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

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Who We Are

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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%
What We Do Now

• 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

2021 U.S. GHG Emissions

- 50% Light Duty Vehicles
- 33% Transportation
- 25% Electric Power
- 22% Industry
- 11% Buildings
- 9% Agriculture
- 10% Off Road
- 2% Rail
- 4% Marine
- 9% Aviation
- 4% Other (Pipeline/Military/Lubricants)

Aviation and marine include emissions from international aviation and maritime transport. Fractions may not add up to 100% due to rounding.
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 H₂ – 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

- 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
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 H₂ will be pure, H2ICE can operate with mixtures of fuel if needed or when H₂ is not available.
- Can readily retrofit existing fleets, therefore, further accelerating decarbonization.
- 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 H₂ R&D at ANL

• **Objective**
  – Integrated computational and experimental research to assess rail/marine engine performance and emissions with high blends of LLCF including H₂

• **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, H₂, and blends with diesel
**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$_2$O 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.
THANK YOU

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