U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Overview of Decarbonization of Off-Road, Rail, Marine, and Aviation Program, Vehicle Technologies Office

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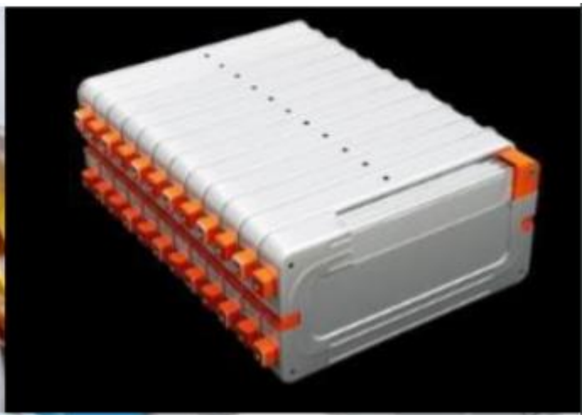



Who We Are

Gurpreet Singh

Combustion

Siddiq Khan

Rail, SuperTruck, and System Efficiency

Kevin Stork

Marine, Aviation, and Fuel Technologies

Nicholas Hansford

Off-Road and Emission Control

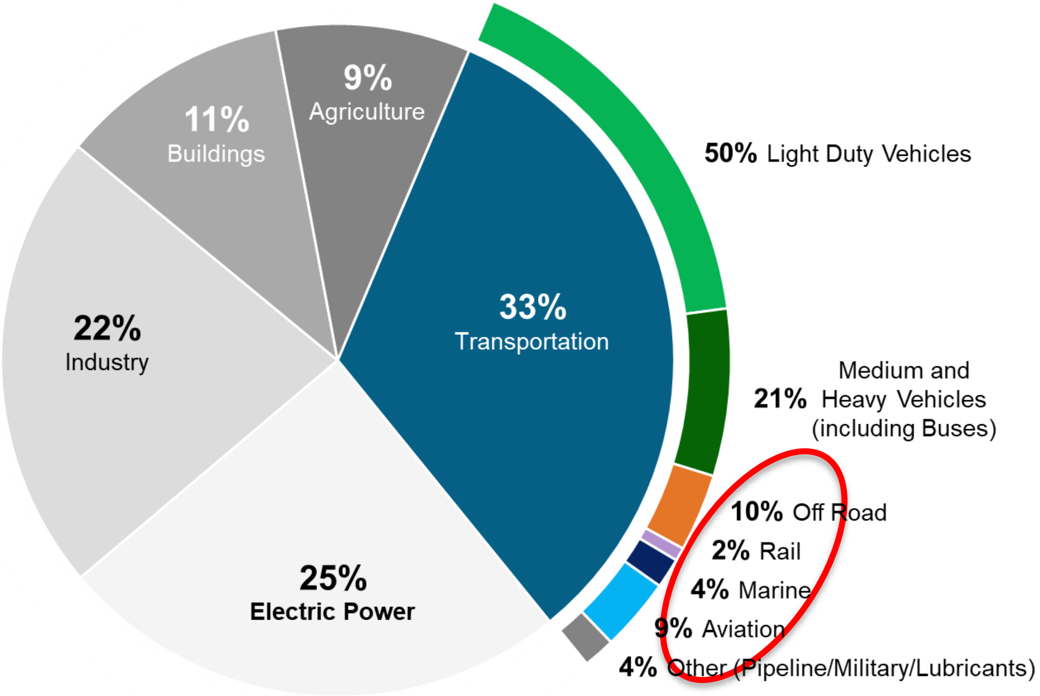
What We have Done Before: SuperTruck and Light-Duty Vehicle R&D

- Our program managed many light- and heavy-duty engine and vehicle R&D including SuperTruck program
- SuperTruck I involved 4 teams with an objective to reduce fuel consumption by 50%. SuperTruck I program successfully commercialized more than 20 technologies
- SuperTruck II, involving 5 teams, started in 2016 and completed in 2023. All SuperTruck II teams have demonstrated more than 100% vehicle freight efficiency improvements. As a result, trucks that went 6 miles per gallon in 2009, can now go 16 miles per gallon
- High efficiency pickup R&D successfully improved engine efficiency by more than 20% while reducing engine mass by more than 15%

Navistar (ST II)

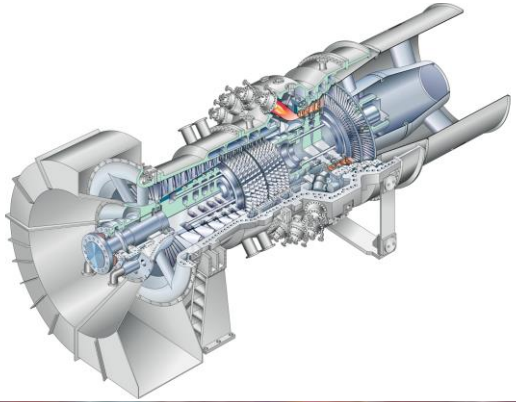
What We Do Now

2021 U.S. GHG Emissions



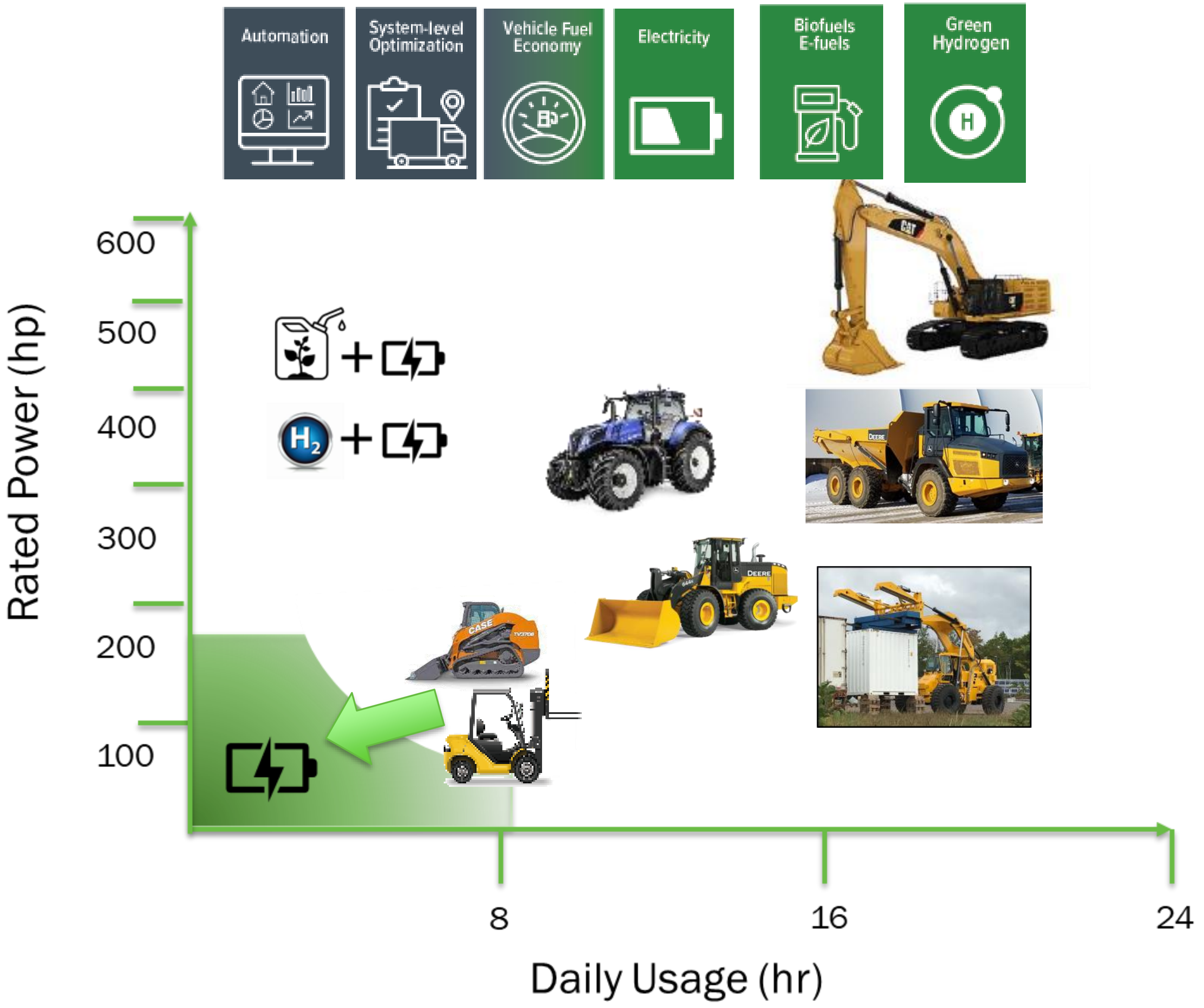
Aviation and marine include emissions from international aviation and maritime transport. Fractions may not add up to 100% due to rounding.

- R&D focused on efficient utilization of renewable fuels, such as advanced biofuels, hydrogen, and e-fuels, to reduce GHG emissions for off-road, rail, marine and aviation sectors
- Impact of renewable fuels on emission control systems to reduce criteria emissions to near-zero levels
- Vehicle-level system integration including hybridization, battery-electric and fuel cell applications for Non-Road sectors
- Completing on-road engine R&D projects

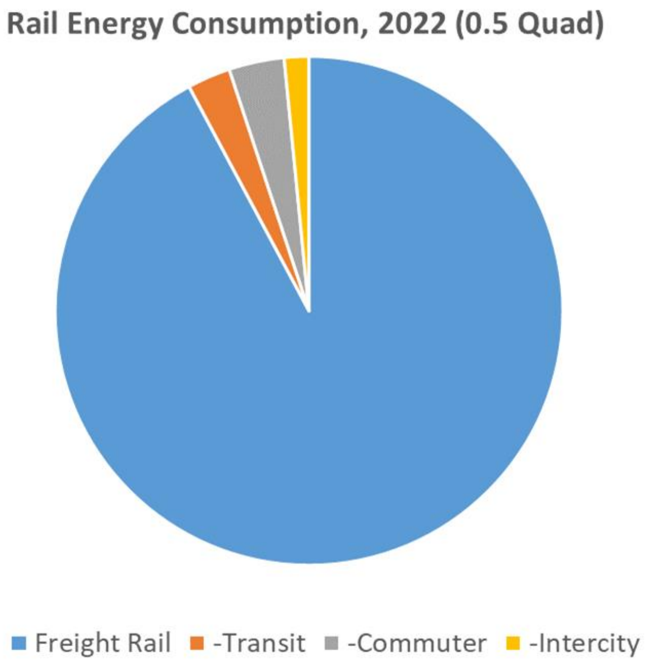


Off-Road R&D strategy

- Good opportunities for reducing energy and carbon intensity; activity expected to grow
- Battery electric equipment for <175hp/limited daily usage
  - Increase vehicle efficiency to allow longer daily usage per charge
  - Enable worksite charging for difficult situations
  - Zero Emission Vehicle (ZEV) mandates at state/local level help facilitate this transition
- High power/usage and remote operation present barriers for battery-electric
  - Hybridization and engine-downsizing, other efficiency improvements for near-term impact
  - Enable use of Low Lifecycle Carbon Fuels (LLCF)
    - Liquid: RD100, E100, M100
    - Gaseous: Clean H_2 – in FC or H2ICE



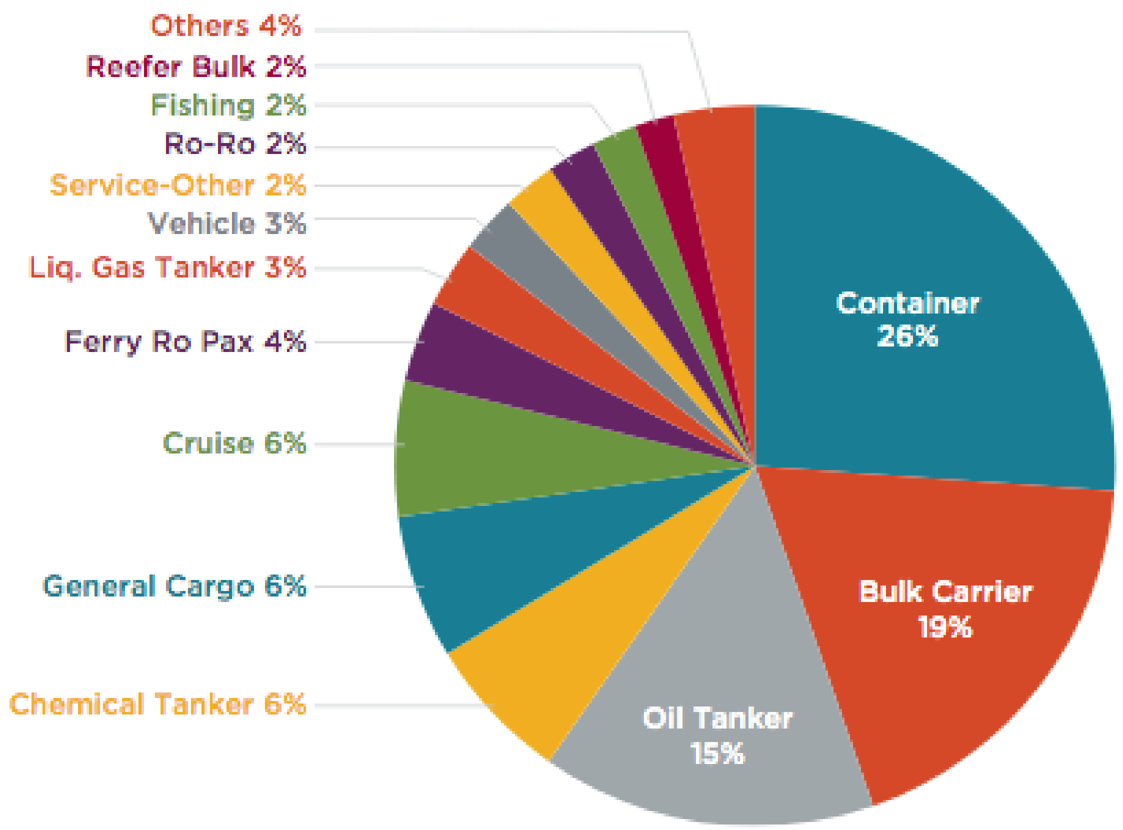
Overview of Rail Decarbonization



- $80-billion freight rail industry provides 167,000 jobs and moves 28% of freight by ton-miles
- Freight rail consume the most fuels. They are powered by huge diesel locomotives that carry ~5,000 gallons of fuel
- Multiple technology solutions to decarbonize rail sector
- Direct (Catenary) or battery electrification,
- H_2 (Fuel Cells and H2ICE)
- LLCF
- No major supply limitation foreseen for electricity /H_2 but the sector needs to leverage solutions used in other applications to achieve scale

Overview of Marine Decarbonization

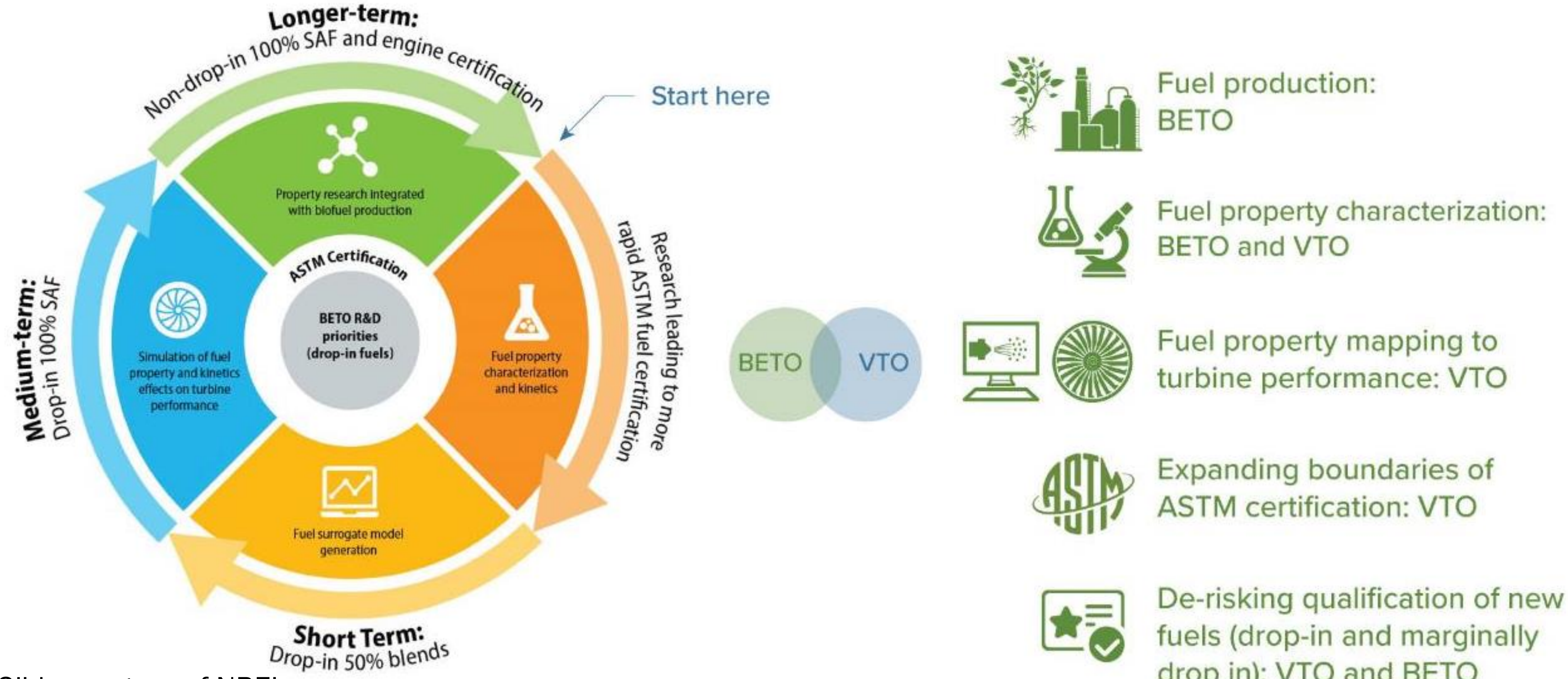
Global Carbon Emissions By Ship Class



"Black Carbon Emissions and Fuel Use in Global Shipping, 2015." ICCT. https://theicct.org/sites/default/files/publications/Global-Marine-BC-Inventory-2015_ICCT-Report_15122017_vF.pdf

- US Fleet of Maritime Vessels
  - 38,000 commercial vessels
  - 11 million motorized recreational boats
  - 6,500 government-owned boats and ships
- 2/3 of GHG emissions from the largest ships
  - Very few large commercial ships – such as container ships – are owned or flagged in the US, but many visit US ports
  - US can be a supplier of low carbon liquid fuels
- Many of the smaller and medium vessels
  - Suitable for electrification
  - Near- and mid-term use of low carbon fuels.
- Government-owned vessels could be potential technology demonstration platforms

The Sustainable Aviation Fuel (SAF) Technology Landscape



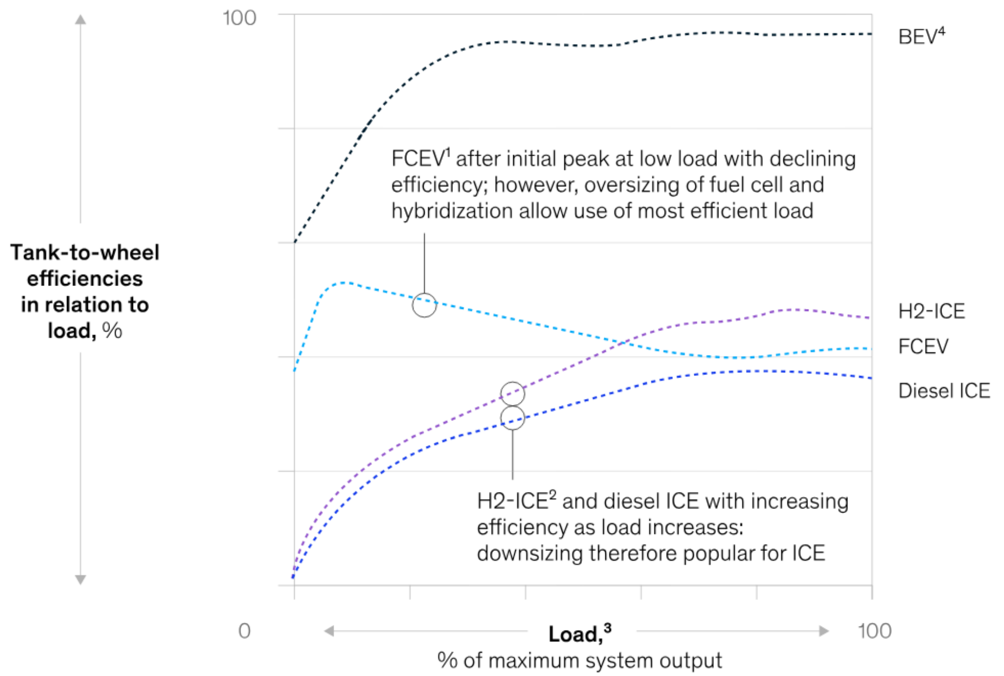
Slide courtesy of NREL

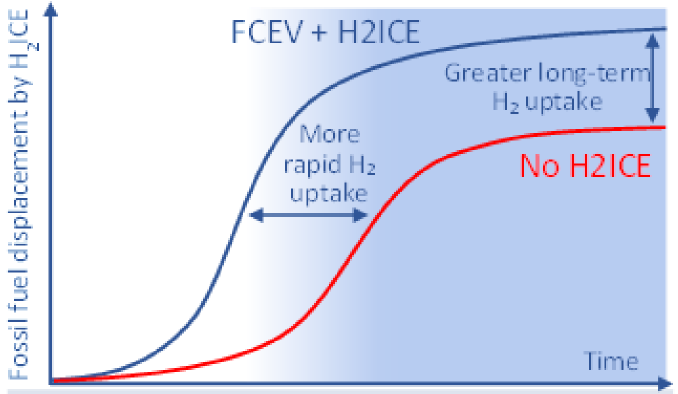
Program R&D Areas: Hydrogen Combustion (H2ICE)

Why H2ICE?

- H2ICE technology is favorable for customers with high power demand and long range; manufacturers have conveyed high confidence in this technology
- Offers zero carbon and ultra-low NOx solution. No PM or SOx emission
- Enables manufacturers use existing facilities and supply chain, use existing labor forces, and fast-to-market
- Although H_2 will be pure, H2ICE can operate with mixtures of fuel if needed or when H_2 is not available
- Can readily retrofit existing fleets, therefore, further accelerating decarbonization

Efficiency variations (lines on graph are illustrative)





H2ICEs can create earlier market pull promoting H2 infrastructure development and can provide greater long-term displacement of fossil-derived fuels.

VTO H_2 and LLCF R&D at ORNL

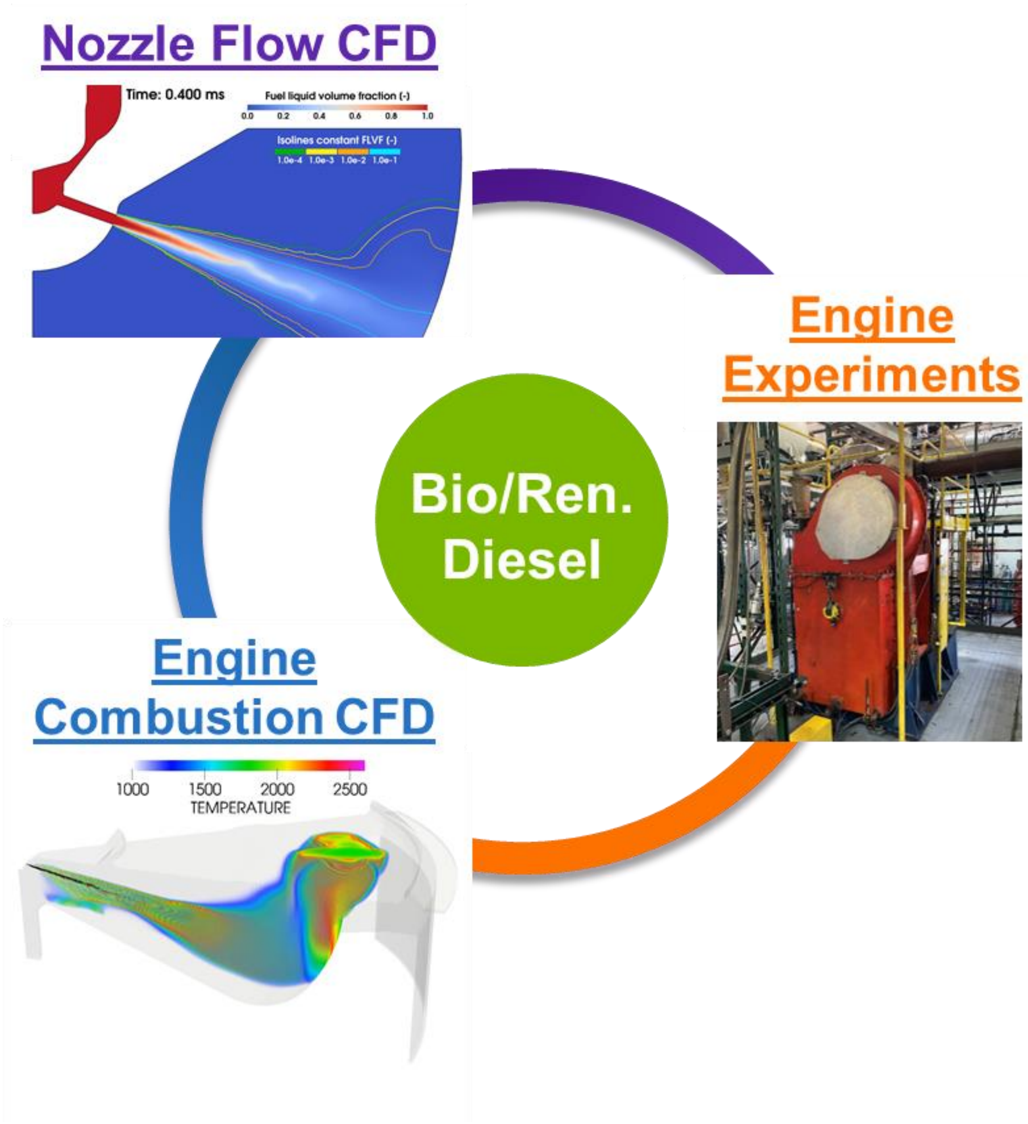
- Install and commission Wabtec single cylinder locomotive research engine at ORNL
- Establish maximum level of low lifecycle carbon fuels (e.g., hydrogen, renewable and bio diesel, methanol etc.) substitution for dual-fuel retrofit strategies while maintaining performance, emissions, and operability with 100% diesel
- Develop and evaluate injection and combustion strategies that approach 100% substitution to enable next-generation locomotive solutions

Wabtec single-cylinder locomotive research engine installed at NTRC

- **Based on production hardware (not scaled) for Wabtec 12-cyl EVO**
- 15.7-L displacement (250mm bore)
- 375 hp at 995 rpm
- Entire assembly is 8.5-ft tall, 41,000+ lbs.

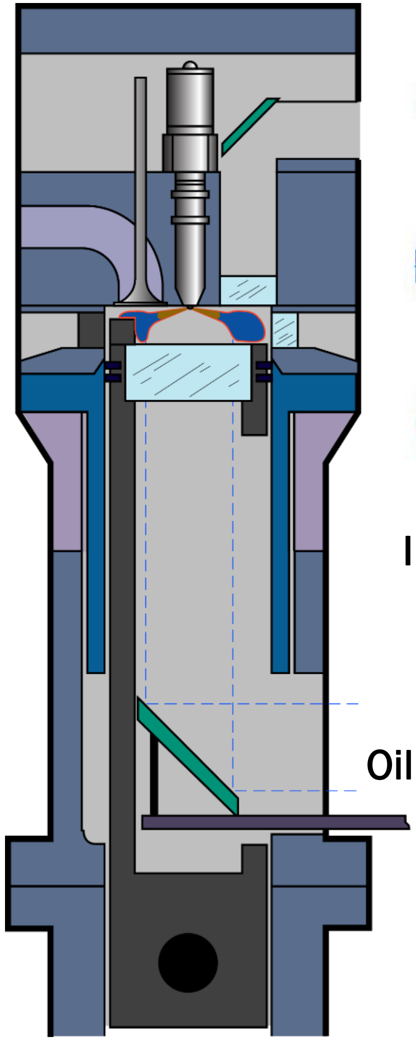
VTO LLCF and H_2 R&D at ANL

- **Objective**
  - Integrated computational and experimental research to assess rail/marine engine performance and emissions with high blends of LLCF including H_2
- **Approach**
  - High-fidelity internal nozzle flow CFD to quantify injector design and fuel property impacts
  - High-fidelity engine combustion CFD to quantify engine design and fuel property impacts
  - Engine tests on Progress Rail 1010J 4-stroke single cylinder locomotive engine
  - **Fuels of interest:** high/low cloud point biodiesel, renewable diesel, H_2, and blends with diesel

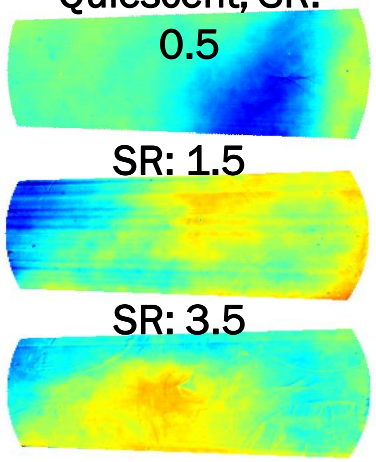


VTO H_2 R&D at SNL

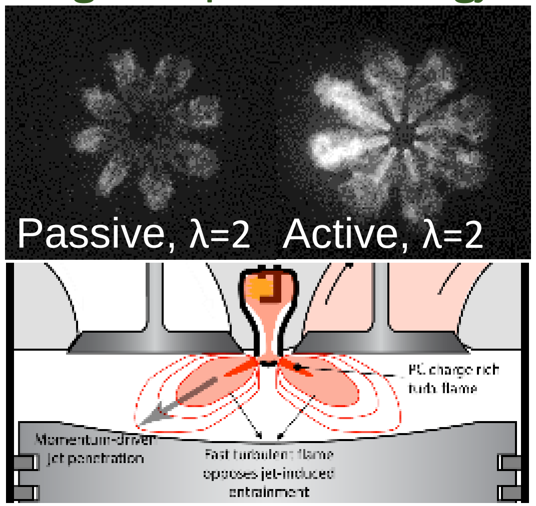
HD (2.34 L/cyl.) optical engine



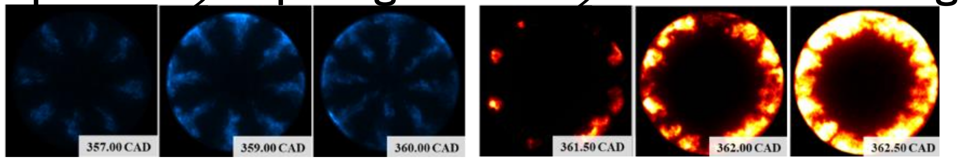
Swirl impact on H_2-DI mixture homogenization



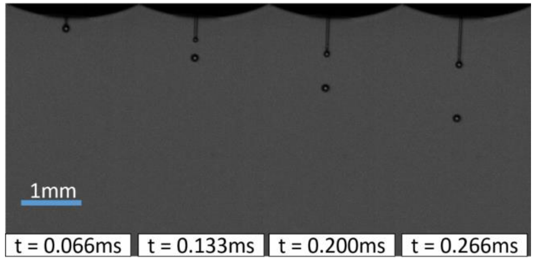
Active H_2 prechamber ignition phenomenology

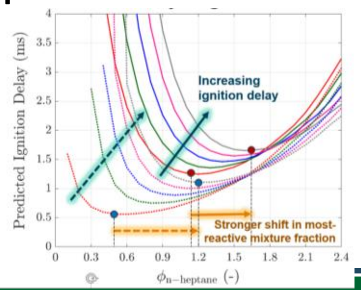


Impact of H_2 on pilot ignition in H_2-diesel dual-fuel eng.



Oil droplet injection pre-ignition experiments and kinetics





General approach

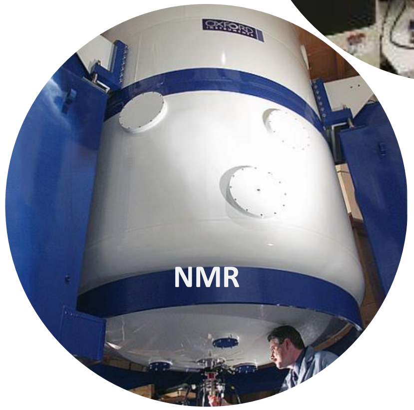
- Combine advanced imaging diagnostics in an optical heavy-duty engine with computer modeling to close the H2ICE knowledge gaps.
- Transfer fundamental understanding to industry through working group meetings, individual correspondence, and publications.

Detailed approach:

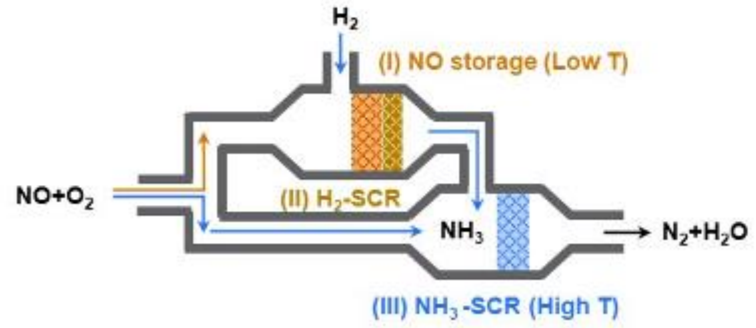
- Novel experimental framework and understanding of the underlying mechanisms behind oil-induced pre-ignition, future testing of oil additives for effective mitigation.
- Mixing tests to optimize in-cylinder mixture formation by improving the injector configuration in synergy with in-cylinder flow - swirl. Continuation of FY23 efforts in low swirl engine.
- Understand the combustion phenomenology of advanced pre-chamber ignition systems.

VTO H2ICE emissions R&D at PNNL

- Identify barriers to high NOx reduction efficiency that SCR catalysts will face in H2ICE exhaust.
- Clarify the detrimental impact of high H_2O content and H_2 slip on the performance and durability of current SCR catalysts.
- Develop approaches to retain high NOx reduction efficiency in H_2/diesel dual-fuel applications including up to 100% H_2.
- Facilitate partner OEMs in predicting SCR catalyst performance and meeting applicable on- & off-road emission standards in H2ICE deployments.
- Pursue novel & advanced SCR catalyst system approaches that capitalize on the opportunities that H_2-fueled applications present.



Advanced H_2-SCR concept



NO adsorption followed by hydrogenation on Ru_1/Ceria selectively produces N_2 & NH_3

THANK YOU

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