Introduction & Foundational Issues, Part A – End uses that are hard to decarbonize
Today's Agenda – Afternoon

<table>
<thead>
<tr>
<th>Section</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-Distance Trucking</td>
<td>1:00-1:50 pm</td>
</tr>
<tr>
<td>Public Comment 3</td>
<td>1:50-2:05 pm</td>
</tr>
<tr>
<td>Aviation</td>
<td>2:05-2:45 pm</td>
</tr>
<tr>
<td>Public Comment 4</td>
<td>2:45-3:00 pm</td>
</tr>
<tr>
<td>Maritime</td>
<td>3:00-3:45 pm</td>
</tr>
<tr>
<td>Public Comment 5 &amp; General Public Comments</td>
<td>3:45-4:30 pm</td>
</tr>
<tr>
<td>Wrap Up</td>
<td>4:30-4:45 pm</td>
</tr>
</tbody>
</table>
Long-Distance Trucking

Dave Schaller – North American Council for Freight Efficiency
Jessie Lund – CALSTART
Edmond Young – Toyota

(speaker order may vary)
Long Haul Trucking Path to Zero Emissions

Dave Schaller
September 2022
MD & HD Industry Segments

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

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

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

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

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

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

**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)

September 2022
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
- Long Haul
  - 7 Fleets
  - 10.1 MPG

2019
- Regional Haul
  - 10 Fleets
  - 8.3 MPG

2021
- All BEVs
  - 13 Fleets
  - New metrics!

March 2022

Run on Less by NACFE

New metrics!
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

4 Market Segment Fact Sheets
Short Regional Haul

November 2021
Regional Haul (Mostly)
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
## Hydrogen & Battery Electric Trucks

### Both Competitors AND Teammates

<table>
<thead>
<tr>
<th>Hydrogen Fuel Cell Trucks</th>
<th>Truck Subsystem</th>
<th>Battery Electric Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes (but less)</td>
<td>Rechargeable Batteries</td>
<td>Yes</td>
</tr>
<tr>
<td>Yes</td>
<td>Electric Drive Motors</td>
<td>Yes</td>
</tr>
<tr>
<td>Yes</td>
<td>High Power Cables</td>
<td>Yes</td>
</tr>
<tr>
<td>Yes</td>
<td>Software Management</td>
<td>Yes</td>
</tr>
<tr>
<td>Yes</td>
<td>Regenerative Braking</td>
<td>Yes</td>
</tr>
<tr>
<td>Yes</td>
<td>Hydrogen Fuel Cell</td>
<td>--</td>
</tr>
<tr>
<td>Yes</td>
<td>Hydrogen Fuel Tank</td>
<td>--</td>
</tr>
<tr>
<td>Hydrogen Station</td>
<td>Refueling</td>
<td>Electric Charging Station</td>
</tr>
<tr>
<td>Large</td>
<td>Electricity Consumption</td>
<td>Large</td>
</tr>
</tbody>
</table>
Hydrogen Fuel Cell Trucks

Current Status

• Several trucks under fleet test
• Others under OEM development
• Both Compressed & Liquid Hydrogen trucks planned
Guidance on Hydrogen

Hydrogen Color Spectrum

**GREEN**
Hydrogen produced by electrolysis of water, using electricity from renewable sources like hydropower, wind, and solar. Zero carbon emissions are produced.

**PINK/PURPLE/RED**
Hydrogen produced by electrolysis using nuclear power.

**YELLOW**
Hydrogen produced by electrolysis using grid electricity.

**WHITE**
Hydrogen produced as a byproduct of industrial processes.

**TURQUOISE**
Hydrogen produced by the thermal splitting of methane (methane pyrolysis). Instead of CO₂, solid carbon is produced.

**BLACK/GRAY**
Hydrogen extracted from natural gas using steam-methane reforming.

**BLUE**
Grey or brown hydrogen with its CO₂ sequestered or repurposed.

**BROWN**
Hydrogen extracted from fossil fuels, usually coal, using gasification.

**Note:** There are no official definitions of these colors, but the above represents common industry nomenclature.
2019 Annual Fleet Fuel Study

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

September 2021
Commercial Electric Vehicle Market

Impacting Factors

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

Projections by ACT Research 2021
Let’s Stay Connected…

… And charged up!

NACFE (@NACFE_Freight & @RunOnLess)

NACFE.org

RunOnLess.com

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.
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)
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
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)

Truck Range

Range (km)

100 200 300 400 500 600 700 800 900 1000 1100 1200 1300

Yard tractor

HD truck

MD truck

MD step van

Cargo van

Other

Technology

Electric

Fuel Cell

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
The first international agreement on zero-emissions trucks and buses

Share of new MHDVs that are zero emissions:

- 100% by 2040
- 30% by 2030
6-STAGE STRATEGY TO ENABLE 100% ZE-MHDVS BY 2040

1. ESTABLISH BEACHHEADS
   - Launch all beachhead ZE-MHDV applications

2. SECURE POLICY ALIGNMENT
   - Secure aligned and ambitious targets and policies

3. LAUNCH LONGHAUL
   - Establish priority zero-emission long-haul corridors by 2025

4. SATURATE CITIES
   - Reach 100% sales in cities by 2030

5. BUILD BACKBONE
   - Build priority freight corridors by 2030

6. COMPLETE NETWORK
   - National networks in place by 2035, complete by 2040
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
TOYOTA ENVIRONMENTAL CHALLENGE 2050
Initial Prototypes

10 Truck Pilot

Production Intent 2023 / TMMK
DRIVING TO ZERO EMISSIONS

KENWORTH T680 FUEL CELL EV

470HP | 350 MI RANGE | 15 MIN REFILL
INITIAL HEAVY-DUTY STATIONS
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
Zero Emissions Kenworth T680 FCEV on the Climb to 14,115-Foot Pikes Peak Summit

14,115 ft SUMMIT
Questions and Comments

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
Aviation

Uisung Lee – Argonne National Laboratory
Dan Rutherford – International Council on Clean Transportation
Michael Winter – Pratt & Whitney

(speaker order may vary)
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
50,000+ Registered GREET Users Globally

North America, 65.9%
Europe, 15.9%
Asia, 12.9%
Other, 6.2%

- Oceania, 1.6%
- Sub-Saharan Africa, 0.8%
- Middle East and North Africa, 1.4%
- South America, 2.4%
- Central America & Caribbean, 0.1%

Academia, Education 52%
Government Agency 7%
Industry 19%
Private Consulting 10%
Non-profit Organization 4%
Research Institution 3%

Ford
International Transport Forum
National Institute of Standards
Argonne National Laboratory
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

Road 72%
Rail 2%
Air 11%
Marine 3%

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.

(SOURCE: FAA 2021)

(SOURCE: DOE 2022)

---

13 Analysis conducted by BlueSky leveraging R&D efforts from the FAA Office of Environment & Energy (AEE) regarding CO₂ 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)**
Carbon cycle via photosynthesis provides key CO$_2$ benefits with biofuel pathways.
GREET provides the carbon intensities for CORSIA

- 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

(Source: Prussi et al. 2021)
SAF LCA results presents significant emission reduction potential

Life-cycle GHG emission results of major SAF pathways using the GREET Aviation Module
For lower life-cycle GHG emissions in SAF production pathways

<table>
<thead>
<tr>
<th>Use waste feedstocksd</th>
<th>Less fossil energy inputs</th>
<th>Avoid fossil carbon inputs</th>
<th>Additional emission credits</th>
</tr>
</thead>
</table>
| • Compared to crops, using waste feedstocks can reduce emissions associated with feedstock production and ILUC impact | • Use renewable H\textsubscript{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

Data selection: Datasets can be selected from the available pathways in LCI

User defined LCI: Users can change the values, and the results will be updated

Co-products handling: allocation methods can be selected (mass-, energy-, market-allocation, or displacement method)

LCA results by aircraft types

LCA results: For the selected metric (GHG, energy use by type, or air pollutant emissions [e.g., CO, NOx, SOx]), LCA results are presented at the process-level
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.
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.
Aviation as a Hard to Decarbonize Sector

Dan Rutherford, Ph.D.
1 September 2022
CES Technical Meeting
Outline

• Background
• Technologies needed to decarbonize aviation
• Conclusions and policy implications
• Questions and discussion
Background
Why are aviation emissions hard to abate?

- Physics
- Economics
- Culture
Aviation requires energy dense fuels

https://twitter.com/kevpluck/status/1368788614709010432?s=20&t=Tqn8Wm_TSwNIMq3IrljZbA
Economics: how low can you 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.

Technologies needed to decarbonize aviation
To what extent can various measures reduce cumulative CO$_2$ emissions from global aviation inline with 1.5ºC, 1.75ºC, and 2ºC targets?
Scenarios

S0: Reference (business-as-usual)
S1: Action
S2: Transformation
S3: Breakthrough

Increasing level of ambition
Our three modeling scenarios consider 6 important parameters:

- Aircraft technology
- Operations
- Sustainable aviation fuels (SAFs)
- Zero emission planes (ZEPs)
- 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
... and don’t forget about traffic growth.

Cumulative global aviation CO$_2$ emissions by scenario and traffic forecast, 2019-2050

- Max tech + base traffic
- Min tech + base traffic
- Max tech + 7% p.a. traffic
- Max tech + 2019 traffic

https://theicct.org/global-aviation-race-jun22/
Conclusions and Policy Implications
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
Pratt & Whitney
ACHIEVING SUSTAINABLE AVIATION

SUMMER 2022

Dr. Michael Winter
Senior Fellow Advanced Technology

POWERING SUSTAINABLE AVIATION™
CLIMATE CHANGE
IMPACTS PEOPLE, ECONOMIES, AND SECURITY
POWERING SUSTAINABLE AVIATION
THE PRATT & WHITNEY APPROACH

Smarter Technology
• Leverage GTF technology
• Hybrid-electric propulsion
• Increased digitization

Cleaner Fuel
• Sustainable Aviation Fuel +
• Hydrogen

Greener Business
• 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

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

Fuel burn and CO\textsubscript{2} per RPK

70%
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 CO₂ 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 CO₂ 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 CO₂
vs. previous generation engines like V2500
most efficient engine

mature reliability
with high durability at entry into service

100% SAF compatible
maximum customer flexibility

NO TECHNICAL DATA | CLEARED FOR PUBLIC RELEASE | COPYRIGHT PRATT & WHITNEY 2022
NEXT GENERATION TECHNOLOGIES
SUSTAINABLE, DURABLE AND EFFICIENT

Advanced Fan Blade

Low Acoustic Fan Case

Ceramic Matrix Composites & Advanced Cooling Technologies

Hybrid Electric Propulsion

Low NOx Combustor

High Overall Pressure Ratio, Small Core

Planetary Fan Drive Gear System (PFDGS)

Sustainable Aviation Fuel
Digital Thread
CORE EFFICIENCY PROGRESS

HIGH TEMPERATURE MATERIALS

CERAMIC MATRIX COMPOSITES

Running in development engines
Dedicated COE opened in 2021
Program anticipated to be ready by 2025

ADVANCED CASTINGS

Baseline GTFA 2024
Asheville production in 2025
ENERGY DENSITY
THE CHALLENGE FOR BATTERY AND HYBRID POWERED AIRCRAFT

Motor Efficiency

Airliner Turbofans
(35K/0.8M cruise)

Turboprops
(25K/0.5M cruise)

Useable Energy Density (kWh/L)

Useable Energy Density (kWh/kg)

CO₂ Emissions (g/kWh)

Cruise Thermodynamic Efficiency

Useable Energy Density (kWh/L)

Tesla Model S
85 kWh

Nissan Leaf
22 kWh

Battery Energy Density

Motor Efficiency

Batteries

Energy Density

Jet A Fuel Only

GTF with Jet A

PT6 with Jet A

Li/Sulfur

Li/LMRNMC

Si/LMRNMC

Li/O₂ closed

Li/O₂ open

Gr/NMC333

Gr/LMRNC

Tesla Model S
85 kWh

Nissan Leaf
22 kWh

0.7

0.6

0.5

0.4

0.3

0.2

0.1

0

0

0.1

0.2

0.3

0.4

0.5

0.6

0

5

10

Energy Density

0

5

10

15

Useable Energy Density (kWh/kg)

0

5

10

15

Useable Energy Density (kWh/L)

0

5

10

15

Useable Energy Density (kWh/kg)

0

5

10

15

Useable Energy Density (kWh/L)

0

5

10

15

Useable Energy Density (kWh/kg)

0

5

10

15

Useable Energy Density (kWh/L)
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

HySILTE
- Direct $\text{H}_2$ combustion system
- Exhaust waste heat recovery
- Electric engine actuation

Challenges

- Airframe integration
- Fuel production and distribution
- Material Compatibility
- Non-$\text{CO}_2$ emissions
<table>
<thead>
<tr>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continued investment in fuel efficiency technology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50% SAF → 100% SAF capable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hybrid-electric</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Demographic data and in-service data available.
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
POWERING SUSTAINABLE AVIATION™

SMARTER. CLEANER. GREENER.
Questions and Comments

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• 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
Maritime

Bryan Wood-Thomas – World Shipping Council
Keegan Plaskon – American Bureau of Shipping

(speaker order may vary)
World Shipping Council
Critical Pathways to Decarbonize the Maritime Sector
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 services 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.
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
kplaskon@eagle.org
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.
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
The Vision of Sustainability

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

Environmental Excellence

- Affordable and Clean Energy
- Responsible Consumption and Production
- Climate Action
- Life Below Water

Social Responsibility

- Good Health and Well-Being
- Decent Work and Economic Growth

Governance – Operational Excellence

- Industry, Innovation and Infrastructure
- Peace, Justice and Strong Institutions
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?
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
## Potential Impacts

<table>
<thead>
<tr>
<th>Type</th>
<th>Percentage</th>
<th>Sample Vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bulk Carriers</strong></td>
<td>87%</td>
<td>11,179 vessels</td>
</tr>
<tr>
<td><strong>Container Ships</strong></td>
<td>88%</td>
<td>5,080 vessels</td>
</tr>
<tr>
<td><strong>Tankers</strong></td>
<td>85%</td>
<td>9,546 vessels</td>
</tr>
<tr>
<td><strong>Gas Carriers</strong></td>
<td>95%</td>
<td>1,705 vessels</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Type</th>
<th>Percentage</th>
<th>Sample Vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bulk Carriers</strong></td>
<td>82%</td>
<td>1,377 vessels</td>
</tr>
<tr>
<td><strong>Container Ships</strong></td>
<td>78%</td>
<td>731 vessels</td>
</tr>
<tr>
<td><strong>Tankers</strong></td>
<td>70%</td>
<td>Sample of 1,110 vessels</td>
</tr>
<tr>
<td><strong>Gas Carriers</strong></td>
<td>80%</td>
<td>128 vessels</td>
</tr>
<tr>
<td><strong>LNG Carriers</strong></td>
<td>54%</td>
<td>98 vessels</td>
</tr>
</tbody>
</table>
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.
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
- LPG/Ethane
- Methanol (Regional)
- Biofuels (Regional)
- Biofuels (Global)
- Hydrogen
- Ammonia

**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
## Alternative Fuels Comparison

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Boiling point (°C)</th>
<th>Safety Risk</th>
<th>Storage volume compared to MGO</th>
<th>Infrastructure</th>
<th>Tank-to-wake CO₂ emissions</th>
<th>Impact on newbuilding ship cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen (H₂, liquid)</td>
<td>-253</td>
<td>High</td>
<td>4.1</td>
<td>Nothing available</td>
<td>None</td>
<td>High</td>
</tr>
<tr>
<td>Ammonia (NH₃)</td>
<td>-33</td>
<td>Medium</td>
<td>3.4</td>
<td>Existing LPG network could be used &gt; 700 LPG carrier</td>
<td>None</td>
<td>Medium</td>
</tr>
<tr>
<td>Methanol (CH₃OH)</td>
<td>65</td>
<td>Low</td>
<td>2.3</td>
<td>Infrastructure in place available in many ports</td>
<td>Similar to MGO</td>
<td>Low</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>-163</td>
<td>Low</td>
<td>1.6</td>
<td>Infrastructure under development, costly to transport</td>
<td>Reduced compared MGO</td>
<td>Medium / High</td>
</tr>
<tr>
<td>Diesel (C_{16}H_{34})</td>
<td>360</td>
<td>Low</td>
<td>1.0</td>
<td>Infrastructure in place worldwide</td>
<td>Same as MGO</td>
<td>Low</td>
</tr>
</tbody>
</table>

* Capturing CO₂ results in lower production efficiency
The Three Fuel Pathways of the Future

**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
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

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 (NH₃)
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
Technology Improvements – Electrification

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

Source: Havyard Group

Source: Wärtsilä Corporation
• 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
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
Potential Fuel Mix Forecast
Life Cycle Analysis of Alternative Fuels

Well-to-Tank
- Energy production
- Transmission
- Electrolysis and Fuel Synthesis
- Storage
- Transport
- Port storage
- Final use

LNG Well-to-Wake Emissions

- LNG Gray (Diesel): -16%
- LNG Gray (Otto): -6%
- LNG Blue (Diesel): -26%
- LNG Blue (Otto): -16%
- LNG Green (Diesel): -97%
- LNG Green (Otto): -87%

Methanol Well-to-Wake Emissions

- Methanol Gray: 14%
- Methanol Blue: -27%
- Methanol Green: -95%

Ammonia Well-to-Wake Emissions

- Ammonia Gray: 48%
- Ammonia Orange: -17%
- Ammonia Blue: -57%
- Ammonia Green: -83%
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

www.eagle.org
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Public Comment – Maritime
General Public Comment
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
Thank you for joining!

Questions? DEEP.EnergyBureau@ct.gov