BUREAU OF ENERGY AND TECHNOLOGY POLICY

Slides for the morning and afternoon sessions are in separate decks. This is the **afternoon** slide deck.

September 1, 2021

Introduction & Foundational Issues, Part A – End uses that are hard to decarbonize

Technical Session 1

CT 2022 Comprehensive Energy Strategy

Session is being recorded

Today's Agenda – Afternoon

Click on the agenda section headings to jump to the relevant slides

Long-Distance Trucking	1:00-1:50 pm
Public Comment 3	1:50-2:05 pm
Aviation	2:05-2:45 pm
Public Comment 4	2:45-3:00 pm
Maritime	3:00-3:45 pm
Public Comment 5 & General Public Comments	3:45-4:30 pm
Wrap Up	4:30-4:45 pm

Click on the presenters to jump to their slides

Long-Distance Trucking

Dave Schaller – North American Council for Freight Efficiency

Jessie Lund – CALSTART

Edmond Young – Toyota

(speaker order may vary)

BUREAU OF ENERGY AND TECHNOLOGY POLICY

North American Council for Freight Efficiency

Connecticut Department of
ENERGY & ENVIRONMENTAL PROTECTION

RUN ON LESS ELECTRIC

Long Haul Trucking Path to Zero Emissions

Dave Schaller

September 2022

MD & HD Industry Segments

Market Size

MD Delivery (Box trucks & step vans)
Total Population: **1,900,000**
Miles: **125/day 25K/year**

Regional Haul (Day cabs & some sleepers)
Total Population: **800,000**
Miles: **450/day 80K/year**

Long Haul (Sleeper Tractors)
Total Population: **1,200,000**
Miles: **600**/day **100K**/year

School Bus (yellow or white)
Total Population: **480,000**
Miles: **??**/day **12K**/year

MD Work Trucks (Dump, stake, service, waste…)
Total Population: **470,000**
Miles: **125/day 25K/year**

Vocational Class 8
(Construction, waste, dump…)
Total Population: **800,000**
Miles: **300/day 65K/year**

Transit Bus (public transportation)
Total Population: **150,000**
Miles: **??**/day **35K**/year

Yard Tractors (holsers, shuttles…)
Total Population: **35,000**
Miles: **10-20**/day @ 10 MPH

Expeditors Class 5-8
(MD & HD rush deliveries…)
Total Population: **25,000**
Miles: **500/day 90K/year**

This slide is under development

Electrification Time Frame

Pathways to HD Truck Charging

1) Fleet Depot Based

2) Opportunity Charging
Stores, Ports, Warehouses…

3) Shared Card Lock Locations

4) Truck Stops

5) Toll Road Rest Areas

6) Interstate Rest Areas

7) Wireless Charging (parked and/or in motion)
8) Mobile Roadside Charging (emergencies & service calls)

7

ZEV Long Haul Challenges

- Battery and Range
  - Cost, size, weight, range, rate of recharging…
- Charging Infrastructure
  - Locations, legal limitations, maintenance…
- Hydrogen Infrastructure
  - Simply not there yet
  - Small molecule that leaks and is corrosive
- Hydrogen storage on truck
  - Density, refill time, tank size…
- Both Battery Electric and Hydrogen will require significantly more power from the grid

Run on Less by NACFE

2017

RUN ON LESS BY NACFE

Long Haul

7 Fleets

10.1 MPG

2019

RUN ON LESS REGIONAL

Regional Haul

10 Fleets

8.3 MPG

2021

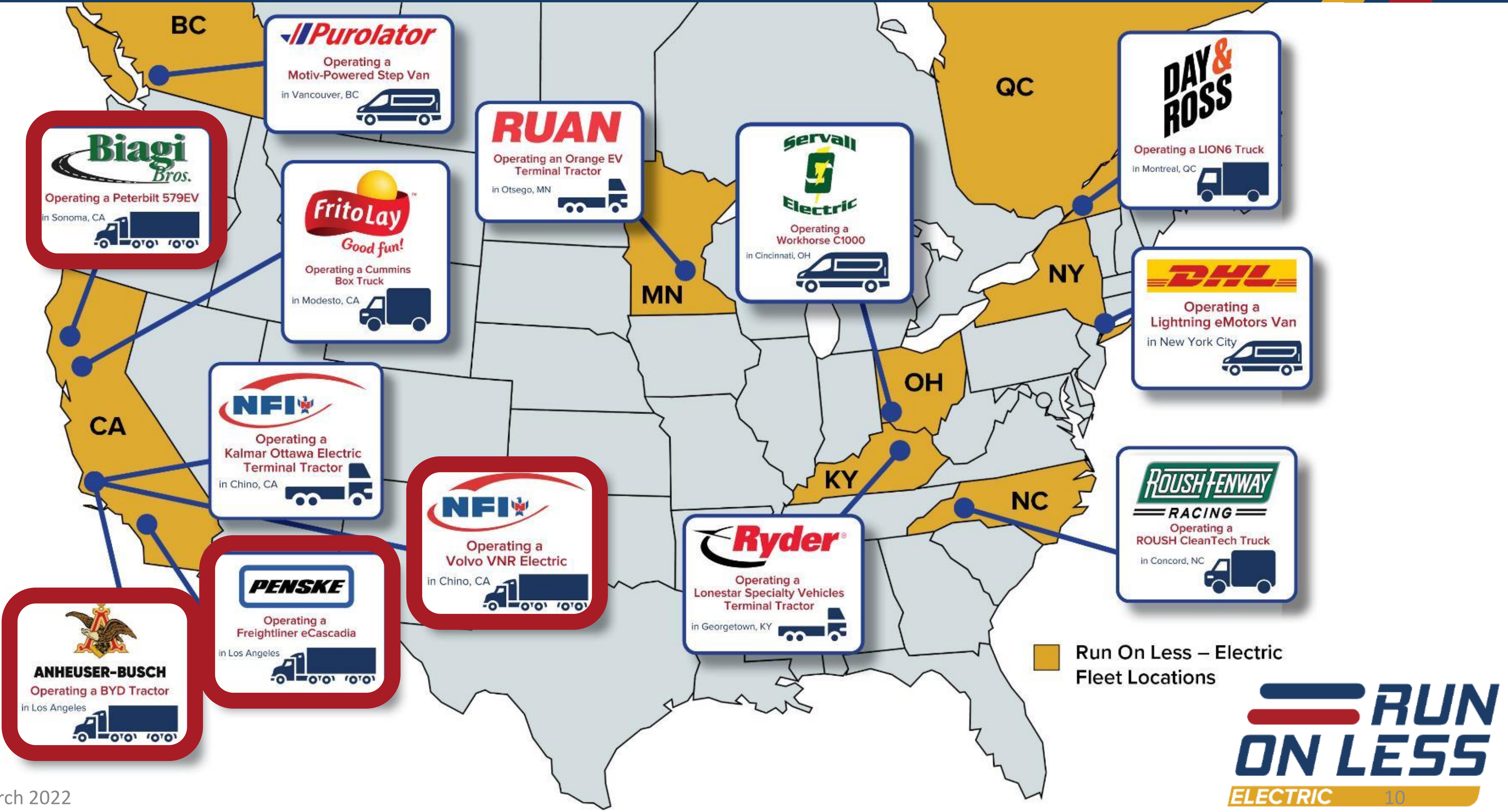
RUN ON LESS ELECTRIC

All BEVs

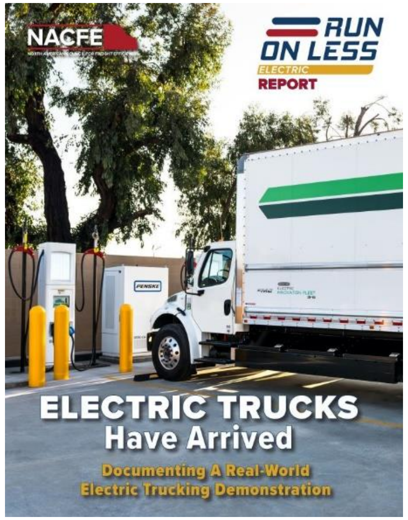
13 Fleets

New metrics!

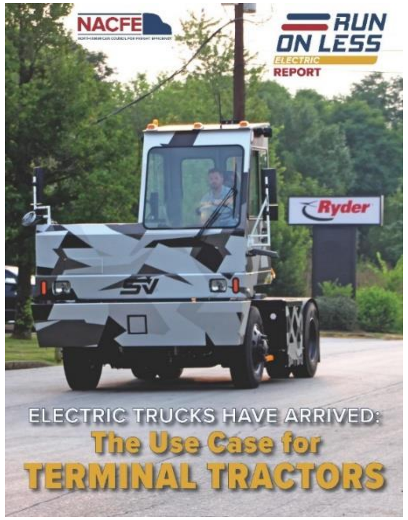
Run on Less – Electric Participants



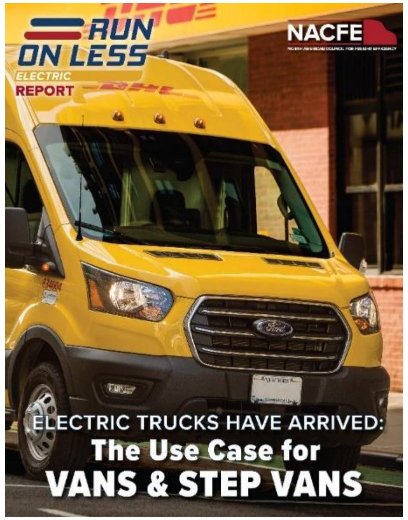
RoL–E Reports



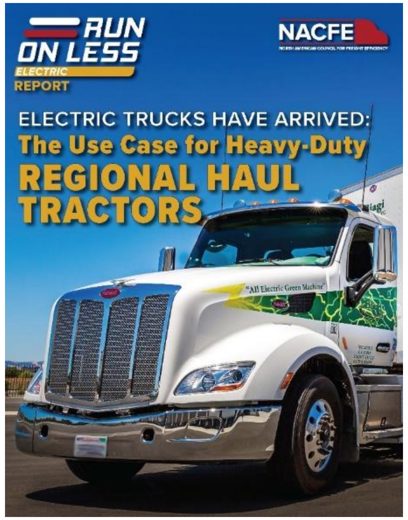
January 12, 2022
Review Of Complete Demonstration:
[Electric Trucks Have Arrived]



March 6, 2022
The Use Case For
[TERMINAL TRACTORS]



April 11, 2022
The Use Case For
[VANS & STEP VANS]



May 5, 2022
The Use Case For
[REGIONAL HAUL TRACTORS]

June 28, 2022
The Use Case For
[MEDIUM DUTY BOX TRUCKS]


MD BOX TRUCKS
Jennifer Wheeler, Senior Program Manager, NACFE
NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY
Market Segment & Fleet Profile Fact Sheet

Operational Characteristics	
Duty Cycle	Return to Base
Use Case	Pickup & Delivery
Average Range	Less than 100 miles
Routes	Variable
Fueling	Centralized
Miles per Gallon	10.0
Replacement Cycle	10.2
Average Age	8.4
Axle Configuration	4X2

[4 Market Segment Fact Sheets]

Short Regional Haul

Regional Haul (Mostly)

NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

Some CBEVs: "Range Extended"

Hyliion "Hypertruck" is being called ERX: Electric Range Extender and runs on CNG or RNG

Several OEMs and suppliers are working on hydrogen fuel cell powered electric trucks

CNG Infrastructure

From DOE Alt Fuels Data Center

NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

Hydrogen & Battery Electric Trucks

Both Competitors *AND* Teammates

Hydrogen Fuel Cell Trucks	Truck Subsystem	Battery Electric Trucks
Yes (but less)	Rechargeable Batteries	Yes
Yes	Electric Drive Motors	Yes
Yes	High Power Cables	Yes
Yes	Software Management	Yes
Yes	Regenerative Braking	Yes
Yes	**Hydrogen Fuel Cell**	--
Yes	**Hydrogen Fuel Tank**	--
Hydrogen Station	Refueling	Electric Charging Station
Large	Electricity Consumption	Large

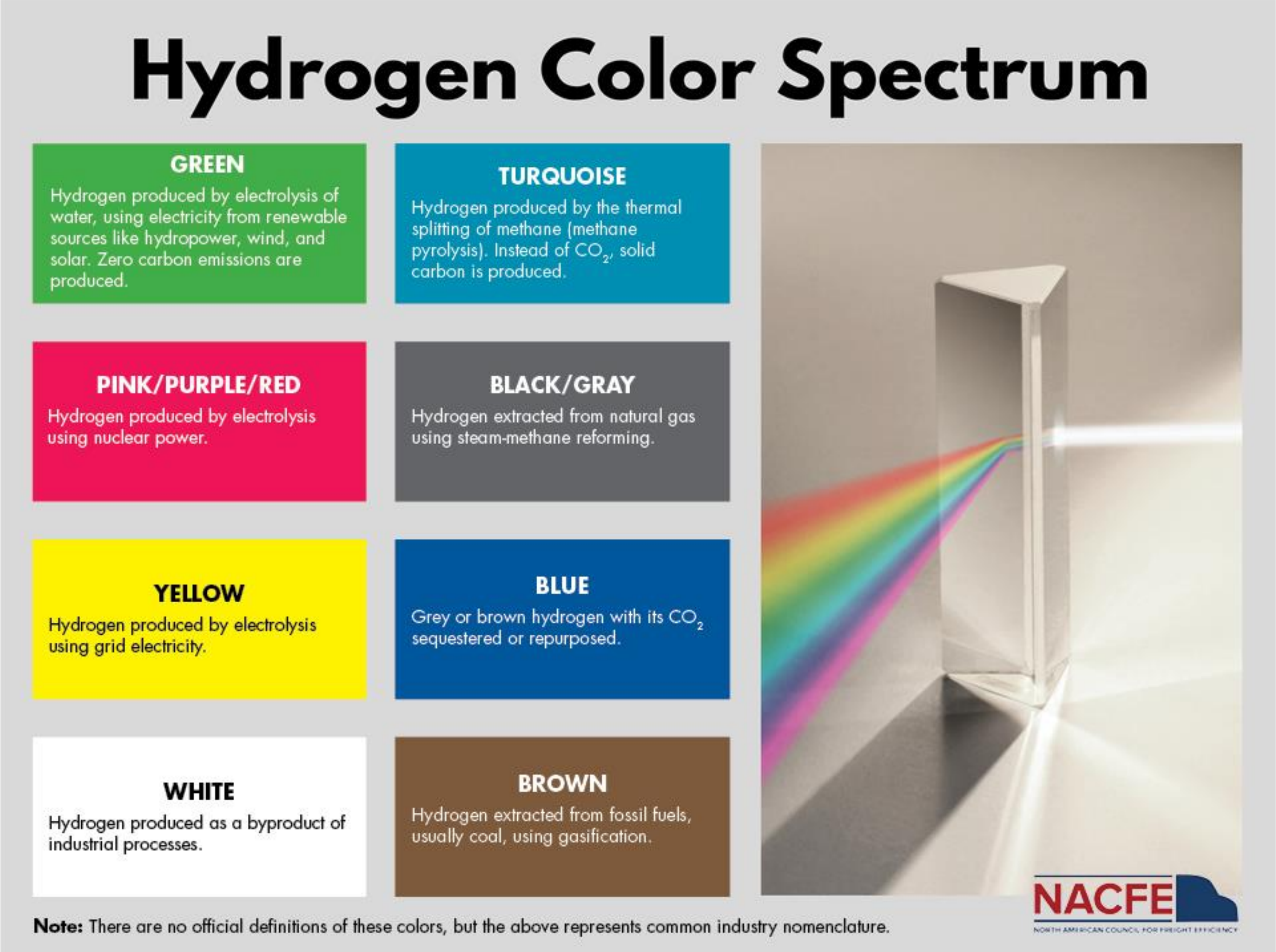
NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

Hydrogen Fuel Cell Trucks

Current Status

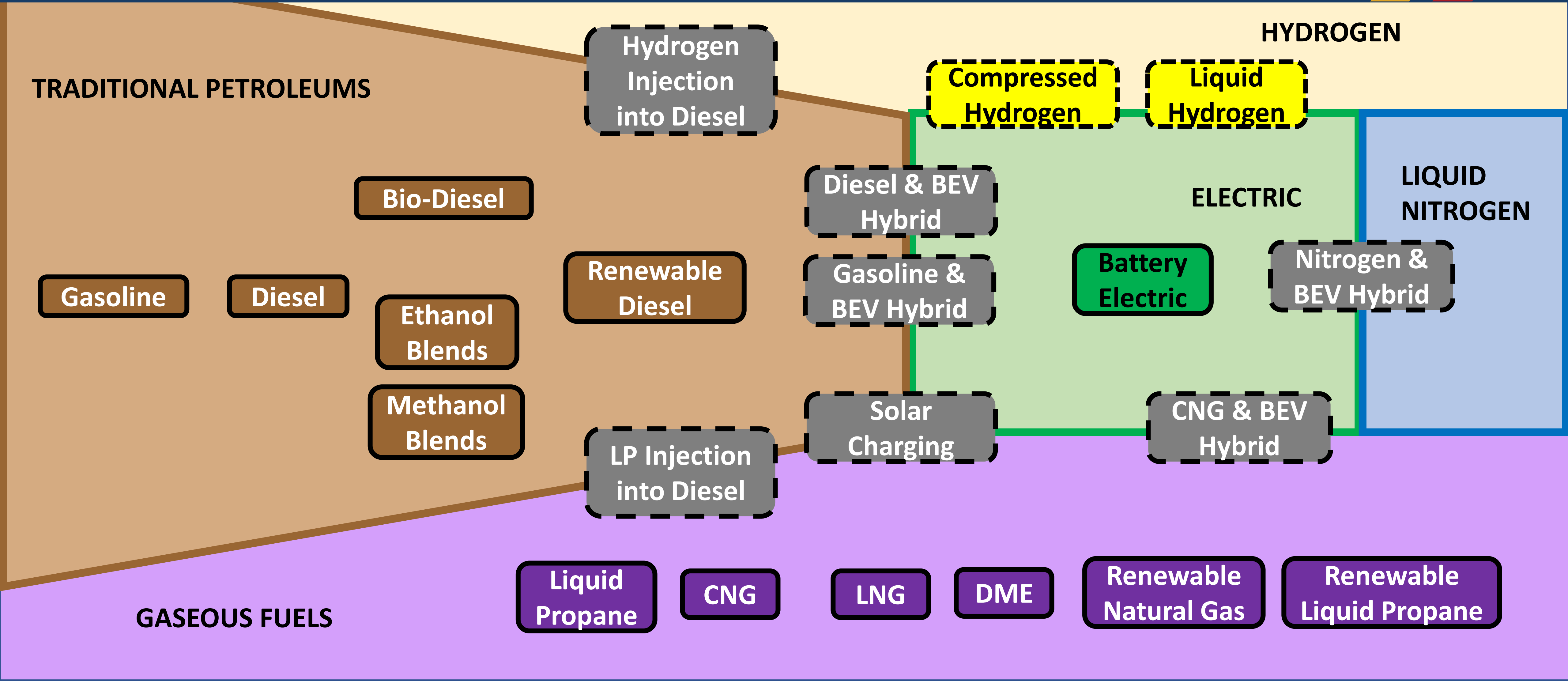
- Several trucks under fleet test
- Others under OEM development
- Both Compressed & Liquid Hydrogen trucks planned

Guidance on Hydrogen

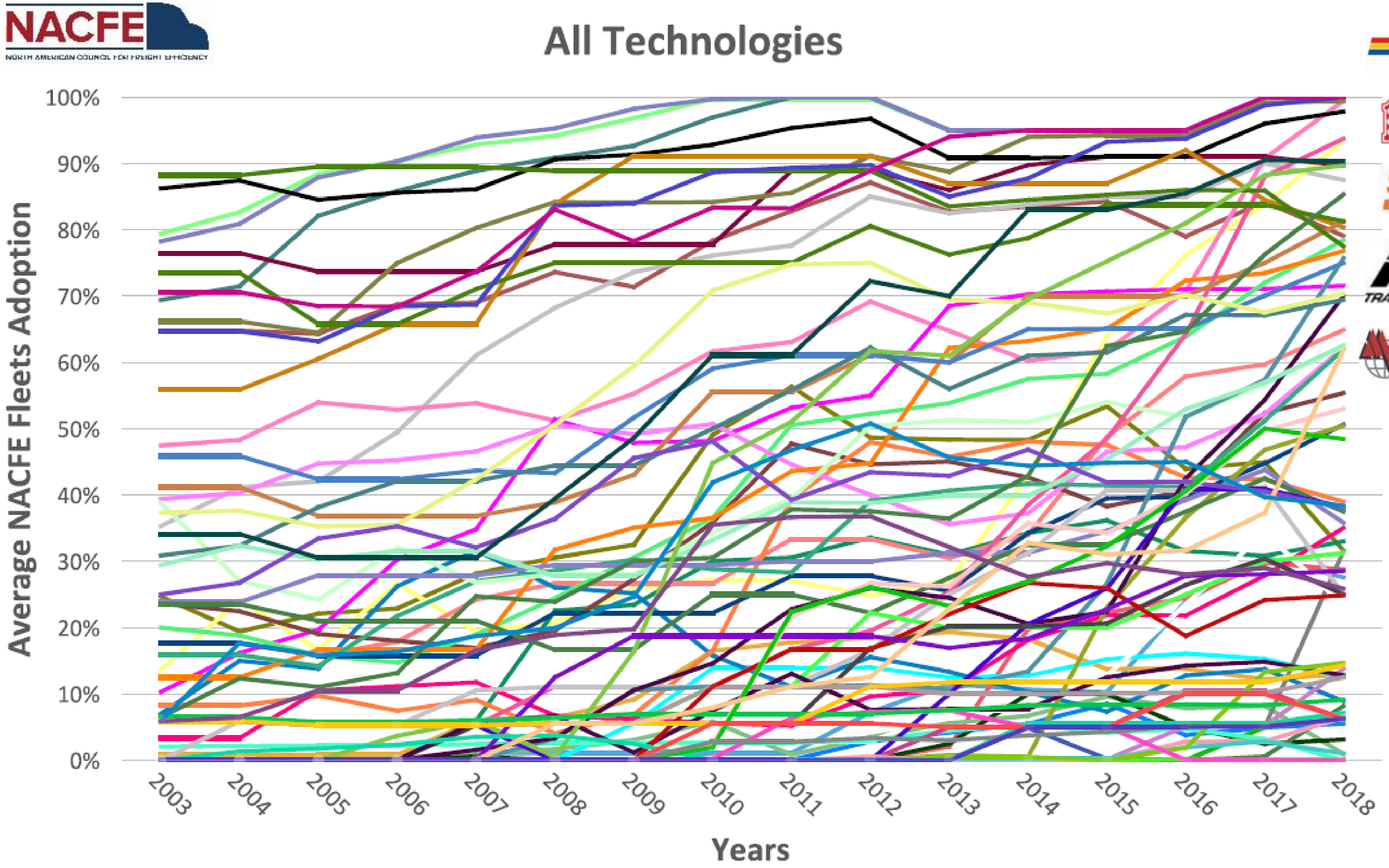


17

Alternative Fuels

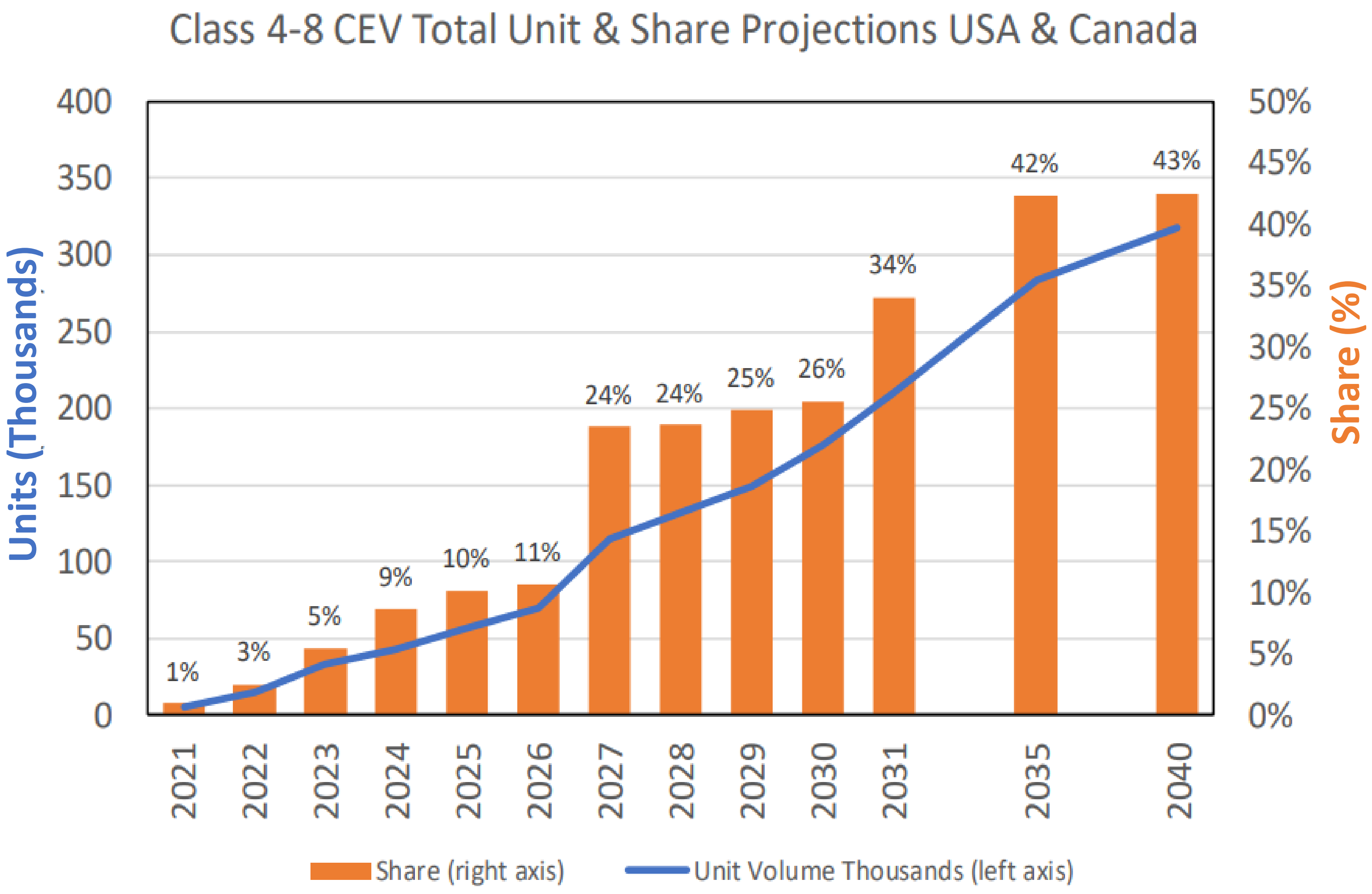


2019 Annual Fleet Fuel Study



https://nacfe.org/annual-fleet-fuel-studies/

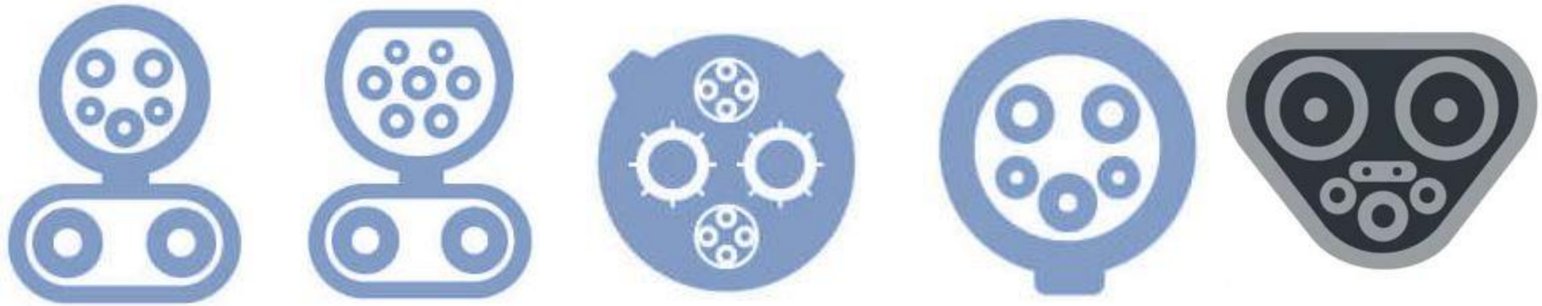
Commercial Electric Vehicle Market



Impacting Factors

- Better Total Cost of Ownership
- Decreasing Battery Costs
- Growing Customer Demand
- Regulatory Pressures

Projections by ACT Research 2021



CCS1 CCS2 CHAdeMO J1772 MCS or CharIN

NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

NACFE.org

Let's Stay Connected…
… And charged up!

RUN ON LESS ELECTRIC

RunOnLess.com

LinkedIn NACFE (& Spanish: NACFE LATAM)

Facebook NACFE

Twitter @NACFE_Freight & @RunOnLess

Vimeo NACFE

Dave Schaller

David.Schaller@NACFE.org

260-602-5713

CALSTART

Decarbonization of Long-Distance Trucking

Jessie Lund, CALSTART

September 1, 2022

CES Technical Meeting 1

WHO ARE WE?

- **CALSTART** is an internationally recognized clean transportation technology consortium, with 300+ members, all dedicated to the growth of the clean transportation industry.

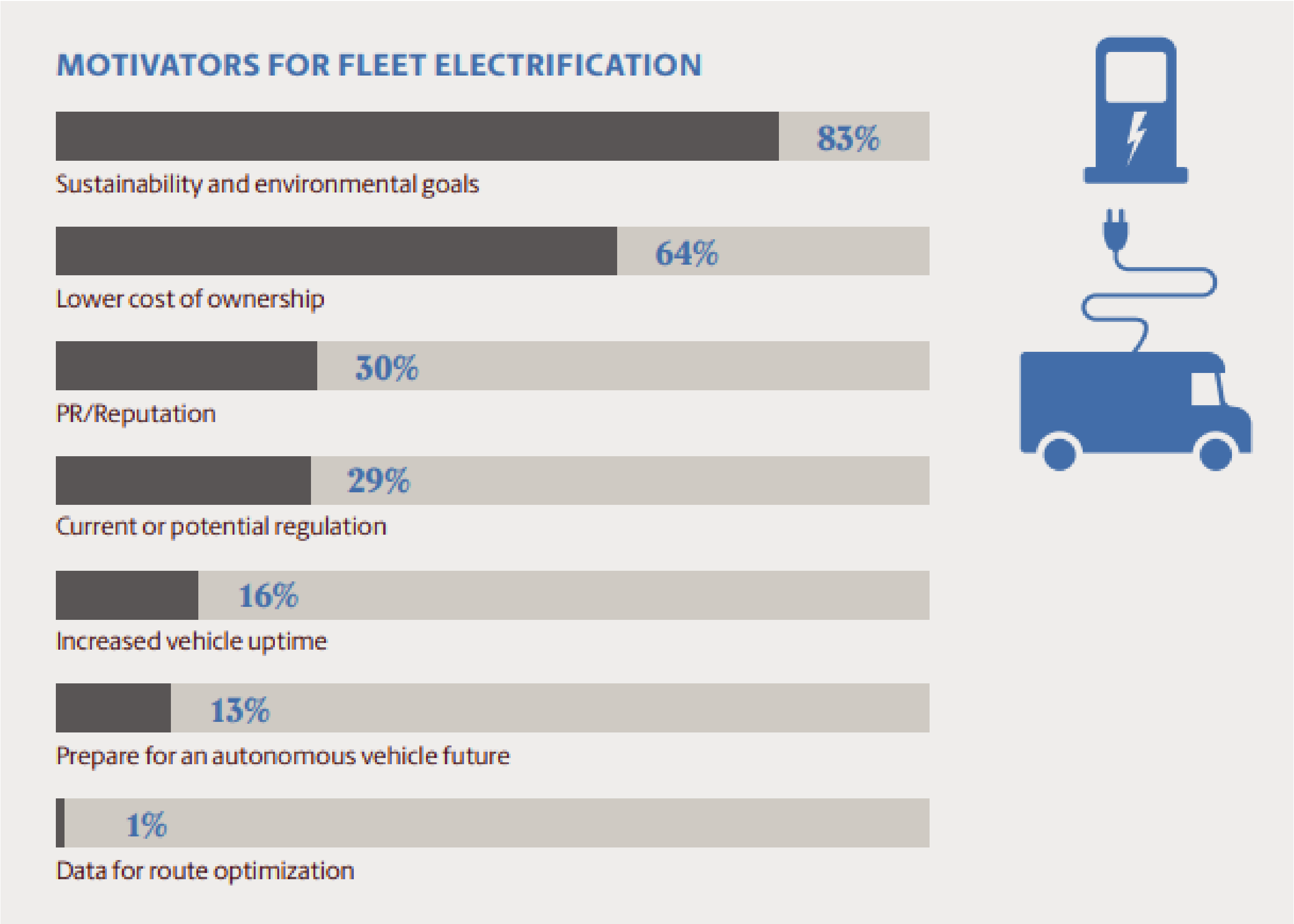
- Founded in 1992, we work with our member companies and agencies to build a high-tech clean transportation industry that creates jobs, cuts air pollution and oil imports, and curbs climate change.

CALSTART MEMBERSHIP

Our 300+ members include manufacturers, suppliers, fleets, technology firms, academic institutions, government agencies, NGOs, power companies, fuel providers, & more

WHAT'S DRIVING ZERO-EMISSION TRUCKS?

- Sustainability goals
- Public health (esp. DACs & drivers)
- Air quality
- Climate crisis
- Performance
- TCO
- Noise
- Regulation (ACT & ACF)

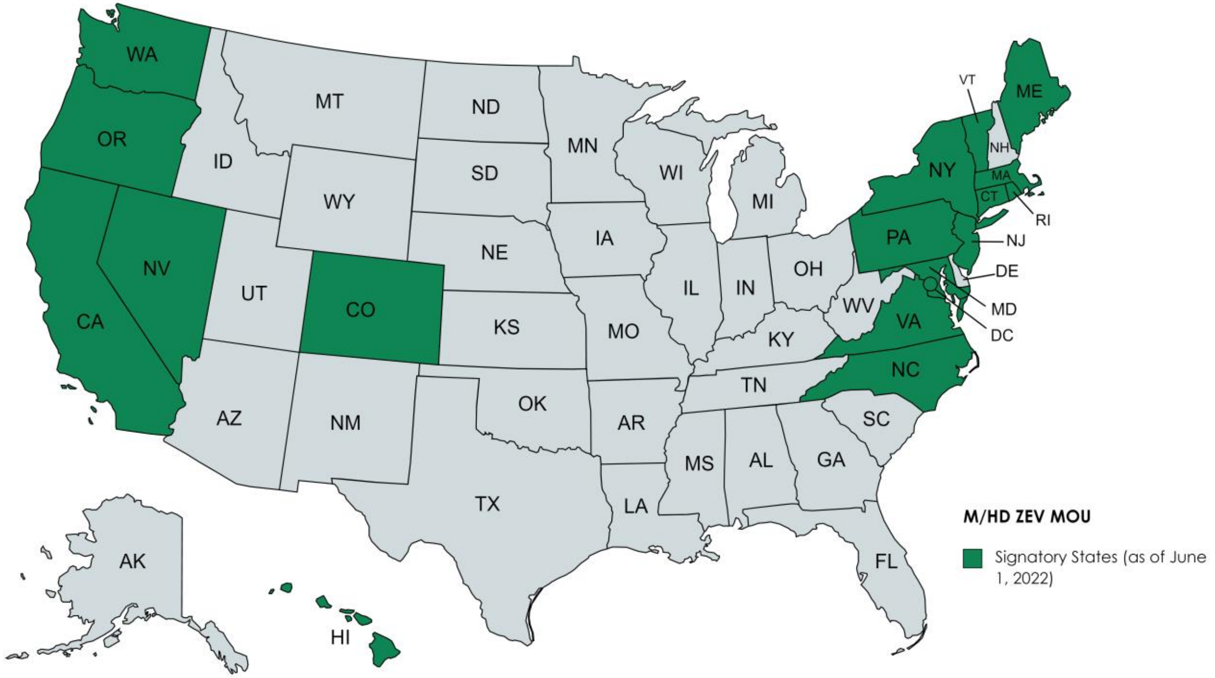


Source: *Curve Ahead: The Future of Commercial Fleet Electrification* (GreenBiz & UPS)

WHAT'S DRIVING ZERO-EMISSION M/HDVS?

MULTI-STATE MEDIUM- AND HEAVY-DUTY ZERO EMISSION VEHICLE

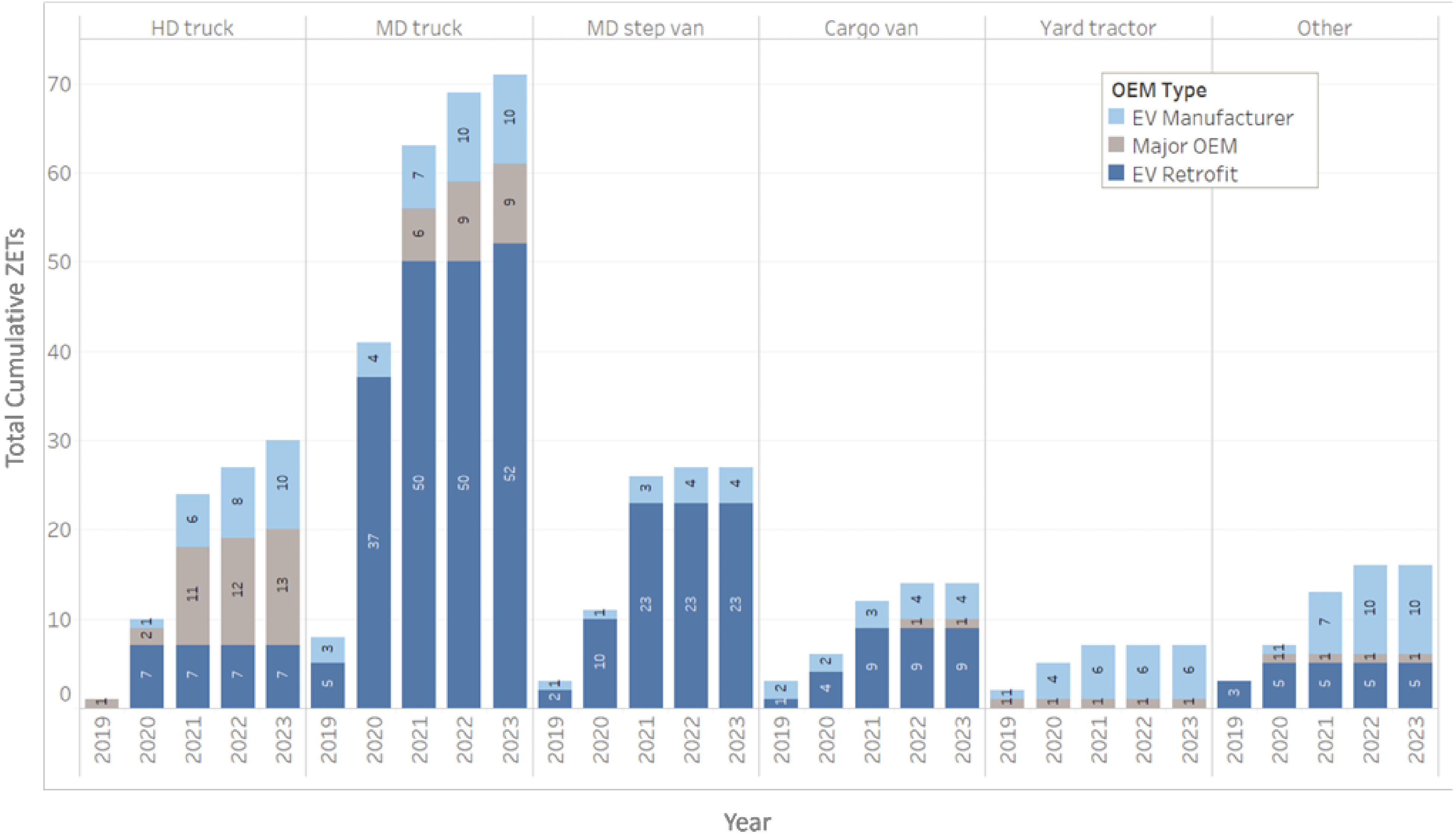
MEMORANDUM OF UNDERSTANDING



17 states + DC have committed to "make sales of all new medium- and heavy-duty vehicles in [their] jurisdictions zero emission vehicles by no later than 2050" (with an interim goal of 30% sales by 2030).

The signatories represent roughly **half the U.S. economy**.

MODEL AVAILABILITY IN THE UNITED STATES (2019-2023)



Source: ZETI

CURRENT DEPLOYMENTS OF ZERO EMISSION MDHD TRUCKS (AND OFF-ROAD YARD TRACTORS)

1,215 Zero Emission Trucks (ZETs) Deployed and Operating in US as of late 2021

- Medium Duty: ~75%
- Yard Tractors: ~20%
- HD Trucks: ~4%

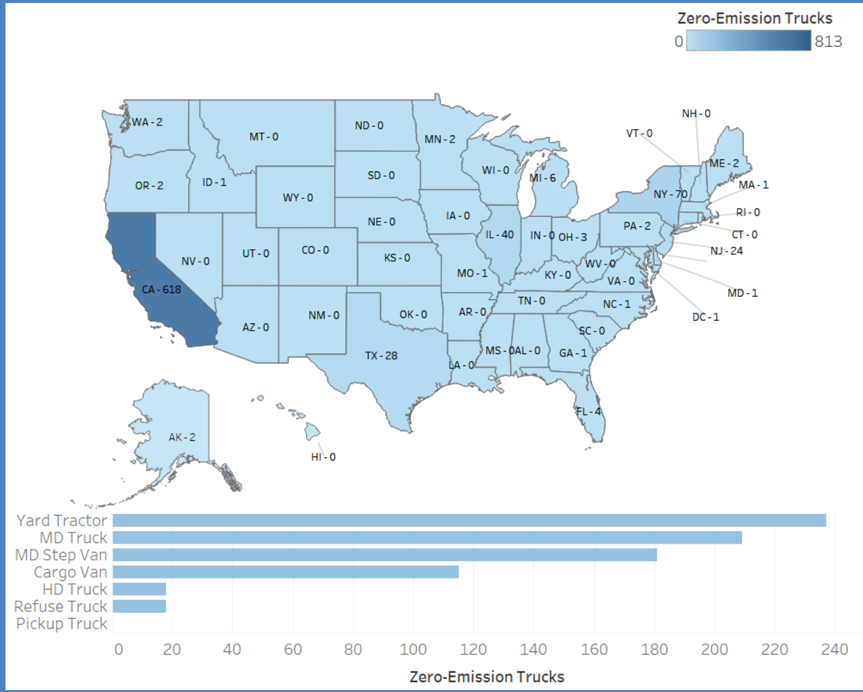
~738 ZETs are in CA (~60% of total US)

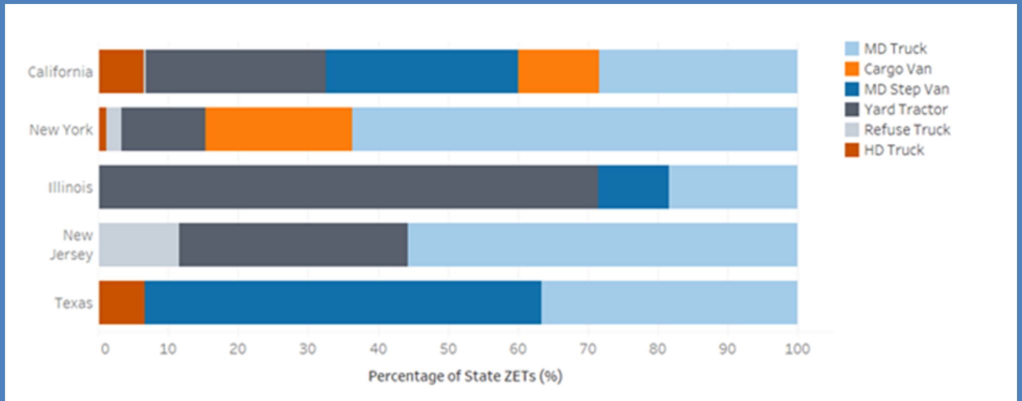
Nationally:

~67% of ZET deployments were from upfitters (Motiv, Lightning eMotors, SEA, etc)

~13% by 'ZET only' mfgs (BYD, Orange EV)

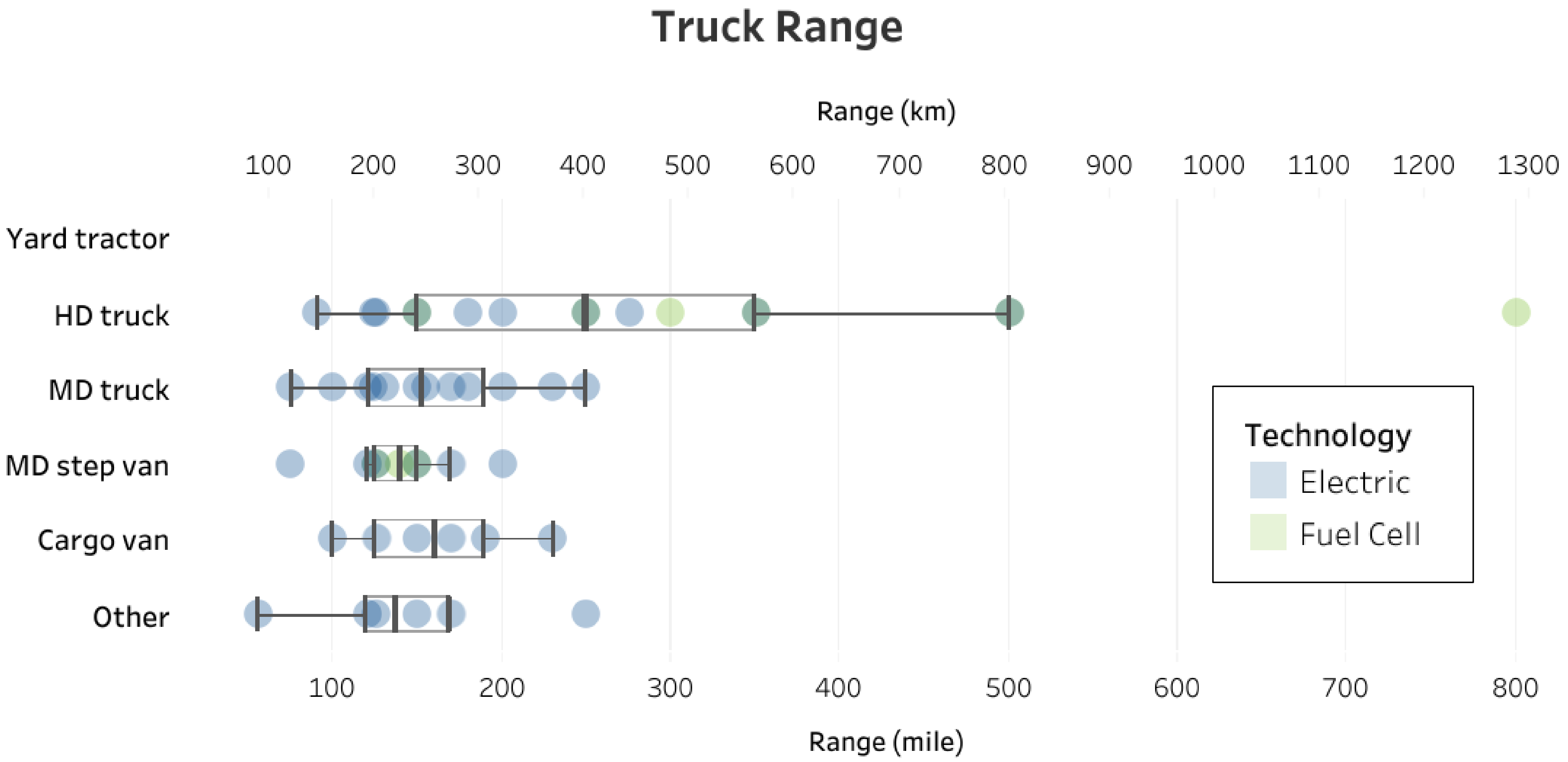
~20% by conventional mfgs (Daimler, Volvo, Navistar, PACCAR, etc)





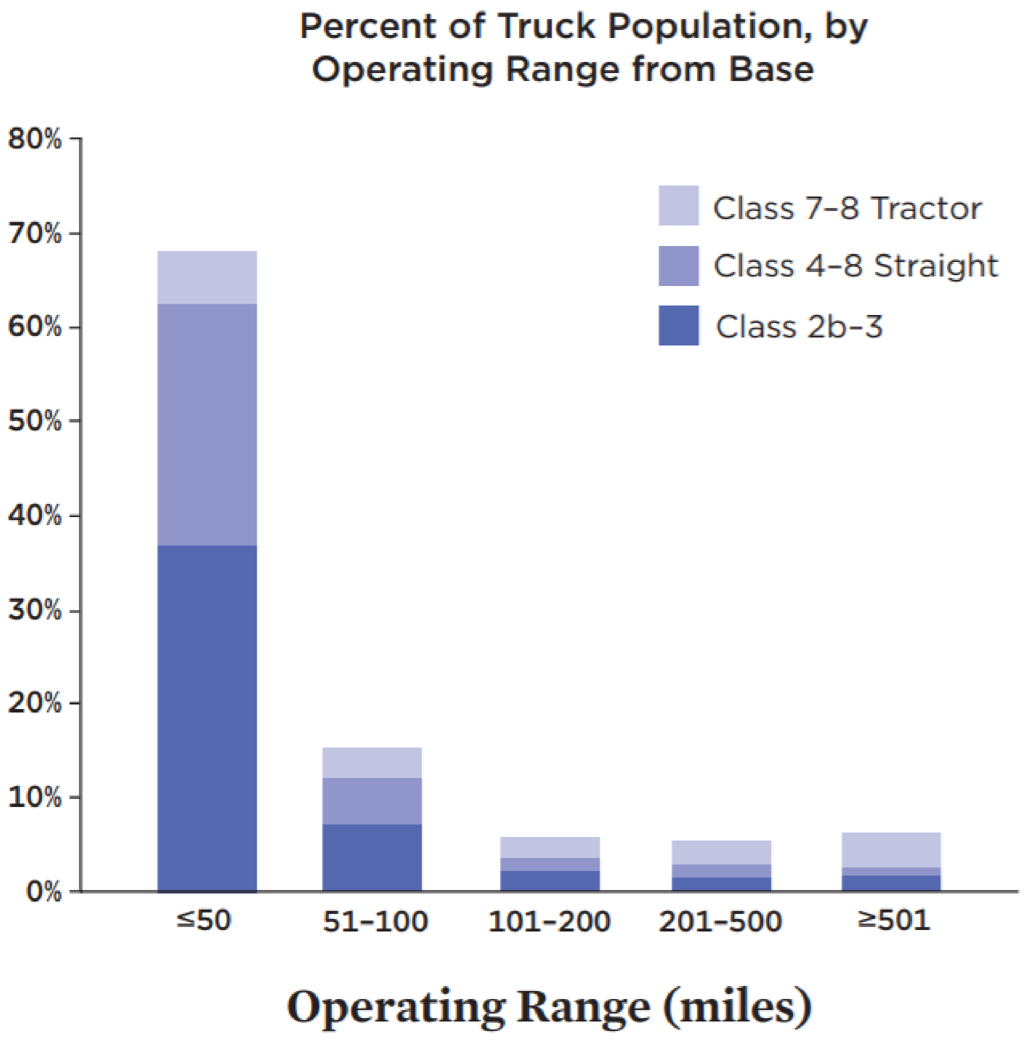
From CALSTART Report: *Zeroing in on Zero-Emission Trucks - The Advanced Technology Truck Index : A U.S. ZET Inventory Report (Jan. 2022)*

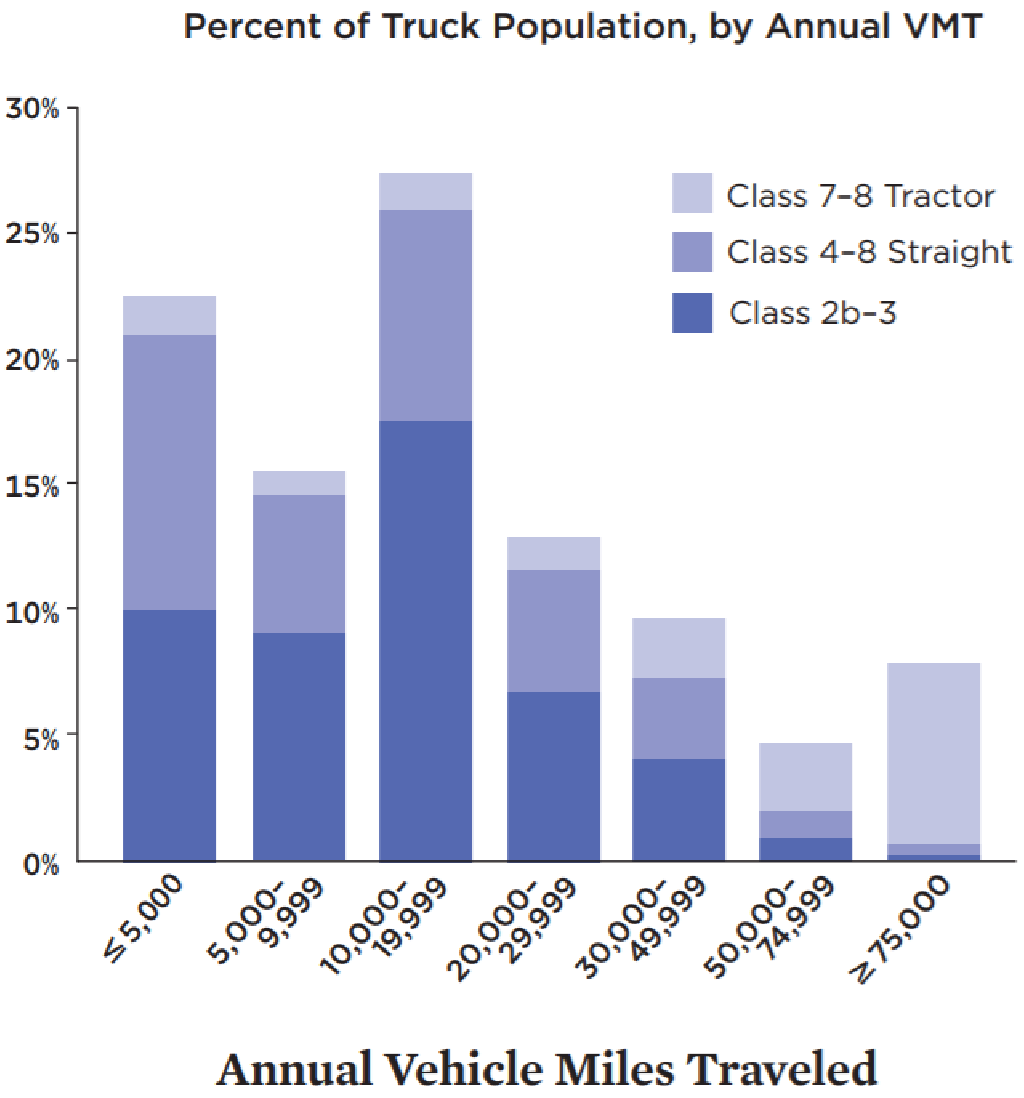
M/HD ZET MARKET



Source: ZETI

MANY VEHICLES' DUTY CYCLES ARE READY FOR ELECTRIFICATION TODAY





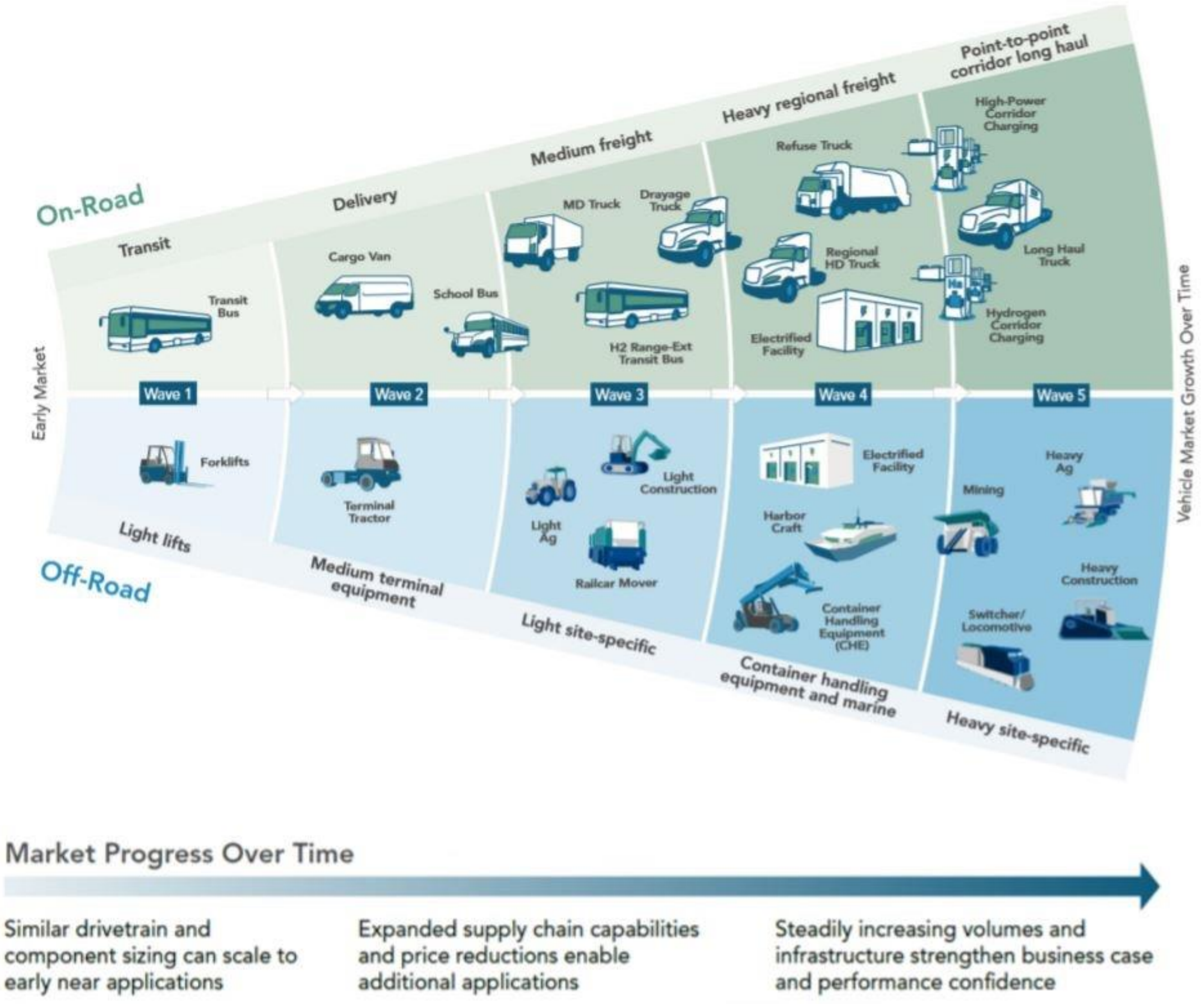
Note: Important to consider daily mileage and dwell time available for charging

Source: VIUS

CHALLENGES FOR LONG-HAUL

- Duty cycle (battery size, weight, range, cost, refill time)
- Charging/refueling infrastructure (access, high power, grid capacity, price, real estate, permitting)
- Utility rates (demand charges, TOU, etc.)
- Workforce availability (service networks, technicians)

BEACHHEADS



Source: CALSTART

GLOBAL MOU

The first international agreement on zero-emissions trucks and buses

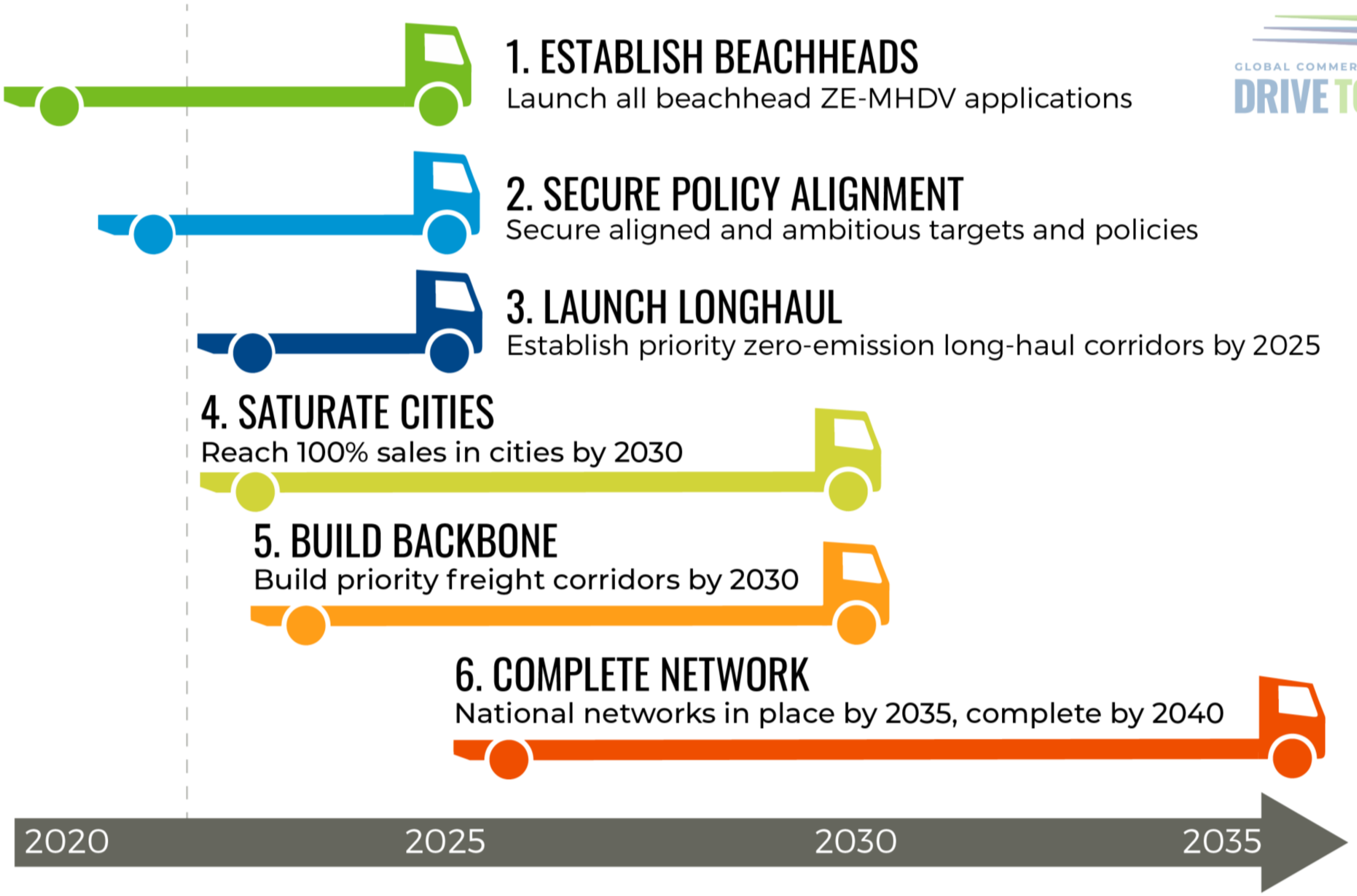
Share of new MHDVs that are zero emissions:

100% by 2040

30% by 2030

Austria
Canada
Chile
Denmark
Finland
Luxembourg
Netherlands
New Zealand
Norway
Portugal
Scotland
Switzerland
Turkey
United Kingdom
Uruguay
Wales

6-STAGE STRATEGY TO ENABLE 100% ZE-MHDVS BY 2040



GLOBAL COMMERCIAL VEHICLE DRIVE TO ZERO

LONG-HAUL TRENDS TO WATCH

- CharIN Megawatt Charging System (MCS)
- Long-haul corridors [West Coast Clean Transit Corridor Initiative (WCCTCI), Research Hub for Electric Technologies in Truck Applications (RHETTA), etc.]
- Tesla battery electric semi
- Hydrogen trucks & infrastructure [drayage pilots, DOE/IIJA funding (SuperTruck 3 awards - *$127 M*, H2Hubs - *$8 B)*]

H2 Fuel Cell Trucks: 2021 Saw Acceleration of Interest

Announcements and Demonstration Awards from Most Major OEMs:

- **Hyundai (CARB-CEC Drayage Pilot)**
- **Nikola TreH2**
- **Navistar (GM)**
- **Cummins (Symbio) H2 CEC Demo**
- **Volvo / Daimler**
- **PACCAR (Supertruck 3)**
- **Daimler Trucks (Supertruck 3)**
- **Ford Class 6 (Supertruck 3)**
- **GM Class 4-6 (Supertruck 3)**
- **Hino/Toyota**
- **Hyzon**

THANK YOU!

Jessie Lund
jlund@calstart.org

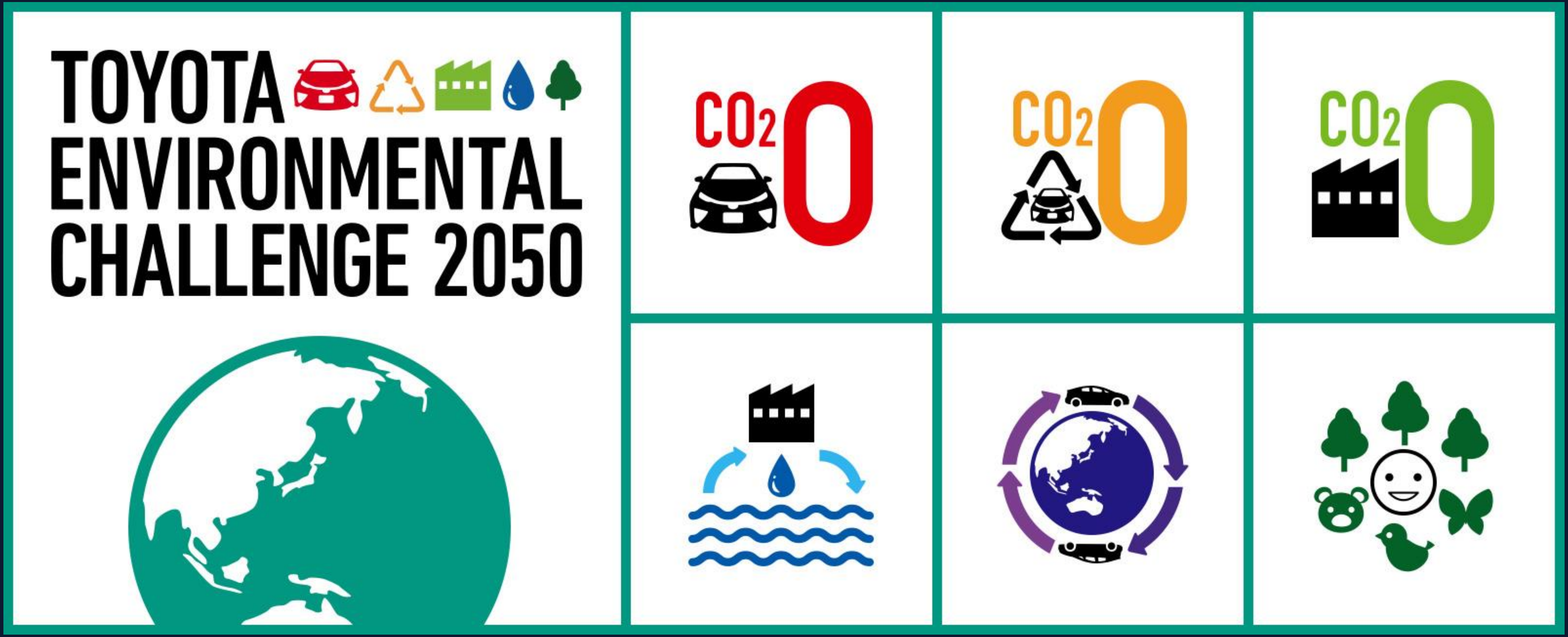
Lead Project Manager, Truck & Off-road
CALSTART

Toyota

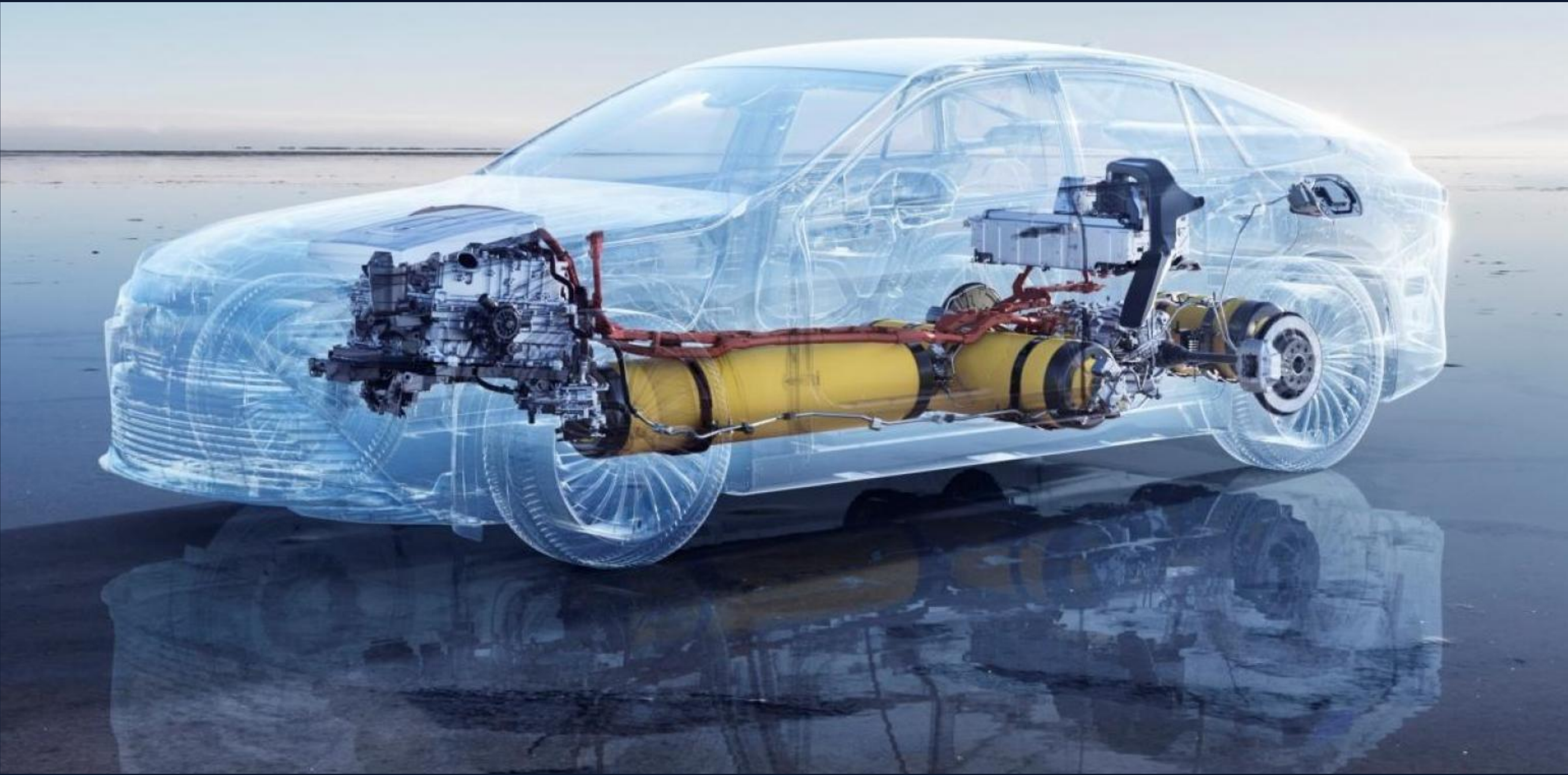
Toyota Fuel Cell Overview

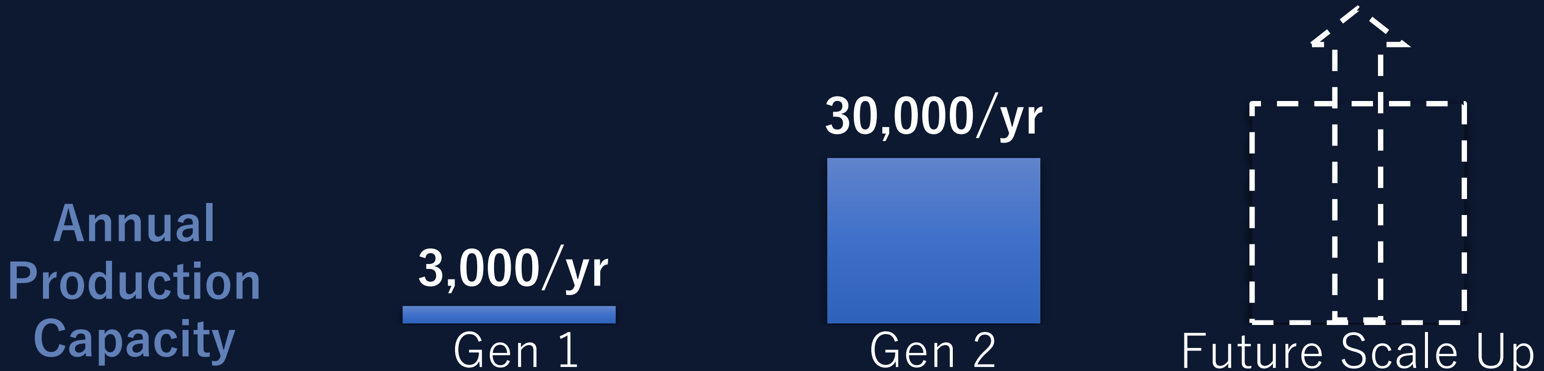
CONNECTICUT
SEPTEMBER 1, 2022

TOYOTA


TOYOTA
ENVIRONMENTAL
CHALLENGE 2050
CO2 0
CO2 0
CO2 0


H2

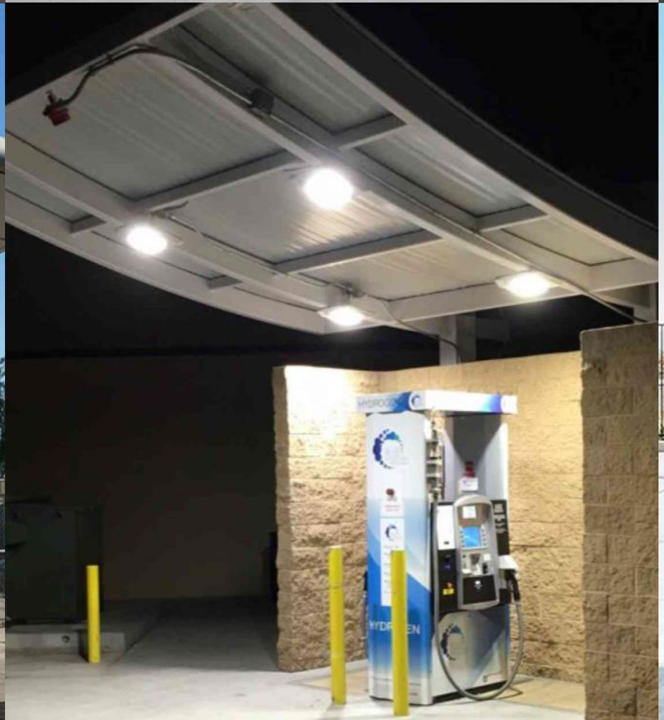



Annual Production Capacity
3,000/yr
Gen 1
30,000/yr
Gen 2
Future Scale Up


H2
H2

Shell
Hydrogen
Hydrogen
Hydrogen

Iwatani
Hydrogen
Station
Iwatani


Hydrogen



ITM POWER
Energy Storage | Clean Fuel
HYDROGEN PRODUCED ON-SITE
ITM POWER
Energy Storage | Clean Fuel

Initial Prototypes

10 Truck Pilot

Production Intent
2023 / TMMK


Zero Emissions Kenworth T680 FCEV on the Climb to 14,115-Foot Pikes Peak Summit
Watch later
Share
DRIVING TO
ZERO
EMISSIONS
KENWORTH T680
FUEL CELL EV
470HP | 350 MI RANGE | 15 MIN REFILL
2:21 / 2:31
YouTube

2

INITIAL HEAVY-DUTY STATIONS

3

NEW HEAVY-DUTY STATIONS

IIJA §40314

$8.0B for H2 HUBs

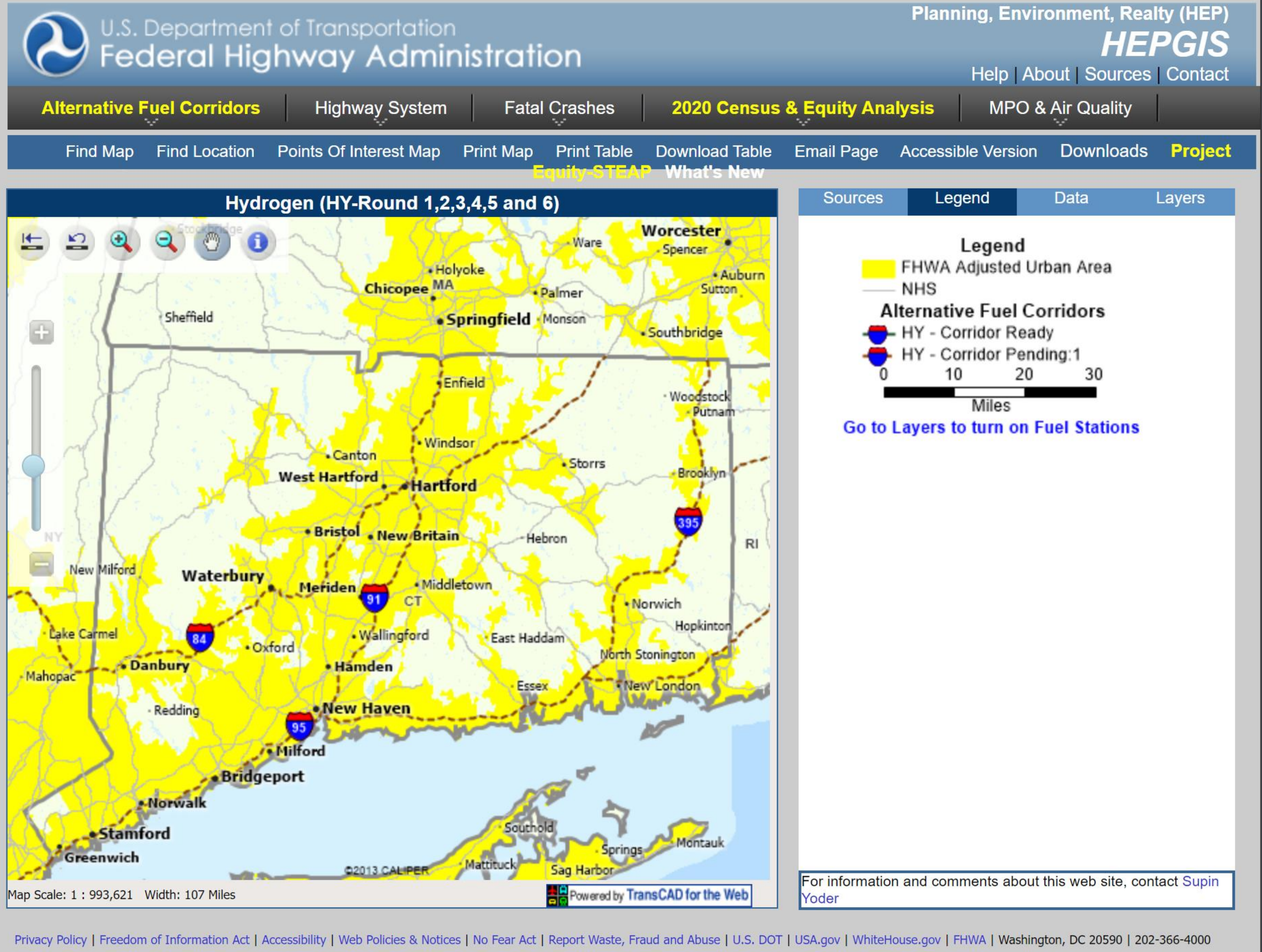
- 50% cost share
- Supports FCETs

IIJA §11401

$2.5B for Alt Fuel Infra:

EV charging, **Hydrogen refueling**, propane and natural gas infra grants for FY22 – FY26

- Discretionary grant program
- $15 million / 80% of project costs
- Hydrogen Alt Fuel Corridor designation critical
- Only state, municipal, regional governments can apply



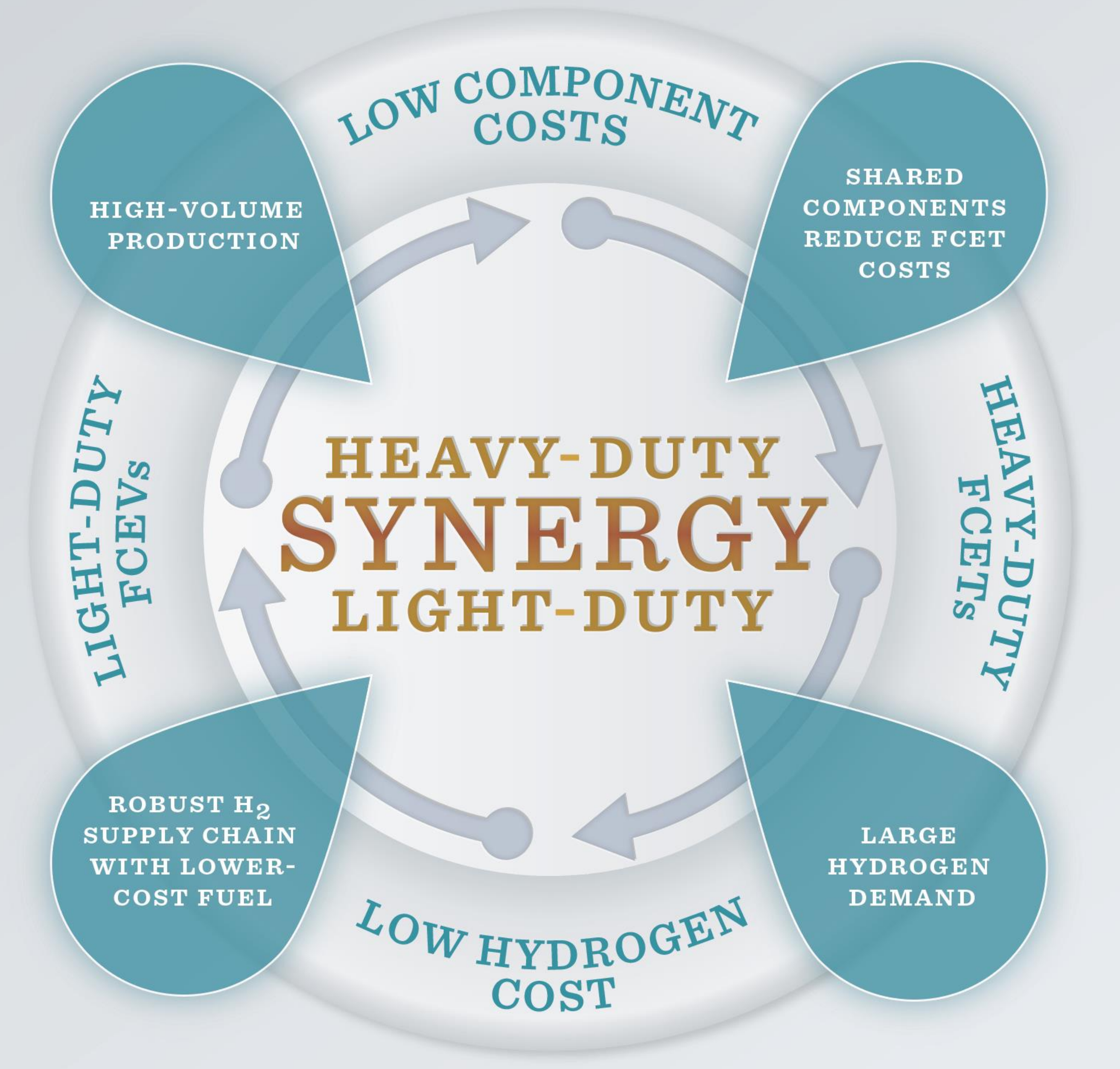
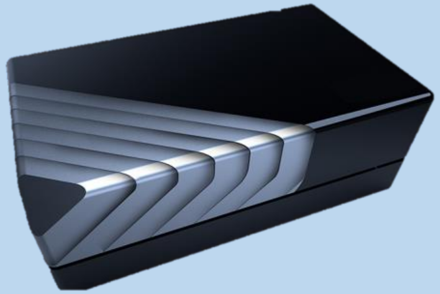


FIGURE 9 | *Economies of scale reduce cost*


FCV
ZERO EMISSION
TOYOTA

TOYOTA

Iwatani
FUEL CELL BUS
TOYOTA



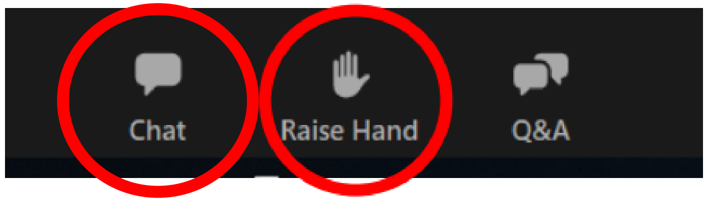
MOTOMACHI
FUEL CELL

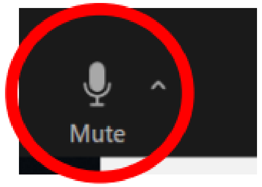

Zero Emissions Kenworth T680 FCEV on the Climb to 14,115-Foot Pikes Peak Summit
14,115 ft SUMMIT
14,115
14,000
6°
KENWORTH TOYOTA
ZERO EMISSIONS
2:13 / 2:30

Thank You!

TOYOTA

Questions and Comments





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At the conclusion of each panel DEEP will hold a brief question and comment period.

If you have a clarifying question, please drop it into the chat to either Jeff Howard or Becca Trietch. DEEP will pose as many questions as time allows to the speakers.

If you would like to make a comment:

- Please use the "Raise Hand" feature if you would like to speak
- After any interested elected officials have provided their comments, you will be invited to provide your comment in the order the hands were raised
- Please unmute yourself, state your name and affiliation
- Given time limitations, please limit your comment to 2 minutes.
- After your comments, please remember to click the "Mute" button

Public Comment – Long-Distance Trucking

BUREAU OF ENERGY AND TECHNOLOGY POLICY

Click on the presenters to jump to their slides

Aviation

Uisung Lee – Argonne National Laboratory

Dan Rutherford – International Council on Clean Transportation

Michael Winter – Pratt & Whitney

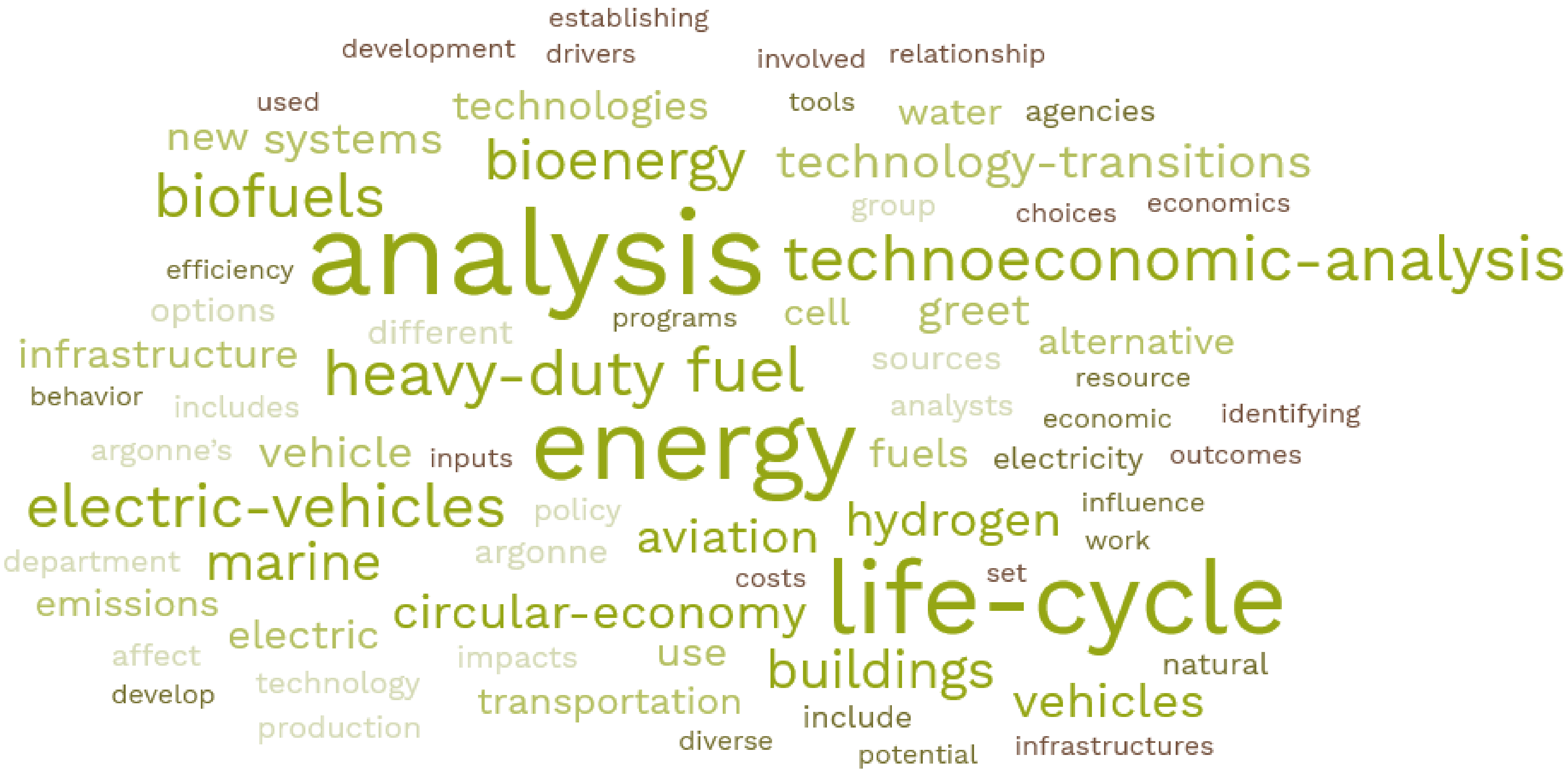
(speaker order may vary)

BUREAU OF ENERGY AND TECHNOLOGY POLICY

Argonne National Laboratory

Argonne's Systems Assessment Center

Providing insights and tools for R&D and policy decisions



GREET Overview

Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies

- Tracks life cycle performance of energy and products
  - Used to inform and guide DOE research
- Argonne has been developing GREET since 1995 with annual updates and expansions.
- Long-term support from U.S. Dept. of Energy
  - Vehicle Technologies Office (VTO)
  - Hydrogen Fuel-Cell Technology Office (FCTO)
  - Bioenergy Technology Office (BETO)
- Expanded from transportation-focus to include a wide range of technologies (Fuels, Vehicles, Chemicals, Plastics, Agriculture, Metals, Concrete, Buildings, Batteries, Electricity Infrastructure)

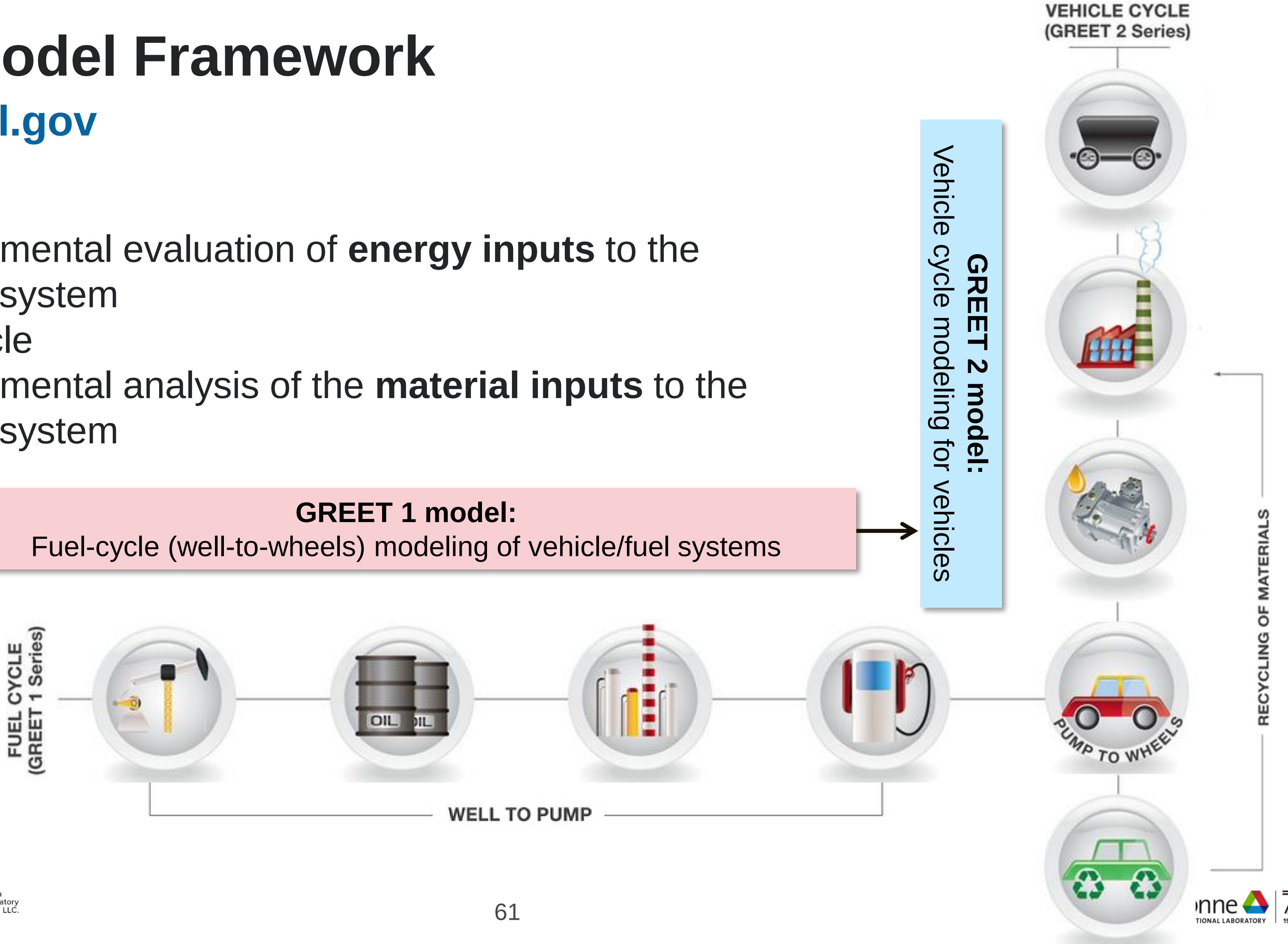
GREET Model Framework

greet.es.anl.gov

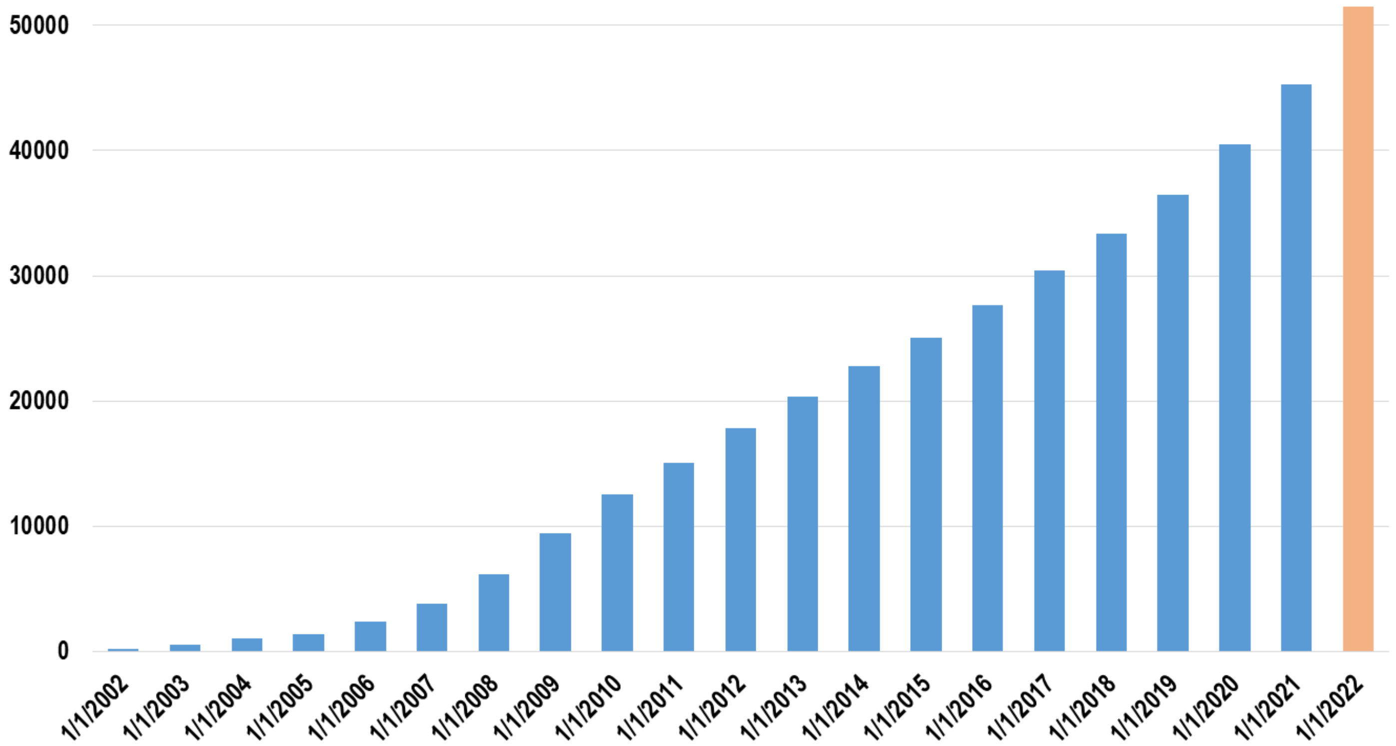
- Fuel Cycle:
  - Environmental evaluation of **energy inputs** to the vehicle system
- Vehicle Cycle
  - Environmental analysis of the **material inputs** to the vehicle system

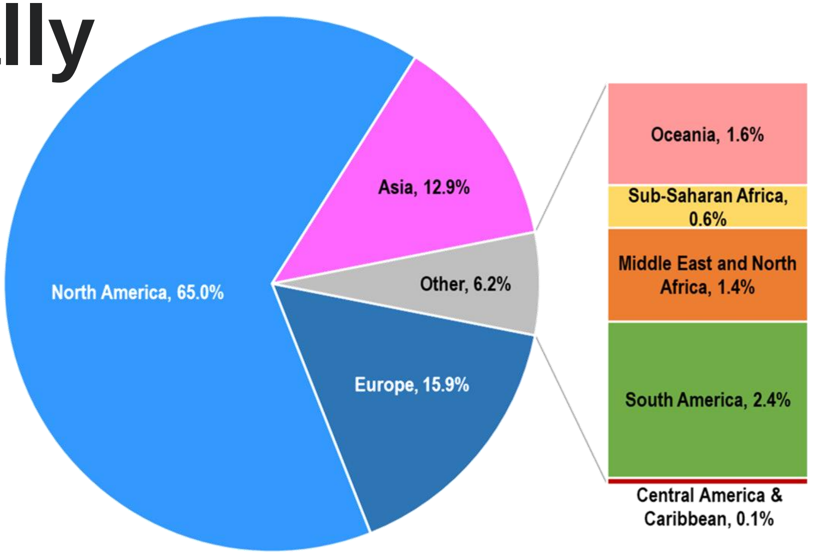
GREET 1 model:
Fuel-cycle (well-to-wheels) modeling of vehicle/fuel systems

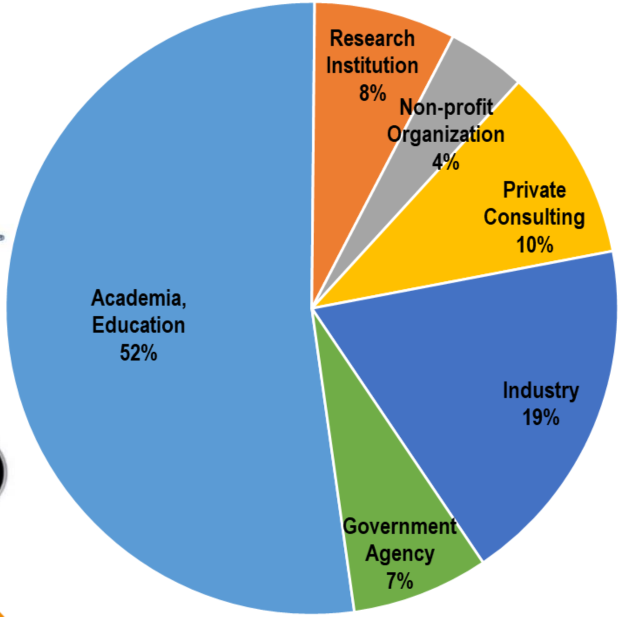
GREET 2 model:
Vehicle cycle modeling for vehicles



50,000+ Registered GREET Users Globally





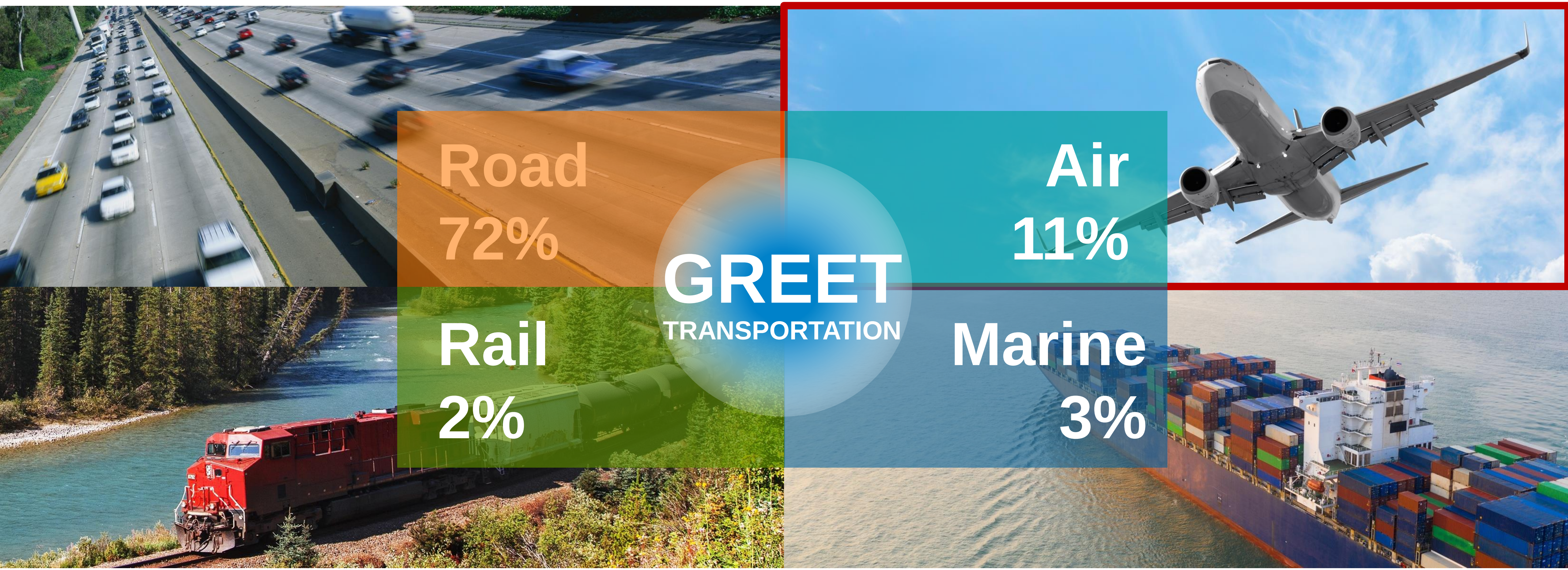


GREET applications by federal, state, and international agencies

- CA-GREET3.0 built based on and uses data from ANL GREET
- Oregon Dept of Environ. Quality Clean Fuel Program
- EPA RFS2 used GREET and other sources for LCA of fuel pathways; GHG regulations
- National Highway Traffic Safety Administration (NHTSA) fuel economy regulation
- FAA and ICAO AFTF using GREET to evaluate aviation fuel pathways
- GREET was used for the US DRIVE Fuels Working Group Well-to-Wheels Report
- LCA of renewable marine fuel options to meet IMO 2020 sulfur regulations for the DOT MARAD
- US Dept of Agriculture: ARS for carbon intensity of farming practices and management; ERS for food environmental footprints; Office of Chief Economist for bioenergy LCA
- Environment and Climate Change Canada: develop Canadian Clean Fuel Standard

GREET Scope

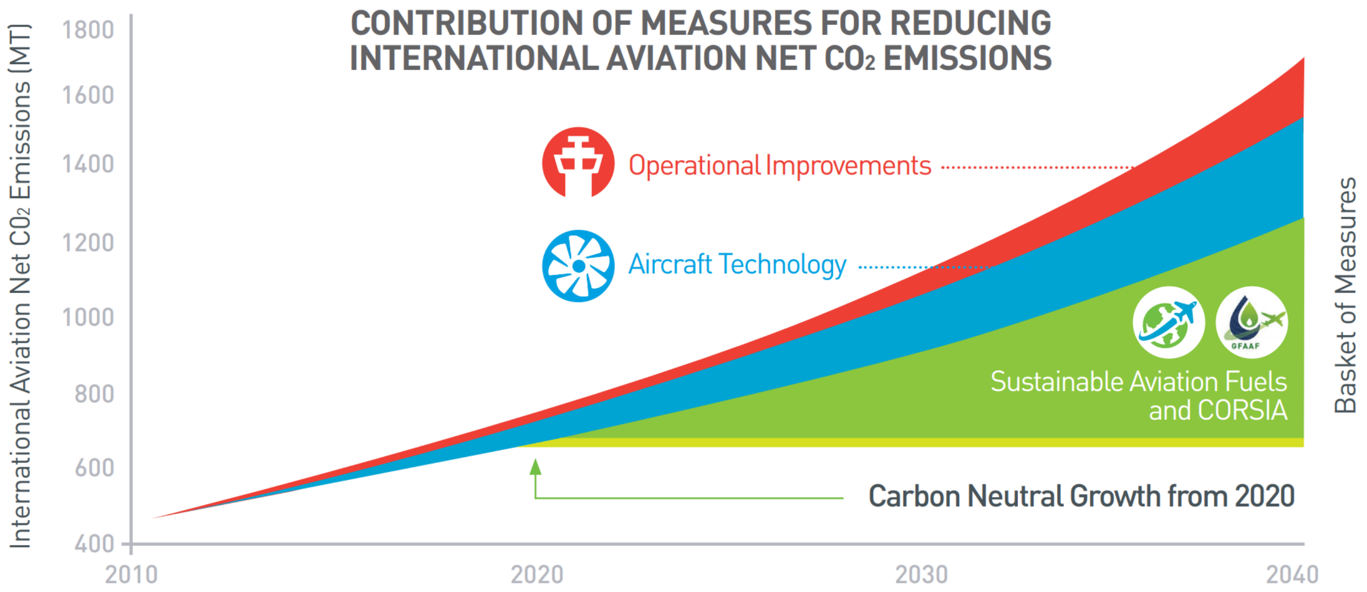
All Transportation Subsectors



Share of US transportation GHG emissions; remaining 12% for US is from pipelines and offroad.

Without mitigation efforts, GHG emissions from the aviation sector would increase over time

- Aviation demand is expected to keep increasing (EIA projection).
- International Civil Aviation Organization (ICAO) established the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) program starting in 2021 to require to offset emissions in the future: **Carbon neutral growth.**



- A market-based mechanism: Airline operators either buy emissions reduction offsets to compensate for any emission increase or use lower carbon fuels.

Sustainable aviation fuels (SAF) can reduce GHG emission from aviation sector

- U.S. SAF Grand Challenge

Requires SAF of 35 billion gallons per year (BGY) by 2050; 3 BGY by 2030.

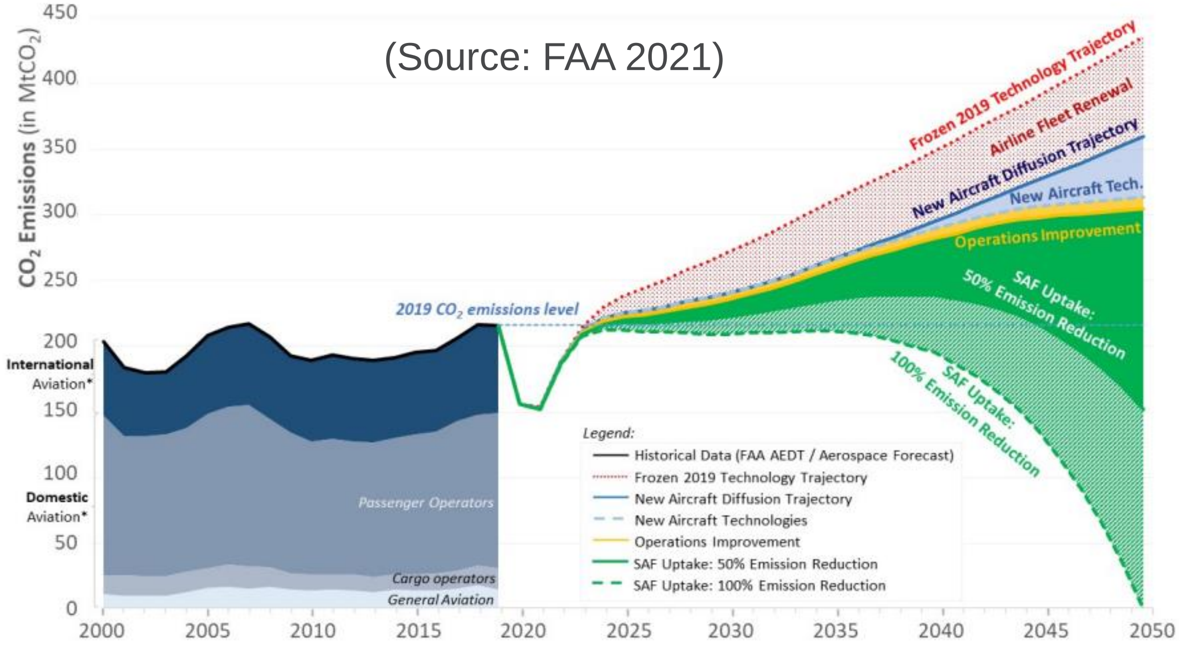
Sustainable Aviation Fuel Grand Challenge

A commercial jet with biofuel tank. Photo courtesy of istock.com.

The SAF Grand Challenge is the result of DOE, DOT, and USDA launching a government-wide Memorandum of Understanding (MOU) that will attempt to reduce the cost, enhance the sustainability, and expand the production and use of SAF while:

- Achieving a minimum of a 50% reduction in life cycle greenhouse gas emissions compared to conventional fuel.
- Meeting a goal of supplying sufficient SAF to meet 100% of aviation fuel demand by 2050.

(Source: DOE 2022)



* Note: Domestic aviation from U.S. and Foreign Carriers. International aviation from U.S. Carriers.

Figure 3. Analysis of Future Domestic and International Aviation CO_2 Emissions[13]

[13] Analysis conducted by BlueSky leveraging R&D efforts from the FAA Office of Environment & Energy (AEE) regarding CO_2 emissions contributions from aircraft technology, operational improvements, and SAF.

LCA has been the basis for SAF programs to boost GHG emission reductions

- Important to adequately estimate emissions for GHG emission reduction targets.

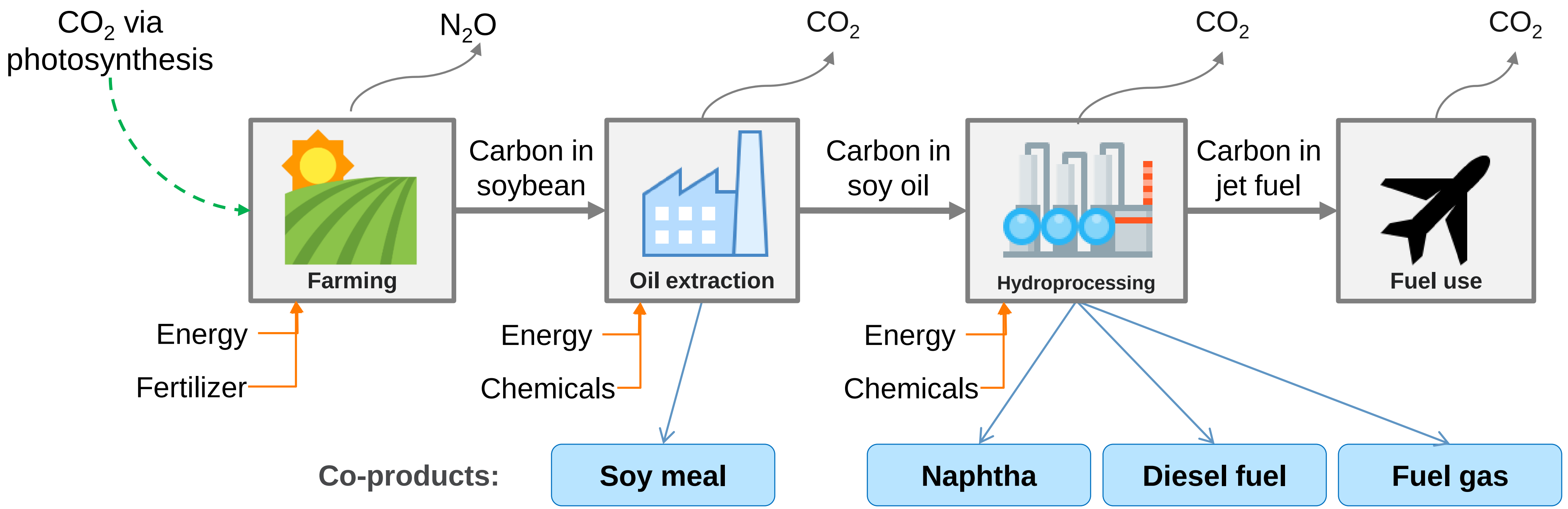
Major SAF GHG emission programs

International	ICAO's CORSIA
Federal	US EPA's RFS
States	CA: LCFS
	OR: Clean Fuels Program
	WA: Clean Fuels Program

Life-cycle analysis (LCA)

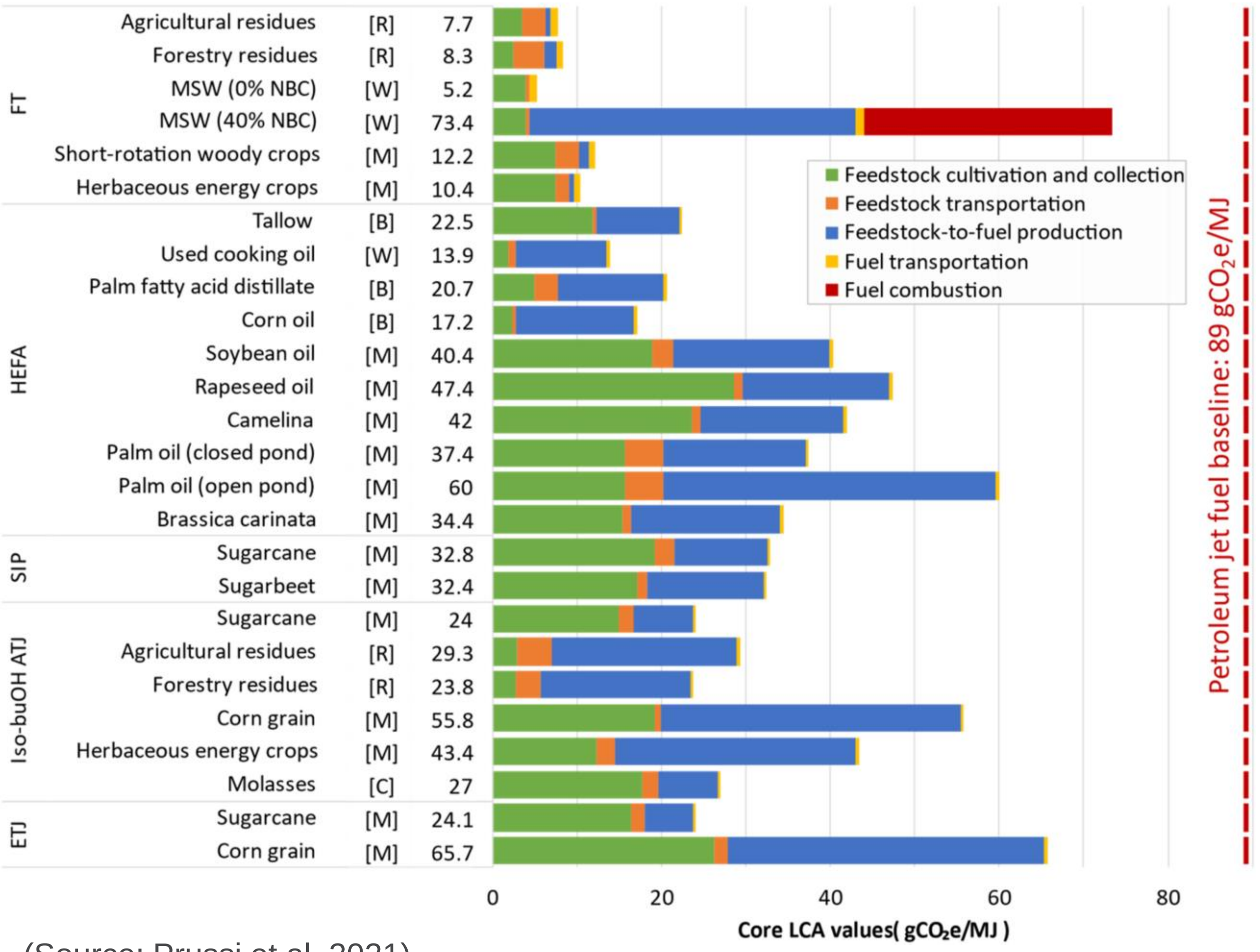
ICAO: International Civil Aviation Organization | CORSIA: Carbon Offsetting and Reduction Scheme for International Aviation
EPA: Environmental Protection Agency | RFS: Renewable Fuel Standard | LCFS: Low Carbon Fuel Standard

LCA of SAFs



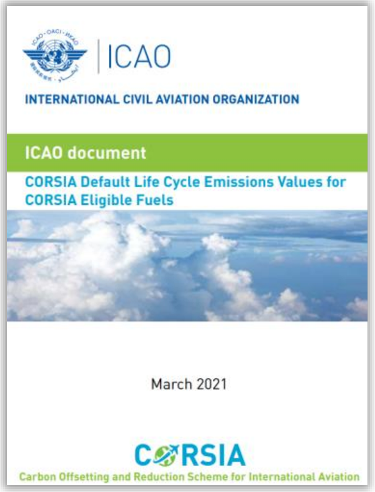
- Carbon cycle via photosynthesis provides key CO_2 benefits with biofuel pathways.

GREET provides the carbon intensities for CORSIA



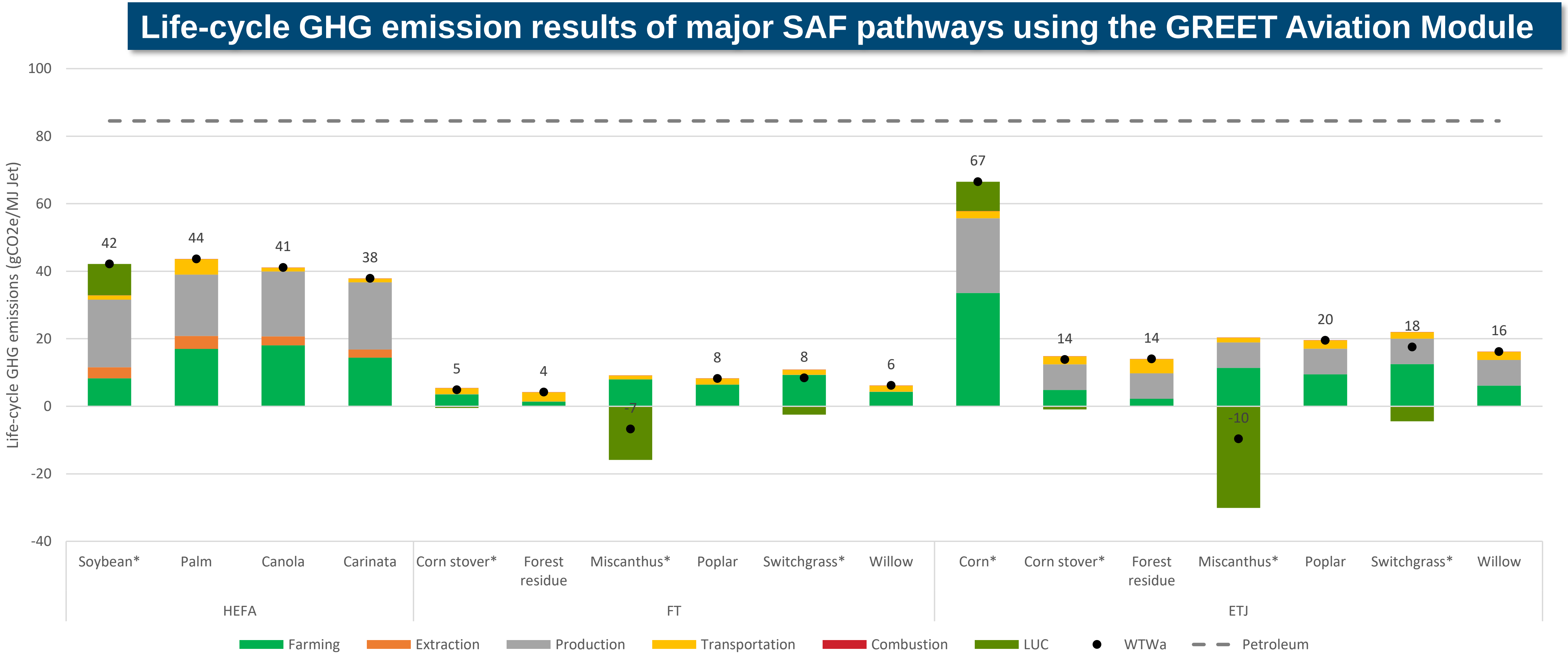
(Source: Prussi et al. 2021)

- Argonne has been a member of ICAO's Fuels Task Group (FTG) since inception
- **Argonne's GREET** was used to calculate the core LCA values of SAFs for CORSIA
- Default LCA values available in CORSIA documents



FT: Fischer-Tropsch | HEFA: hydroprocessed esters and fatty acids
SIP: Synthesized iso-paraffins | Iso-BuOH: Iso-butanol
ATJ: Alcohol-to-jet | ETJ: Ethanol-to-jet | NBC: non-biomass carbon

SAF LCA results presents significant emission reduction potential



* LUC included

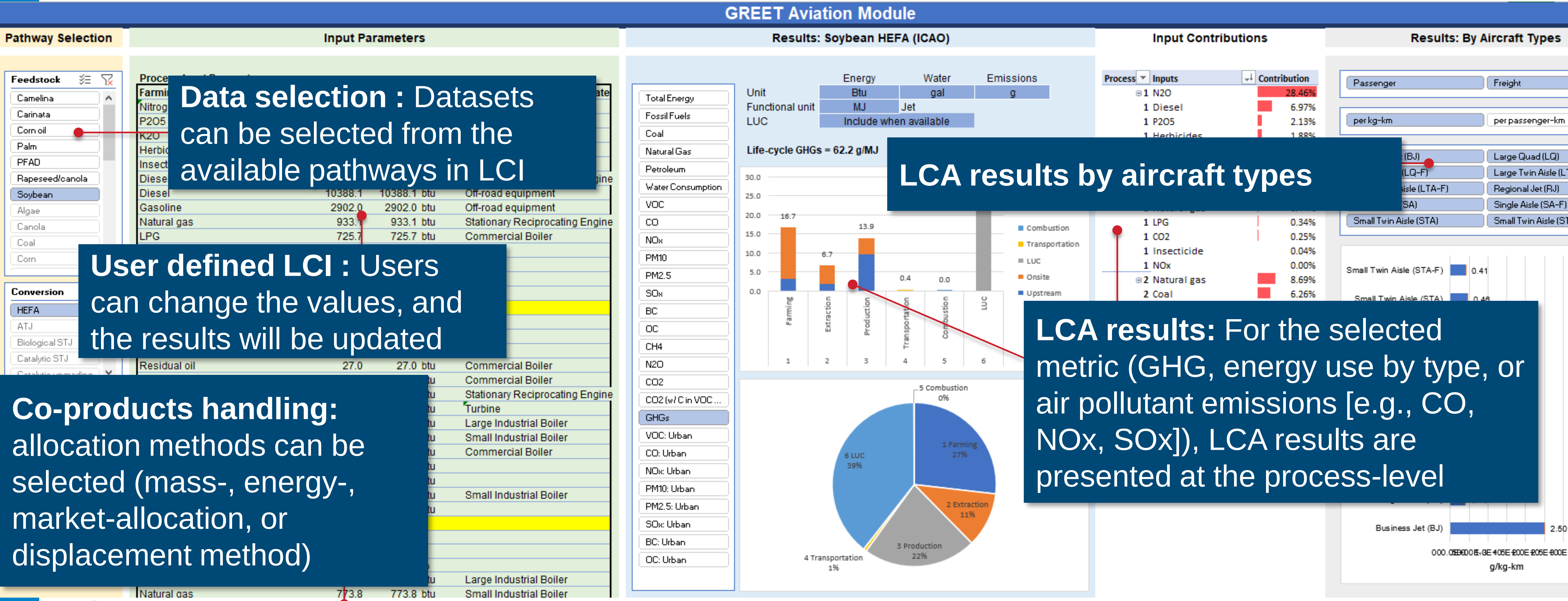
For lower life-cycle GHG emissions in SAF production pathways

Use waste feedstocks	Less fossil energy inputs	Avoid fossil carbon inputs	Additional emission credits
• Compared to crops, using waste feedstocks can reduce emissions associated with feedstock production and ILUC impact	• Use renewable H_2, renewable electricity, renewable natural gas, and biomass • Consider heat integration	• Avoid using fossil feedstocks (e.g., fossil portion in MSW)	• Avoided business-as-usual emissions from conventional waste management practices

New GREET aviation module

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

- **User-friendly interactive interface** using the latest GREET and ICAO datasets



Summary: LCA of the aviation sector

- SAF can play an important role reducing GHG emissions from the aviation sector.
- Emission reductions through SAFs can be quantified through LCAs.
- LCA has been the basis for international, federal, and state-level SAF programs to boost GHG emission reductions.
- LCA can be used to identify emission hotspots and to further decarbonize the SAF production pathways.
- Argonne has supported SAF programs through research activities using GREET.

Argonne National Laboratory

Uisung Lee (ulee@anl.gov)

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

The research effort at Argonne National Laboratory was supported by the Vehicle Technologies Office and Bioenergy Technology Office under the Office of Energy Efficiency and Renewable Energy of the US Department of Energy (DOE) under contract DE-AC02-06CH11357. The views and opinions expressed herein do not necessarily state or reflect those of the US government or any agency thereof. Neither the US government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

International Council on Clean Transportation

Aviation as a Hard to Decarbonize Sector

Dan Rutherford, Ph.D.

1 September 2022

CES Technical Meeting

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

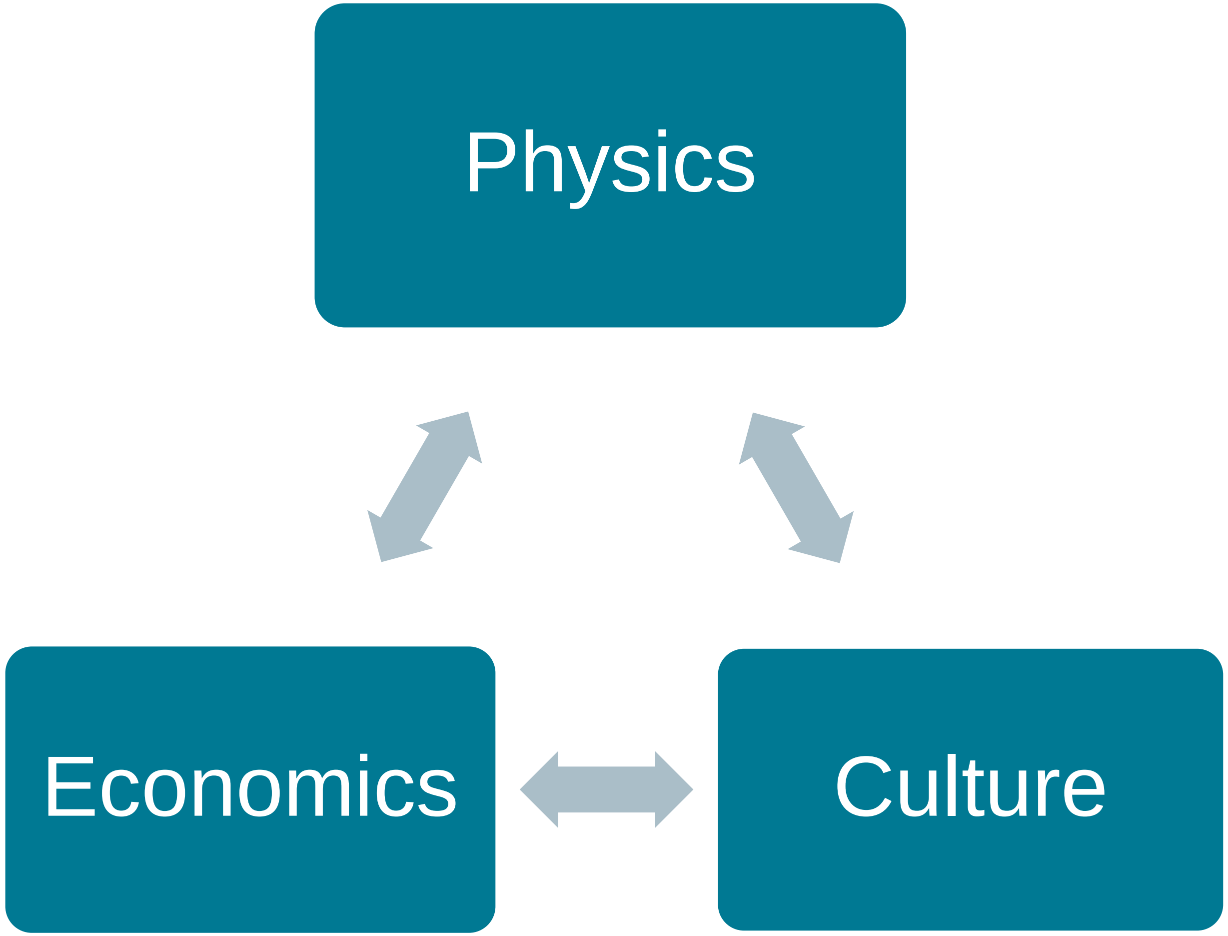
Outline

- Background
- Technologies needed to decarbonize aviation
- Conclusions and policy implications
- Questions and discussion

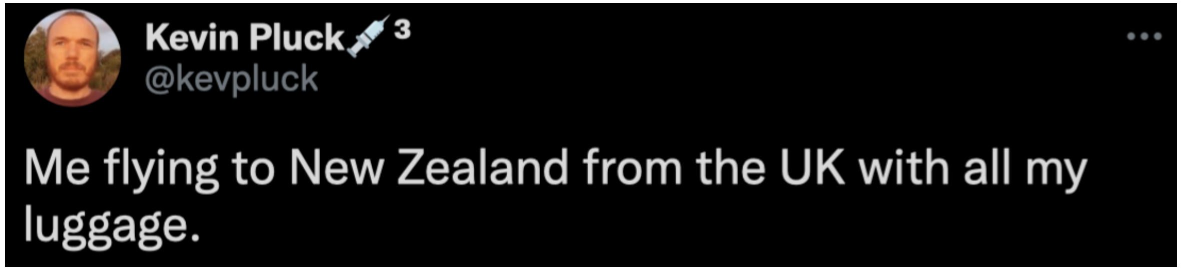
Background

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Why are aviation emissions hard to abate?



Aviation requires energy dense fuels



https://twitter.com/kevpluck/status/1368788614709010432?s=20&t=Tqn8Wm_TSwNIMq3IrljZbA

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Economics: how low can you can go

$3.70/gallon

$13.99/gallon

Culture: the power of frequent fliers

Congress's real reason for passing a budget? The smell of 'jet fumes'

'Jet fumes' is shorthand for lawmakers' fierce desire to get to D.C.-area airports. It often drives legislative business – and that's not a good trend, a former senator says.

https://www.csmonitor.com/USA/Politics/Politics-Voices/2014/1211/Congress-s-real-reason-for-passing-a-budget-The-smell-of-jet-fumes

Technologies needed to decarbonize aviation

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Aviation Vision 2050 report

To what extent can various measures reduce cumulative CO_2 emissions from global aviation in-line with 1.5ºC, 1.75ºC, and 2ºC targets?

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Scenarios

S0: Reference (business-as-usual)

S1: Action

S2: Transformation

S3: Breakthrough

Increasing level of ambition

Key mitigation wedges / technology assumptions

Our three modeling scenarios consider 6 important parameters:

- Aircraft technology
- Operations
- Sustainable aviation fuels (SAFs)
- Zero emission planes (ZEPs)
- Traffic
- Economic incentives

Demand change (Traffic, Economic incentives)

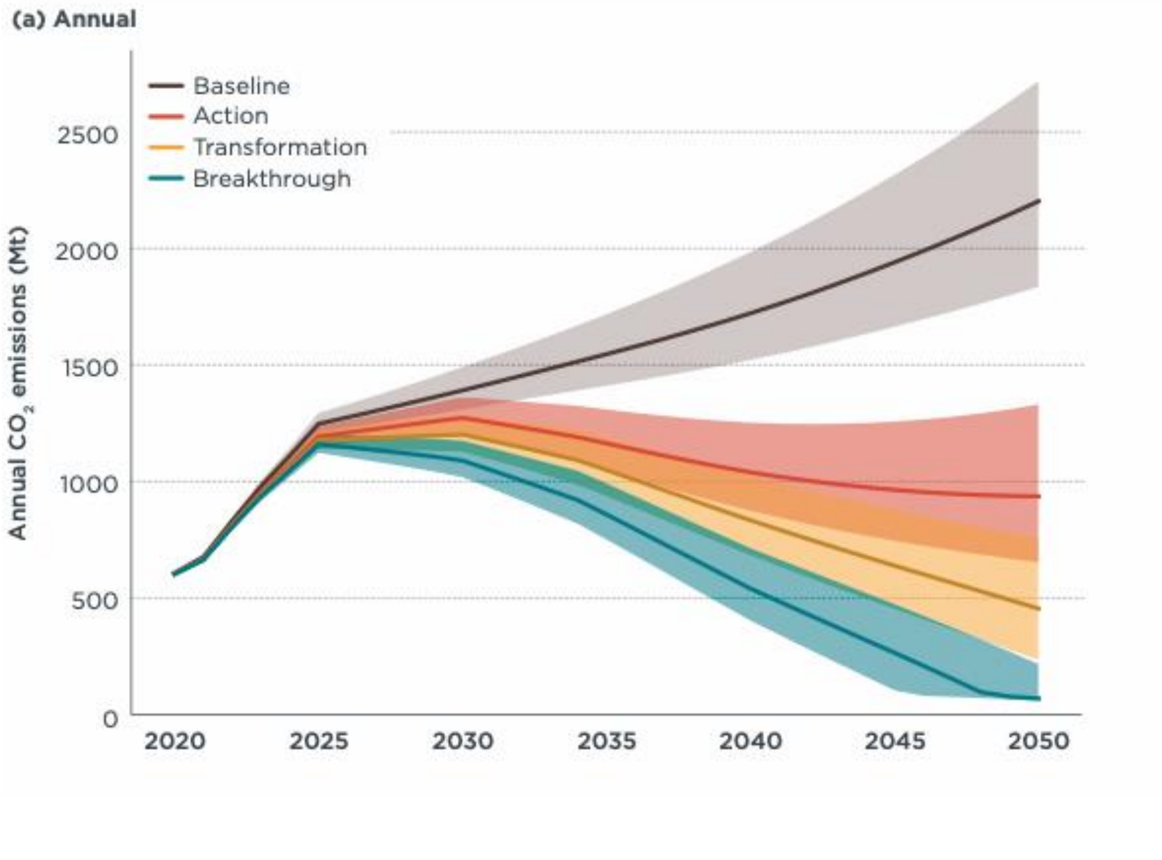
In-depth information on each of the modeling inputs can be found in the study on our website.

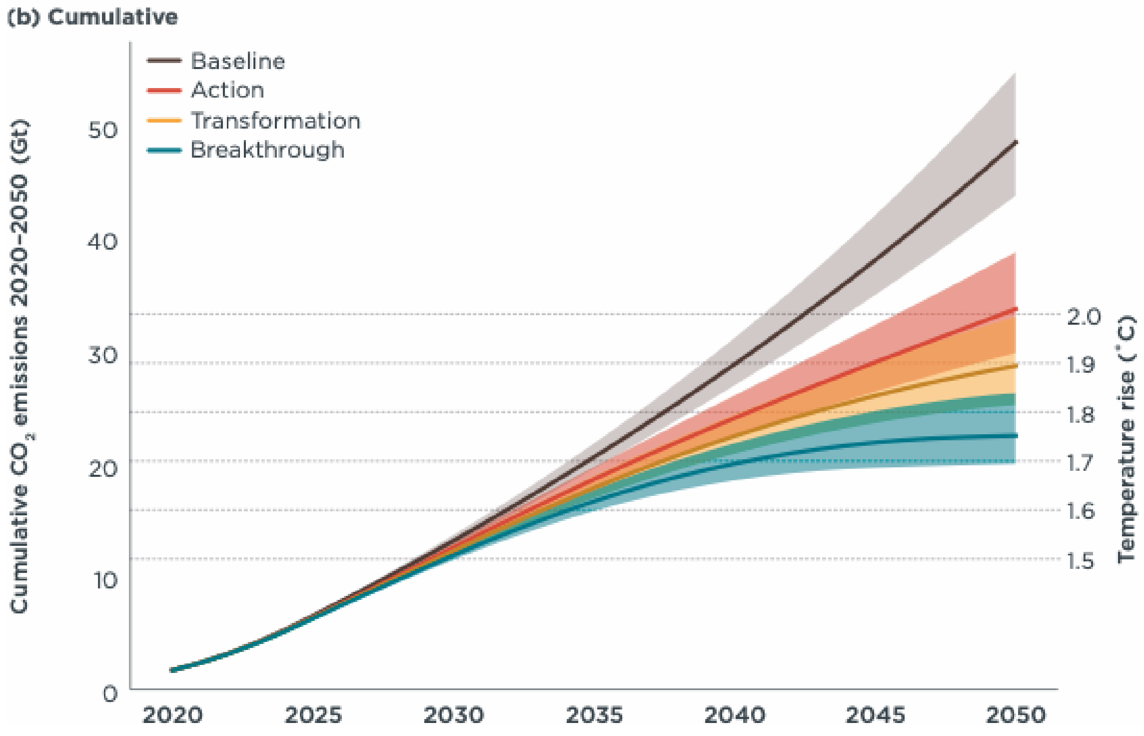
Notes on cumulative emissions

- CO_2 emissions in this analysis are well-to-wake (WTW)
- Non-CO_2 climate impacts are not included
- IPCC global climate budget with temperature targets at 67% probability used
- Aviation's share of global carbon budget maintained at 2.9% fuel use (2.4%) and upstream fuel production (0.5%)

Global CO_2 emissions by scenario and traffic assumptions

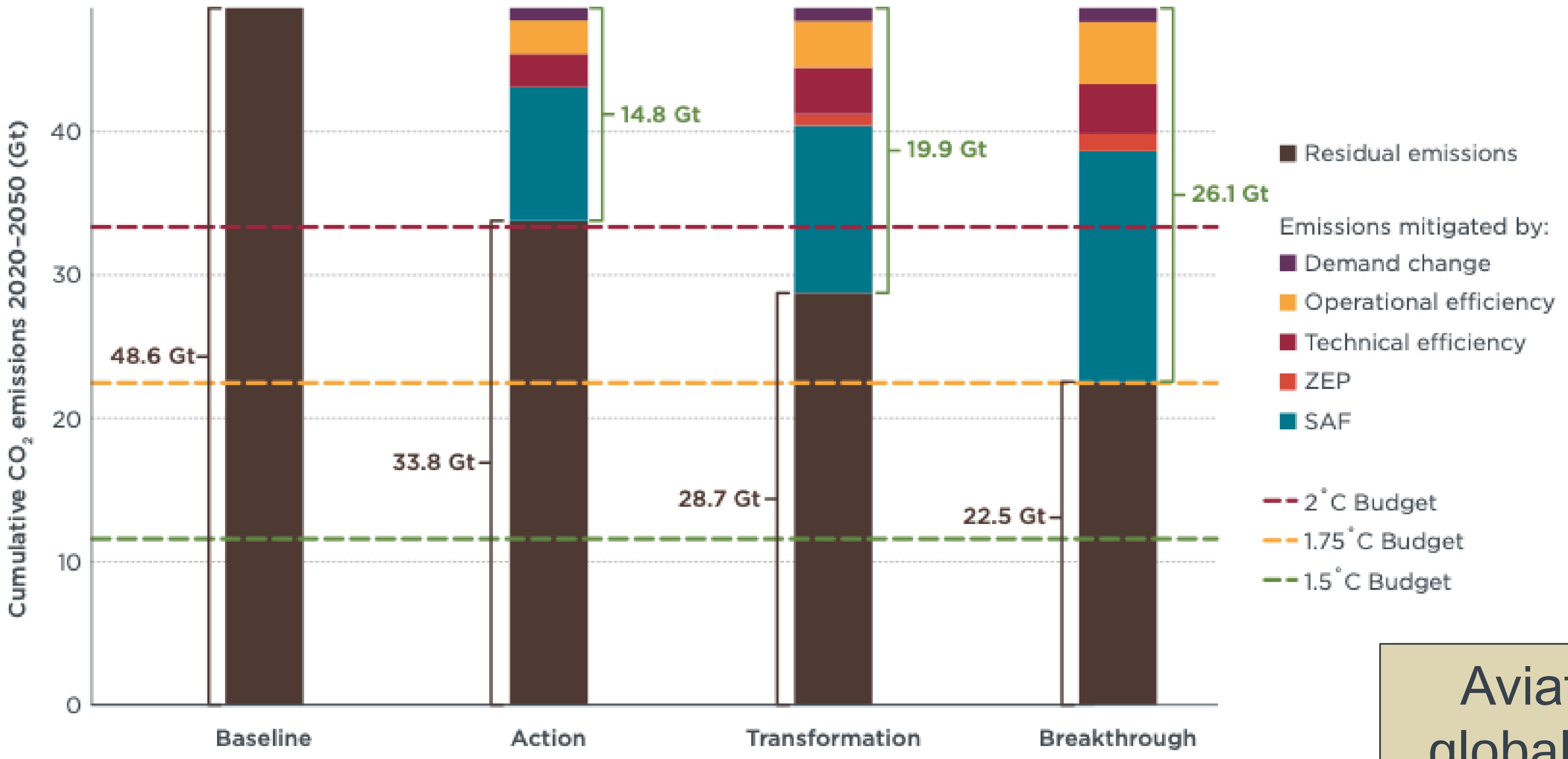
Global aviation CO_2 emissions by scenario and traffic forecast, 2020-2050





The solid line depicts the central traffic forecast; the shaded area depicts the range between the low and high forecasts.

Global cumulative CO_2 emissions and mitigation



Aviation's share of global carbon budget maintained at 2.9%

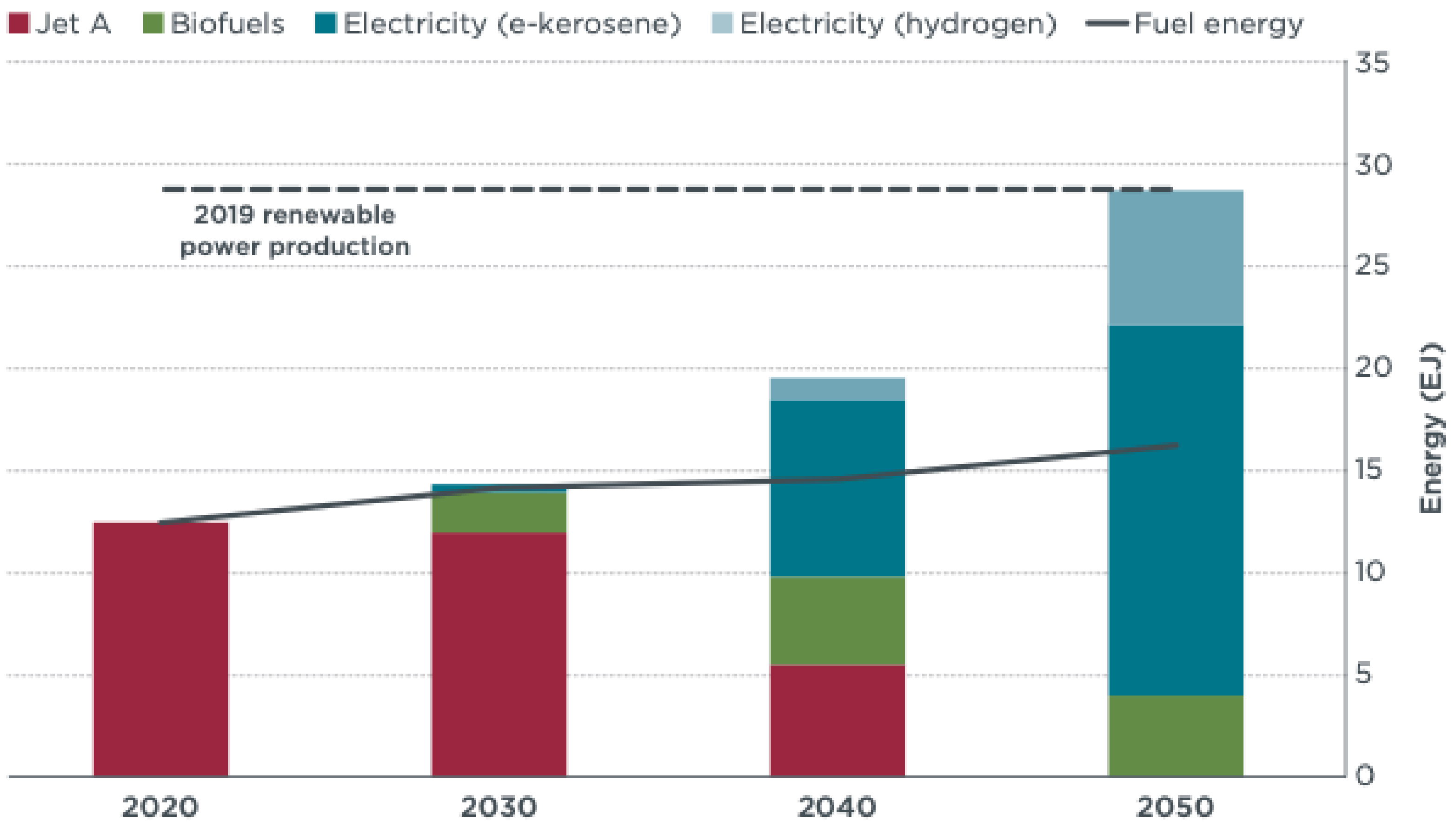
Net-zero aviation implies large volumes of synthetic fuels…

Estimated electricity used to generate aviation fuels:

2020: 0 EJ
2050: 25 EJ

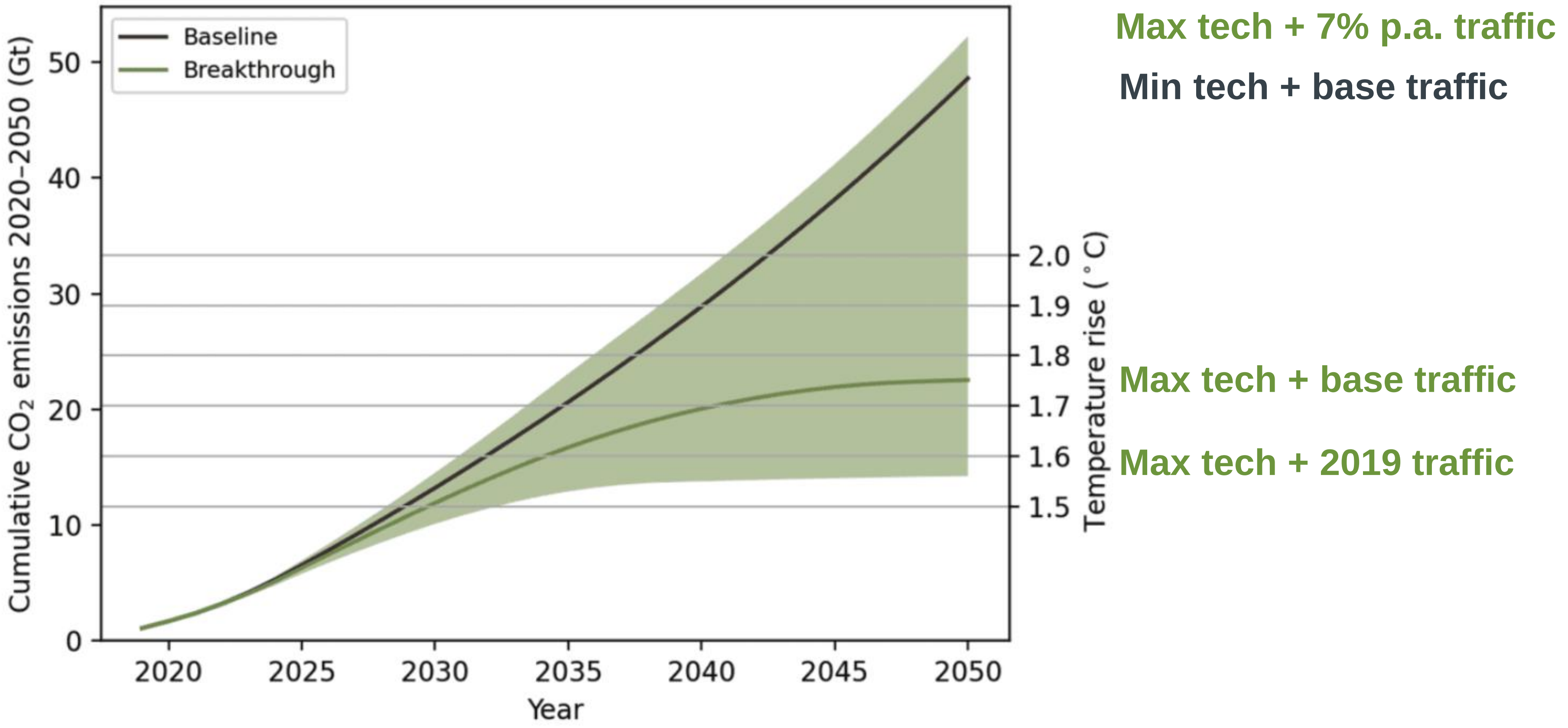
Additional 12.5 EJ energy needed to generate hydrogen and carbon for synthetic aviation fuels

Fuel energy (line) and life-cycle energy (bar) by fuel type under the Breakthrough case



… and don't forget about traffic growth.

Cumulative global aviation CO_2 emissions by scenario and traffic forecast, 2019-2050



https://theicct.org/global-aviation-race-jun22/

Conclusions and Policy Implications

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Conclusions and policy implications

- Aligning aviation with the Paris Agreement is possible but requires significant ambition and investment.
- CO_2 emissions from aircraft need to peak by 2030 at latest, and as soon as 2025.
- Policy menu includes
  - Low carbon fuel mandates/incentives
  - Airframe/engine standards
  - Policies to promote airline efficiency
  - Jet fuel taxes
  - R&D support
  - Demand management/modal shift
  - Measures to address non-CO_2 climate impacts
  - Emissions disclosure for consumers
  - Hybrid measures e.g. a frequent flier levy

Thanks to the Brandon Graver, Sola Zheng, Jayant Mukhopadhaya, Erik Prong, Gary Gardner, and Zoë Bowen Smith!

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THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

Questions?

Enter into the chat or email dan@theicct.org

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THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

Pratt & Whitney


PRATT & WHITNEY
DEPENDABLE ENGINES
GO BEYOND
ACHIEVING SUSTAINABLE AVIATION
SUMMER 2022
Dr. Michael Winter
Senior Fellow Advanced Technology
POWERING SUSTAINABLE AVIATION™
SMARTER.
CLEANER.
GREENER.

CLIMATE CHANGE

IMPACTS PEOPLE, ECONOMIES, AND SECURITY



POWERING SUSTAINABLE AVIATION

THE PRATT & WHITNEY APPROACH

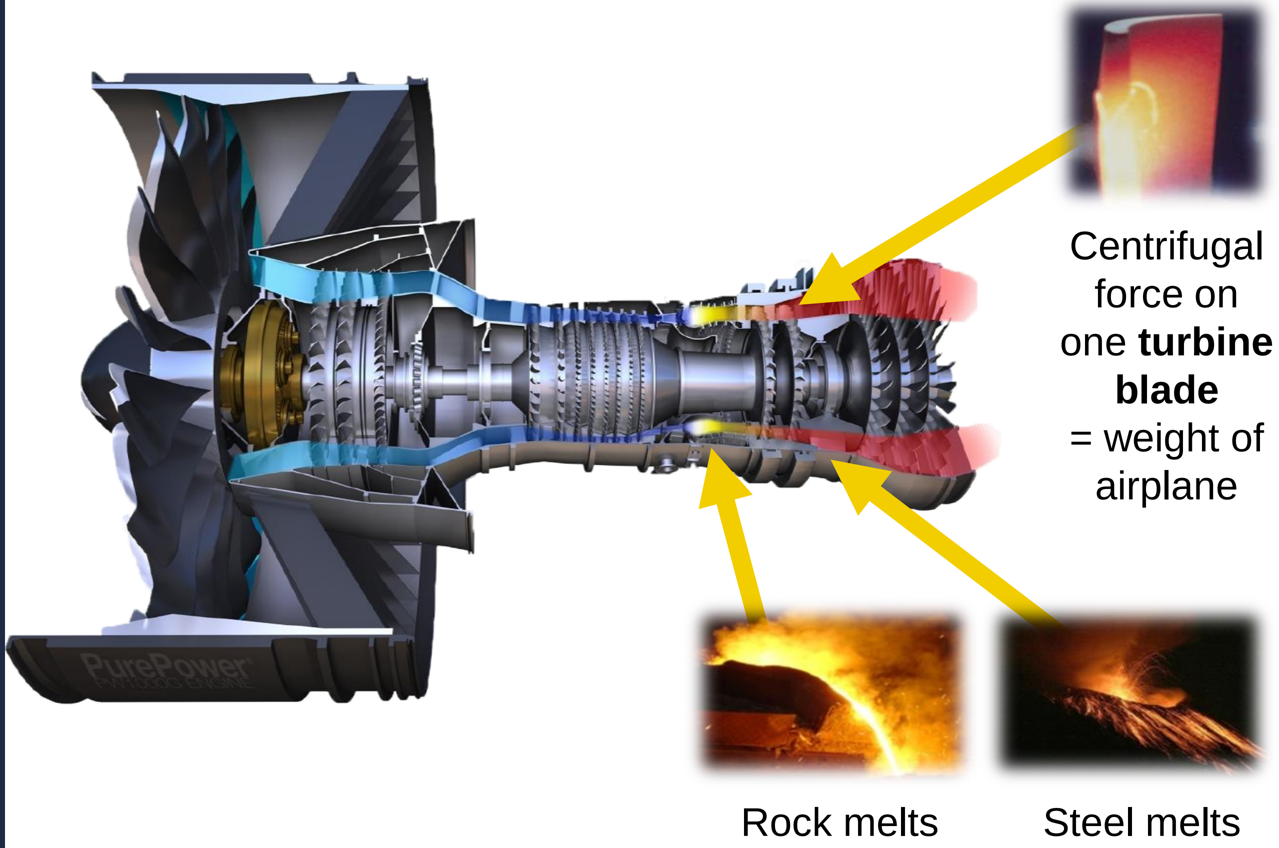
Smarter Technology	Cleaner Fuel	Greener Business
		
• Leverage GTF technology • Hybrid-electric propulsion • Increased digitization	• Sustainable Aviation Fuel + • Hydrogen	• Continual reduction in environmental footprint • World-class turbine airfoil facility in Asheville, North Carolina

QUICK ENGINE BASICS

THE MOST COMPLICATED, INTRICATE MASS-PRODUCED MACHINE KNOWN TO HUMANKIND

- Thousands of parts operating in harmony … at temperatures that can melt rocks
- Supersonic fan blade tip speeds
- Running clearances as small as a width of a hair

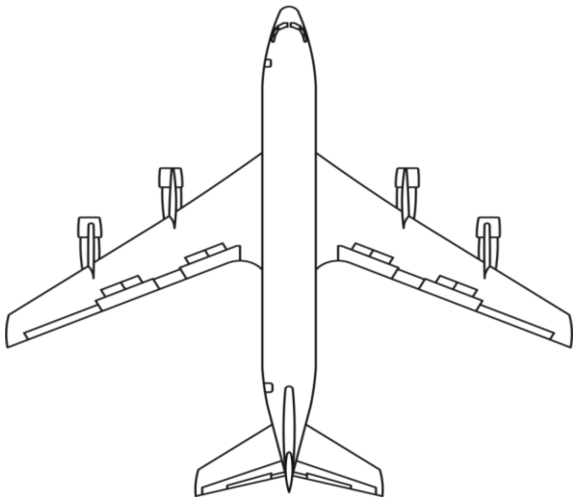
Gas turbine engines have improved fuel efficiency on average 1% every year since the dawn of the jet age – through technological advancements



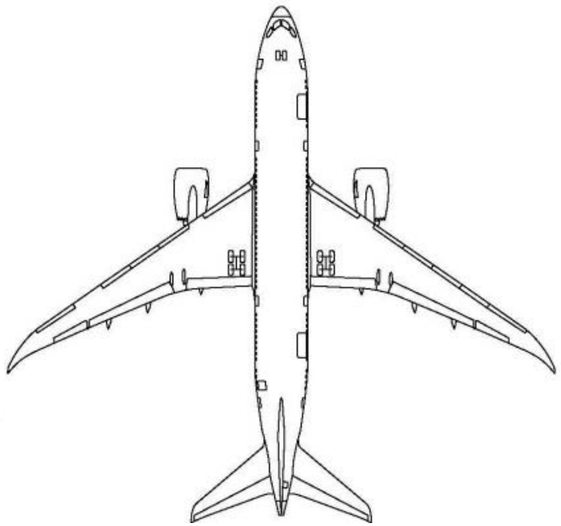
TRACK RECORD OF IMPROVING FUEL EFFICIENCY

DRAMATIC IMPROVEMENTS SINCE THE START OF THE JET AGE

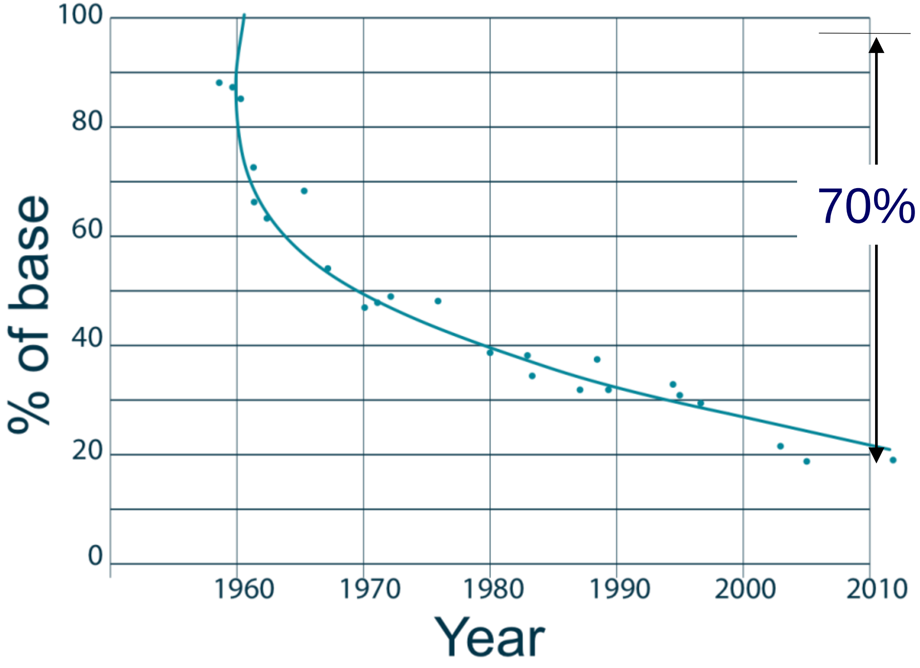
707
5,500 nm



A321XLR
5,500 nm



Fuel burn and
CO_2 per RPK

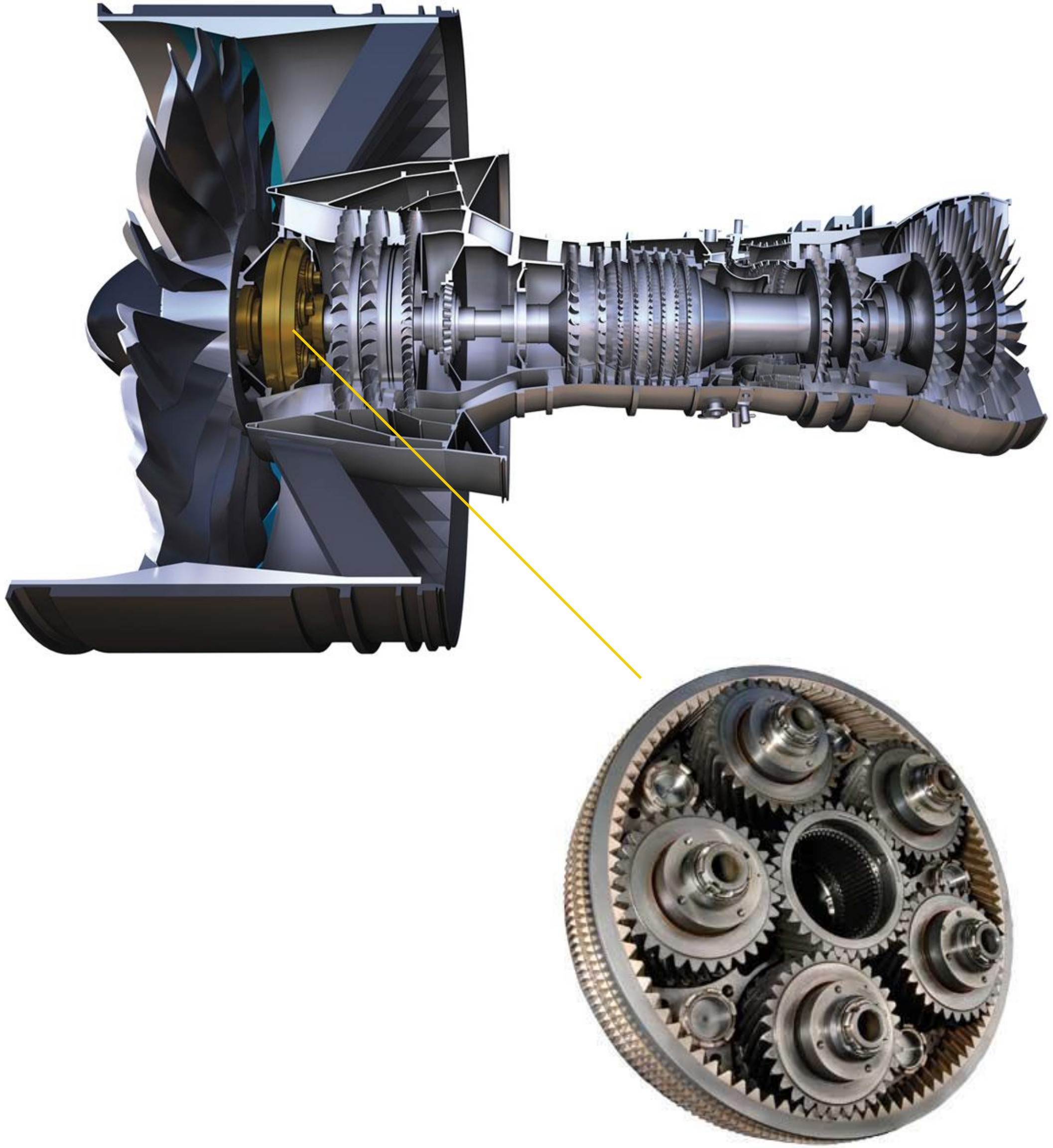


Fewer engines per aircraft
Longer time on wing between shop visits
Data-driven improvements

GTF ENGINE

THE ADDITION OF A GEAR CHANGED EVERYTHING – ALLOWING PARTS TO MOVE AT OPTIMAL SPEEDS

- The turbo-machinery can move at faster speeds; reducing the number of stages needed
- The fan can move at a slower speed allowing for optimal propulsive efficiency
- At launch, the GTF reduced fuel consumption and CO_2 emissions by up to 16%
- More than 800M gallons (3.6 billion liters) of fuel saved to date; more than 8 million metric tonnes of CO_2 avoided
- 75% reduction in the noise footprint



GTF ADVANTAGE ENGINE

MORE CAPABILITY FOR THE A320NEO FAMILY

up to
34K **takeoff thrust**
at sea level
most powerful engine

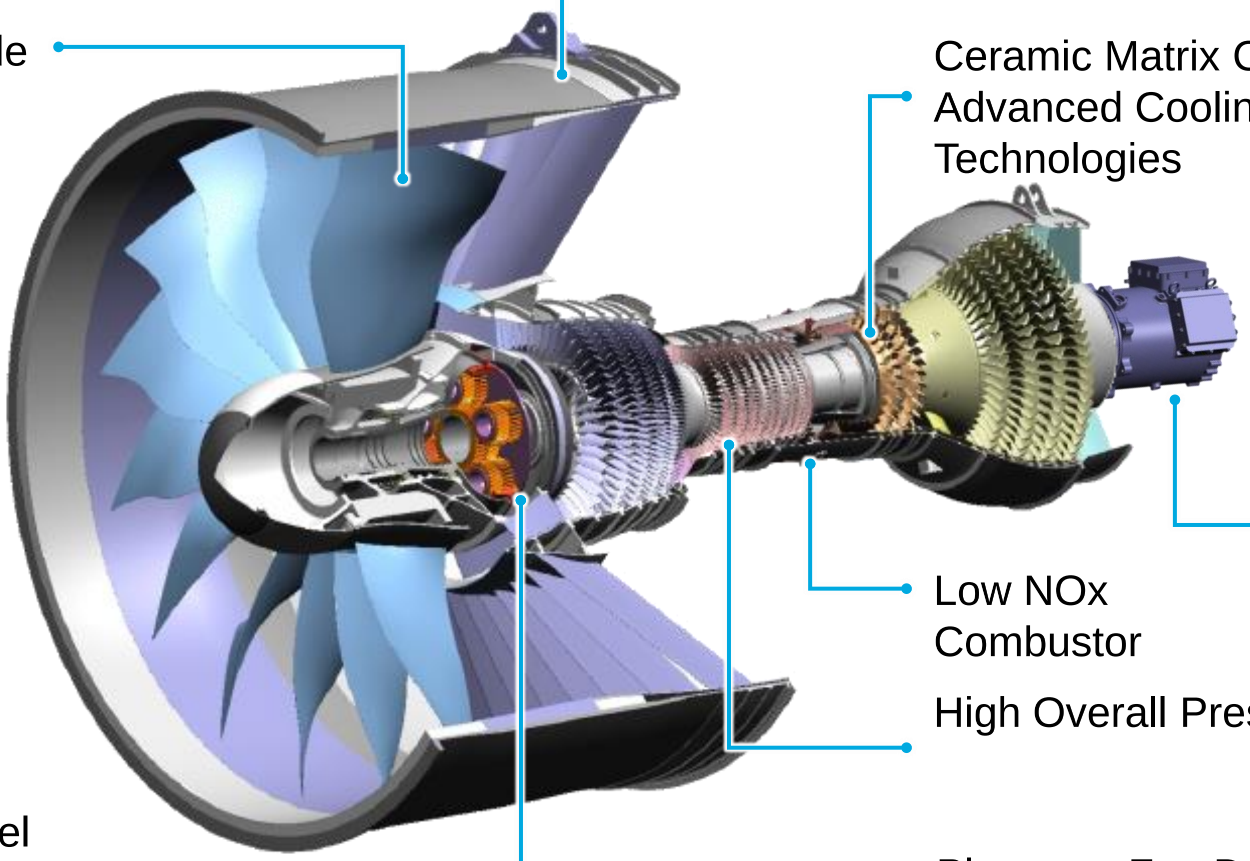
up to
17% **less fuel and CO_2**
vs. previous generation engines like V2500
most efficient engine

mature reliability
with high durability at entry into service

100% SAF compatible
maximum customer flexibility

NEXT GENERATION TECHNOLOGIES

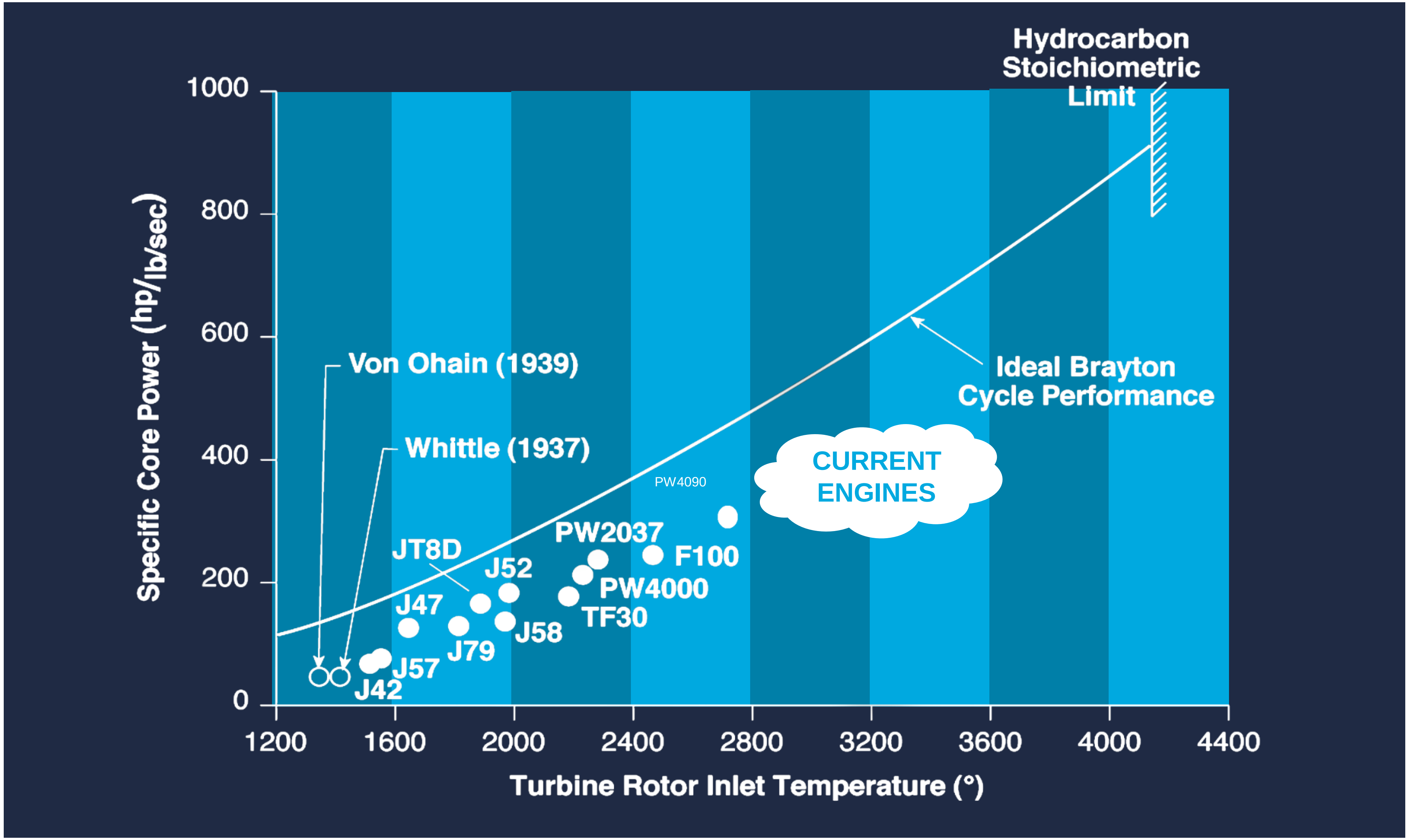
SUSTAINABLE, DURABLE AND EFFICIENT



Sustainable Aviation Fuel

Digital Thread

CORE EFFICIENCY PROGRESS



[After: Koff, "Spanning the World with Jet Propulsion", AIAA, 1991]

HIGH TEMPERATURE MATERIALS

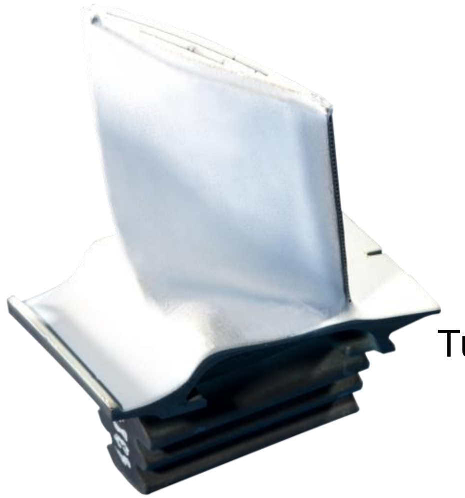
CERAMIC MATRIX COMPOSITES

Running in development engines

Dedicated COE opened in 2021

Program anticipated to be ready by 2025

ADVANCED CASTINGS



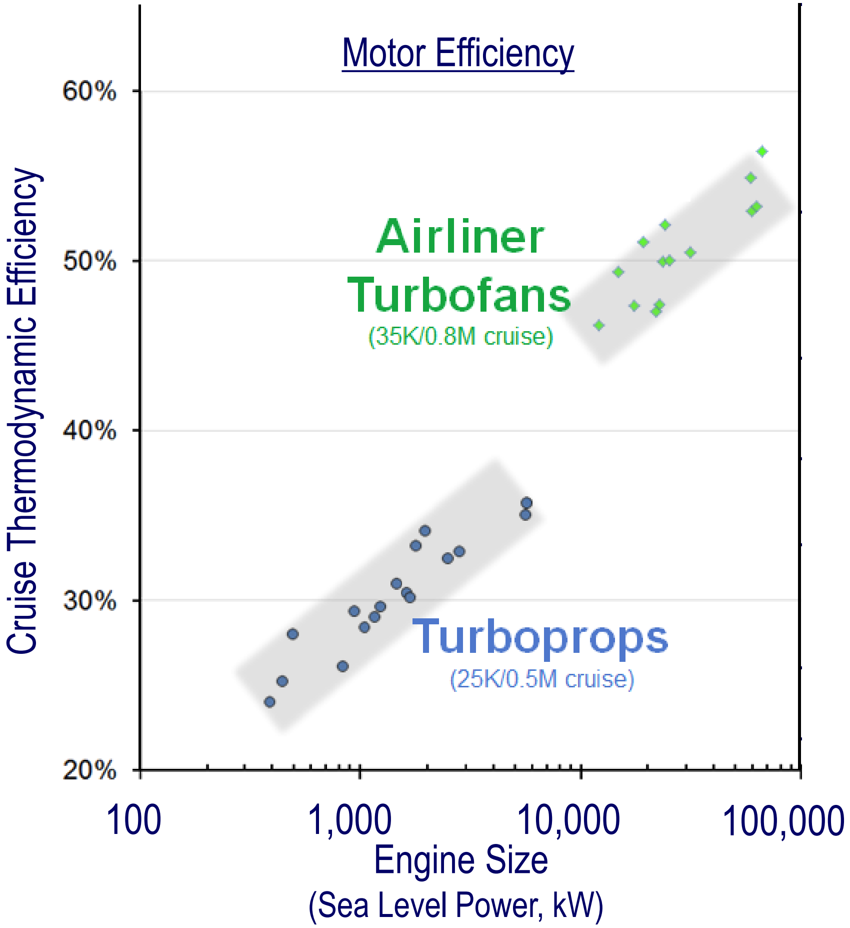
Turbine airfoil

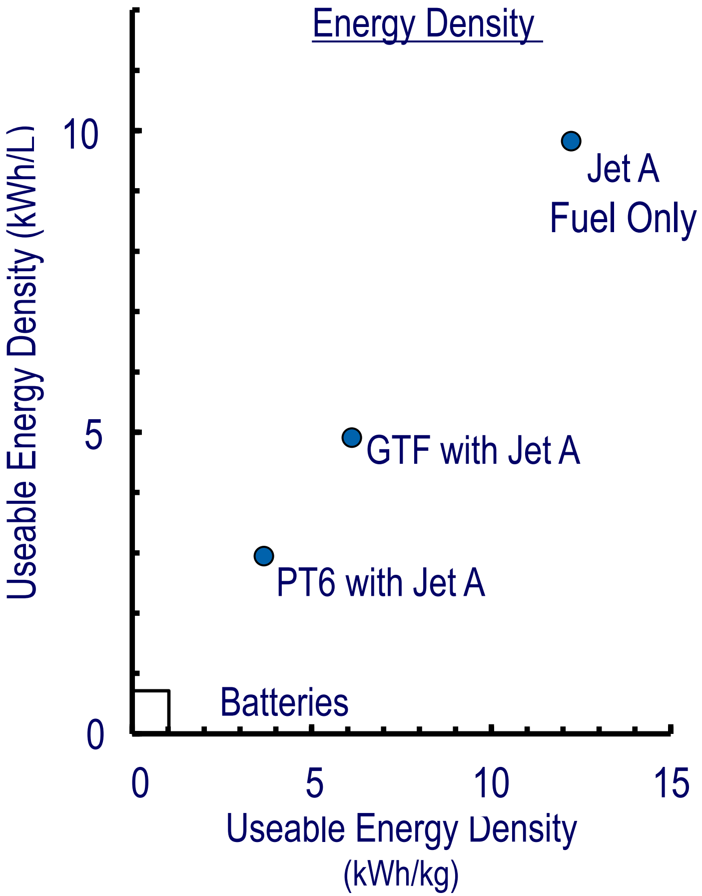
Baseline GTFA 2024

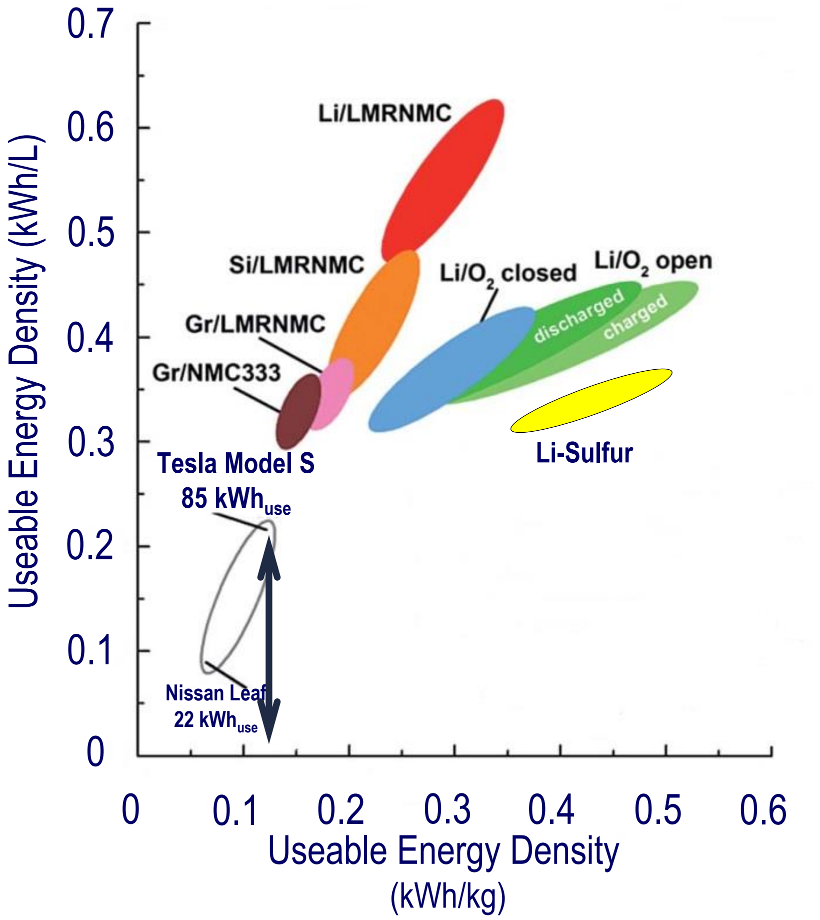
Asheville production in 2025

ENERGY DENSITY

THE CHALLENGE FOR BATTERY AND HYBRID POWERED AIRCRAFT





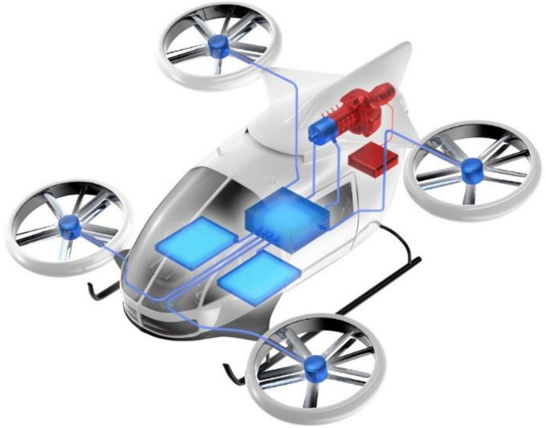


LEADING THE WAY IN HYBRID-ELECTRIC PROPULSION

OPTIMIZING EFFICIENCY ACROSS DIFFERENT APPLICATIONS

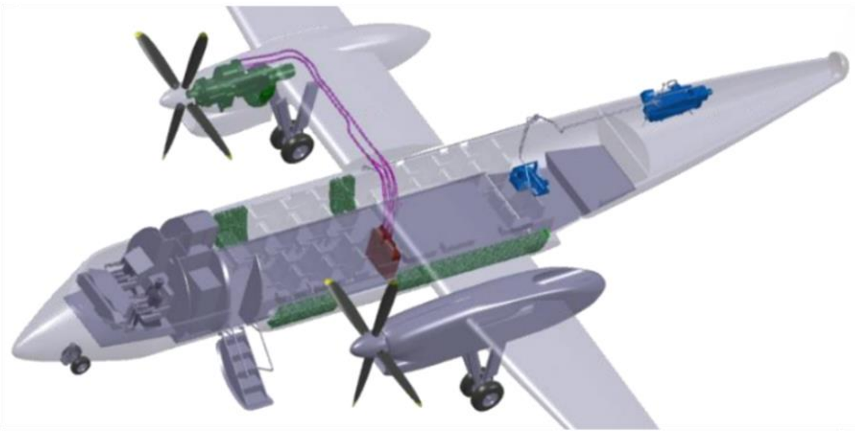
STEP-Tech

- Scalable Turboelectric Powertrain Technology
- Series/distributed propulsion



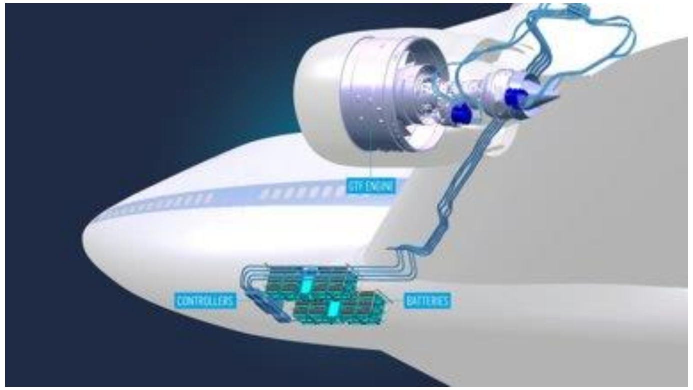
Regional Flight Demonstrator

- Parallel hybrid-electric propulsion
- 30% improvement in fuel efficiency



Single Aisle

- GTF foundational architecture
- Parallel hybrid-electric propulsion



WORKING TOWARDS 100% SAF READINESS

INDUSTRY COLLABORATION KEY TO TESTING AND CERTIFICATION

Supporting up to 50% SAF operational use today

Ground and flight testing up to 100% SAF

Ensure future engines ready for 100% SAF standard

Photo credits: ADAC, Embraer

HYDROGEN

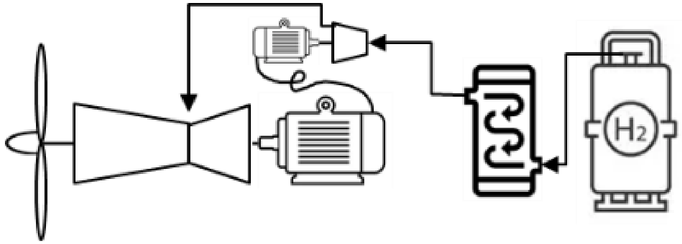
DEVELOPING HYDROGEN PROPULSION SYSTEM TECHNOLOGY FOR ADVANCED ENGINE CYCLES

History

Project Suntan

- Lockheed Martin Skunkworks Program
- Liquid hydrogen engine demonstrator

Opportunities



HySIITE

- Direct H_2 combustion system
- Exhaust waste heat recovery
- Electric engine actuation

Challenges

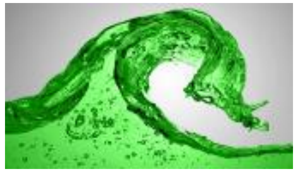
- Airframe integration
- Fuel production and distribution
- Material Compatibility
- Non-CO_2 emissions

PATH TO SUSTAINABLE PROPULSION

DECARBONIZATION OF AVIATION LIKELY THROUGH MULTIPLE PATHWAYS

2020 | 2030 | 2040 | 2050

Continued investment in fuel efficiency technology



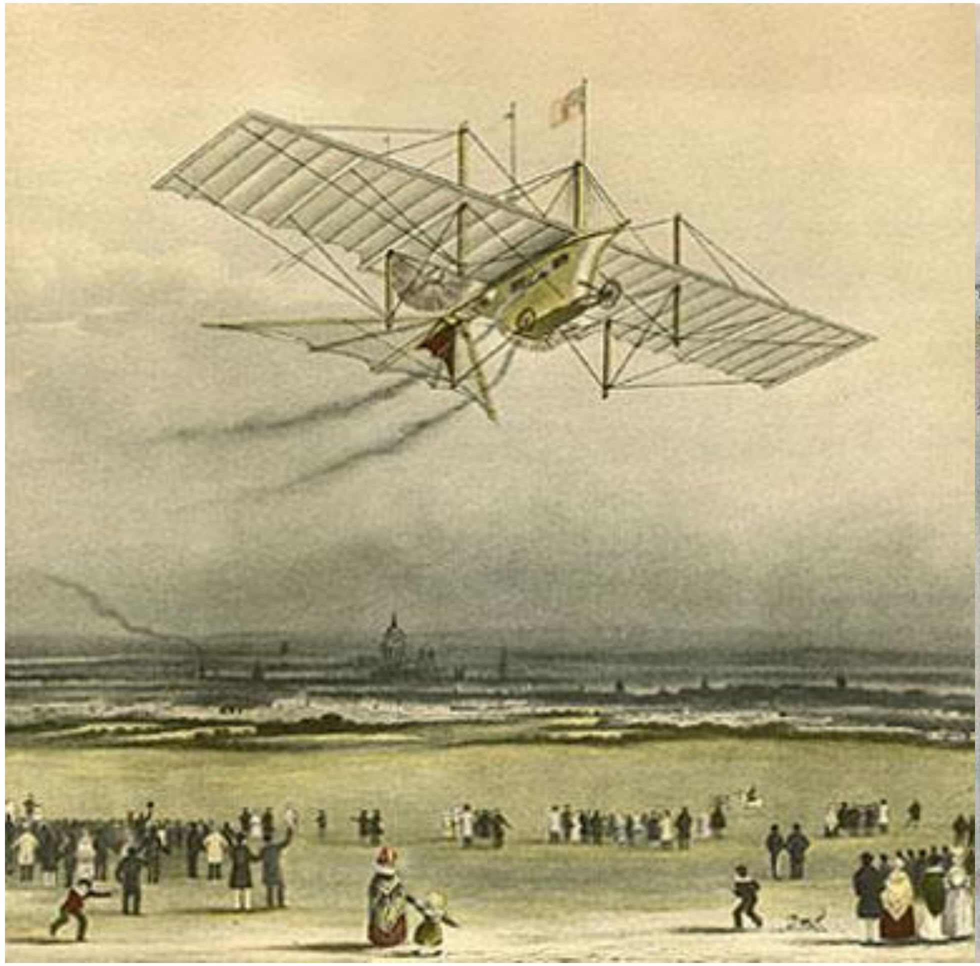
50% SAF → 100% SAF capable

Hybrid-electric

Hydrogen

Demo (dashed line) | In-service (solid line)

AERONAUTICAL INNOVATION

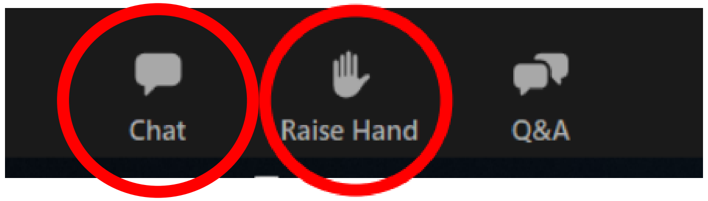


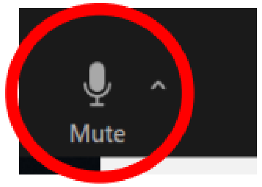
John Stringfellow and William Henson's design for an Aerial Steam Carriage, 1842 UK Patent 9478

1882 Leaving the Opera in the Year 2000
IMAGE: ALBERT ROBIDA / LIBRARY OF CONGRESS


PRATT & WHITNEY
DEPENDABLE ENGINES
GO BEYOND
POWERING SUSTAINABLE AVIATION™
SMARTER.
CLEANER.
GREENER.

Questions and Comments





Lower left of the screen

At the conclusion of each panel DEEP will hold a brief question and comment period.

If you have a clarifying question, please drop it into the chat to either Jeff Howard or Becca Trietch. DEEP will pose as many questions as time allows to the speakers.

If you would like to make a comment:

- Please use the “Raise Hand” feature if you would like to speak
- After any interested elected officials have provided their comments, you will be invited to provide your comment in the order the hands were raised
- Please unmute yourself, state your name and affiliation
- Given time limitations, please limit your comment to 2 minutes.
- After your comments, please remember to click the “Mute” button

Public Comment – Aviation

BUREAU OF ENERGY AND TECHNOLOGY POLICY

Click on the presenters to jump to their slides

Maritime

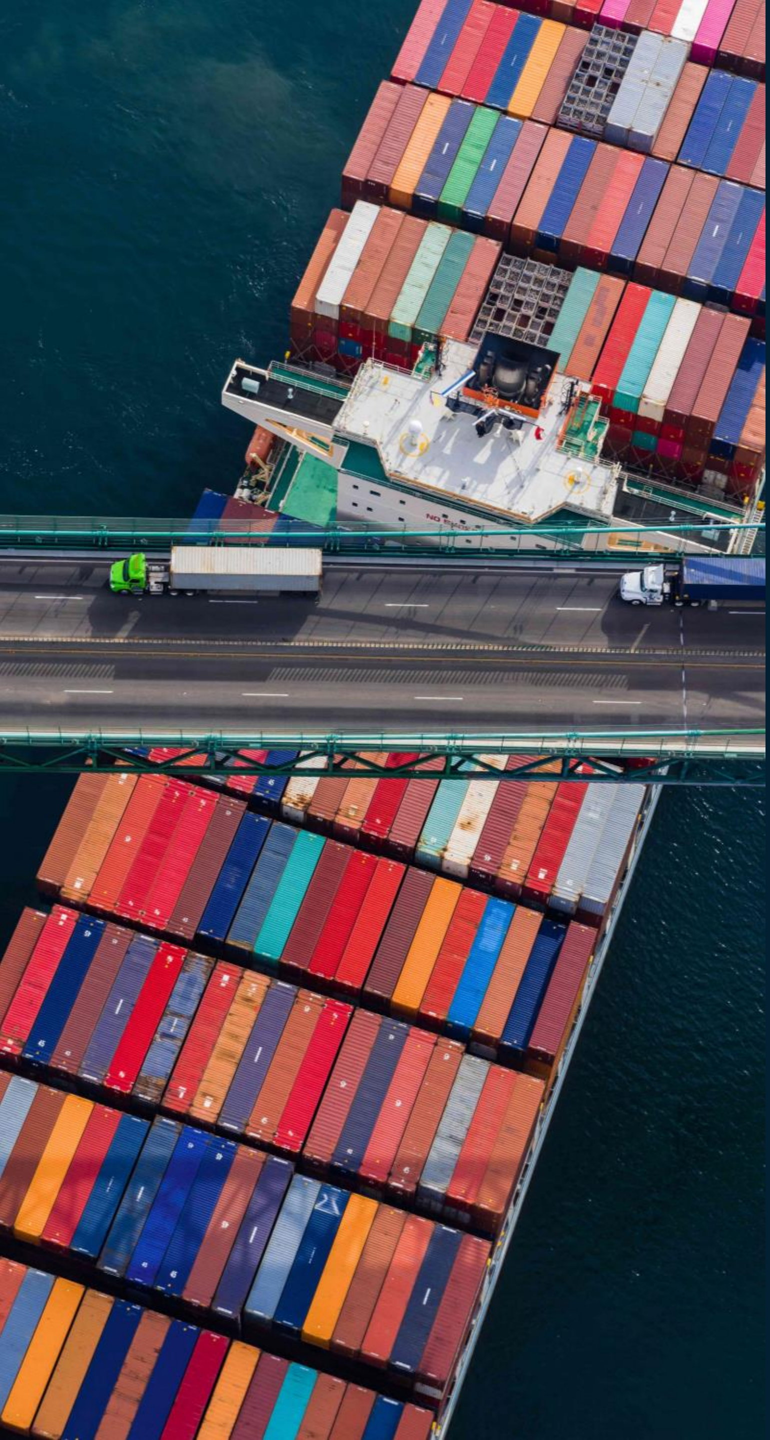
Bryan Wood-Thomas – World Shipping Council

Keegan Plaskon – American Bureau of Shipping

(speaker order may vary)

BUREAU OF ENERGY AND TECHNOLOGY POLICY

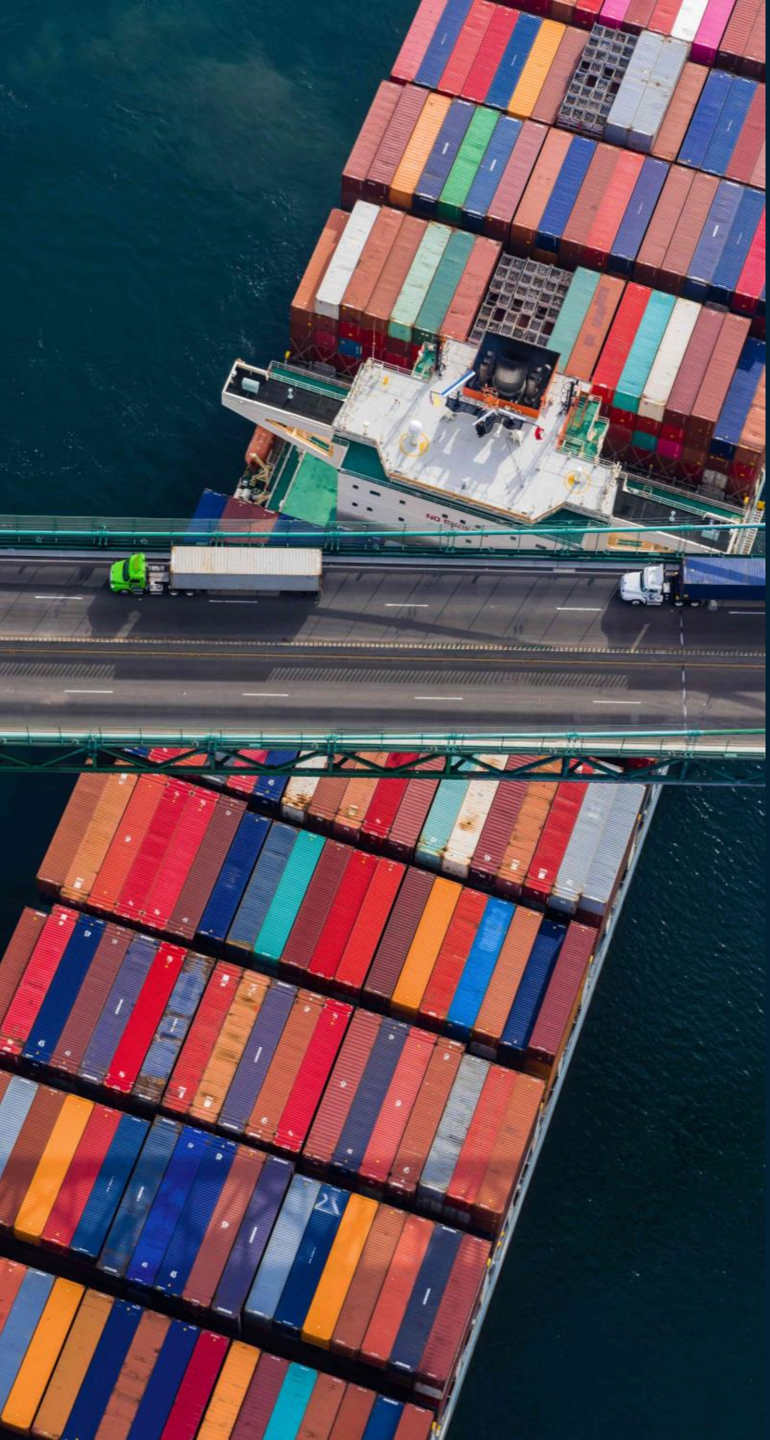
World Shipping Council



World Shipping Council

Critical Pathways to Decarbonize the Maritime Sector

1 September 2022 / Connecticut Comprehensive Energy Strategy Technical Session



A little background:

The World Shipping Council is a non-profit trade association representing the world's container lines and operators of other liner services

Purpose – To shape future growth of a socially responsible, environmentally sustainable, safe shipping industry

WSC Member companies operate 90% of the world's liner servies and transport USD 4 trillion worth of goods annually

Represent our Member companies on regulatory matters globally, nationally, and in regional fora around the world

Office is Washington DC, Brussels, and Singapore.

1 September 2022

Six critical pathways to zero carbon shipping

WSC Member companies (owners and operators of container and roro vessels) are already investing in the development of low and near-zero carbon technologies and fuels.

But to make these investments, to take the necessary commercial risks, we – and all other maritime actors - need a regulatory framework that addresses the key strategic issues.

- Global Carbon Price
- Fuel Life Cycle
- Fuel Supply Development
- Green Corridors
- New Build Standards
- R&D Investment

Net-zero, Zero, and Near-zero

Why understanding these terms is important:

A clear understanding of the relevant fuels, the technologies to produce and use them, and an understanding of the GHG footprint associated with a given fuel and the processes used to produce it is extremely important.

Understanding these terms and the GHG footprint of a given fuel (using Well-to-Wake life-cycle analysis) enables both policy makers and the public to better understand what must occur to make the major energy transition that is required to successfully address the climate challenge.

A few examples of 'near-zero' fuels: e-ammonia, e-methanol, e-LNG, e-diesel …

A few Take-Aways on What Must Happen to decarbonize Shipping and other Sectors

Massive investment in fuel production using 100% renewable energy (e.g., solar, wind, and hydro) is necessary to produce near-zero and zero GHG fuels:

It is not realistic that the transition will occur in a singular point in time across the globe. First-movers will be important and *Green Corridors* where low and near-zero fuels are available will be critical.

At this point in time we have a suite of promising fuel candidates, but there is too much technical and economic uncertainty to anticipate which fuel or fuels will dominate the energy transition.

It will also be necessary to have key regulations in place (e.g., application of a carbon price) to make operation on low and near-zero fuels commercially sustainable.

A GHG Fuel Standard may provide a helpful regulatory path, but demand in the maritime sector alone is unlikely to spur the magnitude of energy production investments necessary.

World Shipping Council

Shaping the future of a sustainable, safe and secure shipping industry.

American Bureau of Shipping

Decarbonizing the Maritime Industry

Keegan Plaskon
Director of Business Development
September 1, 2022

Connecticut Department of Energy
and Environmental Protection: CES technical session

Keegan Plaskon
Director – Eastern Americas
American Bureau of Shipping
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- Introduction
- Class Overview
- Regulatory Highlights
- Maritime Sustainability
- Decarbonization Strategies
- Summary & Conclusions

What is Classification?

Classification societies establish and apply technical standards in relation to the design, construction and survey of marine related facilities including ships and offshore structures

Classification addresses the life cycle of a ship or offshore unit from design to decommissioning

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ABS Mission

To serve the public interest as well as the needs of our members and clients by promoting the security of life and property, and preserving the natural environment.

"Where technology enables, people achieve. It is the dedicated people of ABS who take firm hold of the latest technologies and bring them to bear in the spirit of our mission and in the service of safety."

CHRISTOPHER J. WIERNICKI
Chairman, President and CEO ABS

International Maritime Organization

- Part of the United Nations – members are representative of individual governments
- Forms treaties to protect safety and the environment
- Conventions must be adopted by individual Flag States within respective national laws
- Class Societies act under delegated authority to Flag States to validate vessel compliance

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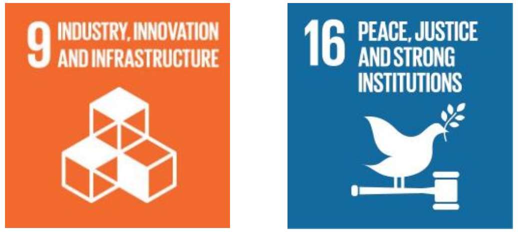
The Vision of Sustainability

International Maritime Organization's (IMO) sustainable development goals (SDGs) as they relate to vessels, fleets and managing organizations.

Environmental Excellence

Social Responsibility

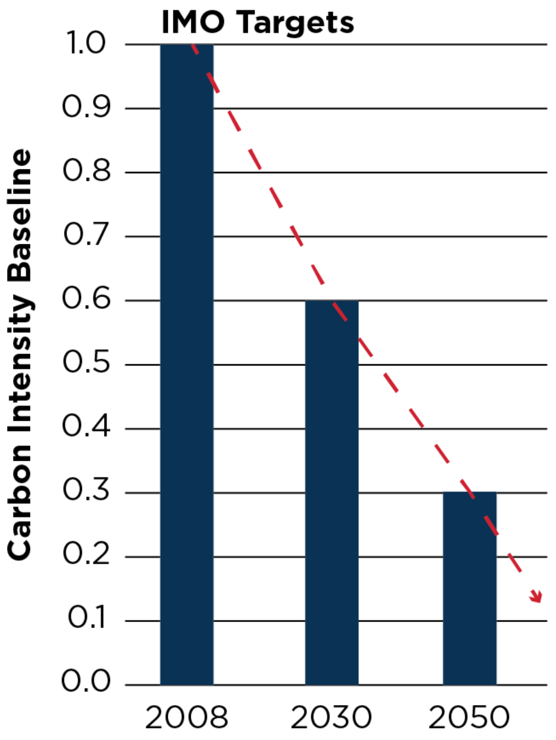
Governance – Operational Excellence

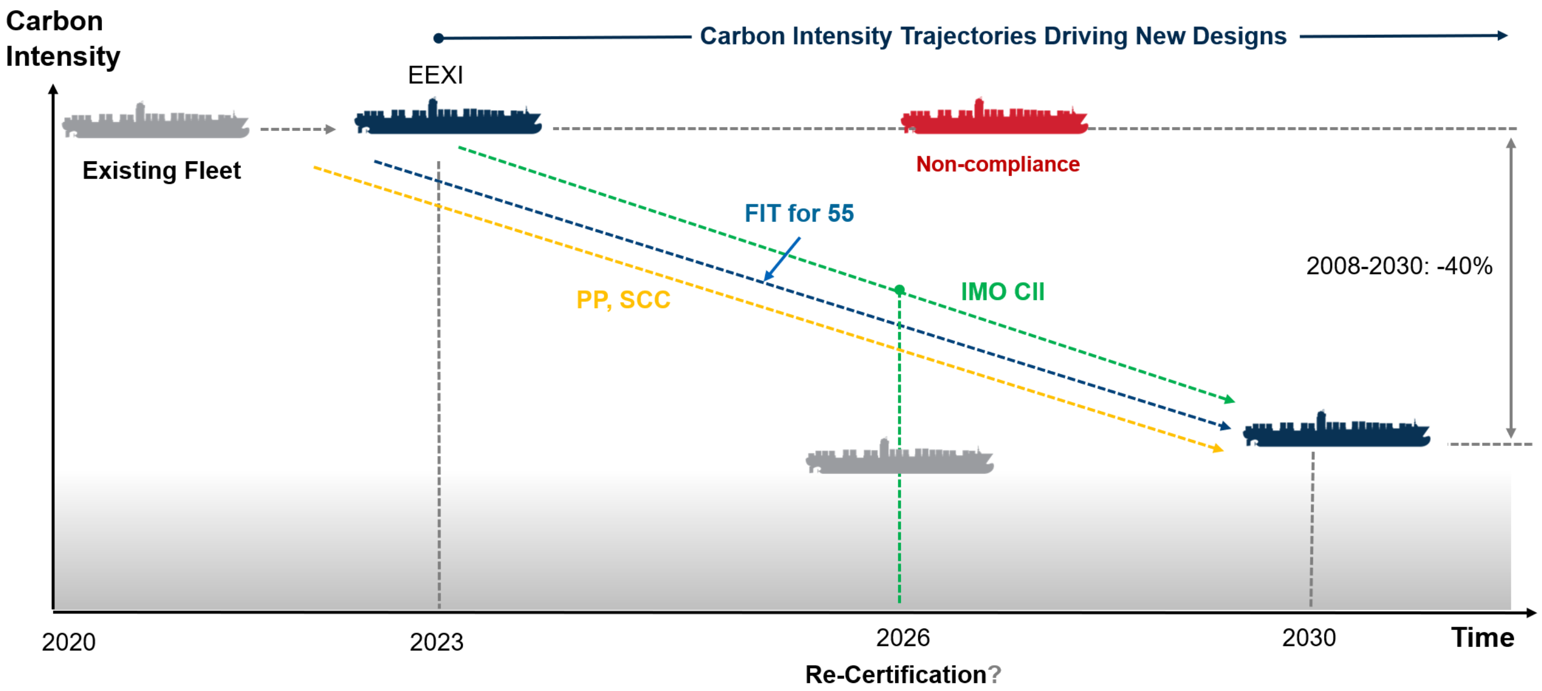


Marine Decarbonization – Regulatory Background

- IMO targets with respect to 2008 levels:
    1. Reduce Carbon Intensity by 40% by 2030
    2. Reduce Carbon Intensity by 70% by 2050
    3. Reduce GHG Emissions by 50% by 2050

- **Should the targets become stricter?**
- **(Net) Zero by 2050?**





Regulatory Background

- The International Maritime Organization (IMO) has agreed on technical and operational measures for individual vessels with the goal of assisting the industry in achieving the IMO's 2030 and 2050 emissions reduction targets

TECHNICAL
EEXI – Energy Efficiency Index for Existing Ships

- For ships over 400 gross tonnage (GT) in line with the Energy Efficiency Design Index (EEDI)

OPERATIONAL
CII – Carbon Intensity Indicator

- For ships over 5,000 GT in line with IMO Data Collection System (DCS)
  - Each ship must have an approved SEEMP on board as of January 1, 2023
  - SEEMP will be subject to verification and company audits

- Entry into force January 1, 2023, on first annual, intermediate or renewal International Air Pollution Prevention (IAPP) survey or the initial International Energy Efficiency Certificate (IEE) survey
- Measures shall be reviewed for effectiveness before January 1, 2026

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Potential Impacts

Number of vessels requiring improvement to become Energy Efficiency Index (EEXI) compliant

Bulk Carriers	87%	Sample 11,179 vessels
Container Ships	88%	Sample 5,080 vessels
Tankers	85%	Sample 9,546 vessels
Gas Carriers	95%	Sample 1,705 vessels

Percent of vessels requiring an operational change or **improvement by 2030 to stay within A, B or C** for Carbon Intensity Index (CII) compliance

	2020	
Bulk Carriers	82%	Sample 1,377 Vessels
Container Ships	78%	Sample 731 Vessels
Tankers	70%	Sample of 1,110 Vessels
Gas Carriers	80%	Sample 128 Vessels
LNG Carriers	54%	Sample 98 Vessels

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Addressing Decarbonization

3 Steps
To Developing a Decarbonization Strategy

1 **Develop a Carbon Footprint and Carbon Intensity Profile:** Analyze your data to know how your vessels perform and stack up against each other. Think holistically.

2 **Consider the Options:** Assess the impact of new technologies, operational changes and alternative fuels on your existing vessels and future built fleet.

3 **Implement a Strategy:** Usher in the new approach through effective change-management.

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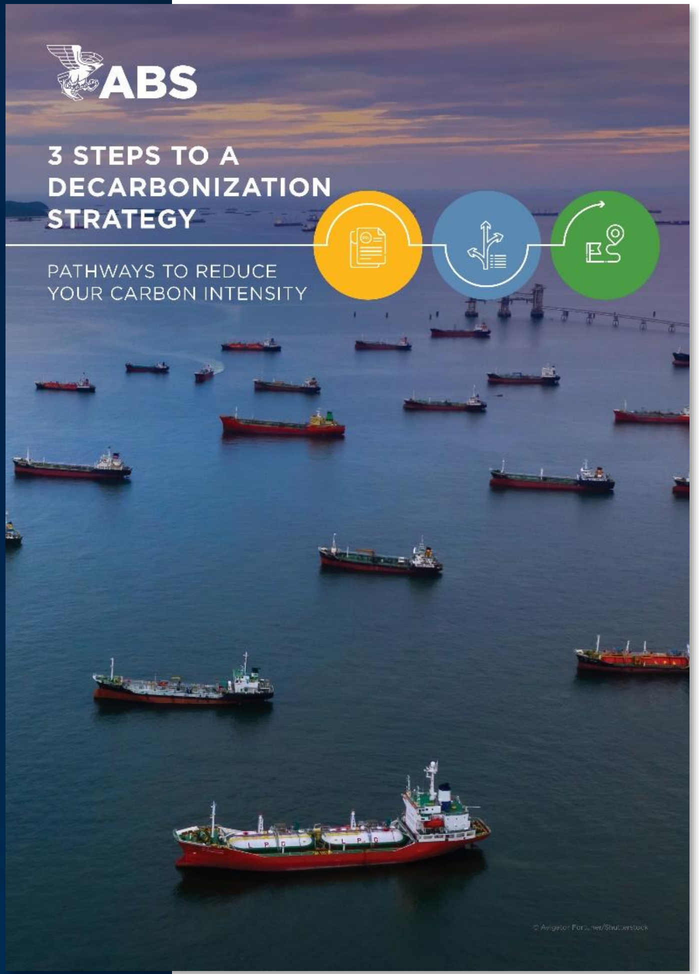
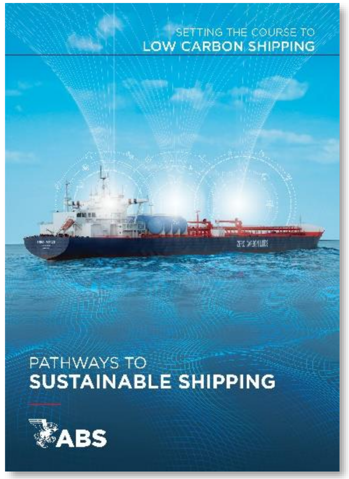
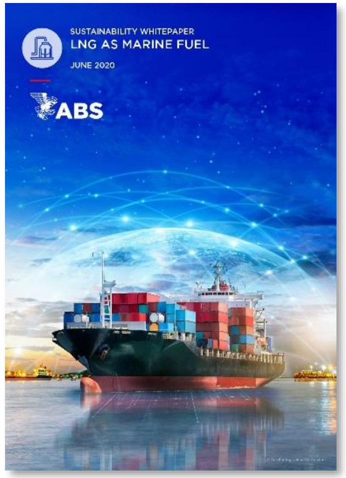
ABS Resources

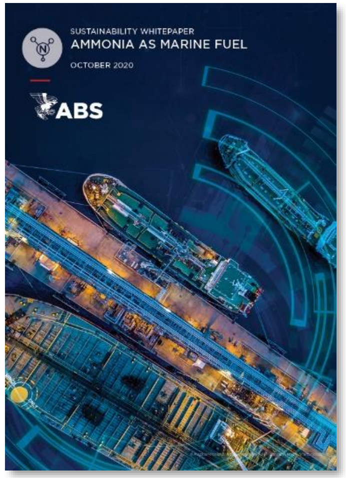
- Three Steps to a Decarbonization Strategy

- Or download one of our additional guidance documents
  - Low Carbon Shipping Outlook
  - Pathways to Sustainable Shipping
  - Fuels Focus Series
    - LNG as Marine Fuel
    - Ammonia as Marine Fuel









Decarbonization Solutions

Alternative Fuels and Energy Sources

- LNG
- Hydrogen
- LPG/Ethane
- Ammonia
- Methanol (Regional)
- Biofuels (Regional)
- Biofuels (Global)

Technology Improvements

- Air Lubrication
- Improved Hull and ESD Options
- Wind/Solar
- Hybrid
- Fuel Cells
- Electric Propulsion
- Cold Ironing
- Carbon Capture (Shore/Ship)

Operational Efficiency

- Weather Routing
- New Charter Arrangements
- Speed Optimization
- Just in Time Shipping
- Vessel Performance Reporting
- Smart Vessel/ Improved Reliability
- Fleet Interactive Performance/ Optimization

Pathway to 2050

2050

Alternative Fuels Comparison

Fuel	Boiling point (ºC)	Safety Risk	Storage volume compared to MGO	Infrastructure	Tank-to-wake CO_2 emissions	Impact on newbuilding ship cost
Hydrogen (H_2, liquid)	-253	High	4.1	Nothing available Costly to establish and transport	None	High
Ammonia (NH_3)	-33	Medium	3.4	Existing LPG network could be used > 700 LPG carrier	None	**Medium**
Methanol (CH_3OH)	65	Low	2.3	Infrastructure in place available in many ports	Similar to MGO	Low
Methane (CH_4)	-163	Low	1.6	**Infrastructure under development, costly to transport**	**Reduced compared MGO**	**Medium / High**
Diesel ($C_{16}H_{34}$)	360	Low	1.0	Infrastructure in place worldwide	Same as MGO	Low

* Capturing CO2 results in lower production efficiency

The Three Fuel Pathways of the Future

Pathway			
Light Gas	LNG	Bio-/Electro-Methane	Hydrogen
Heavy Gas	LPG, MeOH	Bio-/Electro-Fuels	Ammonia
Bio/Synthetic	Bio-/Renewable Diesel	Gas-to-Liquid Fuels	2nd and 3rd generation biodiesel

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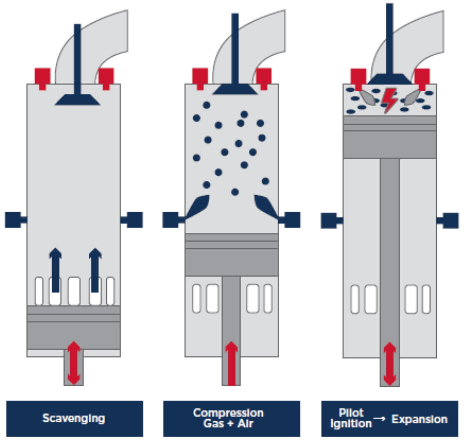
Light Gas Pathway

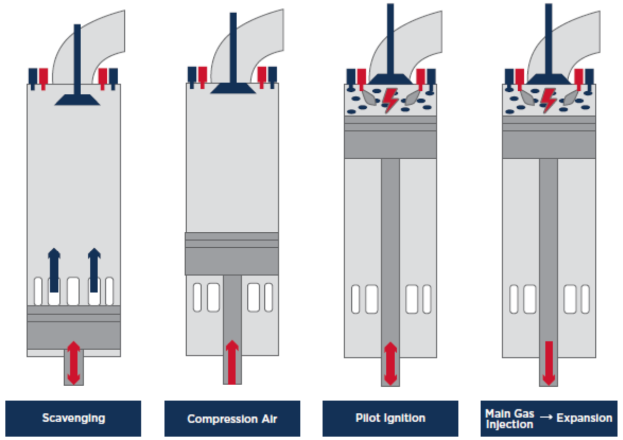
- Current State-of-the-Art
  - ~20% reduction in CO_2 compared to HFO
  - Paradigm shift from static to dynamic fuels
  - Established 2-X and 4-X engine technology
  - Methane slip is an issue
  - Requires holistic vessel design and operation

- Mid- to long-term
  - Synthetic/RNG Natural Gas (SNG/RNG)
  - Hydrogen

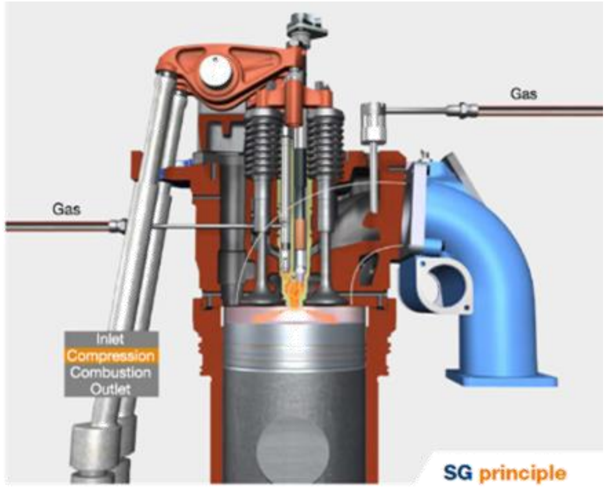
2-X LP Gas Injection



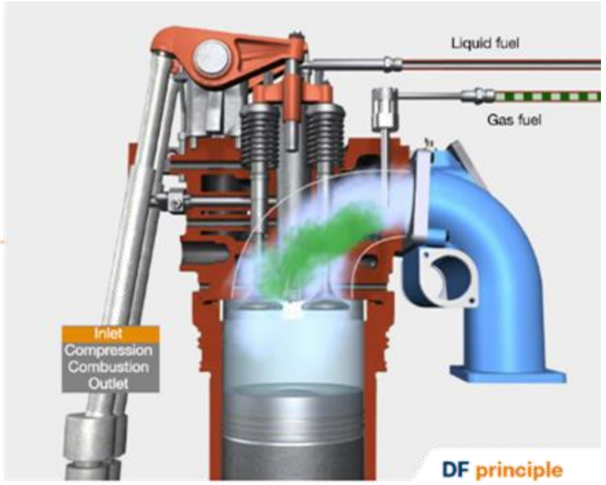
2-X LP Gas Injection



4-X prechamber ignition



4-X dual fuel

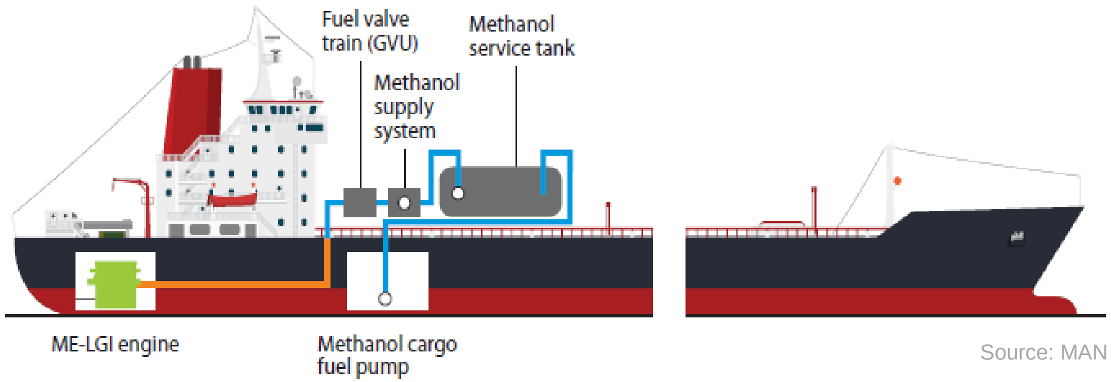


Source: Wärtsilä Corporation

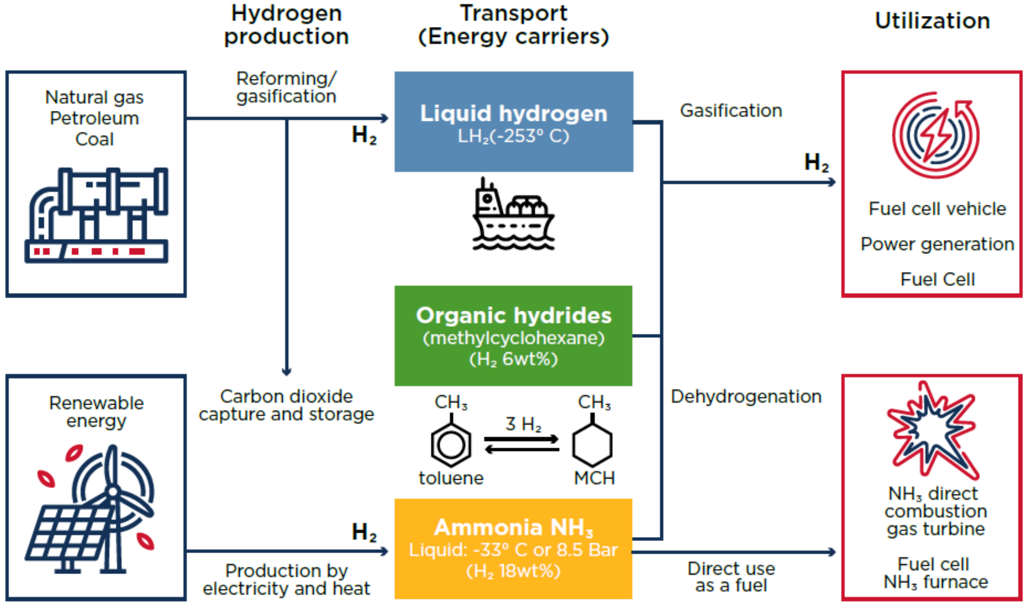
Heavy Gas – Alcohol Pathway

- Current State-of-the-Art
  - Liquified Petroleum Gas (LPG)
  - Methanol

- Mid- to long-term:
  - Bio-LPG and bio-methanol
  - Ammonia (NH_3)



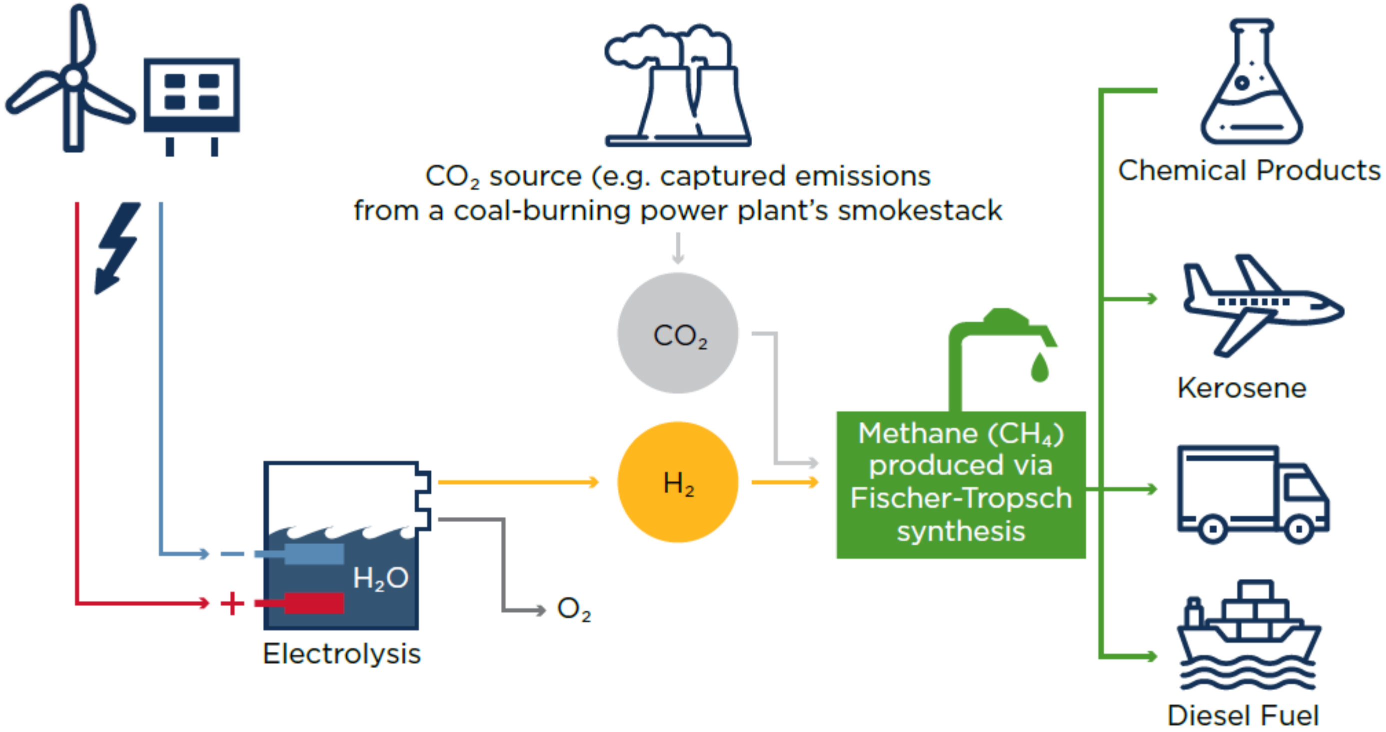
Source: MAN



Bio/synthetic Fuel Pathway

- Current State-of-the-Art
  - Biofuels derived from biomass feedstocks (plants or animal fats)
  - FAME (Fatty Acid Methyl Ester), 1st gen. biodiesel
  - HVO (Hydrotreated Vegetable Oil) or renewable diesel

- Mid- to long-term
  - 2nd and 3rd generation biofuels
  - Electro-fuels



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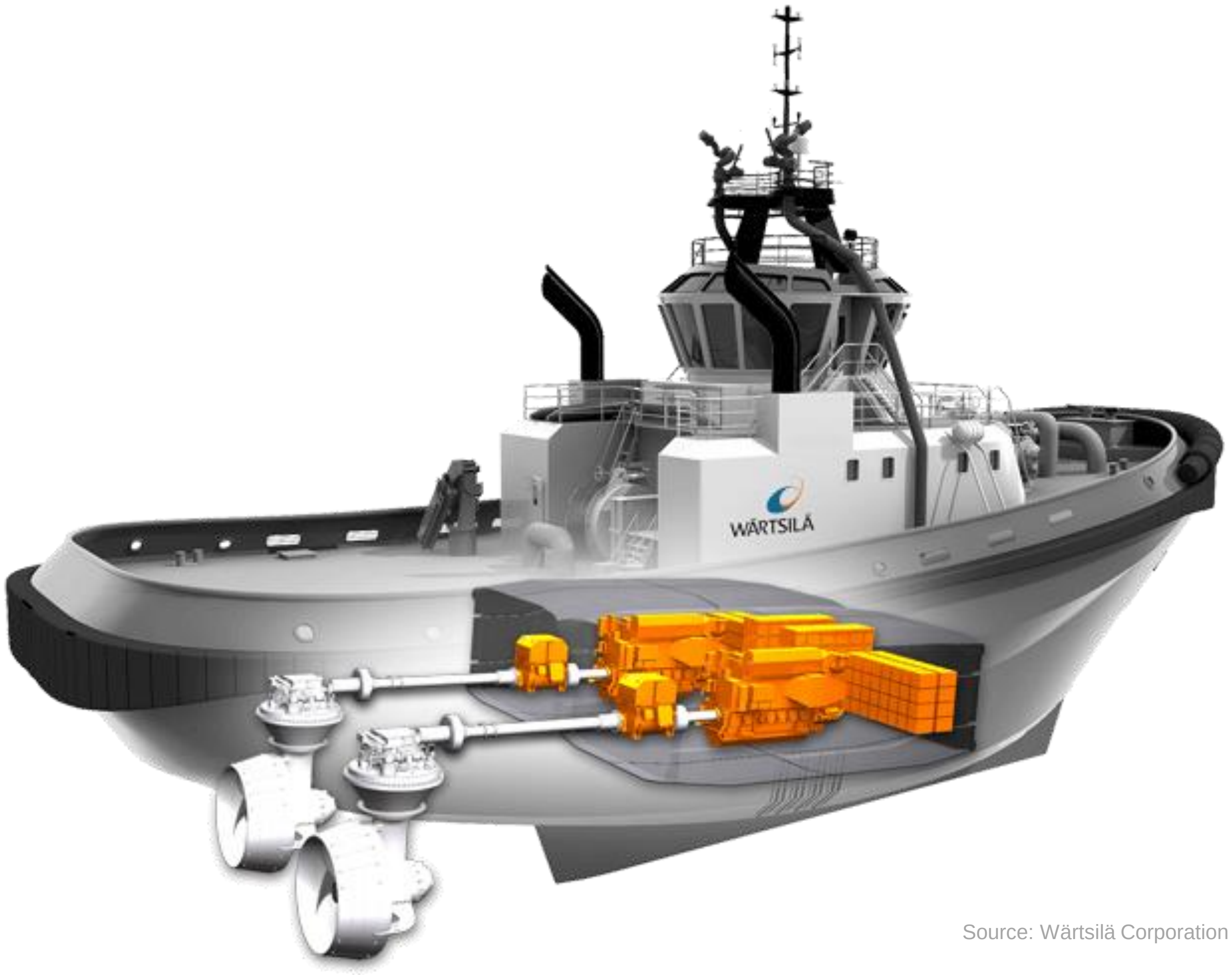
Technology Improvements – Electrification

- Hybrid-electric propulsion systems
- Fuel Cells
- DC power systems:

Source: Havyard Group



Source: Wärtsilä Corporation

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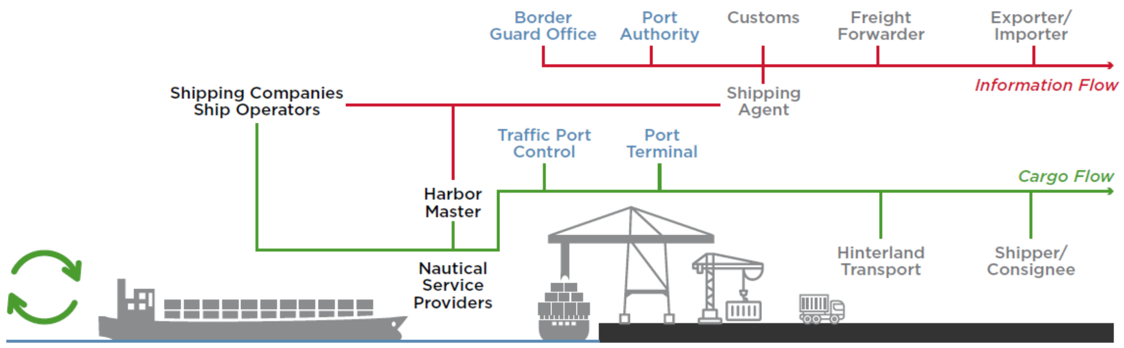
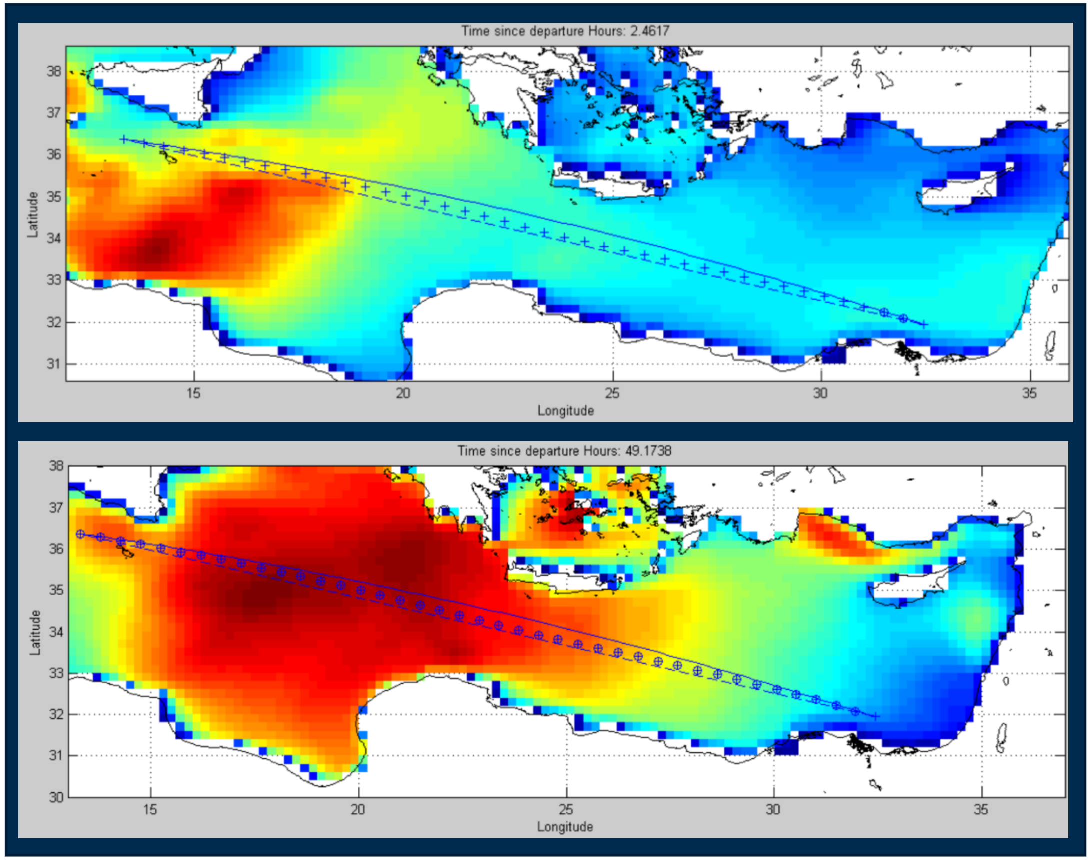
Operational Aspects – Voyage Optimization + JIT

- Routing based on weather, vessel specification, geography
- Objective: minimize fuel consumption
- Just-in-Time (JIT): related concept for minimizing unused time and fuel consumption



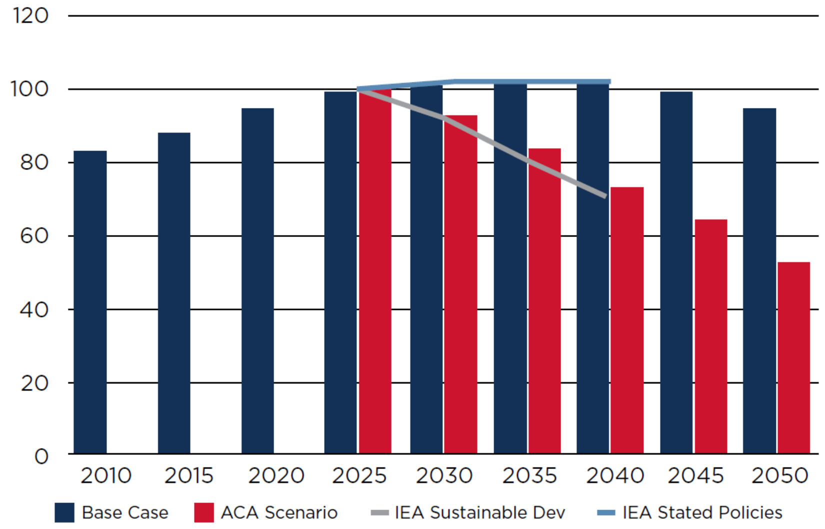


Aframax tanker example: **2%** reduction in fuel consumption

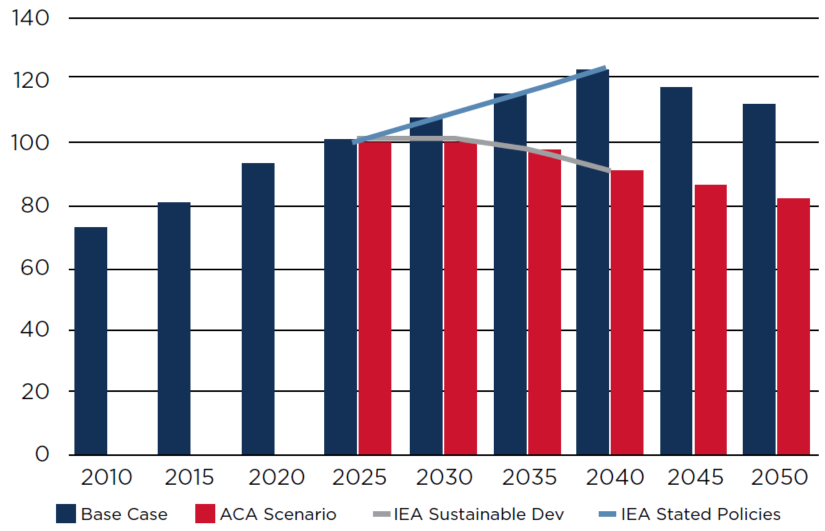
Energy Market Forecast

- Two scenarios considered
  - (i) The base case that follows stated IEA policies
  - (ii) The Accelerated Climate Action (ACA)
- Decarbonization of the global economy will curb the demand for oil, and natural gas primarily after 2040; coal may be used for power generation in developing countries
- Will affect the development of the global tanker and bulk carrier fleet, thus their fuel consumption and emissions

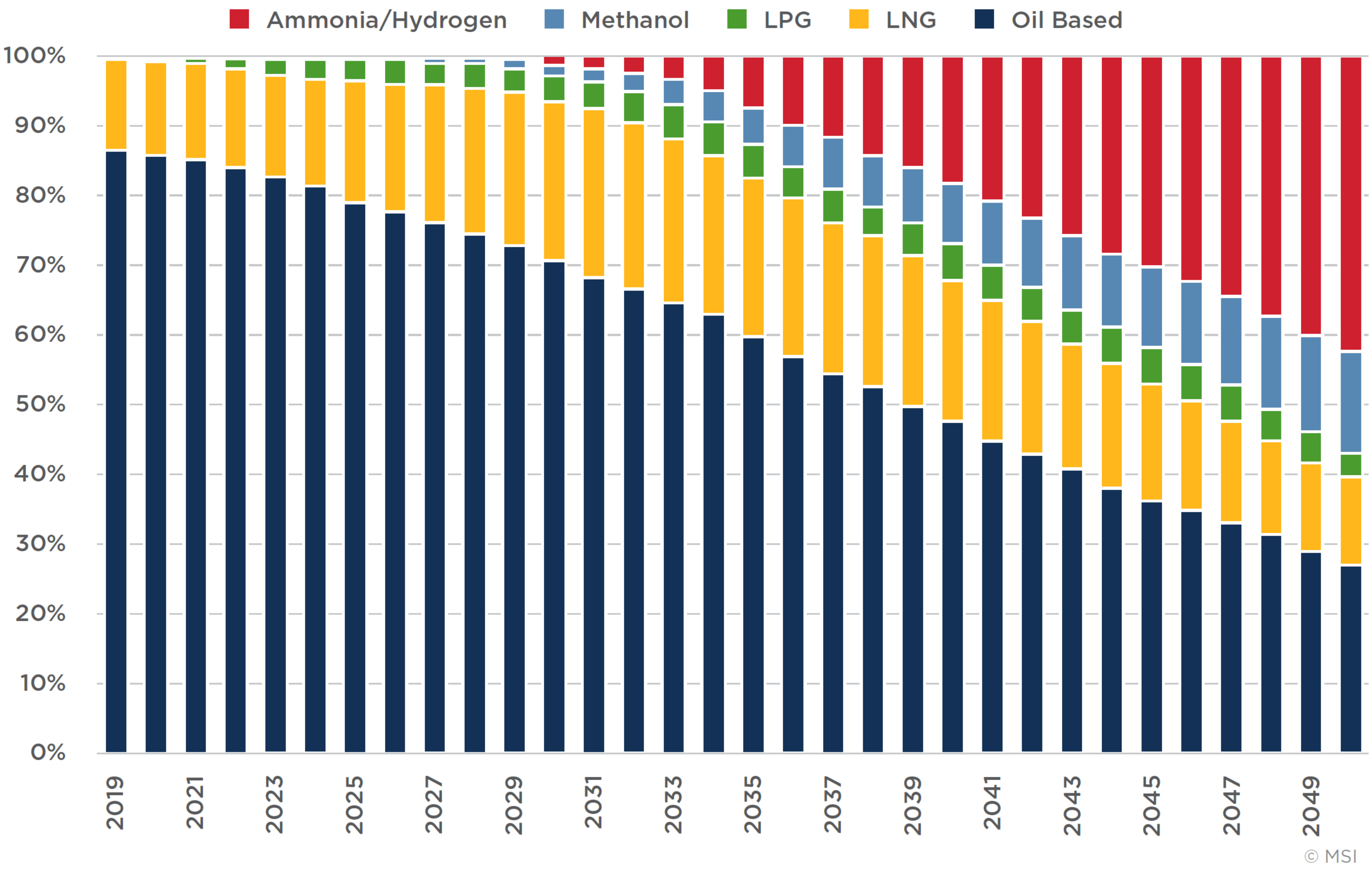
Forecast of oil demand



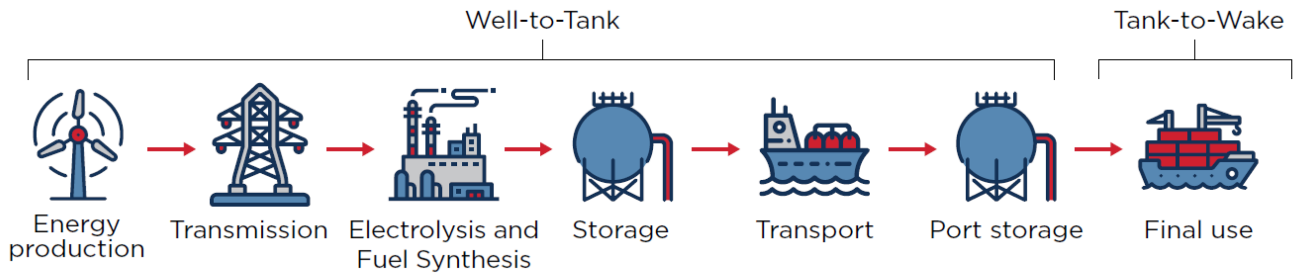
Forecast of natural gas demand

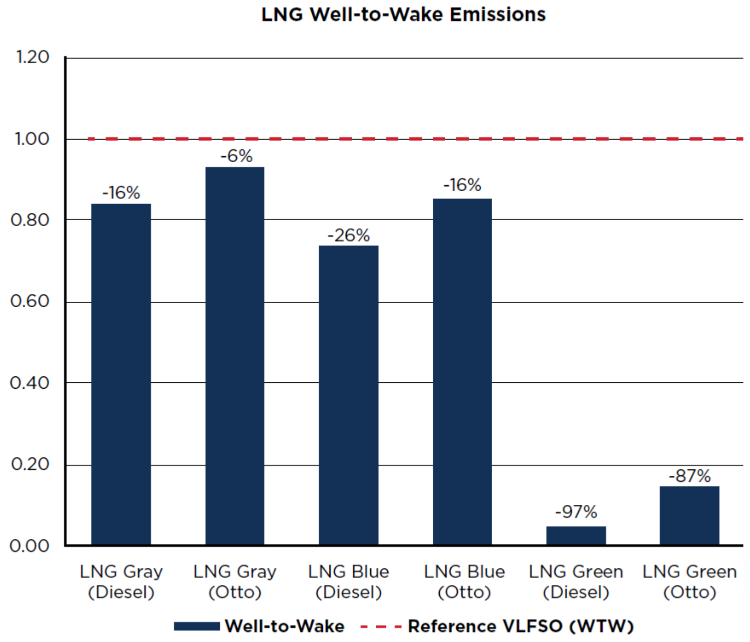


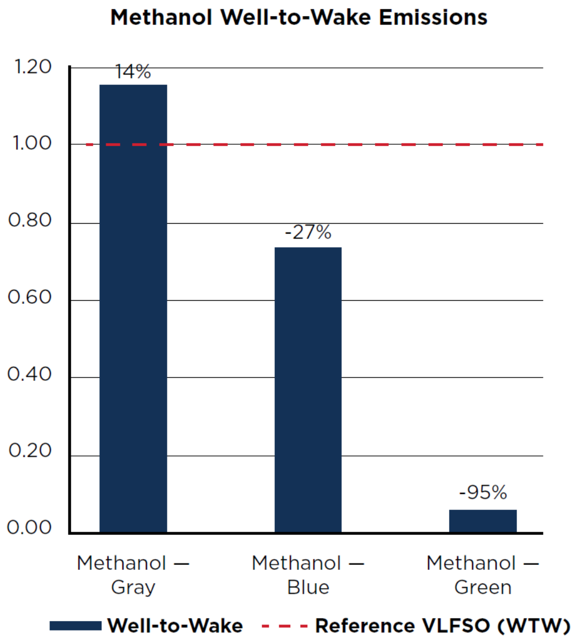
Potential Fuel Mix Forecast

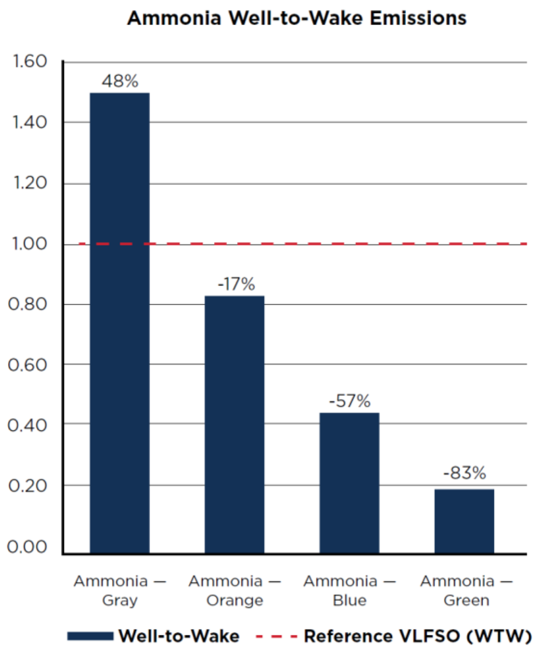


Life Cycle Analysis of Alternative Fuels









Summary and Conclusions

- Three fuel pathways identified
  - (i) Light gas
  - (ii) Heavy gas/alcohol
  - (iii) Bio/synthetic fuels
- Fuel choice is vessel-specific, directly related to its operational profile
- Low- and zero-carbon fuels with low energy content require holistic vessel design
- Decarbonization of the global economy will affect trade volumes and patterns, thus vessel segments as well
- Low- and zero-carbon fuels will increase the capital and operational cost of vessels in the mid-term
- New fuel and power generation technologies will necessitate new regulations

ABS Sustainability Centers

The ABS team of specialists stand ready to assist you with your next sustainability project, contact us today:
Sustainability@eagle.org

Interested in learning more?
Visit: www.eagle.org/sustainability

Thank You

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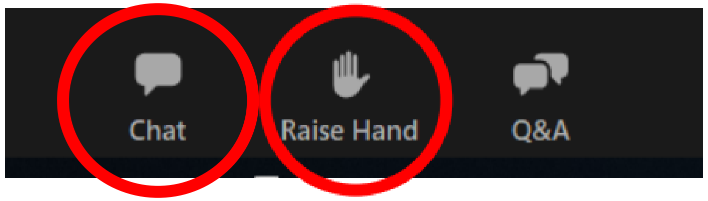
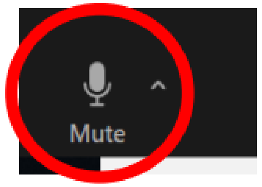
Questions and Comments





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At the conclusion of each panel DEEP will hold a brief question and comment period.

If you have a clarifying question, please drop it into the chat to either Jeff Howard or Becca Trietch. DEEP will pose as many questions as time allows to the speakers.

If you would like to make a comment:

- Please use the “Raise Hand” feature if you would like to speak
- After any interested elected officials have provided their comments, you will be invited to provide your comment in the order the hands were raised
- Please unmute yourself, state your name and affiliation
- Given time limitations, please limit your comment to 2 minutes.
- After your comments, please remember to click the “Mute” button

Public Comment – Maritime

BUREAU OF ENERGY AND TECHNOLOGY POLICY

General Public Comment

BUREAU OF ENERGY AND
TECHNOLOGY POLICY

WRAP UP

Thanks for joining our technical session today!

Written comments related to this session, or the general Comprehensive Energy Strategy can be submitted to:

1. BETP's Energy Filings web page – or –
2. Via email to DEEP.EnergyBureau@ct.gov

All information on upcoming Comprehensive Energy Strategy technical sessions and written comment opportunities can be found on the CES webpage

This slide deck and a recording of this session will be posted on the CES webpage

Written Comments related to this technical session are due
Friday, September 16, 2022, at 5:00 p.m. EST

BUREAU OF ENERGY AND TECHNOLOGY POLICY

Thank you for joining!

Questions? DEEP.EnergyBureau@ct.gov

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