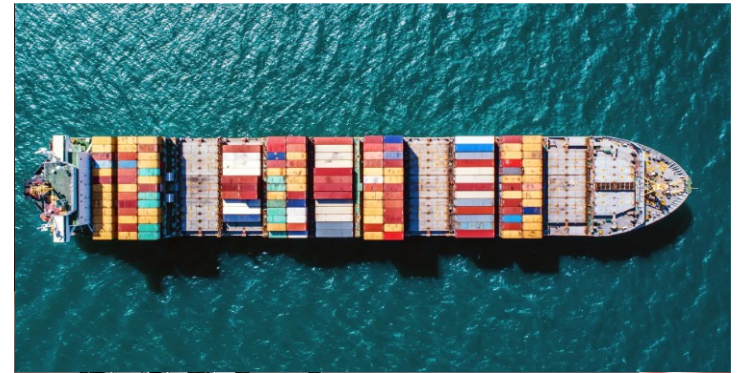


# Maritime Decarbonization Action Plan

Josh Messner, BETO Technology Manager and EERE Maritime Lead

01/12/2024



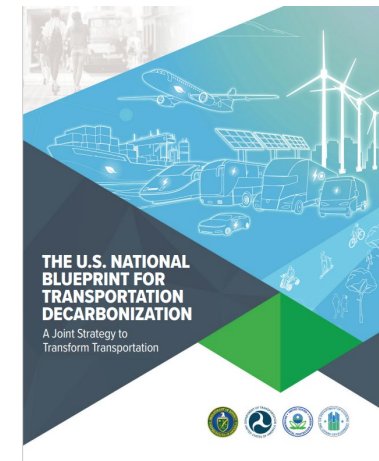
- 
- **Maritime Decarb Action Plan**
  - **Fuel pathways**
  - **GREET**
  - **Billion Ton Study**
  - **BETO Marine Fuels Work**
  - **International Work**
  - **H2 Hub**
  - **Sustainable Aviation Fuel Challenge**

# A Coordinated Approach

Four agency MOU established a historic, whole-of-government approach to transportation decarbonization

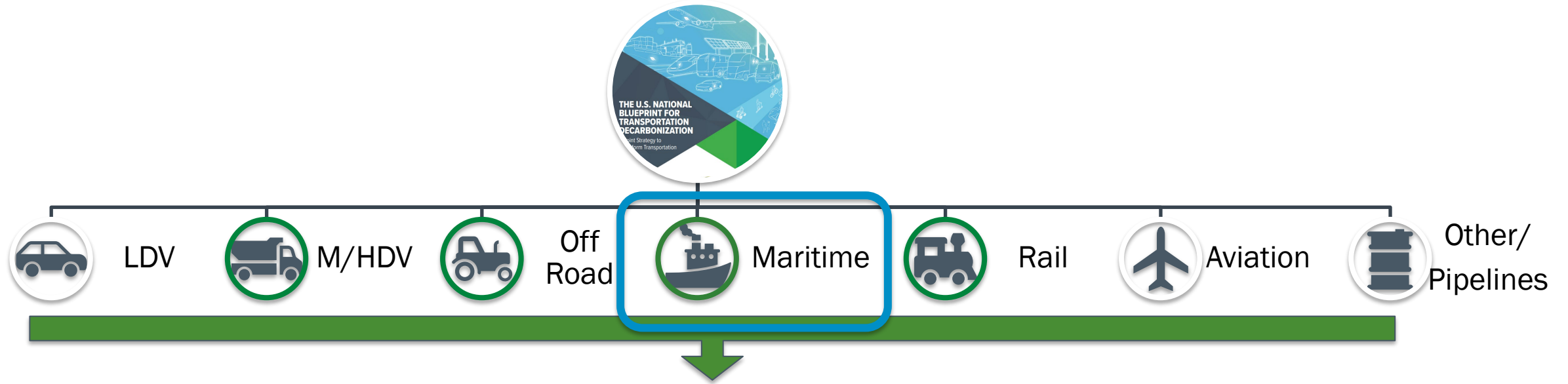
- Consistent and expanded stakeholder outreach
- Clear signals to industry
- Coordination at all staff levels:
  - RDD&D planning and execution
  - Infrastructure deployment
  - Policy & regulation development
  - Data, tools, education and training

Underpinned by a singular aligned transportation decarbonization vision/blueprint



# Transportation Decarbonization Blueprint

## Modal Sector Action Plans



**DEEP DIVE:** Build on the foundation set forth in Blueprint for each sector.

**PATH TO ZERO:** Define strategic actions that leverage advanced and emerging technologies, address barriers with solutions, and support demonstration and research,

**ENGAGEMENT:** Collaborate with stakeholders (industry, non-profits, governments, etc.) to inform actions as critical players for implementation.

**ACCOUNTABILITY:** Establish key metrics to track and monitor progress towards decarbonization.

# Bounding the MAP

## Covered within MAP

### Vessel Types (U.S. Fleet only)

- Recreational Boats, Harbor Craft, Ocean Going

### Low CI Fuels / Energy

- Biofuels (Renewable Diesel, Biodiesel, bio-intermediates), Methanol, Ammonia, Renewable Natural Gas, Electrification, Hydrogen, Small Modular Reactors

### Engine Types

- Full & Hybrid Electric, Dual Fuel, Retrofits, Fuel Cell (H2, NH3, MeOH)

### Fuel Production

- U.S. Fleet Requirements
- Non-U.S. Fleet Bunker Requirement

### Regional Strategies and Workforce Development

## MAP Adjacent

### Shoreside Port Operations

- Covered within the U.S. Zero Emissions Ports Strategy
- Combines multiple modal plan to form strategy  
– Maritime, Rail, Medium-/Heavy-Duty, Off Road

## Excluded from MAP

DOD Fleet or Operations

Non-U.S. Fleet

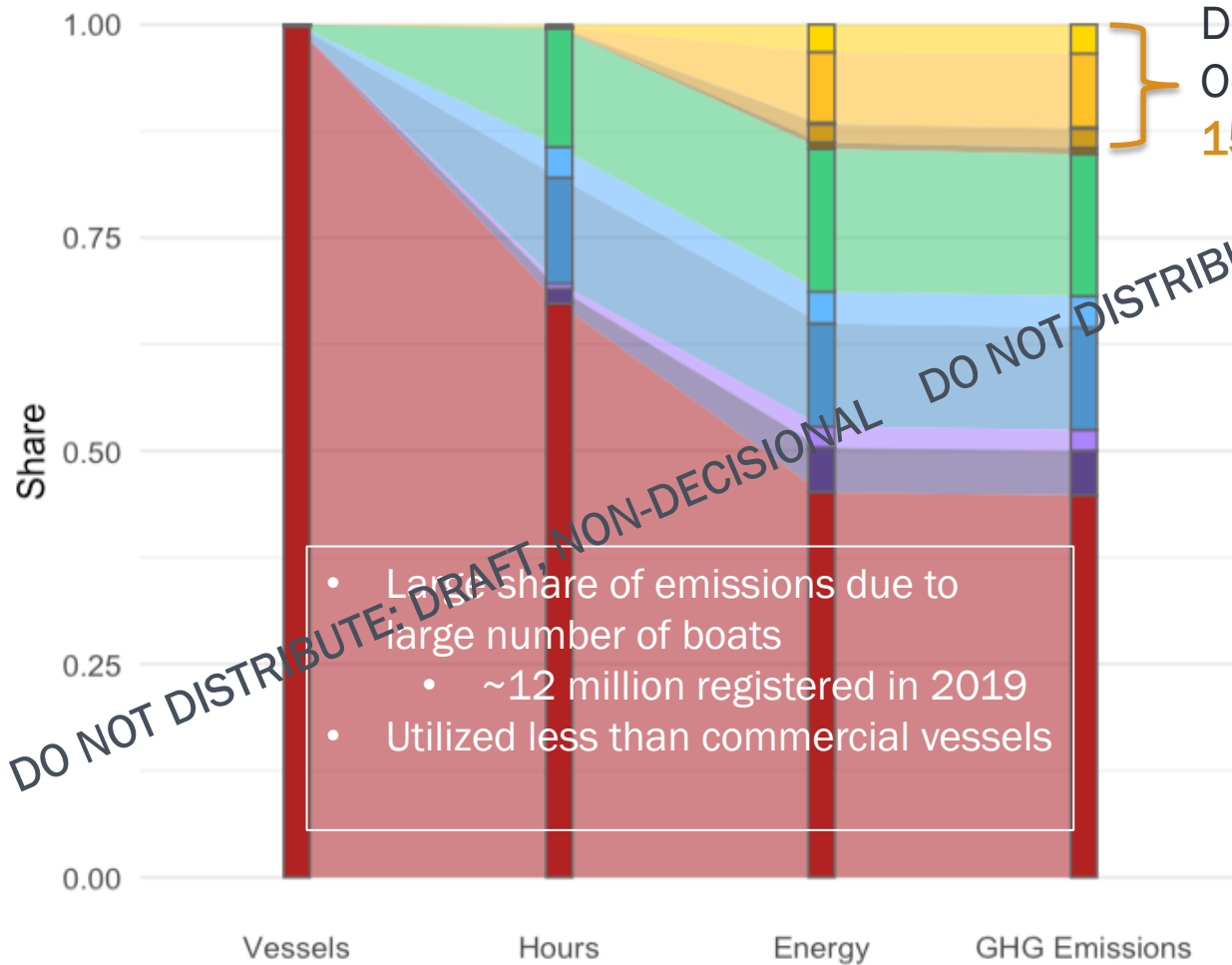
Specific Policy and Regulation



Accounts for volumes

# 2019 Landscape – All Vessels

All Vessels - U.S. Flag Fleet



- Large share of emissions due to large number of boats
  - ~12 million registered in 2019
  - Utilized less than commercial vessels

Despite comprising **<1% of the stock**, Ocean-Going Vessels account for **over 15% of maritime sector GHG emissions**.

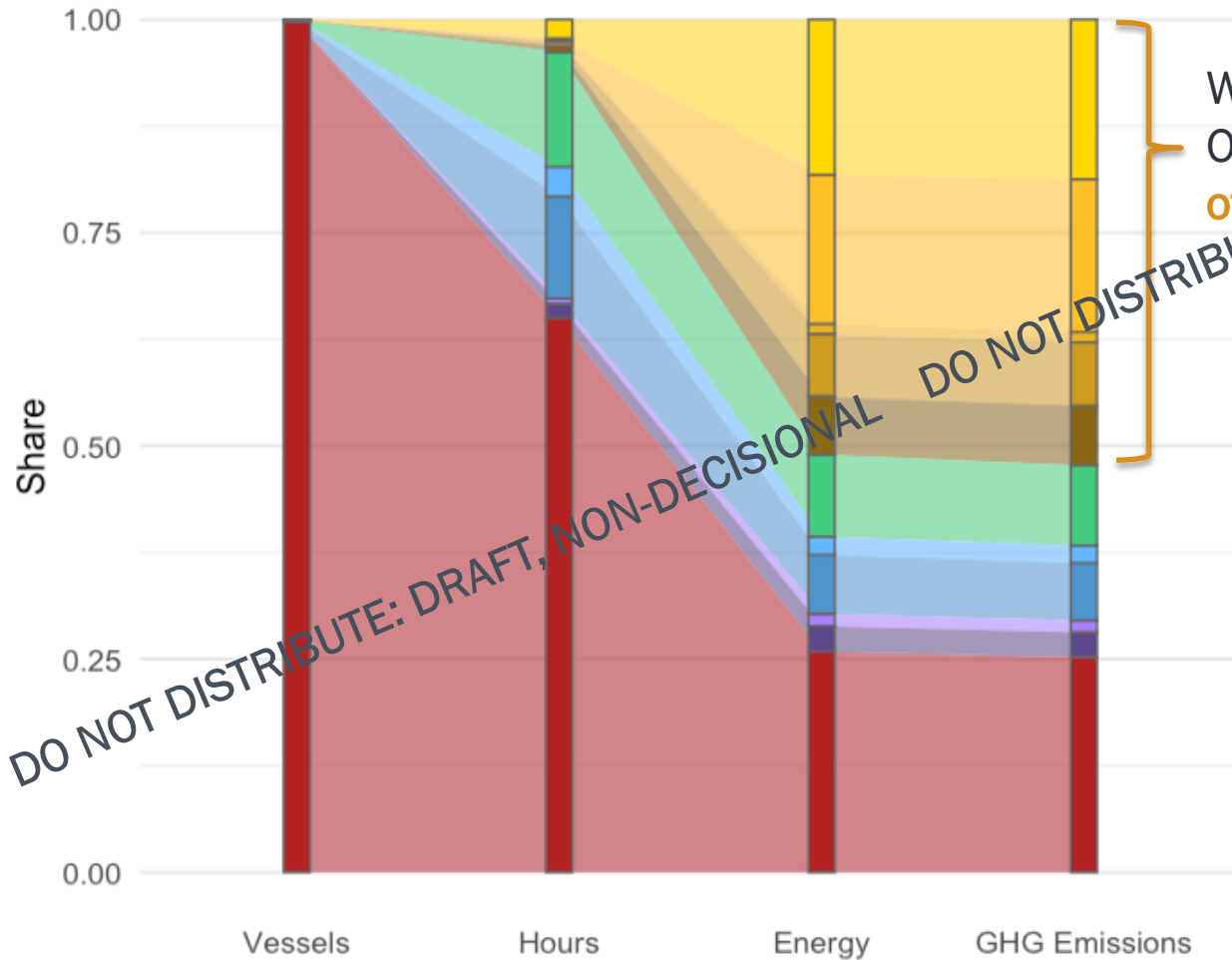
- Bulk Carriers
- Container
- General Cargo
- Tankers
- Vehicle Carriers/RoRo
- Towboat
- Offshore Supply
- Fishing
- Ferry
- Passenger
- Recreational Boats

- Data sources:
- Merchant Vessels of the U.S. (2019) – U.S. Coast Guard
  - EIA-821 (2019) – U.S. Energy Information Administration
  - National Census of Ferry Operators (2018, 2020) – Bureau of Transportation Statistics
  - Activity and Fuel Burn Modeling: Volpe National Transportation Systems Center, Energy Analysis & Sustainability Division
  - GREET (2021 version) – Argonne National Lab
  - National Recreational Boating Safety Survey – U.S. Coast Guard

Note: Preliminary estimates – subject to change

# 2019 Landscape – All Vessels

All Vessels - All U.S. Bunkering



When considering all U.S. bunkering, Ocean-Going vessels account for over **50%** of marine sector GHG emissions.

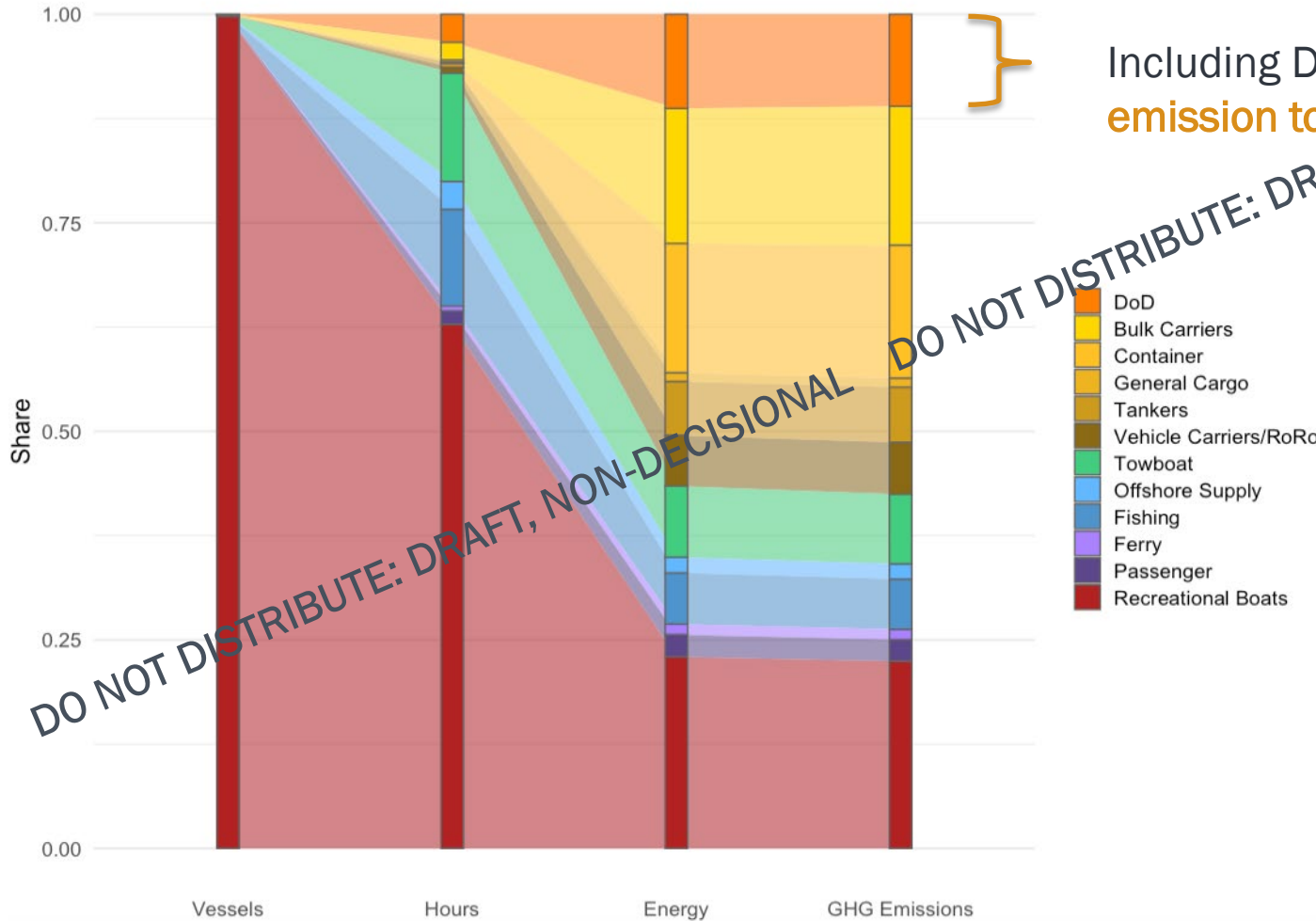
- Bulk Carriers
- Container
- General Cargo
- Tankers
- Vehicle Carriers/RoRo
- Towboat
- Offshore Supply
- Fishing
- Ferry
- Passenger
- Recreational Boats

- Data sources:
- Merchant Vessels of the U.S. (2019) – U.S. Coast Guard
  - EIA-821 (2019) – U.S. Energy Information Administration
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  - GREET (2021 version) – Argonne National Lab
  - National Recreational Boating Safety Survey – U.S. Coast Guard

Note: Preliminary estimates – subject to change

# 2019\* Landscape – All Vessels \*2020 DoD data used

All Vessels - All U.S. Bunkering



Including DoD vessels adds 10% GHG emission to US maritime sector emissions

DO NOT DISTRIBUTE: DRAFT, NON-DECISIONAL

Data sources:

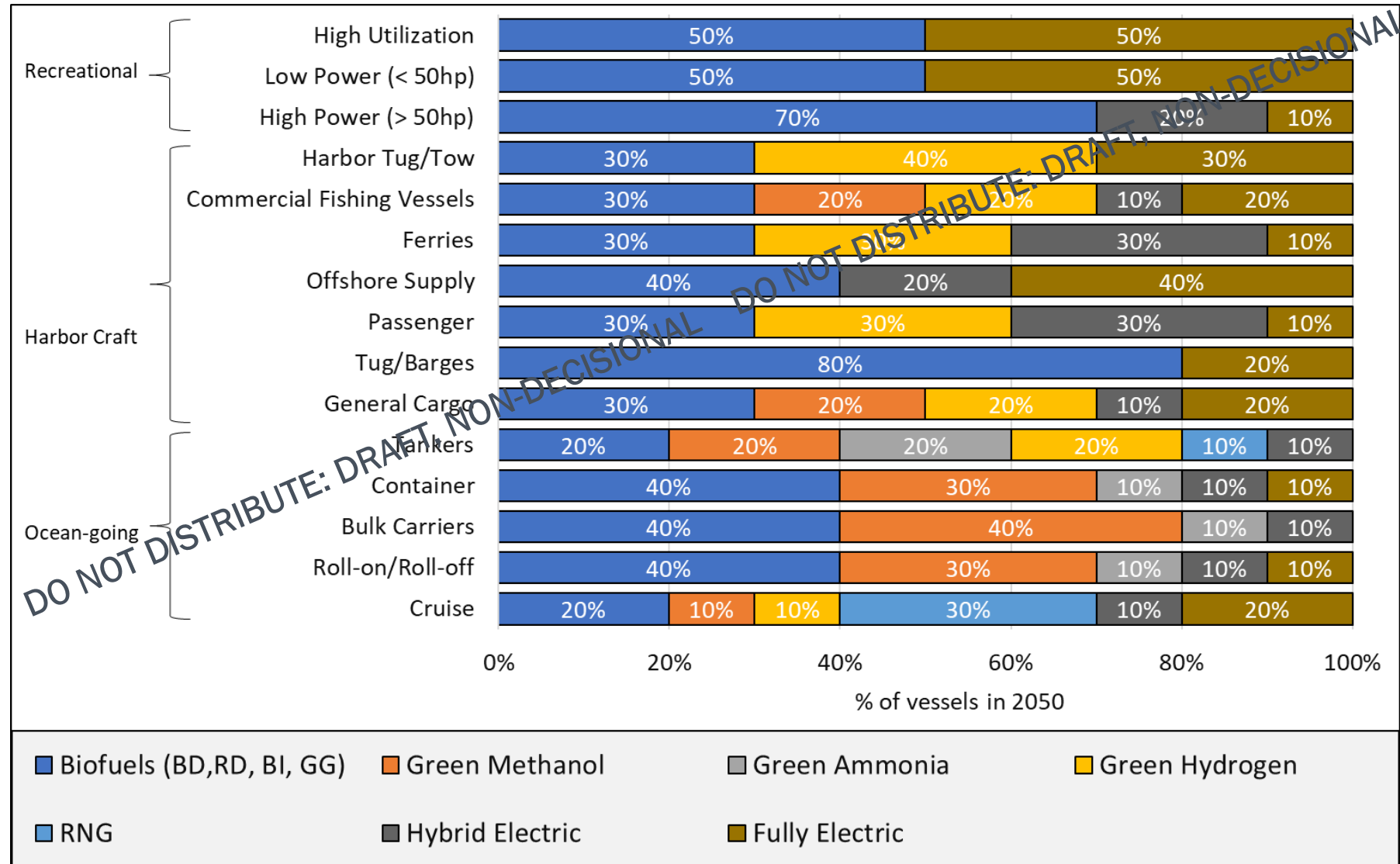
- Merchant Vessels of the U.S. (2019) – U.S. Coast Guard
- EIA-821 (2019) – U.S. Energy Information Administration
- National Census of Ferry Operators (2018, 2020) – Bureau of Transportation Statistics
- Activity and Fuel Burn Modeling: Volpe National Transportation Systems Center, Energy Analysis & Sustainability Division
- GREET (2021 version) – Argonne National Lab
- National Recreational Boating Safety Survey – U.S. Coast Guard
- Department of Defense Plan to Reduce GHG Emissions (2023) - Office of the Under Secretary of Defense for Acquisition and Sustainment
- Defense Logistics Agency Energy Fiscal Year 2022 Fact Book - DLA

Note: Preliminary estimates – subject to change



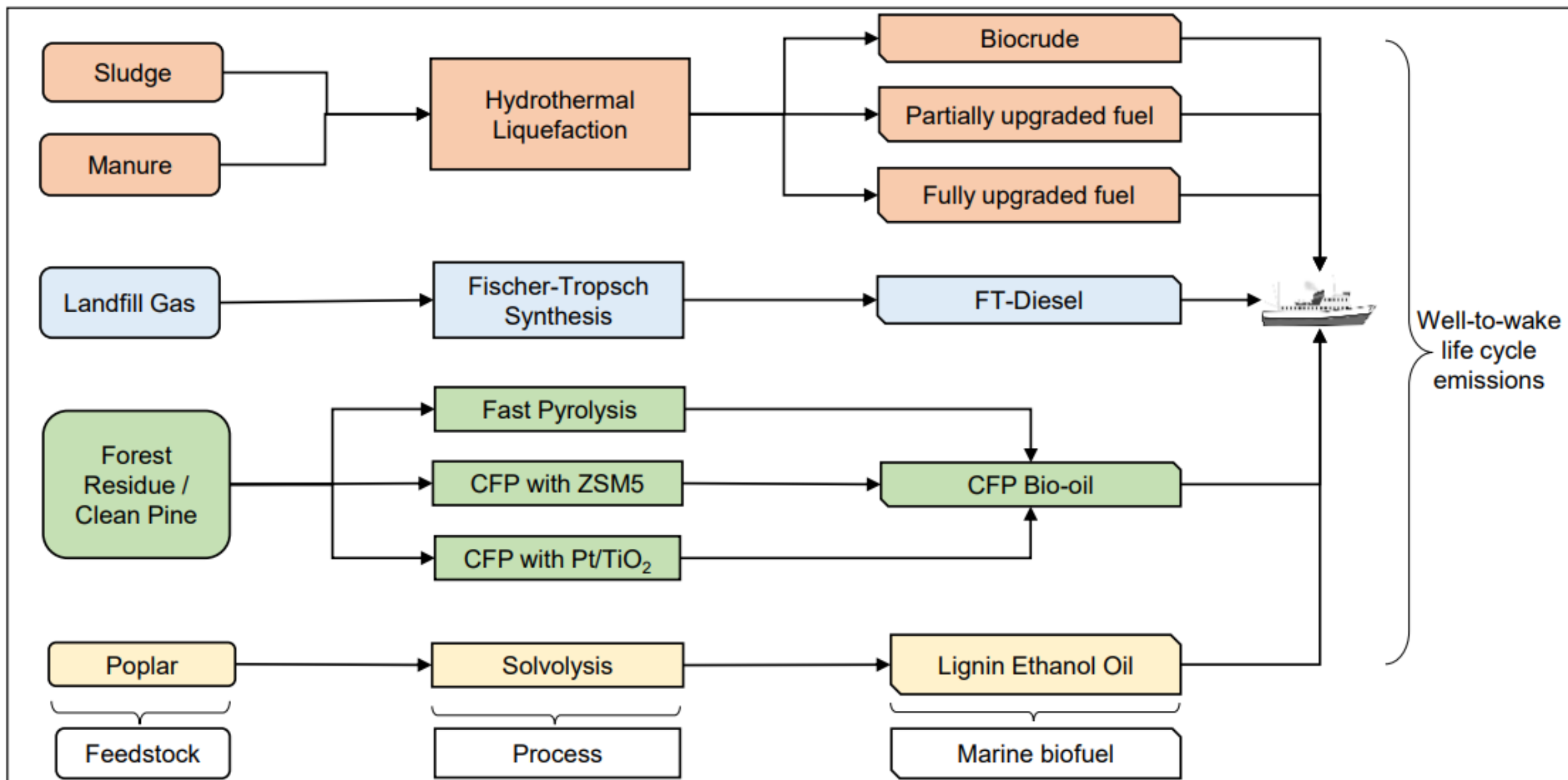
# Draft Vessel Composition for 2050

- Major factors influencing projection decision:
  - Market Characteristics
    - Annual replacement rate
    - Alternative fuel availability
    - Adoption rate of advanced technologies
  - Route Characteristics
    - Route predictability
    - Route distance
  - Vessel Characteristics
    - Vessel size
    - Cargo to power ratio
    - Energy efficiency

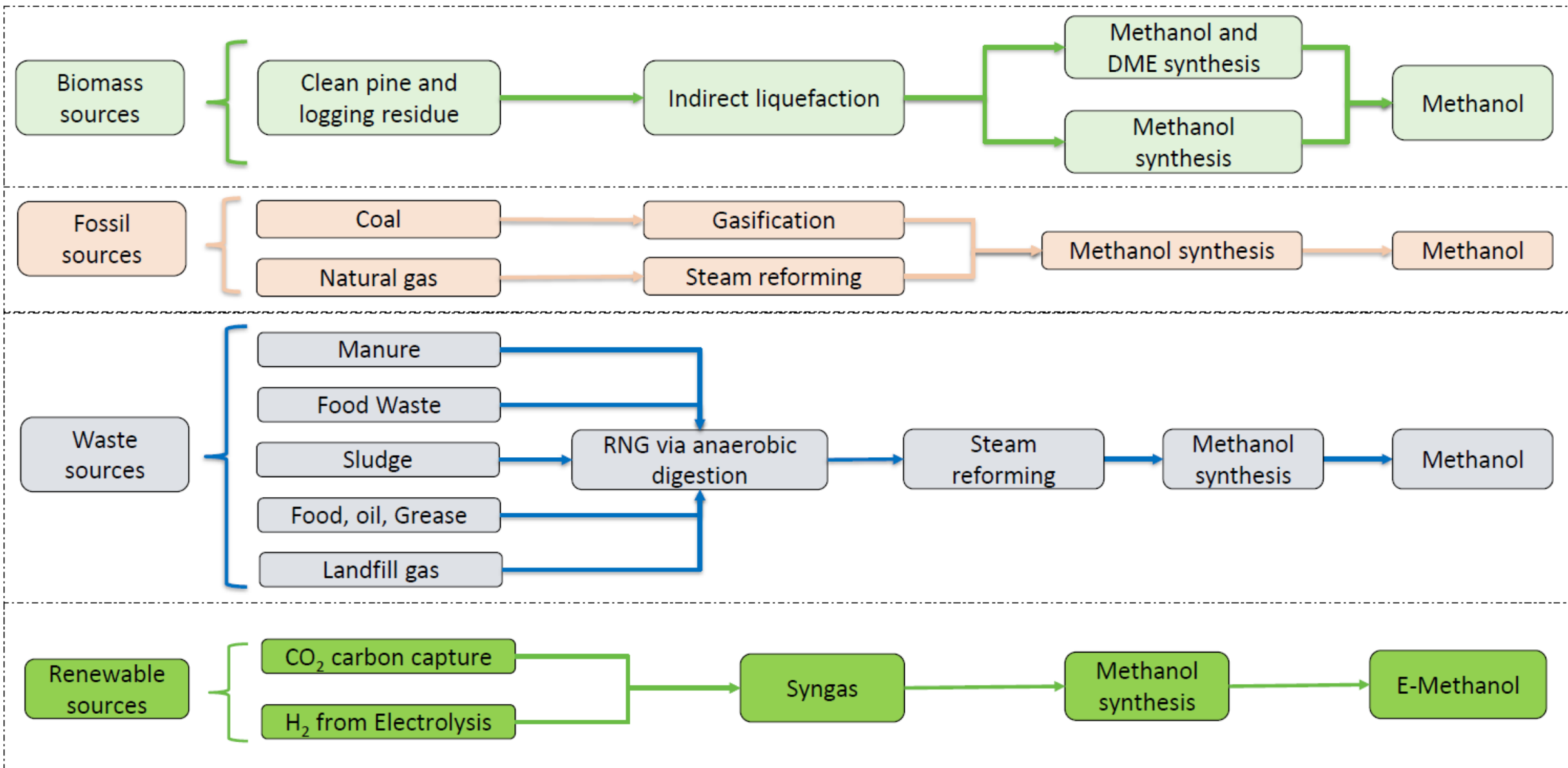


BD: Biodiesel; BI: Bio-Intermediates; GG: Green Gasoline; RD: Renewable Diesel; RNG: Renewable Natural Gas

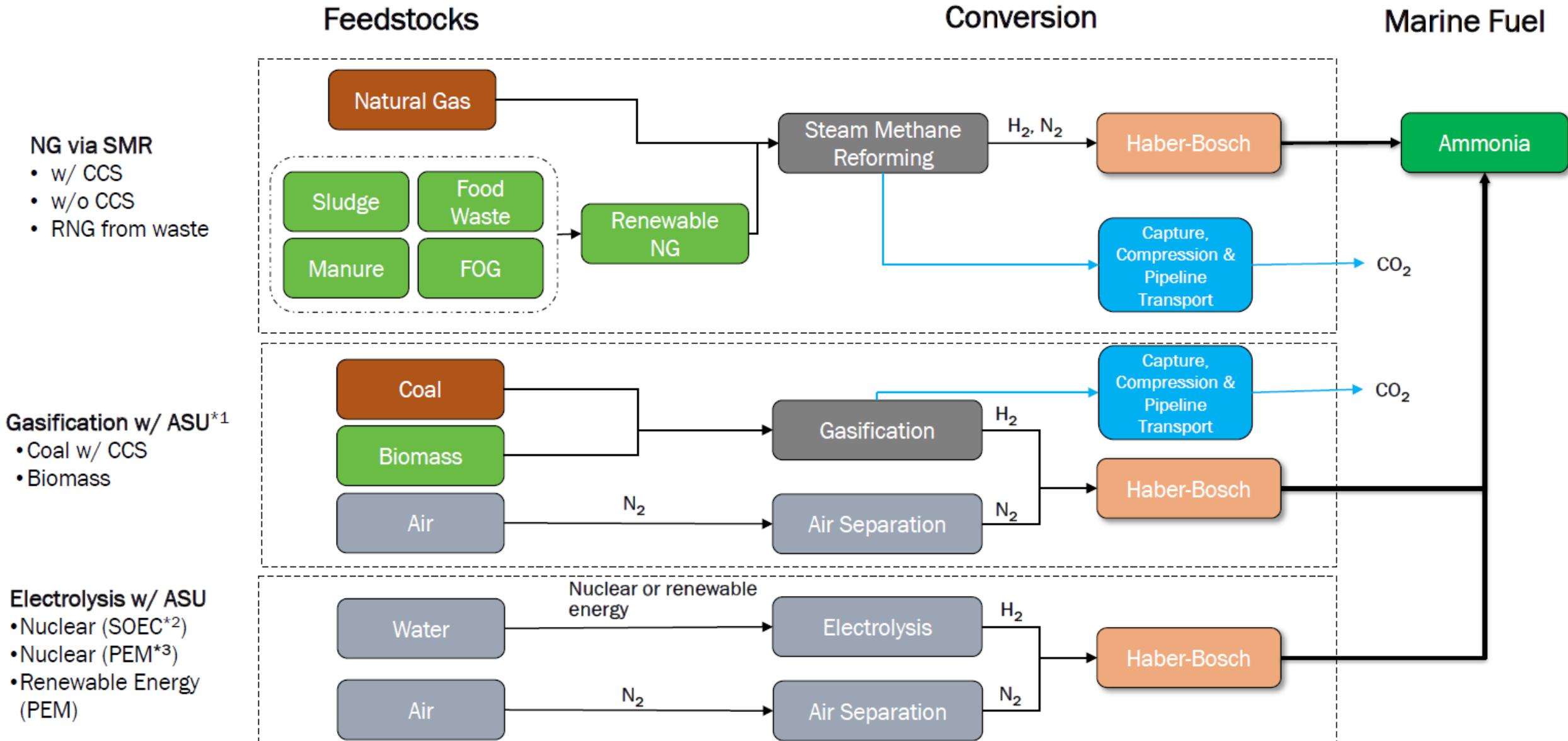
# Marine Bio-Oil Pathways



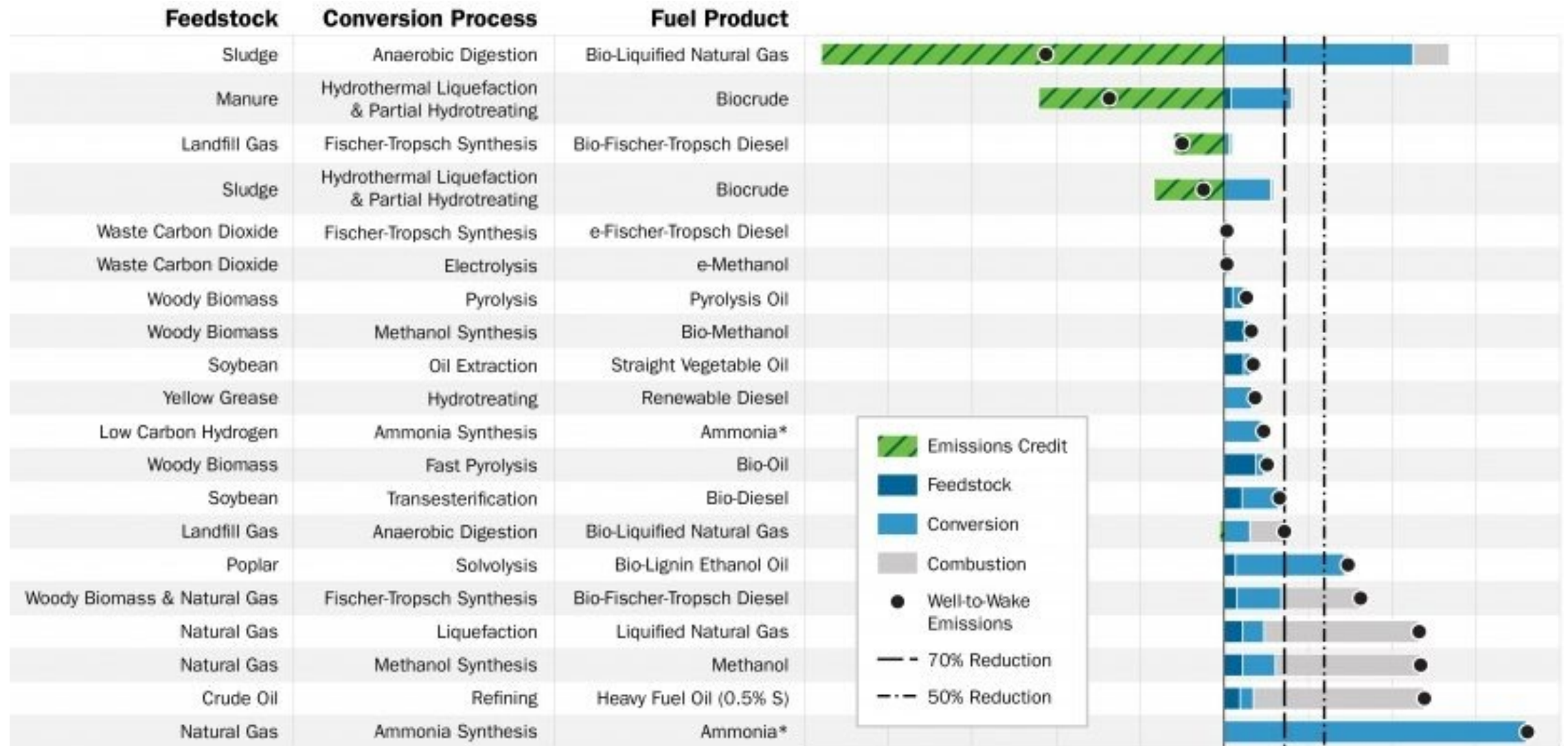
# Methanol Pathways



# Ammonia Pathways



# Maritime Fuel Pathways and Initial LCA



\*Life cycle analysis for ammonia as a fuel assumes no nitrous oxide emissions. In practice, nitrous oxide formation may occur and would increase the carbon intensity of ammonia fuels.

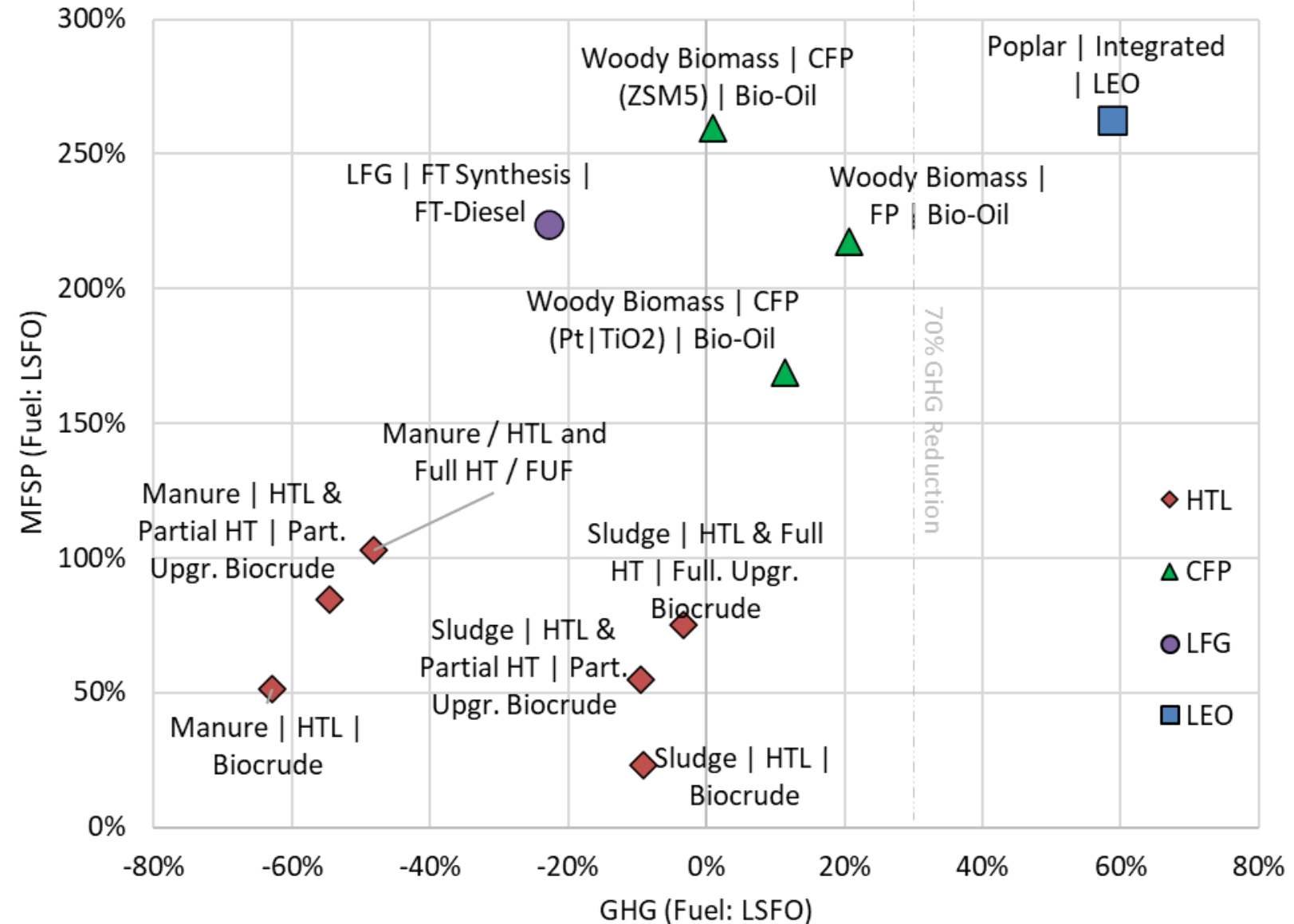
g CO<sub>2</sub>e/MJ = grams of carbon dioxide equivalent per megajoule

**Life Cycle Greenhouse Gas Emissions, g CO<sub>2</sub>e/MJ**

(GHG reductions are relative to conventional heavy fuel oil)

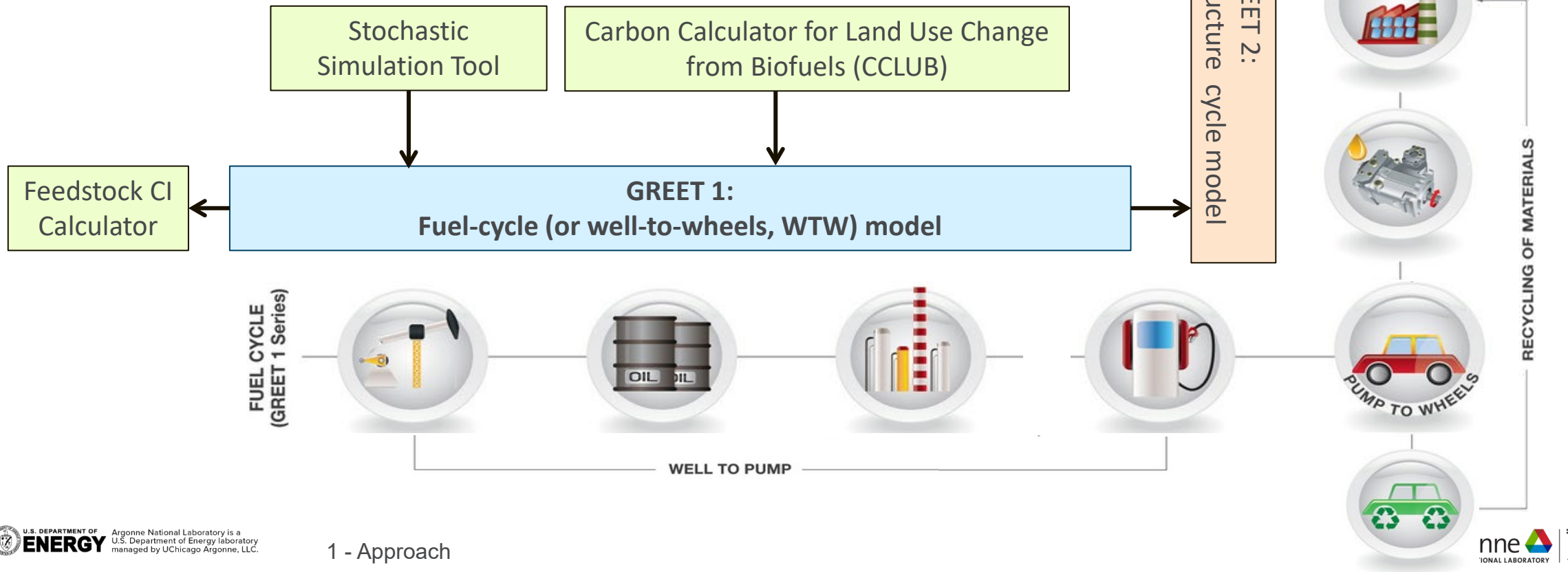
# Cost versus GHG for biomass pathways

- Bio-Oil Pathways Offer GHG Reductions with Range of Costs
- HTL pathways offer negative GHGs at or below the cost of conventional fuel.
- Catalytic fast pyrolysis of more abundant wood resources will benefit from further R&D to reduce cost.



# The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) Model Framework

- Argonne has been developing the GREET life-cycle analysis (LCA) model since 1995 with annual updates and expansions
- BETO has been a major GREET sponsor since the beginning
- GREET is available at [greet.anl.gov](http://greet.anl.gov)
- GREET Outputs: GHG emissions, Criteria Air Pollutant emissions, Energy Use, and Water Consumption



(Vehicle manufacturing cycle as the example)

# REET Sustainability Metrics Include Energy Use, Criteria Pollutants, Greenhouse Gases, and Water Consumption

## Energy use

- Total energy: fossil energy and renewable energy
- Fossil energy: petroleum, natural gas, and coal
- Renewable energy: biomass, nuclear energy, hydro-power, wind power, and solar energy

## Air pollutants

- VOC, CO, NO<sub>x</sub>, PM<sub>10</sub>, PM<sub>2.5</sub>, and SO<sub>x</sub>
- Estimated separately for total and urban (a subset of the total) emissions

## Greenhouse gases

- CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, black carbon, and albedo
- CO<sub>2e</sub> of the five (combined with their global warming potentials)

## Water consumption

- Addressing water supply and demand (energy-water nexus)



# DOE is the Main Sponsor for GREET Development and Application

- DOE EERE
  - Vehicle Technology Office
  - Hydrogen and Fuel Cell Technology Office
  - Bioenergy Technology Office
  - Building Technology Office
  - The Strategic Analysis Office
- DOE ARPA-E
- DOE Fossil Energy and Carbon Management Office
- DOE Nuclear Energy Office
- Other federal agencies
  - Federal Aviation Administration of DOT
  - Federal Maritime Administration of DOT
  - Federal Rail Administration of DOT
  - USDA
  - The National Institute of Standards and Materials of Department of Commerce
  - Bureau of Offshore Energy Management of Department of Interior
- Numerous trade associations and corporate sponsors in energy, automotive, materials, and agriculture sector



U.S. DEPARTMENT OF  
**ENERGY**

# Informing Policies and Regulations

California Environmental Protection Agency  
 **Air Resources Board**



- **CA-GREET** is an adaptation of Argonne’s GREET model
- **Oregon Clean Fuels Program** also uses an adaptation of Argonne’s GREET model
- **U.S. EPA** uses GREET with other sources for **Renewable Fuels Standard** pathway evaluations
- **National Highway Traffic Safety Administration** for fuel economy regulation
- **Federal Aviation Administration** and **International Civil Aviation Organization** using GREET to evaluate aviation fuel pathways
- **USDRIVE** Well-to-Wheels Report
- **U.S. Maritime Administration** - renewable marine energy options for IMO GHG intensity and sulfur limits
- **U.S. Dept. of Agriculture bioenergy LCA** and carbon intensity of farming practices
- **Canadian Clean Fuel Standard** for Environment and Climate Change Canada fuel pathways
- LCA results for use in different provisions of the 2021 **Bipartisan Infrastructure Law** and the 2022 **Inflation Reduction Act**

# New GREET Marine Module

Energy Systems



**GREET Marine Module**

Pathway: Select a Fuel and Feedstock

Reset Selection

Feedstocks

Feedstock	Feedstock Input	Type	User defined	Default	Unit	Note
Logging Residue	Diesel	Input		195,360	btu / dry ton	Landing Process
Logging Residue	Electricity	Input		11,423	btu / dry ton	Receiving & Ho
Logging Residue	Diesel	Input		8,720	btu / dry ton	Storage
Logging Residue	Electricity	Input		276,460	btu / dry ton	Preprocessing
Logging Residue	H <sub>2</sub>	Input		954,190	btu / dry ton	Preprocessing
Clean Pine	Diesel	Input		139,510	btu / dry ton	Harvest And Cr
Clean Pine	Diesel	Input		23,940	btu / dry ton	Landing Process
Clean Pine	Electricity	Input		42.0	btu / dry ton	Receiving & Ho
Clean Pine	Diesel	Input		8,360	btu / dry ton	Storage
Clean Pine	Electricity	Input		348,230	btu / dry ton	Preprocessing
Clean Pine	H <sub>2</sub>	Input		954,190	btu / dry ton	Preprocessing

Conversion

Conversion Input	Type	User defined	Default	Unit	Note
Clean Pine	Input		0.0748	ton / mtonbu	
Forest Residues	Input		0.0748	ton / mtonbu	
Diesel	Input		2,273	btu / mtonbu	
Sand makeup	Input		0.0	g / mtonbu	
Cooling tower chemical	Input		0.729	g / mtonbu	
Boiler chemical	Input		0.0	g / mtonbu	
Boiler feed water chem	Input		1.48	g / mtonbu	
Clastic	Input		170.43	g / mtonbu	
Hydrotreating catalyst	Input		0.0	g / mtonbu	
Hydrotreating Catalyst	Input		0.0091	g / mtonbu	
Hydrocracking Catalyst	Input		0.0	g / mtonbu	
Fixed Bed VPU Cataly	Input		10.33	g / mtonbu	
Displaced electricity	Output		101,122	btu / mtonbu	
Displaced MBH	Output		0.6645	kg / mtonbu	
Displaced acetone	Output		3.543	g / mtonbu	

Transportation

Material	Leg	Mode	LD (share)	LD (mi)	Default (share)	Default (mi)
Clean Pine	Field to Plant	Truck			100.0%	510
Logging Residue	Field to Plant	Truck			100.0%	104.0
Marine fuel	US Terminal to Bulk Terminal	Barge			0.0%	620.0
Marine fuel	US Terminal to Bulk Terminal	Pipeline			0.0%	400.0
Marine fuel	US Terminal to Bulk Terminal	Rail			20.0%	800.0
Marine fuel	US Terminal to Bulk Terminal	Truck			63.0%	60.0
Marine fuel	Bulk Terminal to Refueling Station	Truck			100.0%	30.0

Results: Biooil - Catalytic Fast Pyrolysis of Woody Biomass (PV/TIO2)

Metrics

Total energy

Fossil fuels

Coal

Natural gas

Hydrogen

Water consumption

VOC

CO

NOx

PM10

PM2.5

SOx

BC

OC

CH4

Update Results

Save Results

Life Cycle Result: 1.08E+1 g GHGs / MJ Fuel

Functional Unit: MJ Marine Fuel

Bar chart showing GHGs (g / MJ) for Feedstock, Conversion, Combustion, and Total. The Y-axis ranges from -80 to 100. The X-axis categories are Feedstock, Conversion, Combustion, and Total. The values are approximately: Feedstock: -60, Conversion: -20, Combustion: 80, Total: 10.

## GREET Marine Module

Click to save and extract the .zip file [GREET Marine Module\\_2022\\_v1.zip](#) to your hard drive. It contains the interactive excel file "GREET Interactive Marine Module", GREET fuel cycle database (GREET1\_2022) that works in the background, and the instruction manual.

### GREET Marine Module 2022\_v1

November 7, 2022

The GREET team at the Systems Assessment Center of Argonne National Laboratory is pleased to announce release of the first GREET Marine Module.

The Systems Assessment Center at Argonne National Laboratory has developed an interactive standalone marine module (GREET Marine Module) to have a consistent marine fuels' life-cycle analysis platform with the most up-to-date datasets. It is intended to evaluate the environmental impact of various marine fuel production pathways including both fossil- and bio-derived marine fuels. For easy access, this module uses Microsoft Excel with Visual Basic for Applications (VBA) to enable an interactive user interface.

In this first release, we have added the background datasets for marine fuels with the most up-to-date [GREET 2022 excel module](#). We made the GREET Marine Module dynamic, which interacts with the GREET fuel cycle model (GREET1) by directly reading upstream life cycle energy uses and emissions for key inputs to various stages in various marine fuel production pathways. The dynamic version enables changing the default input parameters of the GREET1 model to user defined inputs. The connection to GREET1 model is automatic and it works in the background to show the results in the interactive GREET Marine Module excel file.

For detailed instructions on how to use the module, please refer to the [GREET Marine Module Introduction](#).

### Download tool and documentation

- [GREET Marine Module 2022\\_v1 - Zip file \(19.9 MB\)](#)
- [Instruction Manual \(2.84 MB pdf\)](#)

**Technical contact:** [greet@anl.gov](mailto:greet@anl.gov)

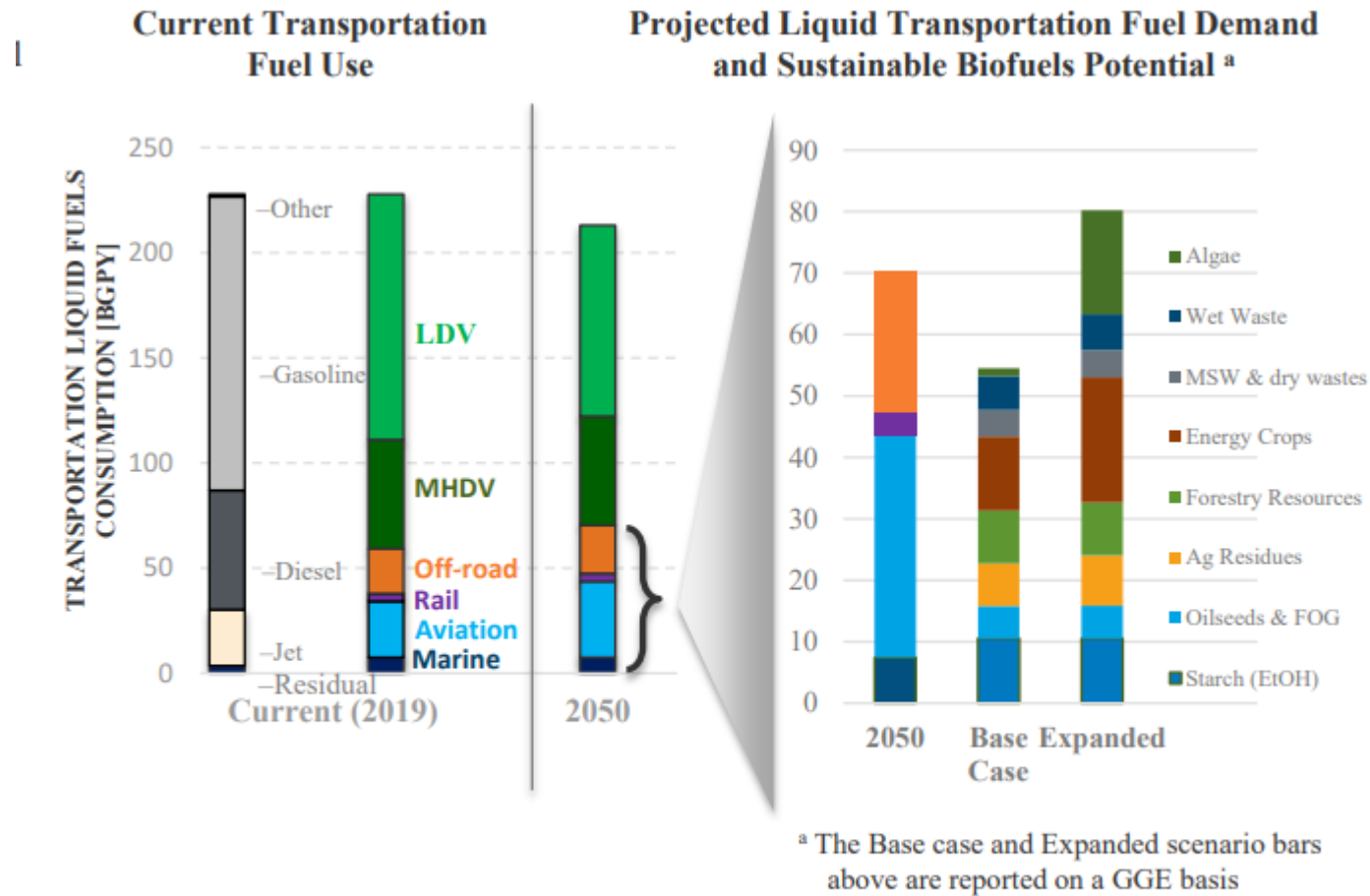
The GREET Marine Module is developed with Microsoft Office 365. For best performance, we highly recommend using Microsoft Office 365 to run the module.

To download and open GREET Marine Module:

- Click to save [GREET Marine Module\\_2022\\_v1.zip](#) file to your hard drive
- When the download is completed, extract the zip file
- Double click "GREET Interactive Marine Module.xlsm," and choose to "Enable Macros," if prompted.

### Prior Revisions

# US Biomass Supply Projections



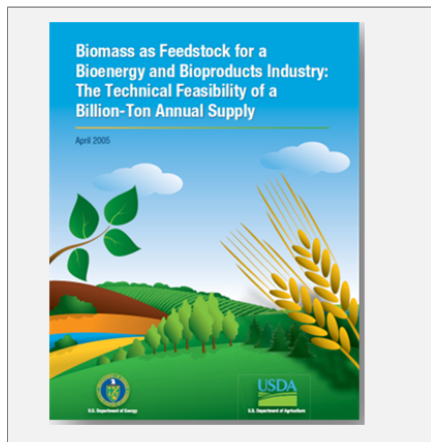
<sup>1</sup> Hydrogen inputs are assumed to be sourced from steam reformed natural gas without carbon capture and sequestration.

# 2023 Billion-ton Report, in Preparation

To inform research, development, and deployment strategies.

- Policy agnostic
- End-use agnostic
- Not predictions
- Not targets

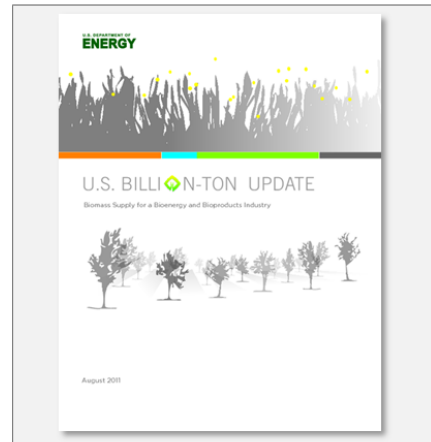
2005



Supply...

Can we displace 30% of the country's petroleum consumption?

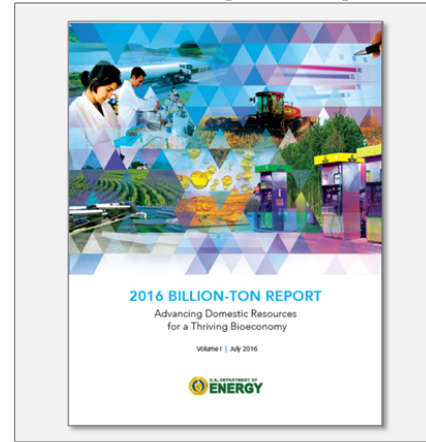
2011



...Cost...

- County-level supplies by cost.
- Economic model of ag+energy crops.

2016 (BT16)



...Sustainability.

- 44 feedstocks w/ modeled crop yields
- Forest model
- Delivered costs
- 2 Volumes + visualization tools



2023 (BT23)



Add new feedstocks  
Update waste and algae Refine forest resources

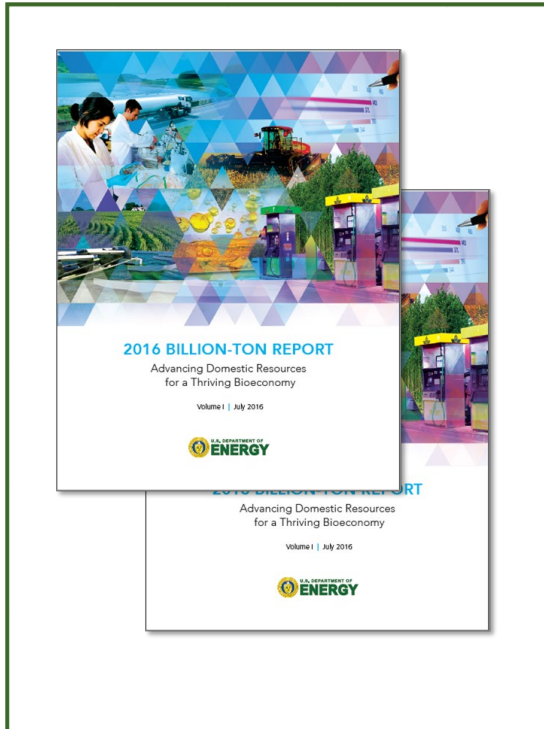
# Billion Ton 2016 Products

[Report landing page](#)

[Interactive visualizations](#)

## Reports

Volumes 1 & 2



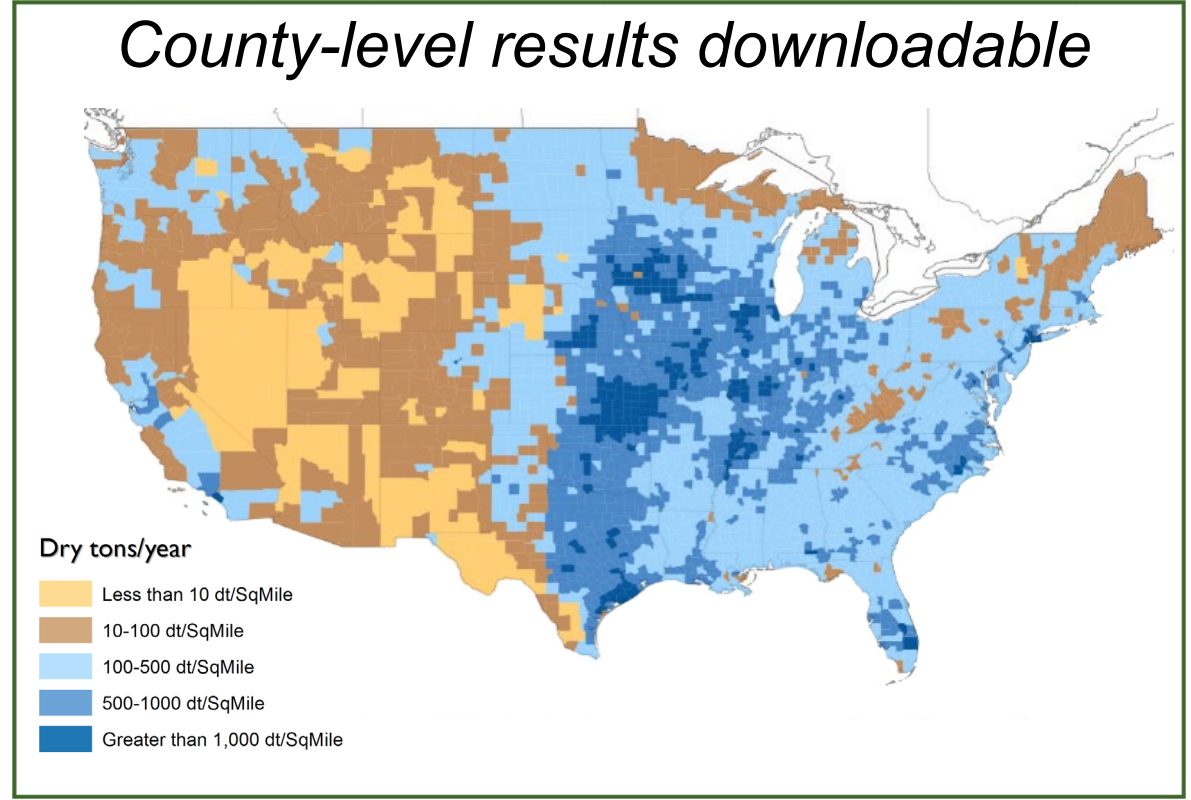
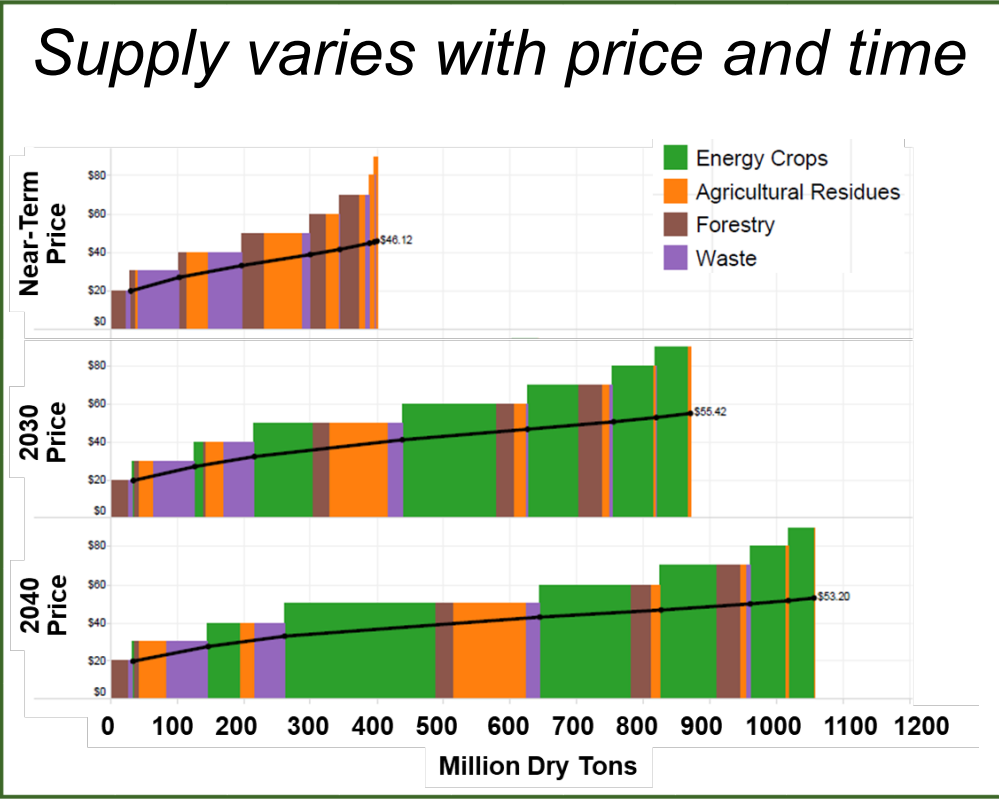
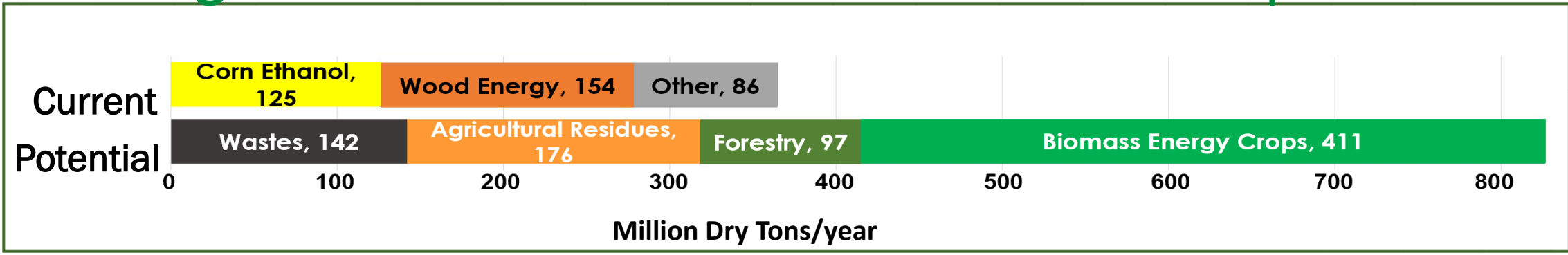
per dry ton per year for the base-case scenario. Feedstock supply is reported by default as a density value, potential county-level supply divided by county land area. Supply quantities in blue are correlated to having a feedstock density of 100 dry tons per square mile or more, which corresponds to the approximate minimum quantity to supply a hypothetical facility at 2,000 dry tons per day.

**2040 Combined potential supplies at \$60/dt or less, roadside.**  
**Forestry: Moderate housing, low energy demand (base). Agriculture: 1% yield increase (BC1). Wastes: All.**

## Data download tool

Year	Scenario	Biomass Price	Resource	State	USDA Region	Fips	Production	Production Unit	Production Density	Harvested Acres	Yield	Yield Unit	Land Area	Resource Category	Resource Form	Resource Type	Land Source	Class	Section	Forest Region
2033	High housing, high energy demands	70	Hardwood, lowland whole trees	Vermont	North East	50	20,114	dt	2.18	387	0	dt/ac	9,216.670068	Forestry				TREE	PPRS	NE
2033	High housing, high energy demands	70	Hardwood, upland logging residues	Vermont	North East	50	207	dt	0.02	48	0	dt/ac	9,216.670068	Forestry				RSDP	PPRS	NE

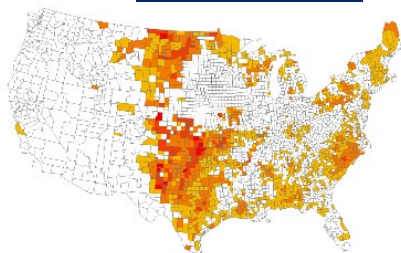
# Building on State-of-the-Art: 2016 Billion-ton Report



# Feedstocks Being Updated in BT23

## Economic and spatial data

- 2023 USDA baseline data
- Updated costs & food demands
- 2022 Spatial data for environmental effects



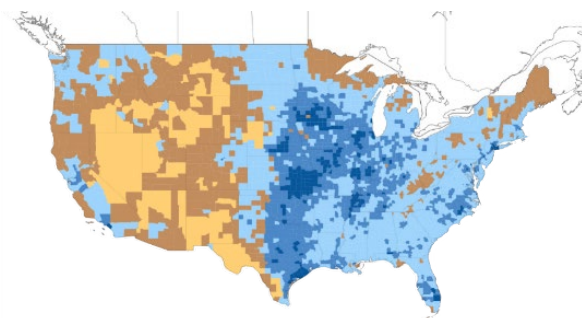
## Wastes

- Adding county-level fats, oils, and greases
- Accounting for mature-market price competition



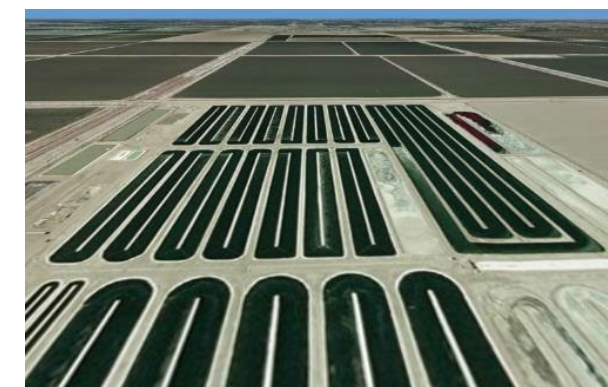
## Agricultural and Forestry Residues

- Agricultural residues (e.g. corn stover)
- Logging residues, thinnings, pine plantations
- Biomass crops



## Micro- (“pond”) algae

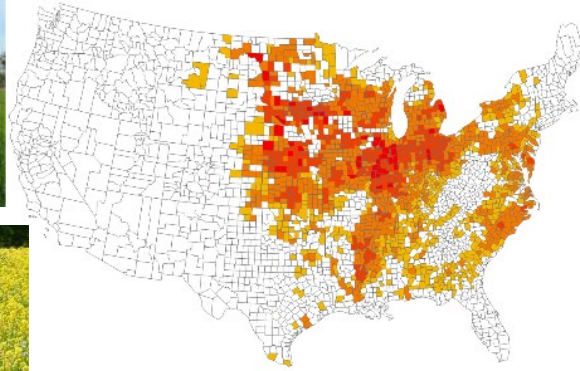
- Updating to 2021 Microalgae Harmonization
- Updating to latest microalgae yield and costs





# New Feedstocks in BT23

## Oilseed crops for SAFs



## Macro- (“seaweed” algae)

- Collaboration with ARPA-E



MarineCadastre.gov



## Western Forest Fuels for biomass with USFS

- Biomass from 2022 USFS Wildfire Crisis Strategy



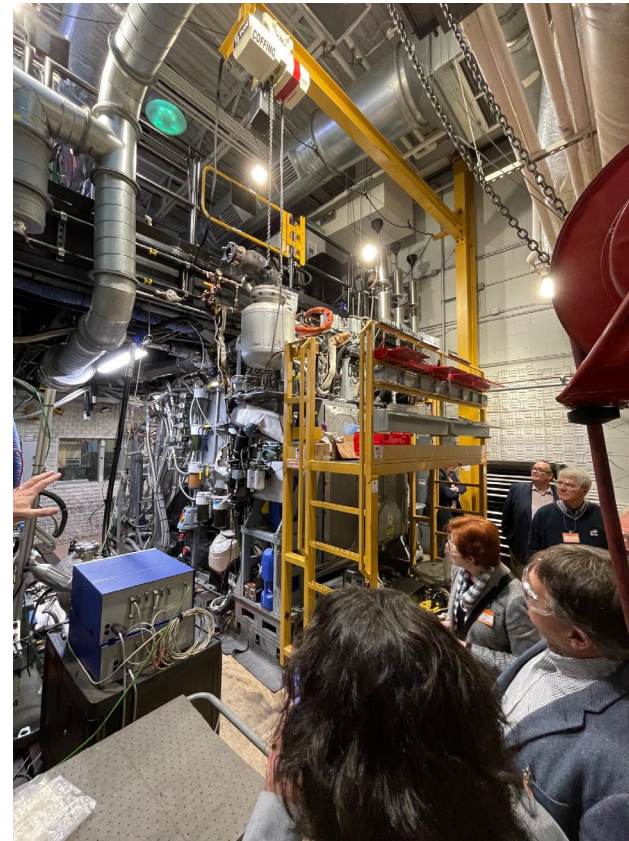
## CO<sub>2</sub> to e-fuels

- Proximity to renewable electricity
- High concentration (e.g. fermentation)



# BETO Maritime Work

- Increasing blending of HFO and bio-intermediates
- Use of biofuels as pilot fuel
- “Smaller” 4 stroke engines at ORNL and ANL
  - MeOH and Ammonia (VTO)
    - BD/RD as pilot
  - Bio-oil / biocrude blends
- Larger 2 stroke cross head single cylinder test engine at ORNL
  - 15% biofuels blends
  - Ammonia retrofit
    - Bio-intermediates, BD, RD as pilot fuel



- **Lab Projects (ORNL, PNNL, NREL, ANL)**
  - Bio-intermediate blends, straight biofuels, biofuel/intermediates as blends
    - Characteristics, miscibility, engine testing
  - Co-production of SAF and Sustainable Marine Fuels
  - LCA and TEA
  - Marine GREET module
  - Fuel burn modeling
  - Scalable Biofuel Supply at U.S. Ports
- **FOA Projects**
  - Allowable product in most BETO FOA
    - Comstock (pre-pilot)
    - UC Riverside (pre-pilot)
    - Unnamed Demo Project (co-production)

- **International work**
  - MI: Zero-Emission Shipping Mission
    - Mission Co-lead and Fuels Pillar Lead
    - Green Shipping Corridor Hub
    - US/ROK Green Shipping Corridor Pre-feasibility Study (with MMM)
    - Scalable Biofuel Supply for International Ports (with RMI)
    - Port Readiness Level Tool (with IAPH)
  - Green Shipping Challenge
    - Green Shipping Corridor Initiation Project
      - GSC between U.S. and developing countries (Panama, PBSP, more to come)
    - U.S. / UK Green Shipping Corridor Task Force
  - IMO LCA discussion

# Mission Innovation: Zero-Emission Shipping Mission



## Co-leads

**Denmark**  
Ministry of Industry, Business and Financial Affairs, Ministry of Climate, Energy and Utilities and Ministry of Foreign Affairs

**Norway**  
Ministry of Climate and Environment

**The United States**  
U.S. Department of Energy

**Global Maritime Forum**  
Representing the Getting to Zero Coalition

**Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping**

## Core Mission Members

**The United Kingdom**  
Department for Transport

**Morocco**  
Ministry of Energy Transition & Sustainable Development

**India**  
Ministry of Science and Technology

**Singapore**  
Maritime and Ports Authority

## Mission Support Group

**France**  
Ministry of the Sea

**Ghana**  
Ghana Maritime Authority

**South Korea**  
Ministry of Trade, Industry and Energy

## New to the Mission

**Australia**

**European Commission**

**Executive Committee Chair**  
Michael Berube  
US DOE, EERE, DAS-T

- **Zero-Emission Shipping Mission (ZESM): Progression to Net-Zero Emission Fuels State of the Industry**
  - Run through BETO
  - Information on the maritime industry's current alternative fuels trajectory, the driving forces behind it, and the key barriers to achieving this transition
- **Zero-Emission Fuels at Ports (biofuels portion)**
  - GMF, RMI (e-ammonia, bio-methanol, e-methanol, RNG, hydrogen)
  - NREL (biofuels) contingent on DAST and Dept State funds
- **Share performance data of engines using zero-emission fuels**
- **Assess effectiveness of biofuels as a pilot fuel**
- **Research biofuel fuel properties and blend ratios for compatibility**
- **Global biomass assessment (in development)**
  - Biofutures Initiative, Biorefineries Mission
  - NREL, MMM, others

# Green Shipping Challenge

Encourages countries, ports, companies, and other actors in the shipping value chain to come forward with concrete announcements that will help put the shipping sector on a pathway this decade to align with the goal to limit global temperature rise to 1.5 degrees C.

## US Commitments

### – Facilitating Green Shipping Corridors Worldwide

- Green Shipping Corridor Initiation Project (*BETO Managing*)
  - Panama and Pacific Blue Shipping Partnership (8 pacific islands led by Fiji)
- Green Corridors Hub (*BETO Managing*)

### – Facilitating U.S. Green Shipping Corridors

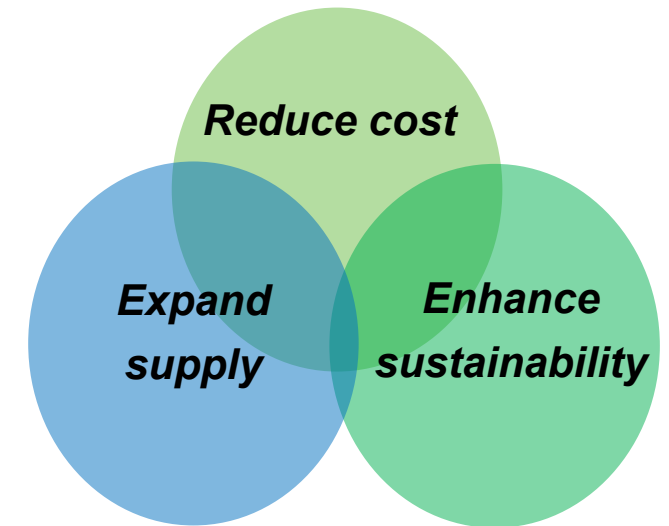
- ROK / US Green Corridor (*BETO Managing*)
- Canada / US Great Lakes St. Lawrence Seaway Green Corridor (*BETO consults*)
- UK-US green shipping corridor task force (*BETO on Task Force*)

### – Creating a U.S. National Action Plan for Maritime Decarbonization

- DOE, DOT (OST & MARAD), EPA, HUD (*BETO consult and review*)

# SAF Grand Challenge

- Agreement by the Departments of Transportation, Energy and Agriculture coordinated with EPA
- Achieve 3 billion gallons of domestic SAF production in 2030 and put U.S. on trajectory to 35 billion gallons per year by 2050
- At least a 50% reduction in life cycle greenhouse gas emissions, as compared to conventional jet fuel
- Multi-agency roadmap to focus federal actions to support industry scale-up





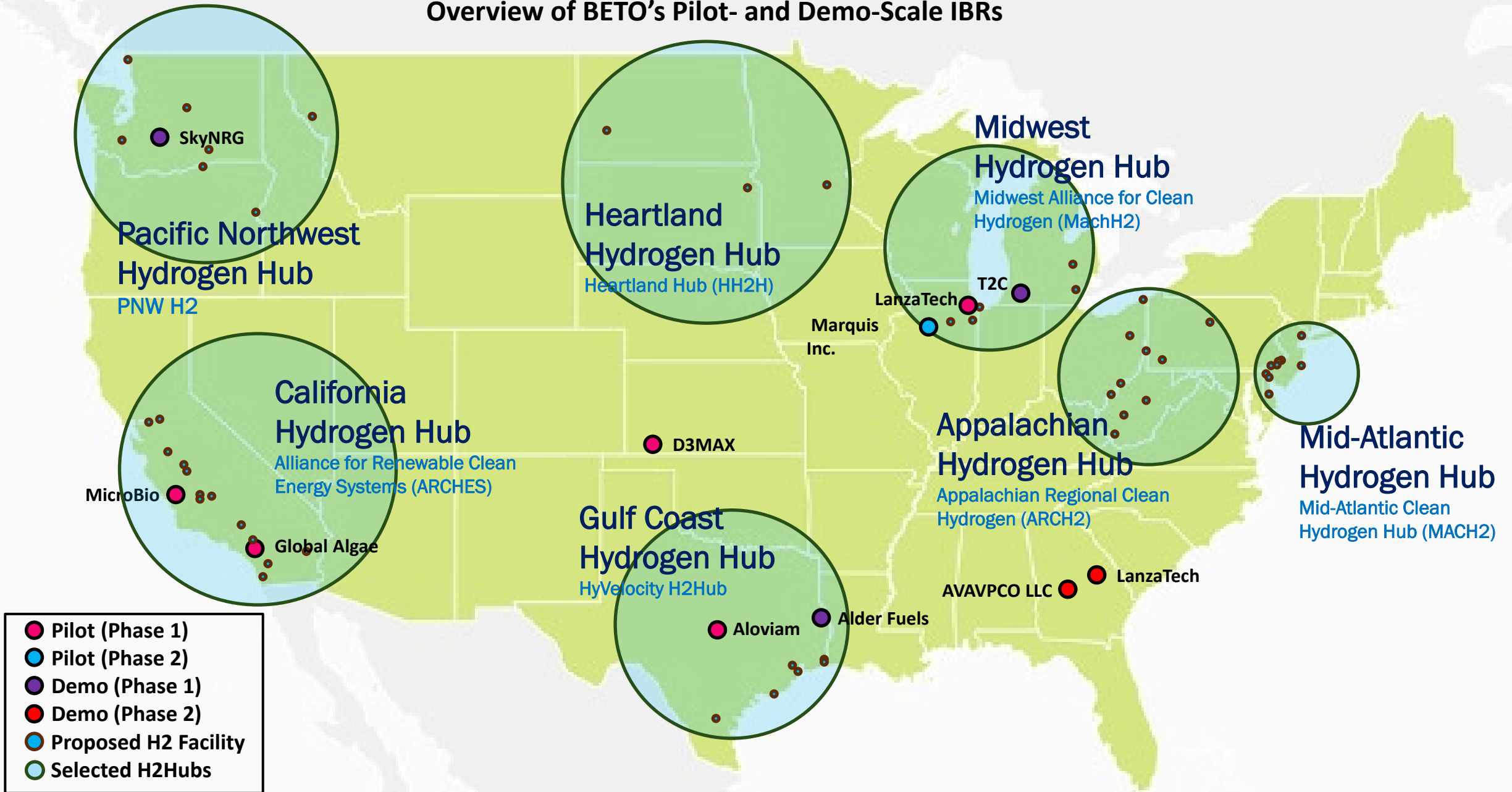
# SAF Grand Challenge Roadmap

- A coordinated approach to federal agency actions that derisks technology, supply chains, and markets, and reduces barriers
  - Actions that support near-term production
  - Ongoing innovation to support future production
  - Data collection and analysis to support markets for SAF through strong policies and focus on sustainability



<https://www.energy.gov/sites/default/files/2022-09/beto-saf-gc-roadmap-report-sept-2022.pdf>

# Overview of BETO's Pilot- and Demo-Scale IBRs





**Thank You**

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