This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

SAND2022-3625C

Sustainable Diesel Fuels & Ducted Fuel Injection: A Path Forward for Heavy-Duty Engine Applications

Charles J. Mueller (cjmuell@sandia.gov), **Christopher W. Nilsen, Drummond E. Biles, Boni F. Yraguen, & Gustav Nyrenstedt**
Sandia National Laboratories, Livermore, California

Research supported by: ***U.S. Dept. of Energy, Vehicle Technologies Office***
Program managers: ***Kevin Stork, Michael Weismiller, & Gurpreet Singh***

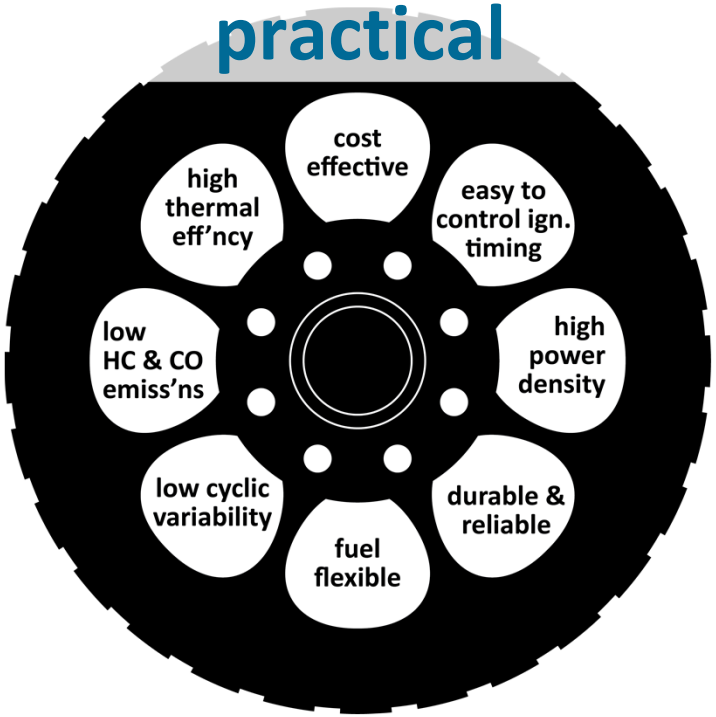
SAE WCX22 Panel Discussion:
Low Lifecycle Carbon Fuel Effects on Emissions & Aftertreatment
Room 330A, Huntington Place, Detroit, Michigan
April 5, 2022

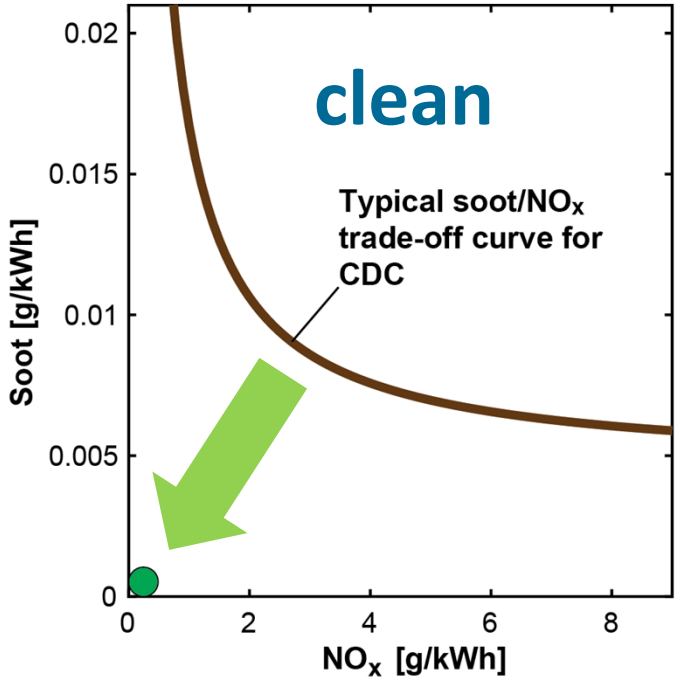
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

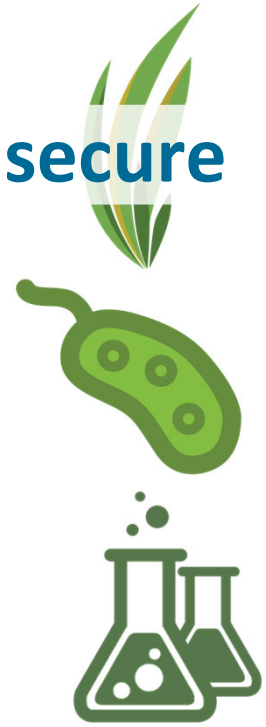
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Objective: Maintain all the desirable attributes of conventional diesel combustion (CDC)…

practical





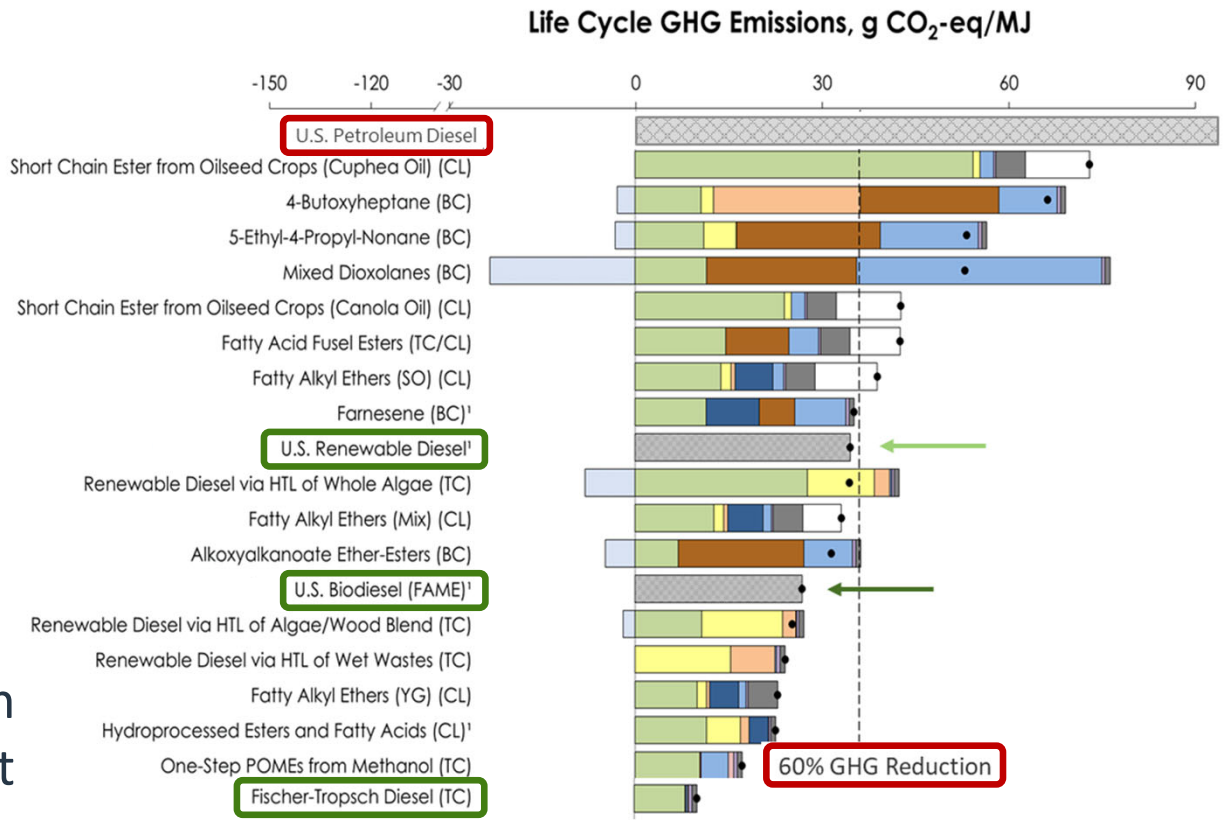


…with 10X – 100X lower soot & nitrogen oxides (NO_x) emissions

…while achieving net-zero carbon with home-grown fuels.

What are our best low-net-carbon fuel options in the diesel boiling range?

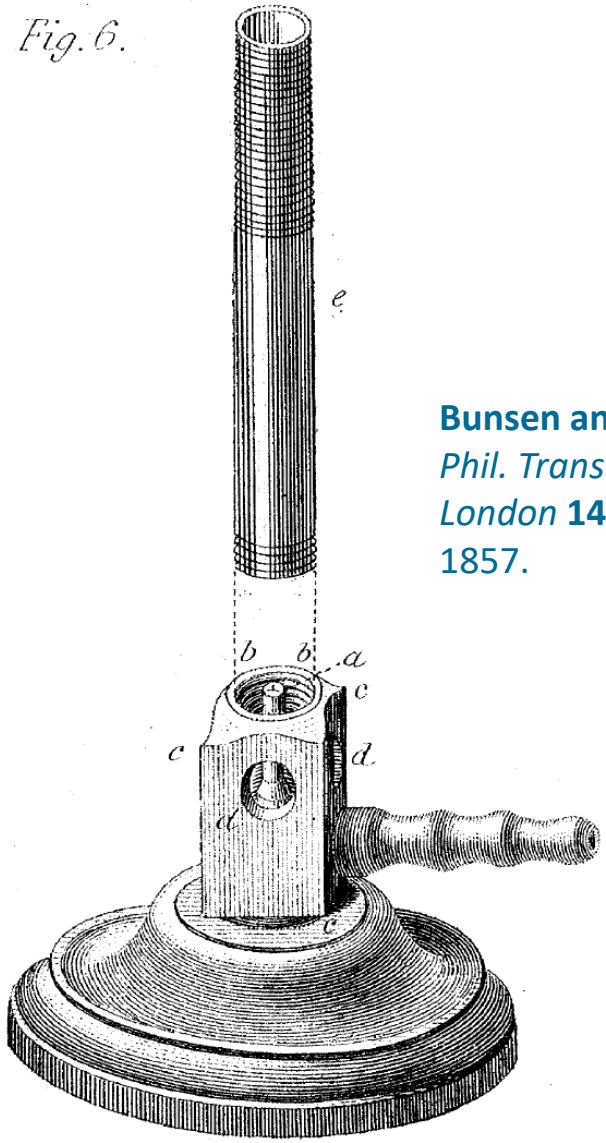
- **DOE-funded Co-Optimization of Fuels & Engines program addressed this**
- **Multiple blendstocks give >60% GHG reductions, e.g.:**
  - Renewable diesel
  - Biodiesel
  - Fischer-Tropsch diesel
- **But there's a problem**
  - None of these blendstocks can provide 10X – 100X lower soot & NO_x emissions



Gaspar et al., PNNL Report 31421 (2021).

What is ducted fuel injection (DFI)?

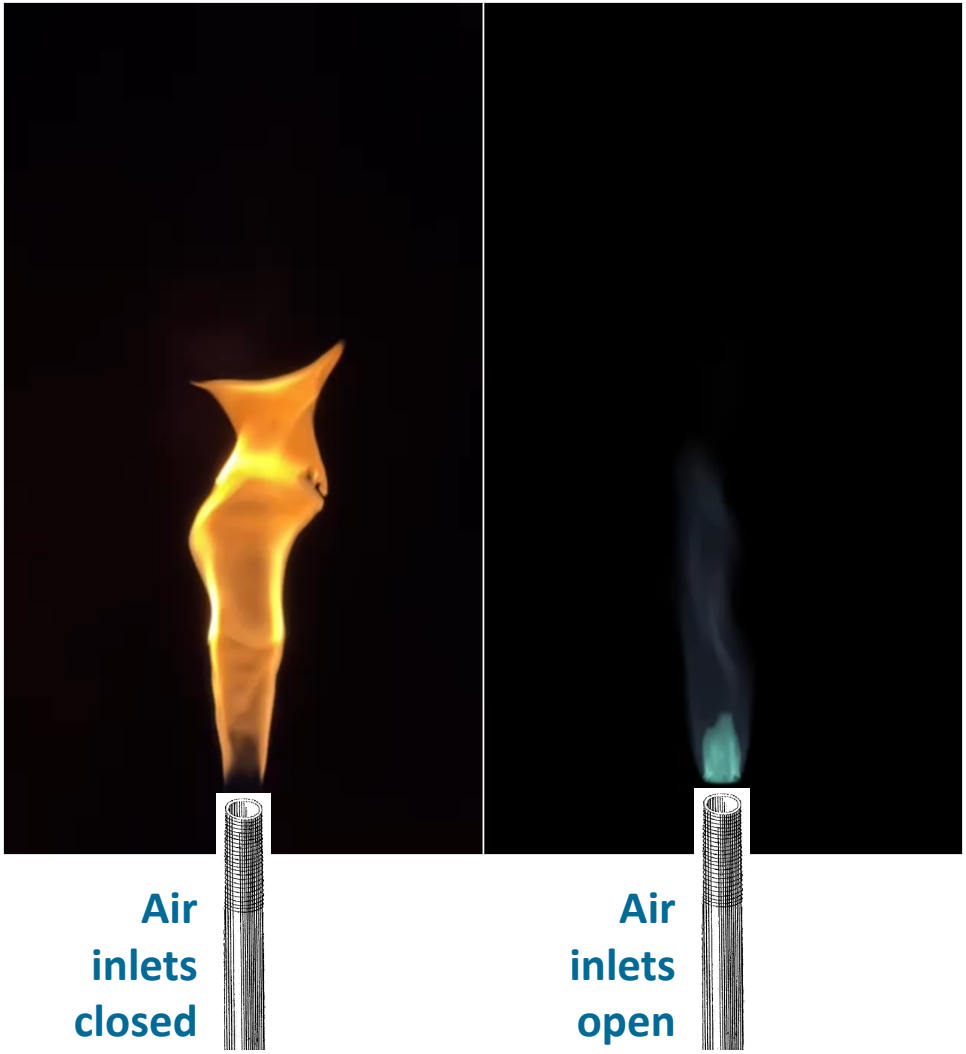
- **DFI is a simple, mechanical approach for improving diesel combustion**
  - Motivated by Bunsen burner concept



Bunsen and Roscoe, *Phil. Trans. Royal Soc. London* **147**:355-380, 1857.

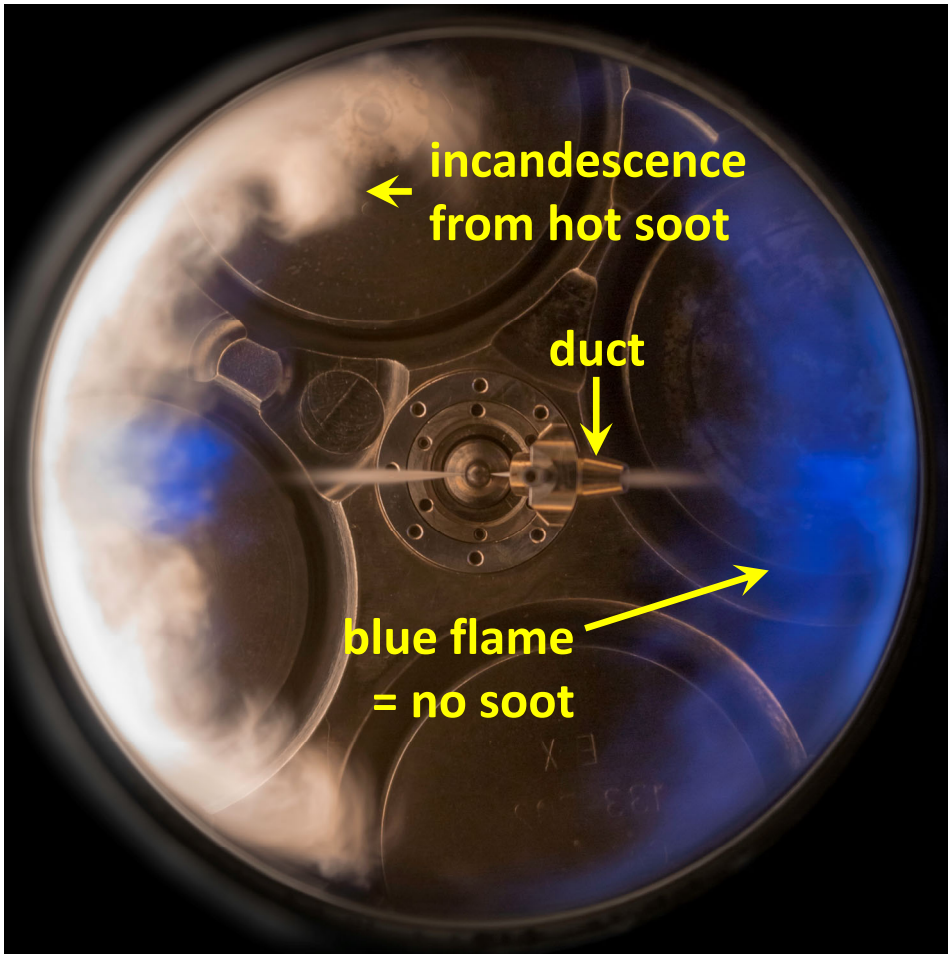
What is ducted fuel injection (DFI)?

- **DFI is a simple, mechanical approach for improving diesel combustion**
  - Motivated by Bunsen burner concept



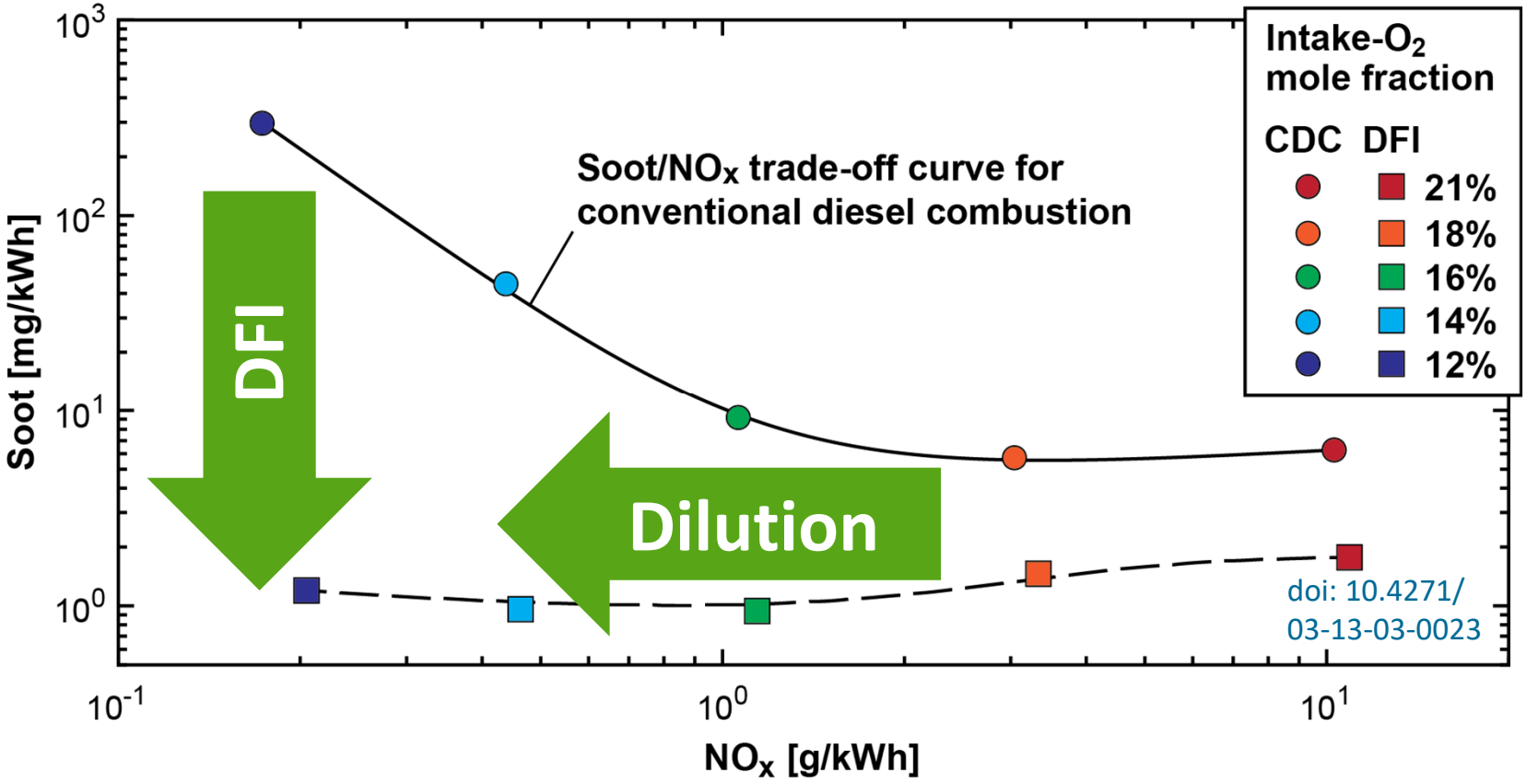
What is ducted fuel injection (DFI)?

- **DFI is a simple, mechanical approach for improving diesel combustion**
  - Motivated by Bunsen burner concept
- **Engine experiments have shown that DFI is effective at curtailing or even eliminating soot**



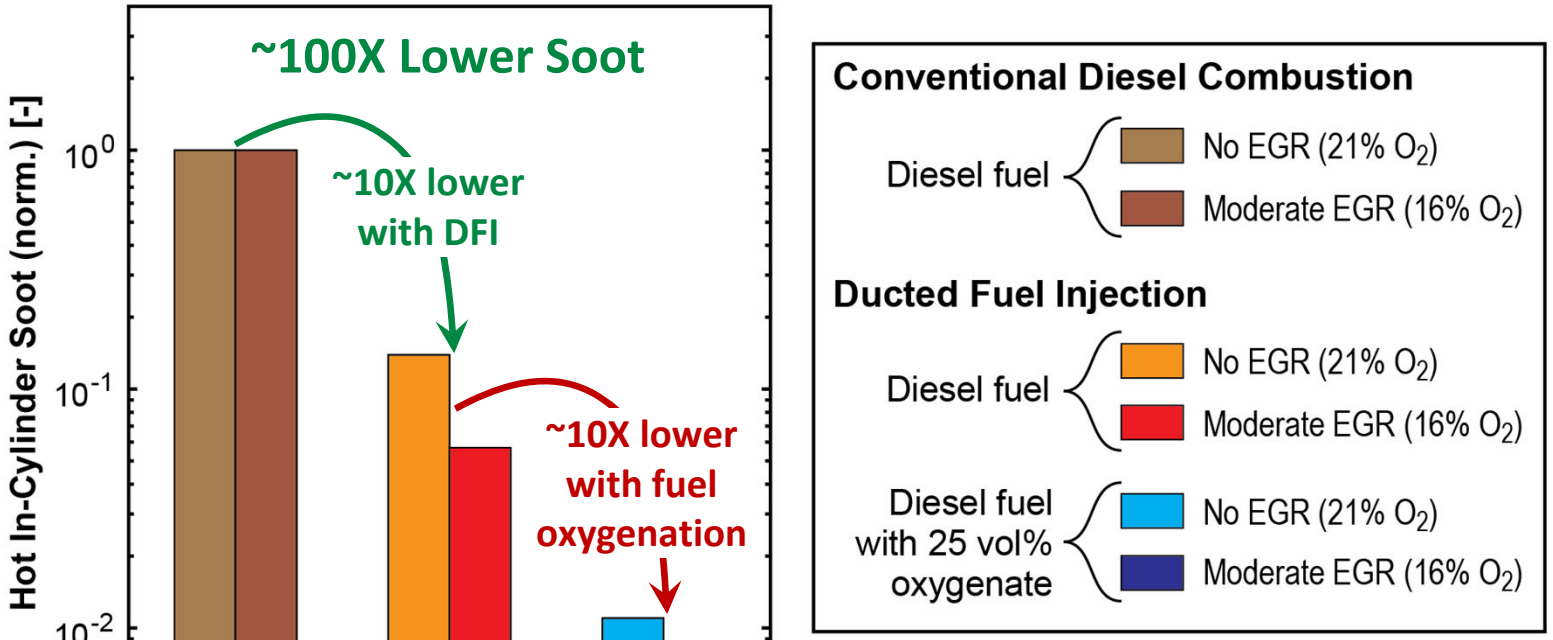
S. Ashley, https://www.scientificamerican.com/article/can-diesel-finally-come-clean/

With DFI, NO_x can be controlled via dilution without excessive soot, breaking the soot/NO_x trade-off.



*Optical-engine results for ~6.8 bar gross indicated mean effective pressure, 1200 rpm, steady state, 4-hole injector, No. 2 diesel fuel

In addition, DFI is synergistic with low-net-carbon, oxygenated & other renewable fuels.



doi: 10.1016/j.jaecs.2021.100024

*Optical-engine results for ~2.6 bar gross indicated mean effective pressure, 1200 rpm, steady state, 2-hole injector

Take-away message

Sustainable diesel fuels + ducted fuel injection provide a path to heavy-duty diesel engines with:

- at least 80% lower net-carbon emissions,
- at least 80% lower engine-out soot & NO_x emissions,
- no significant degradation in other emissions or efficiency relative to conventional diesel combustion,
- no massive investments in new infrastructure required,
- no widespread replacement of vehicles/machines required, &
- only a small change to engine hardware required.

Additional information on Sandia DFI research

1. Initial DFI proof-of-concept experiments in constant-volume combustion vessel (CVCV, one-duct configuration): https://doi.org/10.1016/j.apenergy.2017.07.001
2. Investigating duct geometric parameter and operating-condition effects in CVCV (one-duct configuration): https://doi.org/10.1016/j.apenergy.2018.05.078
3. First DFI experiments in an engine (two-duct config., diesel fuel): https://doi.org/10.4271/03-12-03-0021
4. YouTube video for R&D 100 Special Recognition Silver Medal in "Green Tech": https://youtu.be/1dijtRUZeLw
5. Article in Scientific American: https://www.scientificamerican.com/article/can-diesel-finally-come-clean/
6. Engine operating-parameter sweeps (four-duct config., diesel fuel): https://doi.org/10.4271/03-13-03-0023
7. Non-reacting Reynolds-Average Navier-Stokes modeling of DFI: https://doi.org/10.4271/03-13-05-0044
8. Engine experiments at higher-load and idle conditions (four-duct configuration, diesel fuel): https://doi.org/10.4271/03-14-01-0004
9. Particle number and mass emissions of DFI: https://doi.org/10.1177/14680874211010560
10. Oxygenated/sustainable fuel effects on DFI: https://doi.org/10.1016/j.jaecs.2021.100024
11. Injector orifice diameter, duct length, and duct diameter effects: https://doi.org/10.1016/j.jaecs.2021.100030