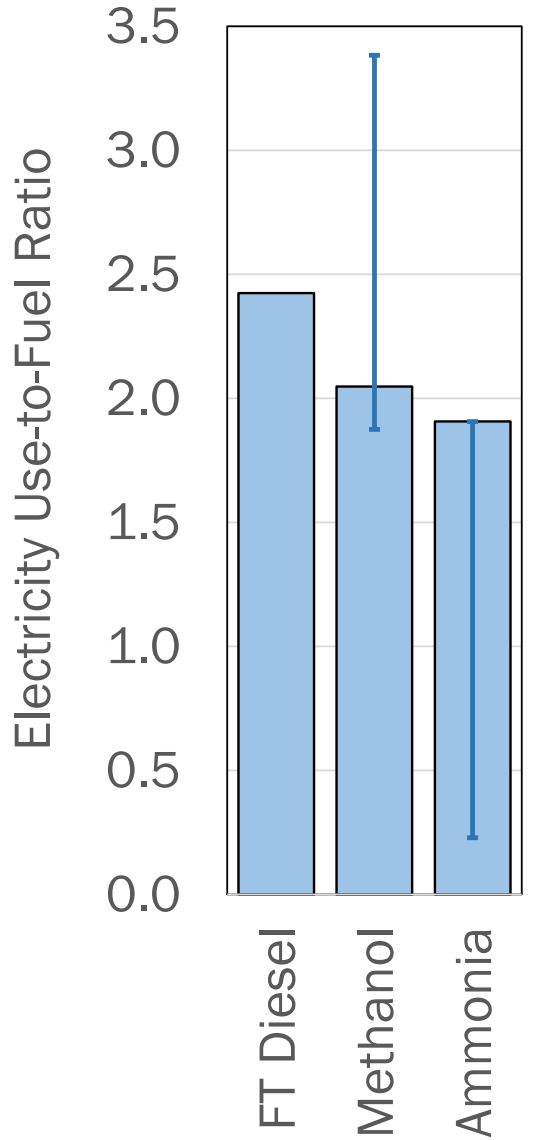
E-Methanol, E-FT Diesel, and Green Ammonia

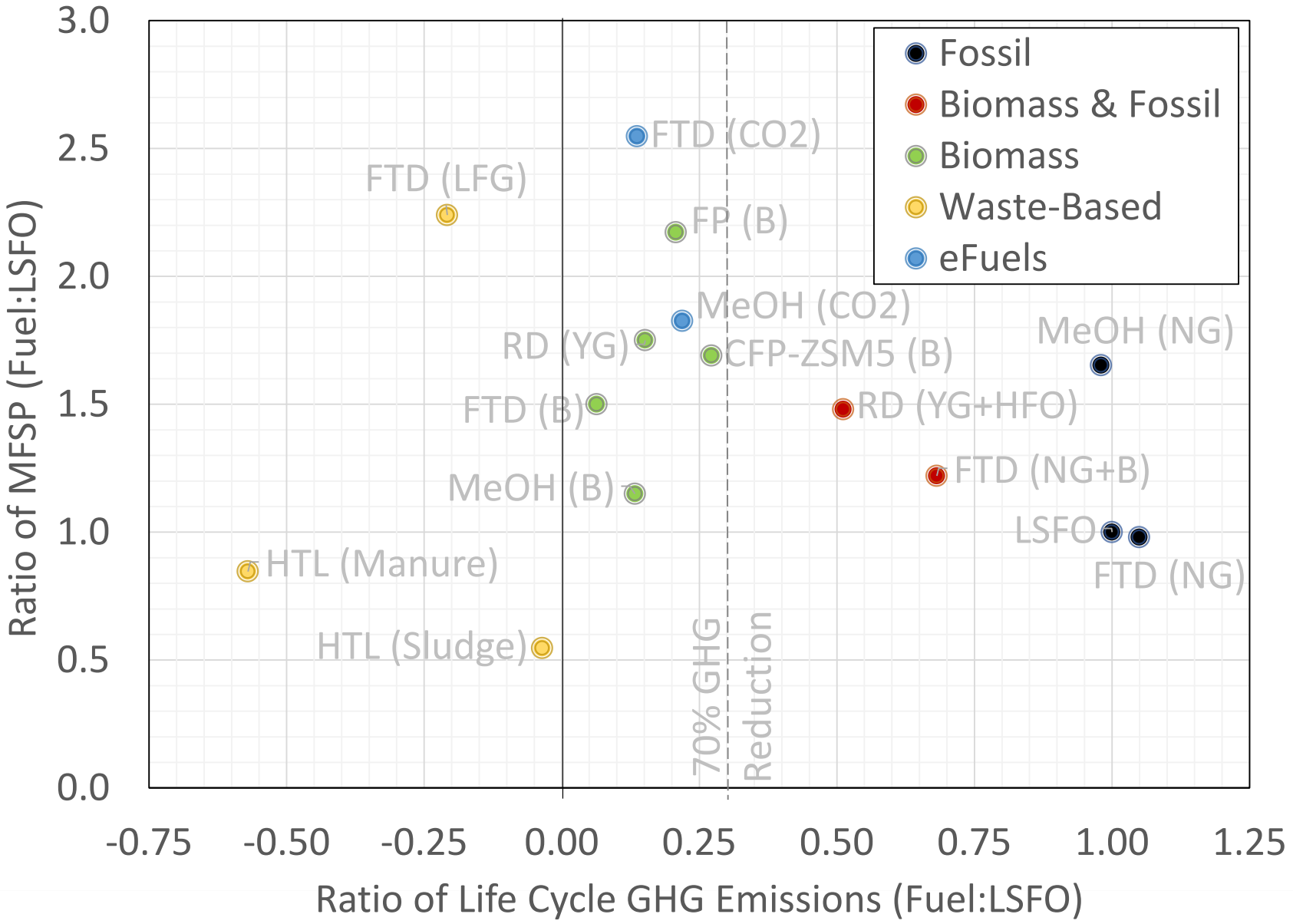
- **Opportunity to use future low-carbon, low-cost electricity**
- **Potential compliment to bio-based pathways in the longer-term**
- **Research needed to better characterize ammonia as a fuel**
- **Significant electricity demand**
  - Competing with other uses of renewable electricity
  - 30%–40% increase in global electricity demand



Multiple Promising Pathways: Greenhouse Gas and Cost

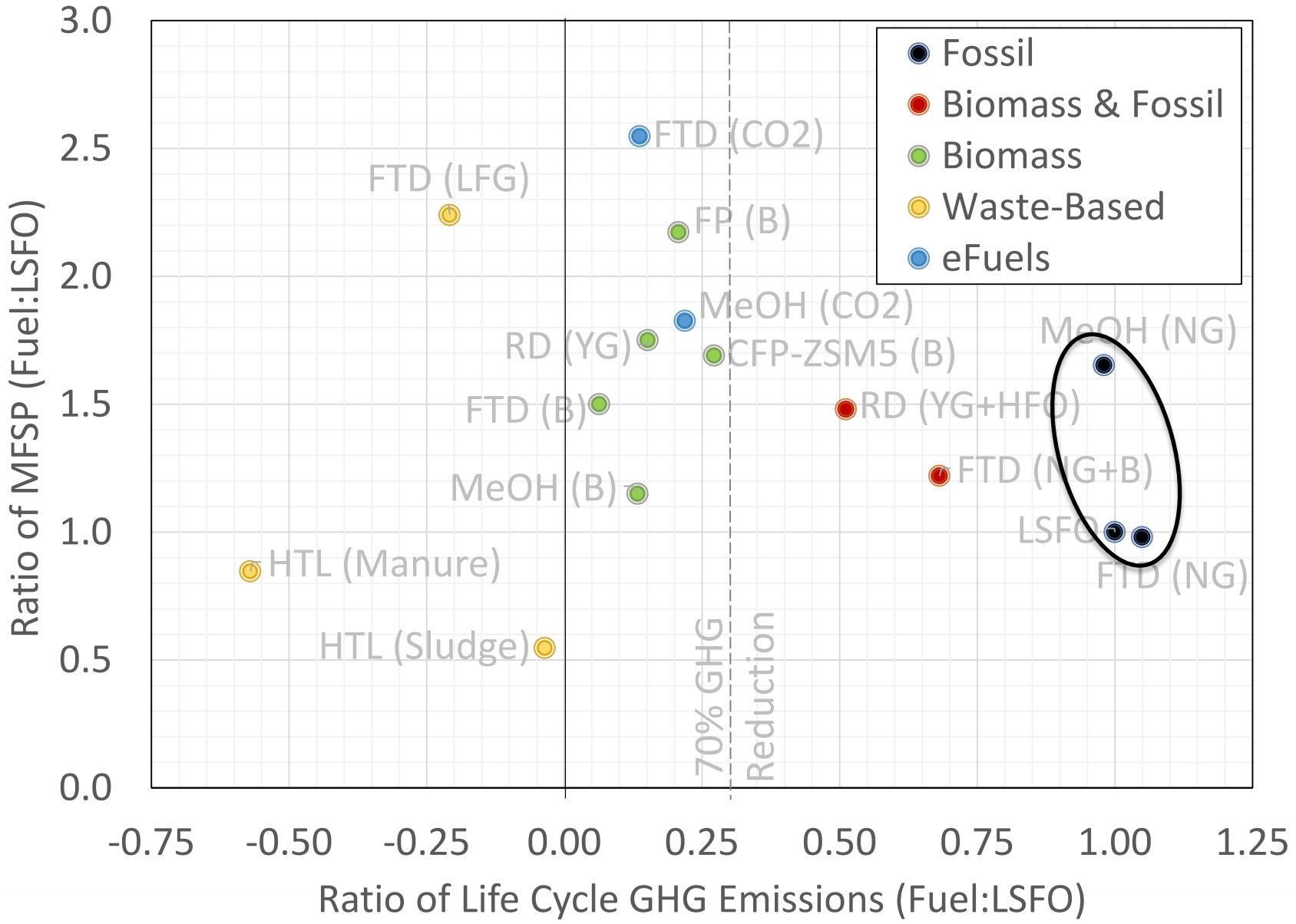
Comparing life cycle greenhouse gas emissions and minimum fuel selling price (MFSP) of marine fuel alternatives

Values are ratio of alternative fuel to conventional low sulfur fuel oil (LSFO)



Multiple Promising Pathways: Greenhouse Gas and Cost

Fossil fuels offer reasonable prices with greenhouse gas drawbacks

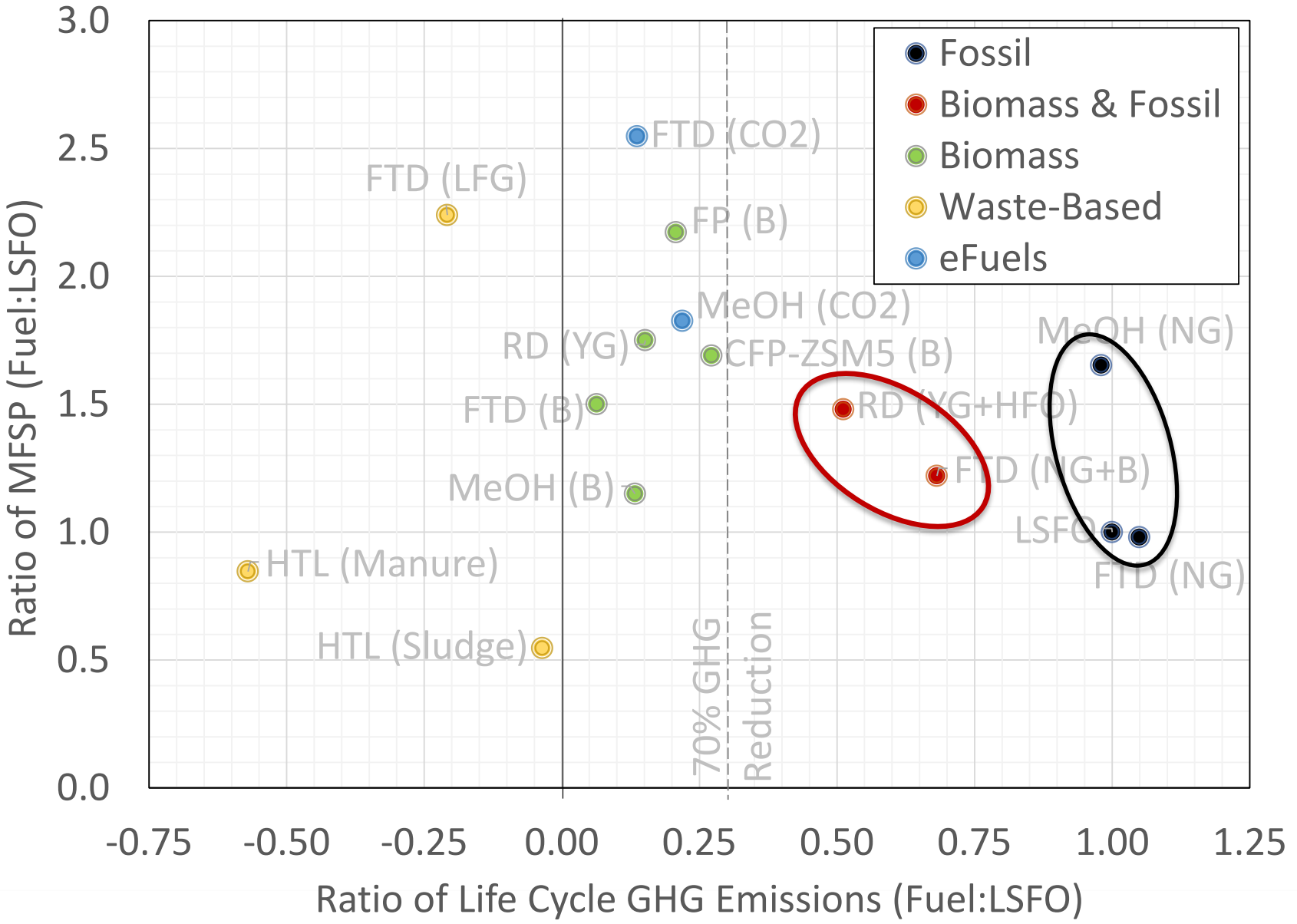


Multiple Promising Pathways: Greenhouse Gas and Cost

Select fossil-biomass "co-feed" pathways offer greenhouse gas and price compromise

Potential bridge to deeper decarbonization

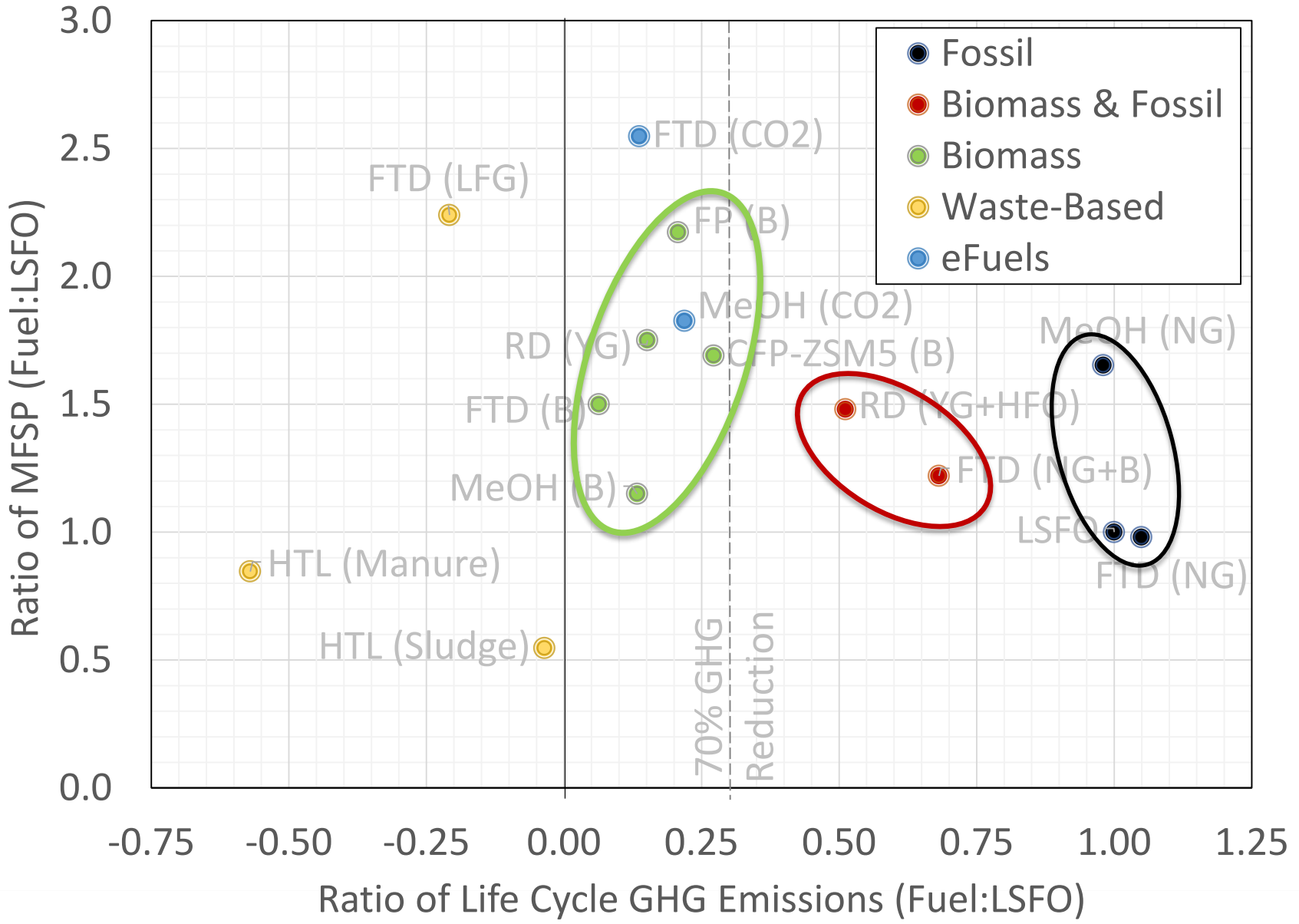
Higher marginal cost of greenhouse gas abatement



Multiple Promising Pathways: Greenhouse Gas and Cost

Biofuels can achieve significant greenhouse gas reductions

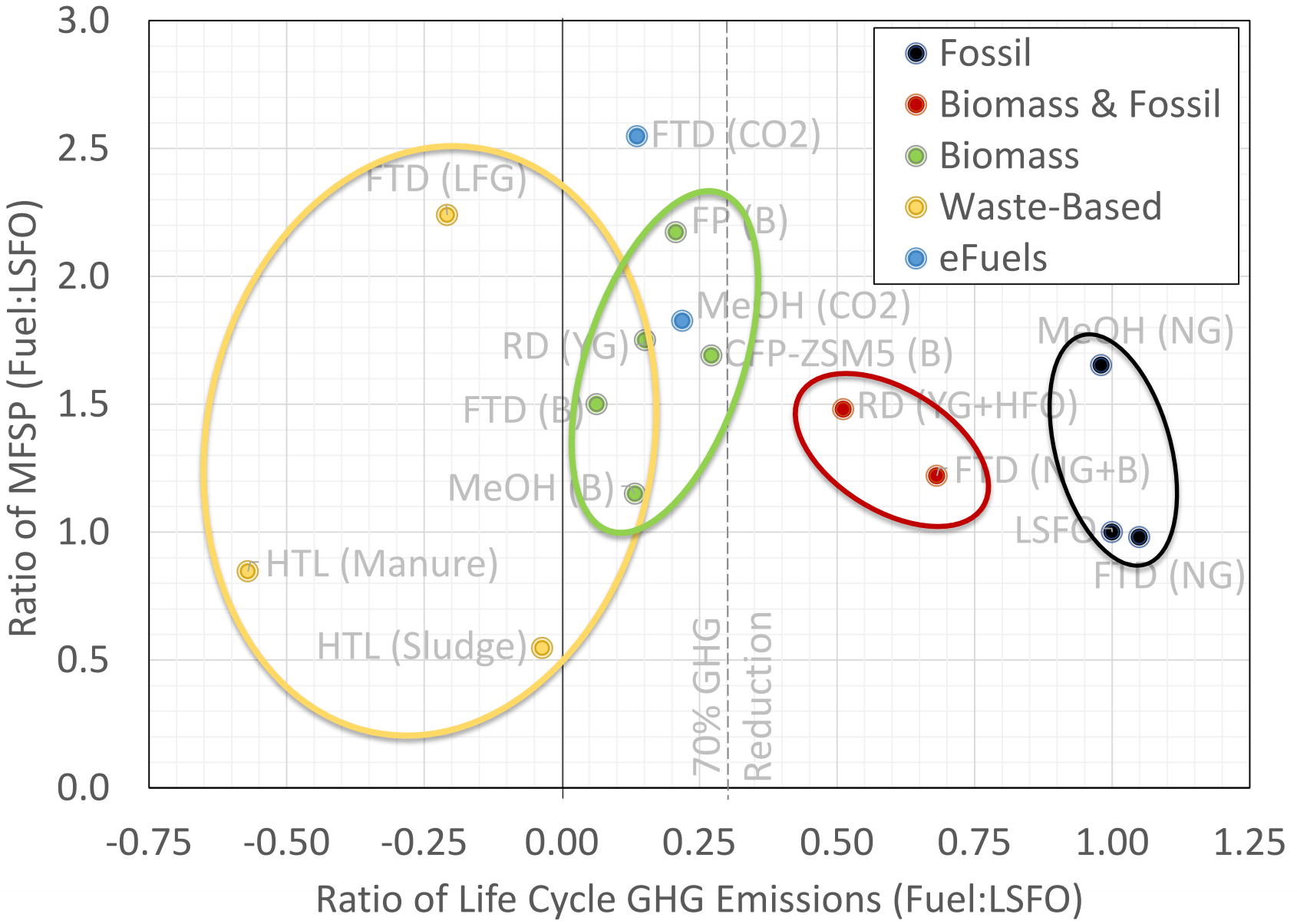
Prices can approach those of conventional low sulfur fuel oil



Multiple Promising Pathways: Greenhouse Gas and Cost

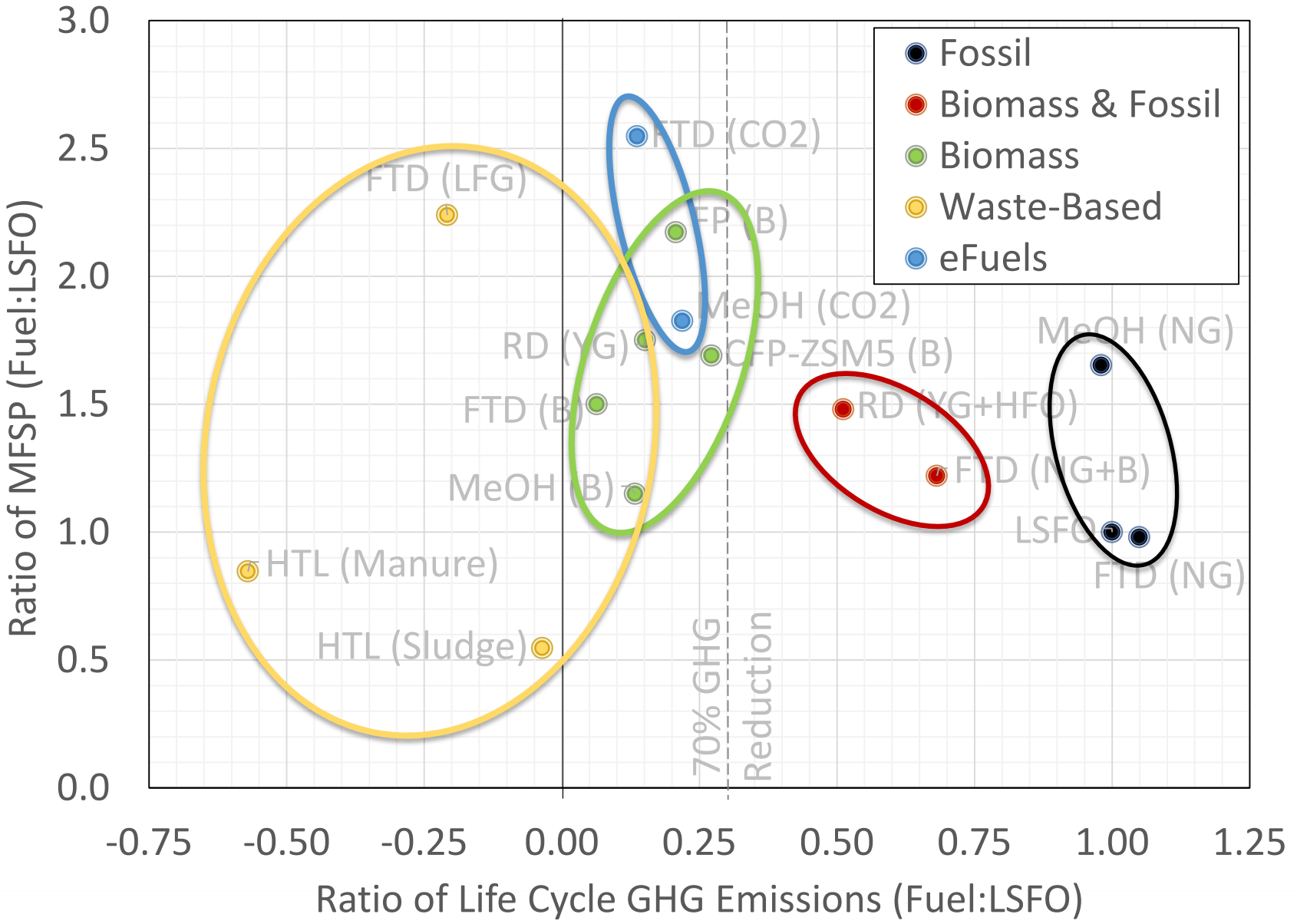
Select waste-based pathways can achieve net-negative greenhouse gas emissions

Promising costs suggest potential to compete with conventional low sulfur fuel oil



Multiple Promising Pathways: Greenhouse Gas and Cost

E-fuels, produced from captured CO_2 and renewable electricity, could significantly increase low-carbon fuel supply

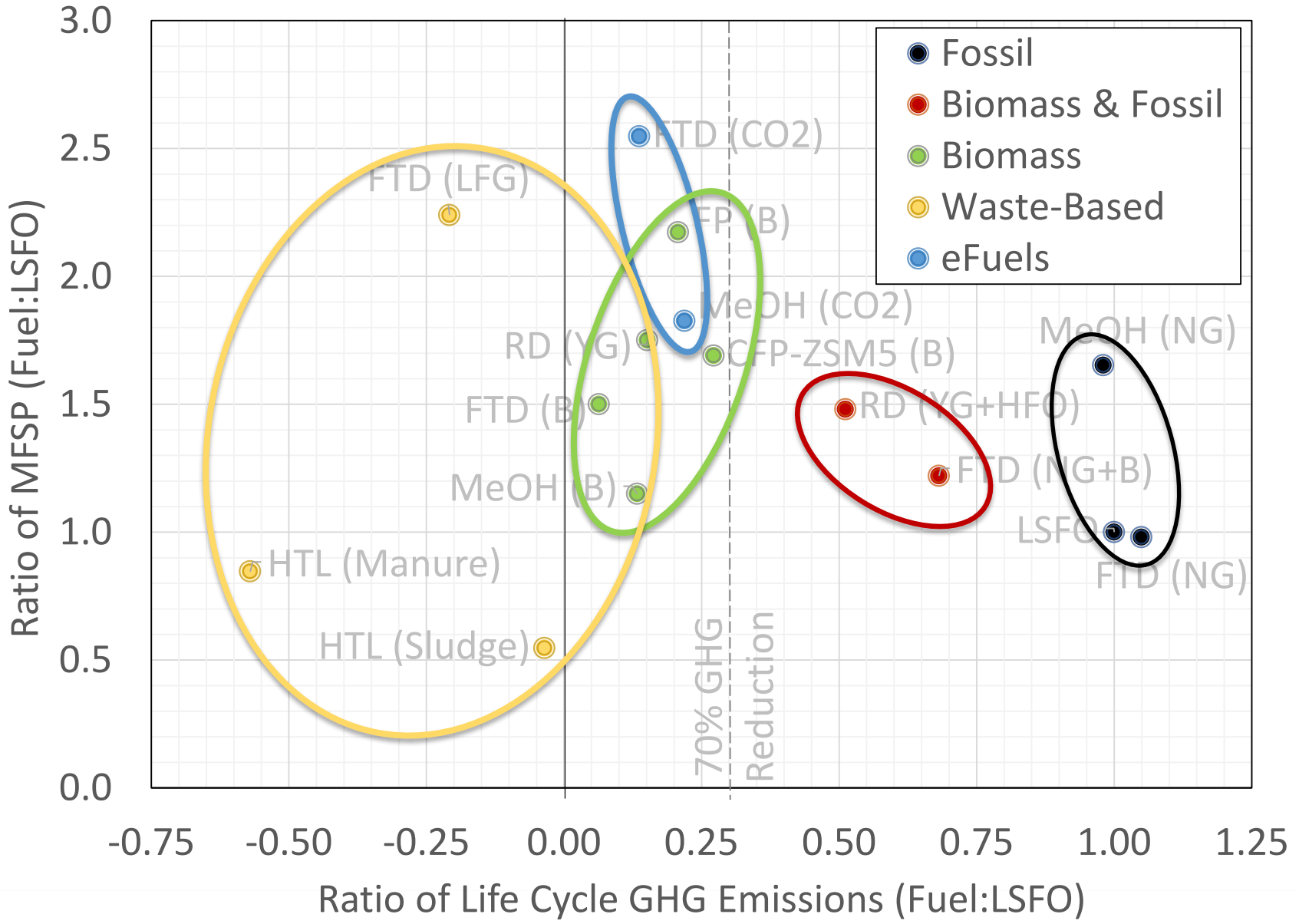


Multiple Promising Pathways: Greenhouse Gas and Cost

Promising pathways could reduce GHG emissions, relatively modest price increase

Multiple pathways needed to meet demand

Industry experience important to optimize production



Conclusion and Perspectives

- International and national policies driving maritime shipping toward low-carbon fuels
- Harmonized life cycle analysis is critical to guide the way
- Multiple biofuel pathways offer significant GHG reductions, bio-oils and methanol may offer reasonable price premiums
- Research and development needed to drive commercialization of a sustainable, low-carbon heavy fuel oil alternative

Maersk Mc-Kinney Moller Center for Zero Carbon Shipping

MISSION INNOVATION

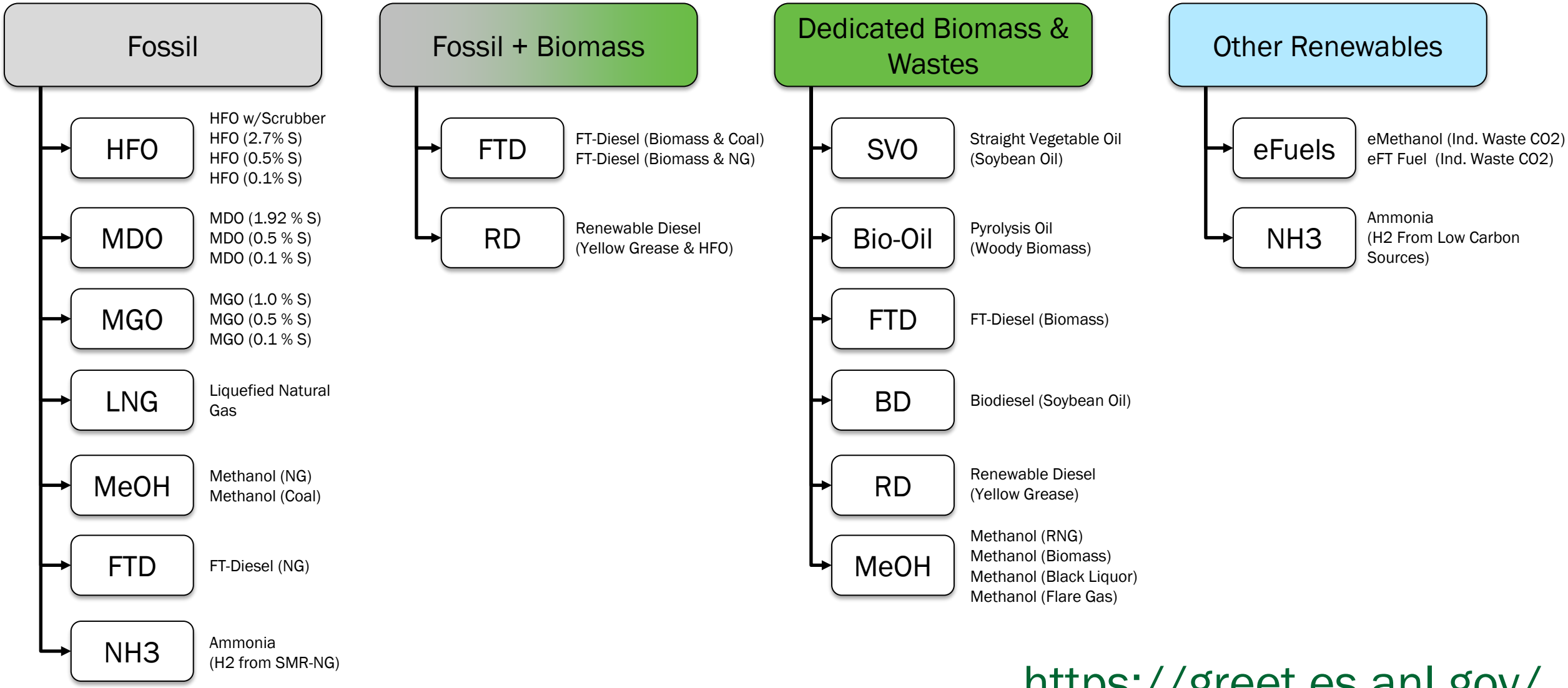
GLOBAL MARITIME FORUM

SEA CARGO CHARTER

POSEIDON PRINCIPLES

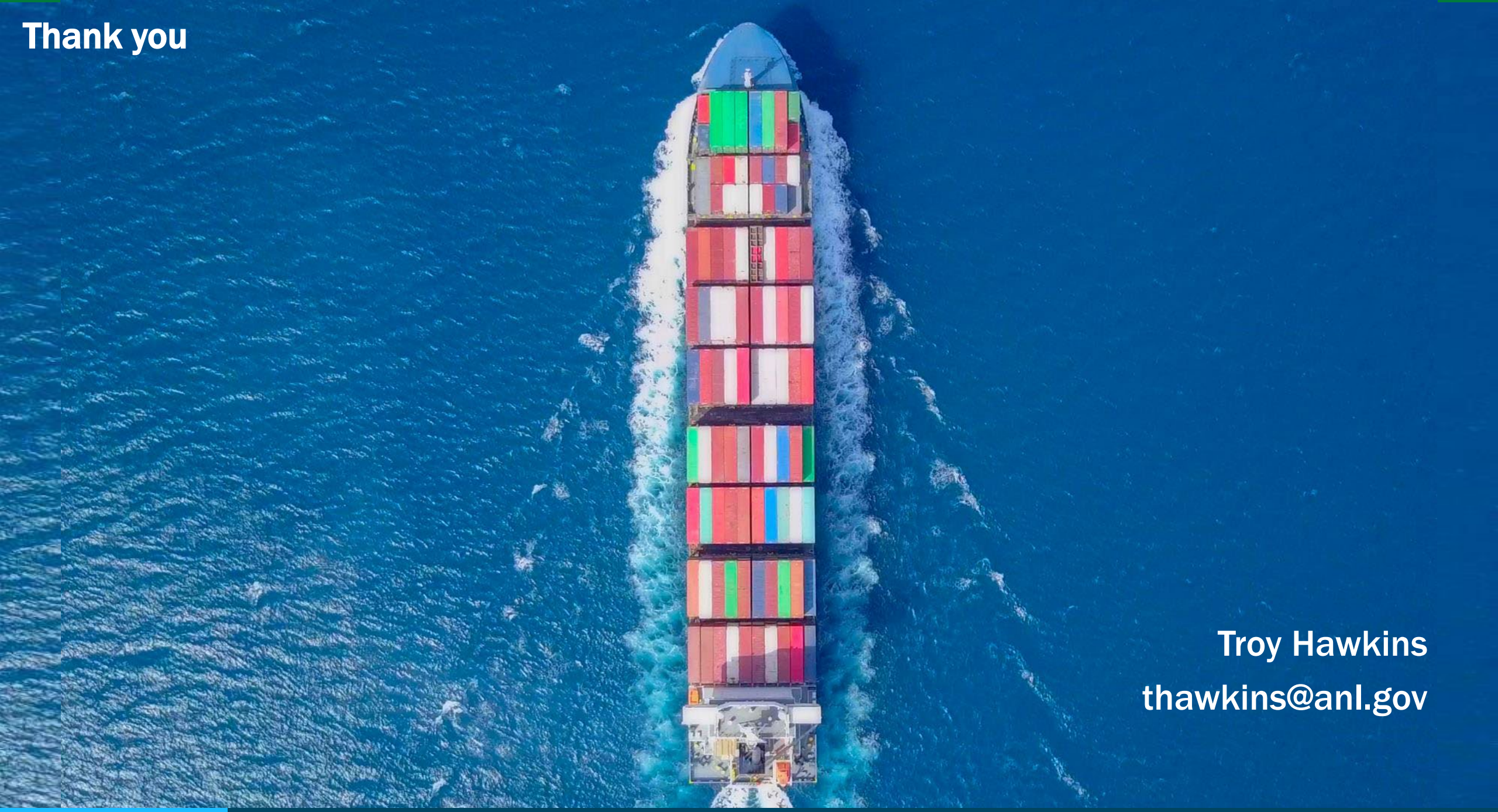
WPCAP

Publicly-Available LCA Models: GREET 2021



https://greet.es.anl.gov/

Thank you



Troy Hawkins
thawkins@anl.gov

Photo source: https://www.shutterstock.com/image-photo/large-container-ship-roaring-across-sea-1217473543

Dr. Lee Kindberg
Head of Environmental Sustainability–North America
Maersk

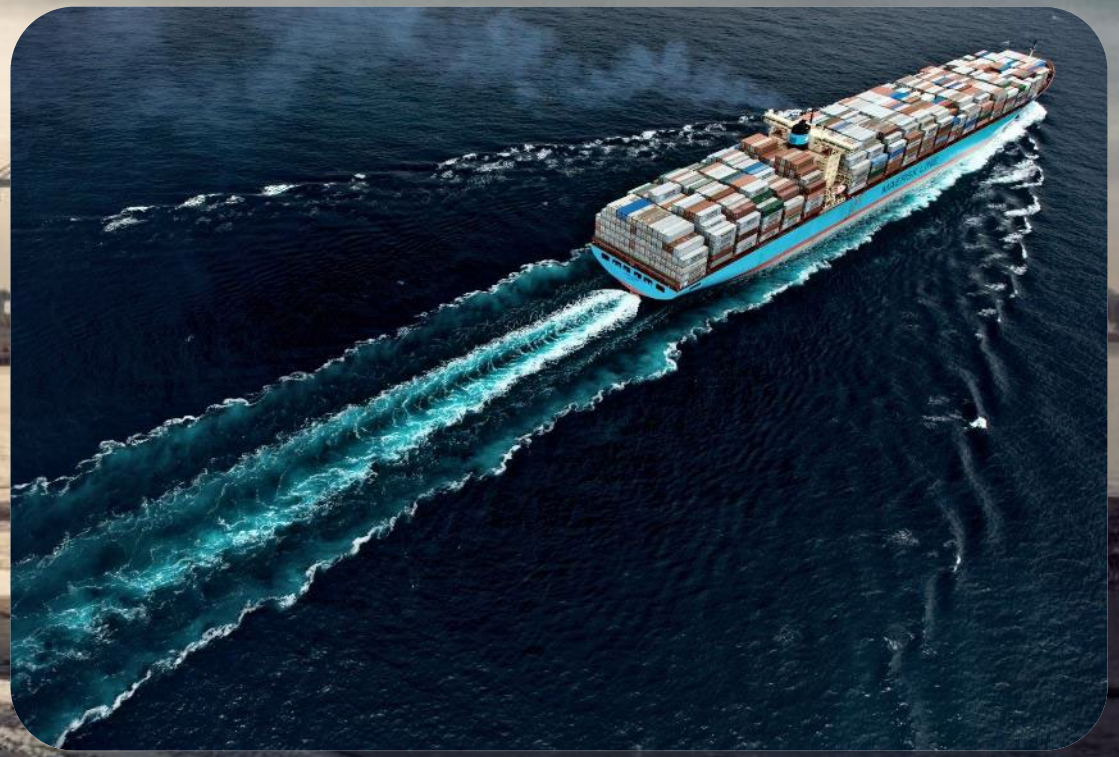
Marine Fuels for the Future

March 2022 | Dr. Lee Kindberg

MAERSK

The climate challenge in shipping is huge

- While it is the most energy efficient way to move goods, shipping emits **3%** of global CO_2 emissions. (Around 3.5 Gigatons (Gt) of CO_2 emissions yearly)
- Maersk's 700+ container ships emit **0.1%** of Total global CO_2 emissions.
- One very large container ship consumes **7,000** ton of fuel oil on a trip from Europe to Asia and back.



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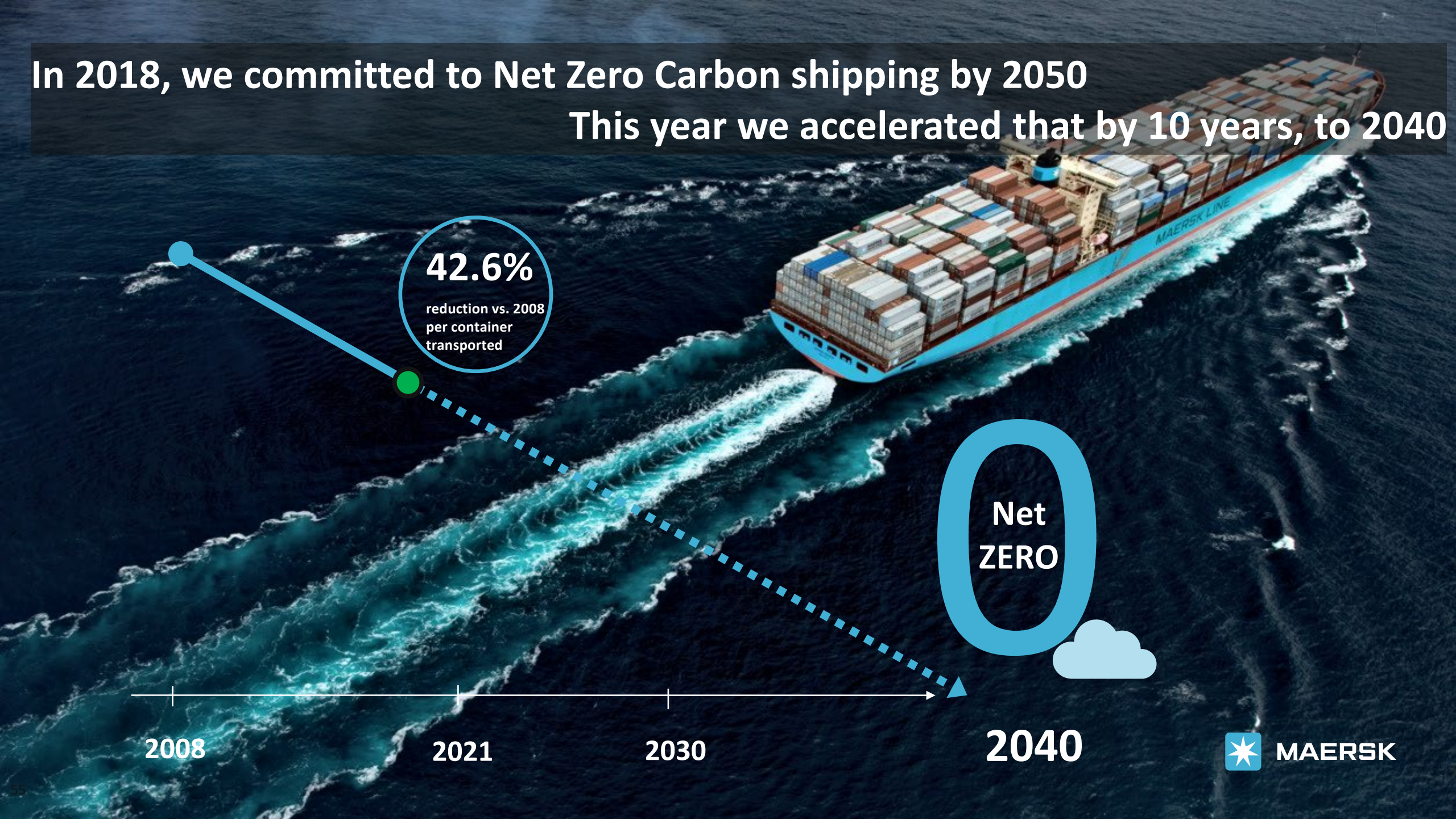
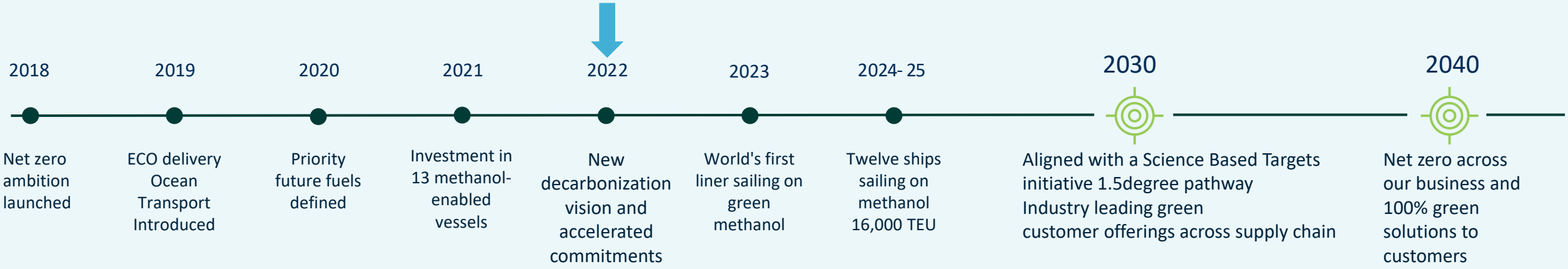

In 2018, we committed to Net Zero Carbon shipping by 2050
This year we accelerated that by 10 years, to 2040
42.6%
reduction vs. 2008 per container transported
Net ZERO
2008
2021
2030
2040
MAERSK

Roadmap to deliver net zero by 2040



OUR DECARBONISATION COMMITMENTS

2030: Industry-leading green offerings

- Ocean: Min 25% of cargo transported with green fuels
- Air: min. 30% of cargo transported with Sustainable Aviation Fuels
- Contract logistics and cold chain: Min. 90% green operations (scope 1 and 2)
- Inland transportation: Industry leading green offering (quantitative targets to be defined in 2022)

2030: Aligned with Science Based Targets initiative 1.5-degree pathway

- Ocean ~50% reduction in emissions intensity Terminals ~70% absolute reduction (scope 1 & 2) 2020 Baseline for both
- Natural Climate Solutions used above and beyond 1.5-degree target to sequester atleast 5million tonnes GHG in 2030

2040: Net zero across our business and 100% green solutions to customers

- 100% Green solutions to our customers
- Net Zero greenhouse gas emission across the whole business/all scopes
- Aligned with Science Based Target net zero criteria

Our **customer commitment** to decarbonise their supply chains in time

... a **societal commitment** to act and have impact in this decade

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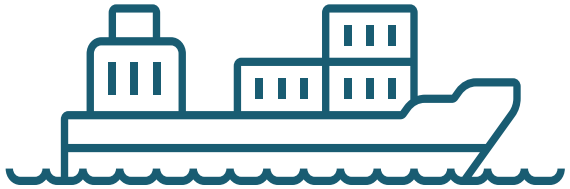
Customer demand for green shipping is increasing

- even at a price premium

Procure certified, sustainable biofuel (or other green fuels in the future)



Use sustainable biofuel on selected container vessels in our network

Customer can buy carbon neutral shipping globally

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Potential fuels identified
- their pros and cons

Biodiesel
(incl. advanced biofuels)

- ☑ Biodiesel market already exists
- ☑ Can be used as drop-in fuel in existing vessels and engines
- ☒ Limited availability of sustainable biomass feedstock
- ☒ Price pressure due to competing demand

Green methanol
(bio-methanol and e-methanol)

- ☑ Can be produced from both biomass and renewable electricity
- ☑ Already in operation today
- ☑ Well-known handling
- ☒ Bio-methanol: biomass availability of biomass feedstock
- ☒ E-methanol: Availability of biogenic CO_2 source

Green ammonia
(e-ammonia)

- ☑ Can be produced at scale from renewable electricity alone
- ☑ Fully zero emissions fuel
- ☒ Safety and toxicity challenges
- ☒ Infrastructure challenges at ports
- ☒ Future costs depends on cost of renewable electricity

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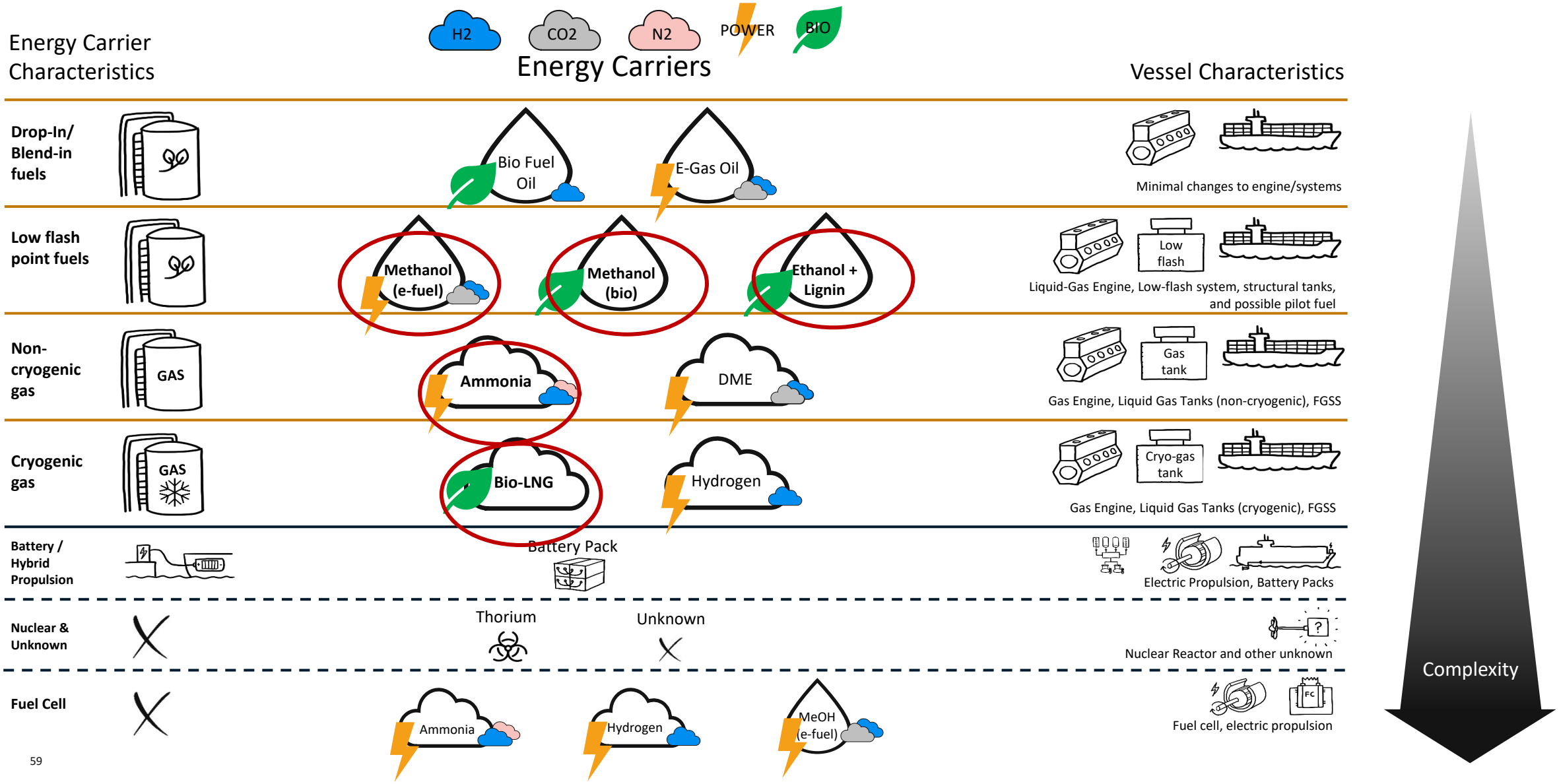
Potential carbon-neutral fuels



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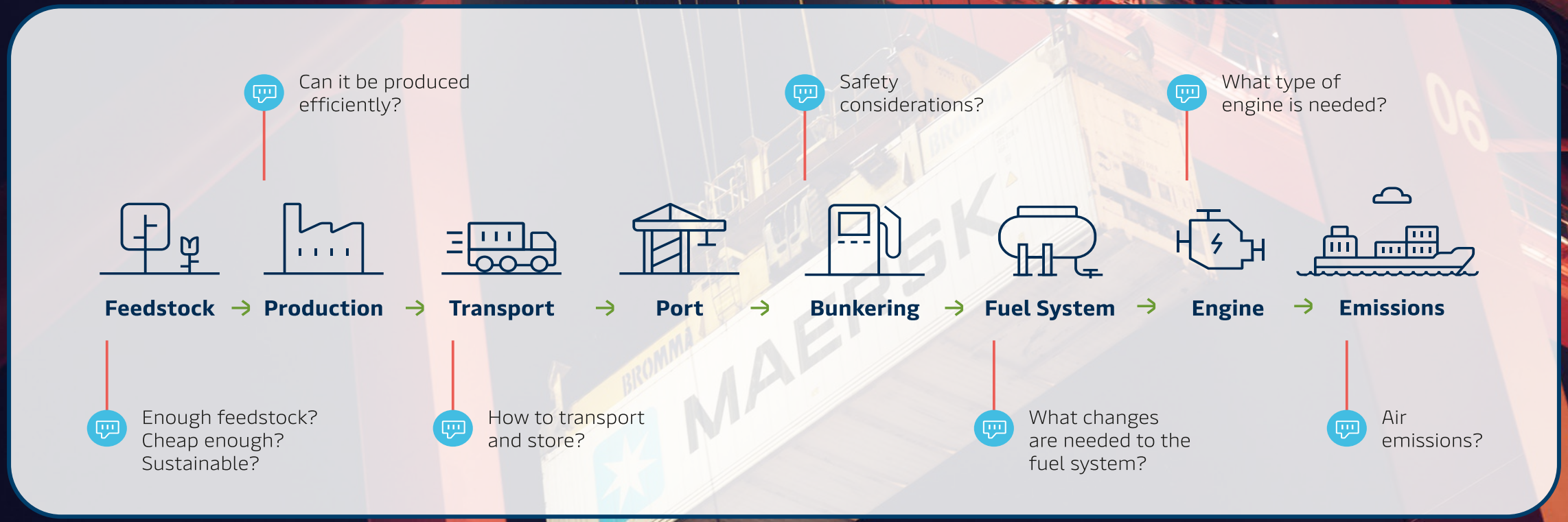
Main focus continue to be: ”liquified energy” (whether fuel cells or combustion engines)

New fuels are not enough
- we need to build a new ecosystem



1. Price

2. Scalability

3. Sustainability

4. Tech. viability

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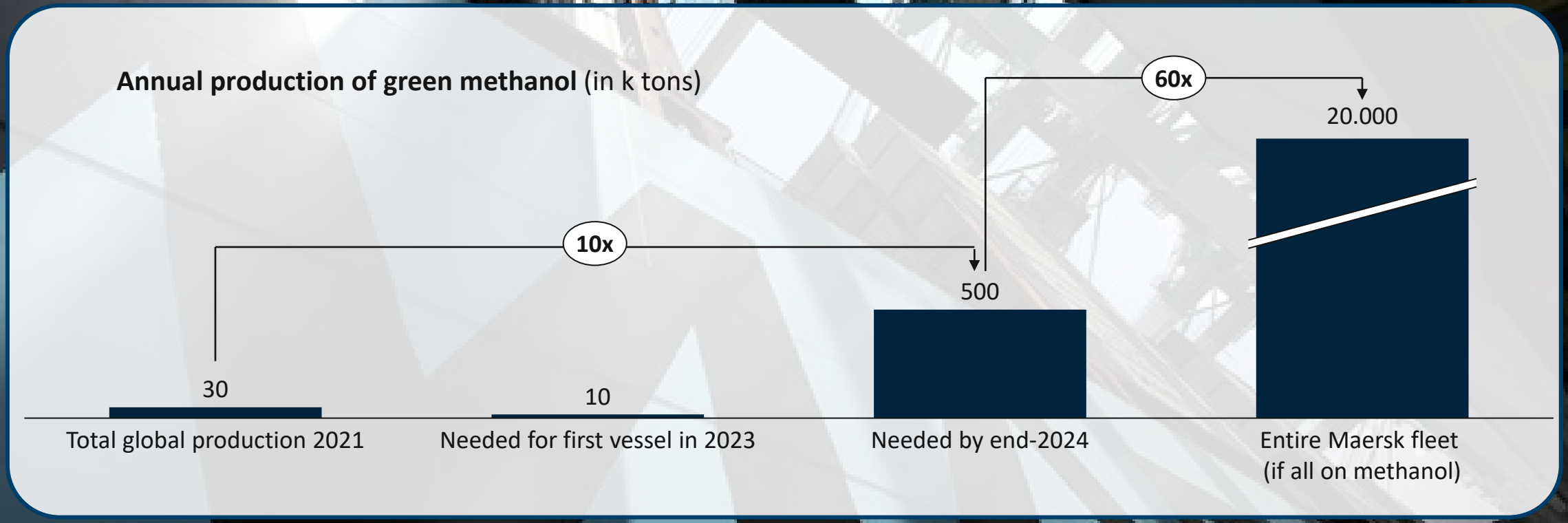
It will be quite a leap to get to scale
– but it can be done



Our first ”pilot scale” carbon neutral container ship in 2023

Our first series of 12 large carbon neutral container ships in 2024

Thank you

Dr. Lee Kindberg

Maersk Head of Environment & Sustainability North America

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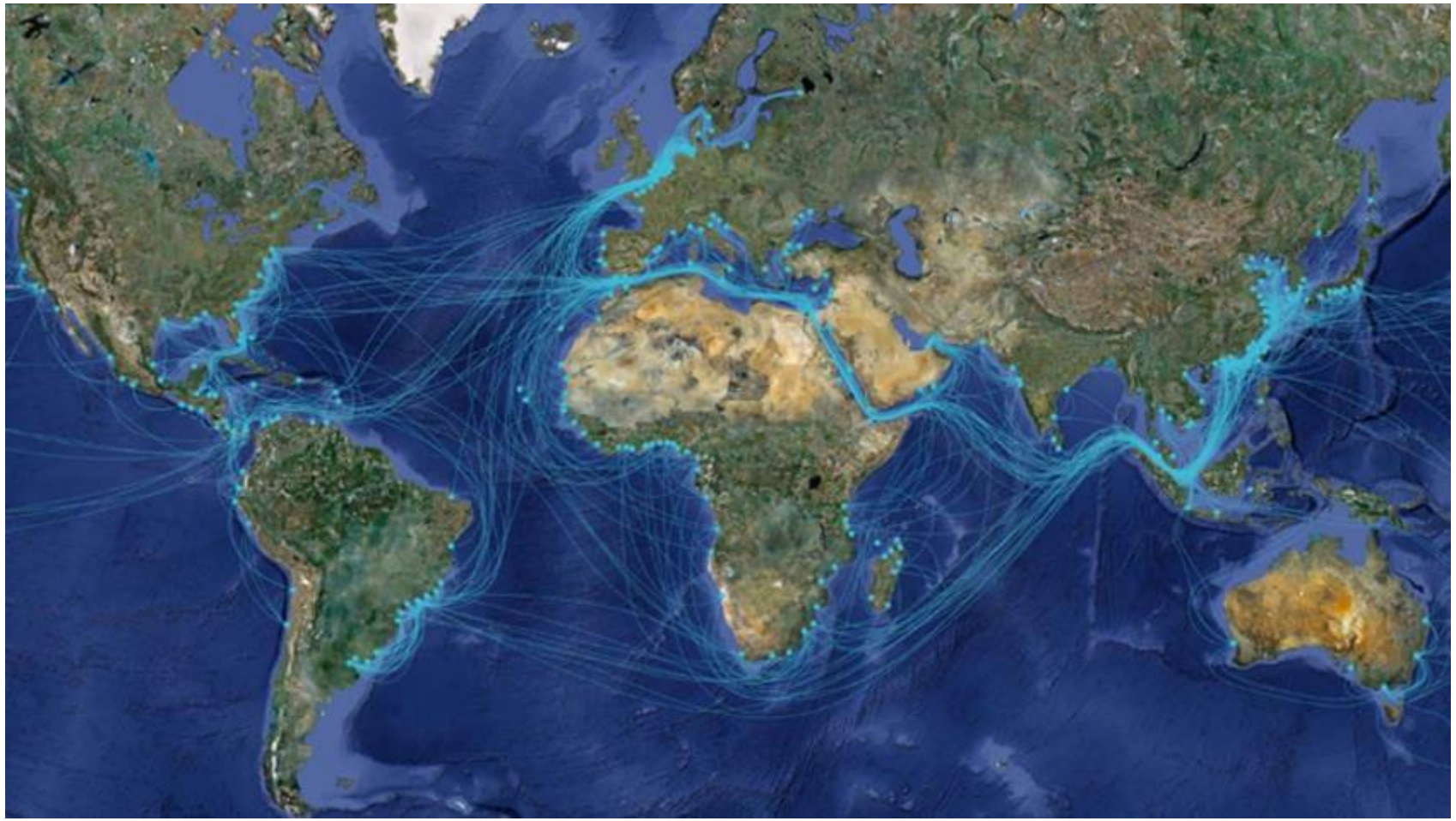

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Thank you!

Today's Presentation:

Current State of Sustainable Marine Fuels

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