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Biodiesel + Ducted Fuel Injection → Cost-Effective Eco-Friendly Vehicles & Machines

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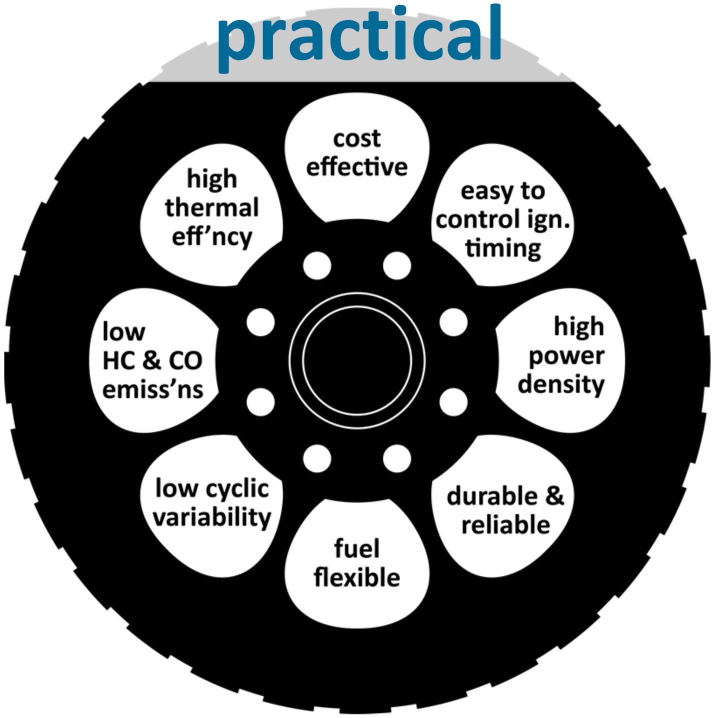
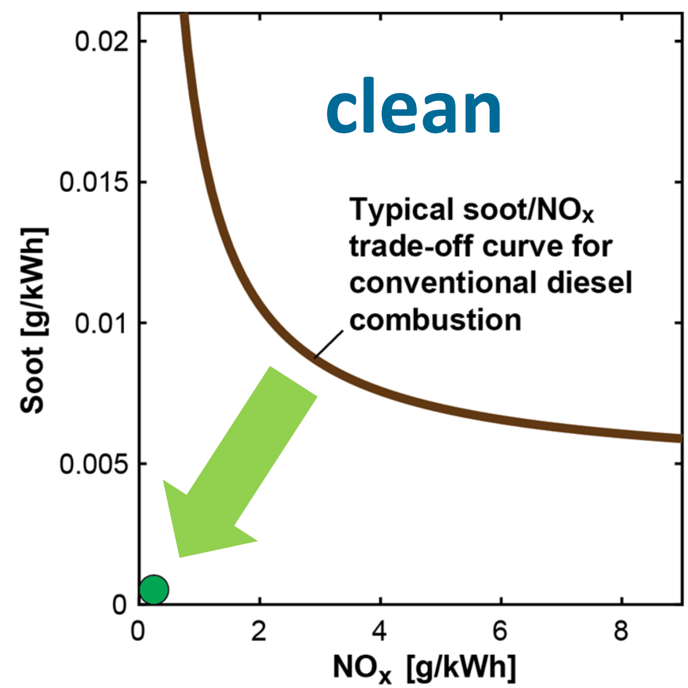
Objective: Maintain all the desirable attributes of conventional diesel combustion…



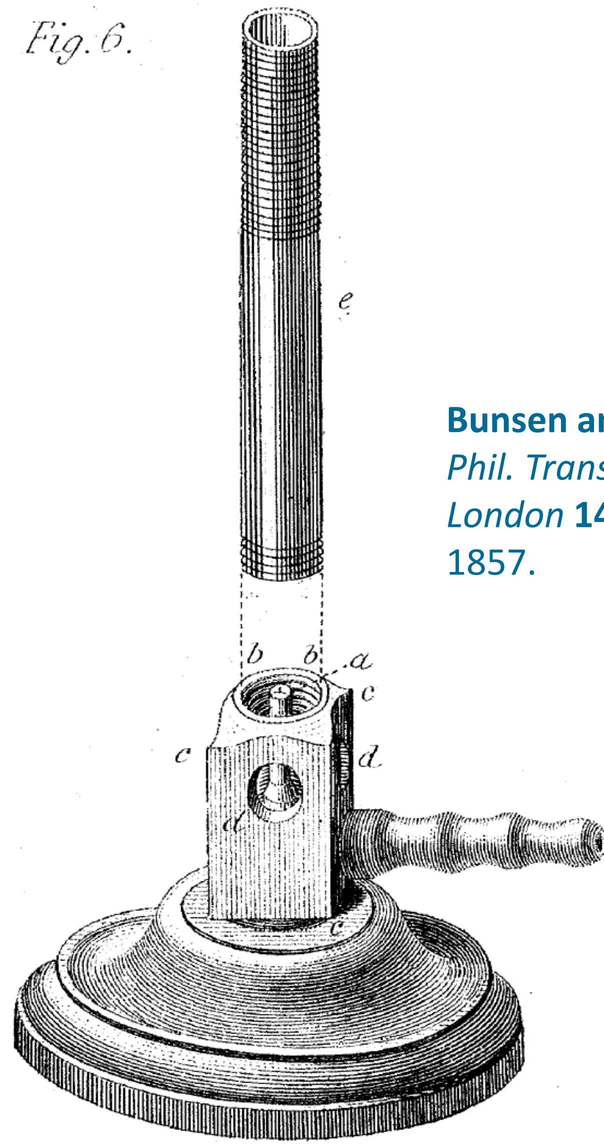


…while achieving net-zero carbon with home-grown fuels

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

What is ducted fuel injection (DFI)?

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

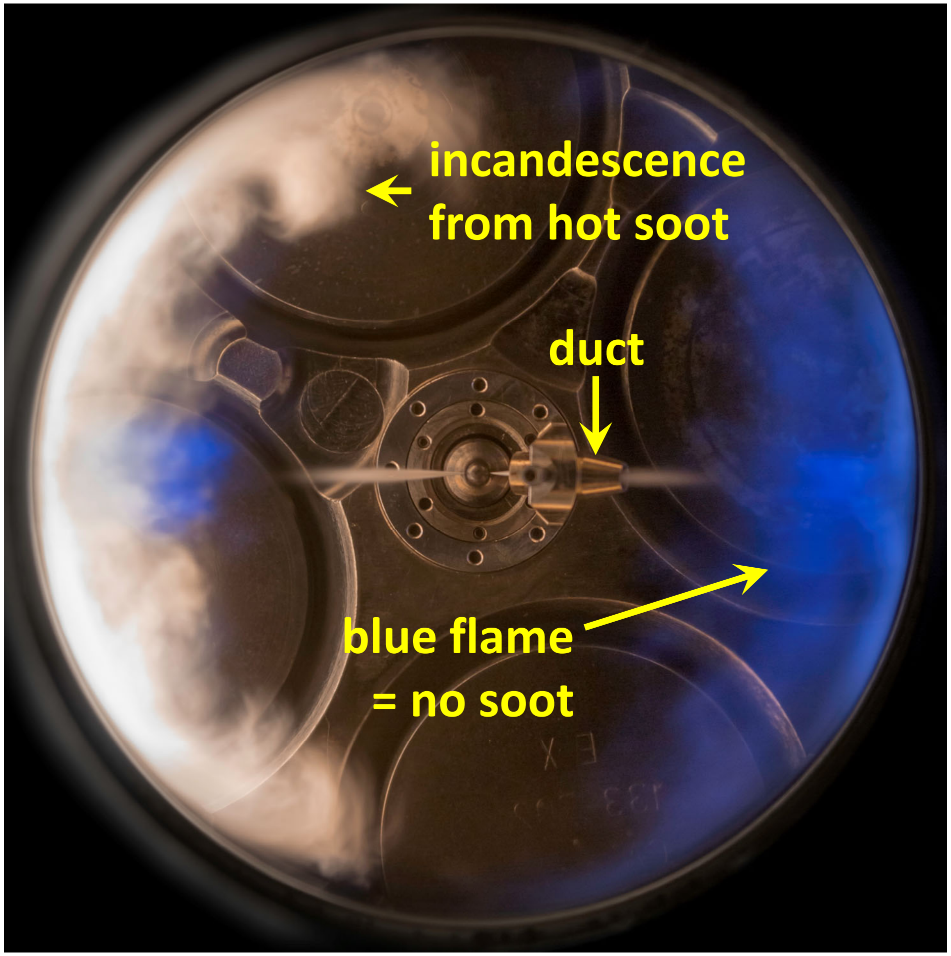


Bunsen and Roscoe, *Phil. Trans. Royal Soc. London* **147**:355-380, 1857.

What is ducted fuel injection (DFI)?

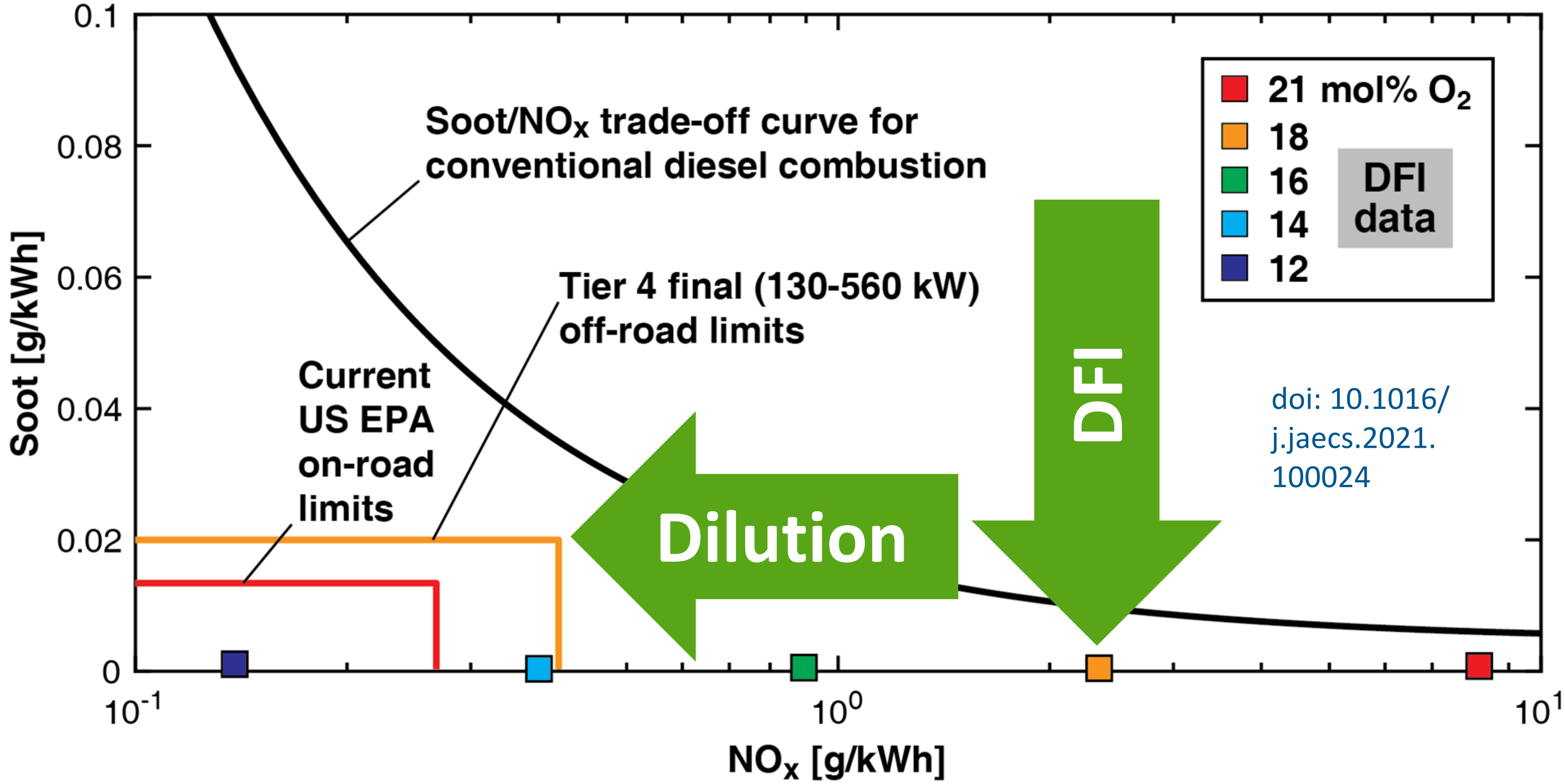
- **DFI is a simple, mechanical approach for improving diesel combustion**
  - Motivated by Bunsen burner concept
- **Engine experiments have shown that DFI is effective at curtailing or even eliminating soot**

Note: Foundational DFI patent assigned to National Technology & Engineering Solutions of Sandia, LLC. U.S. Patent No. 9,909,549.



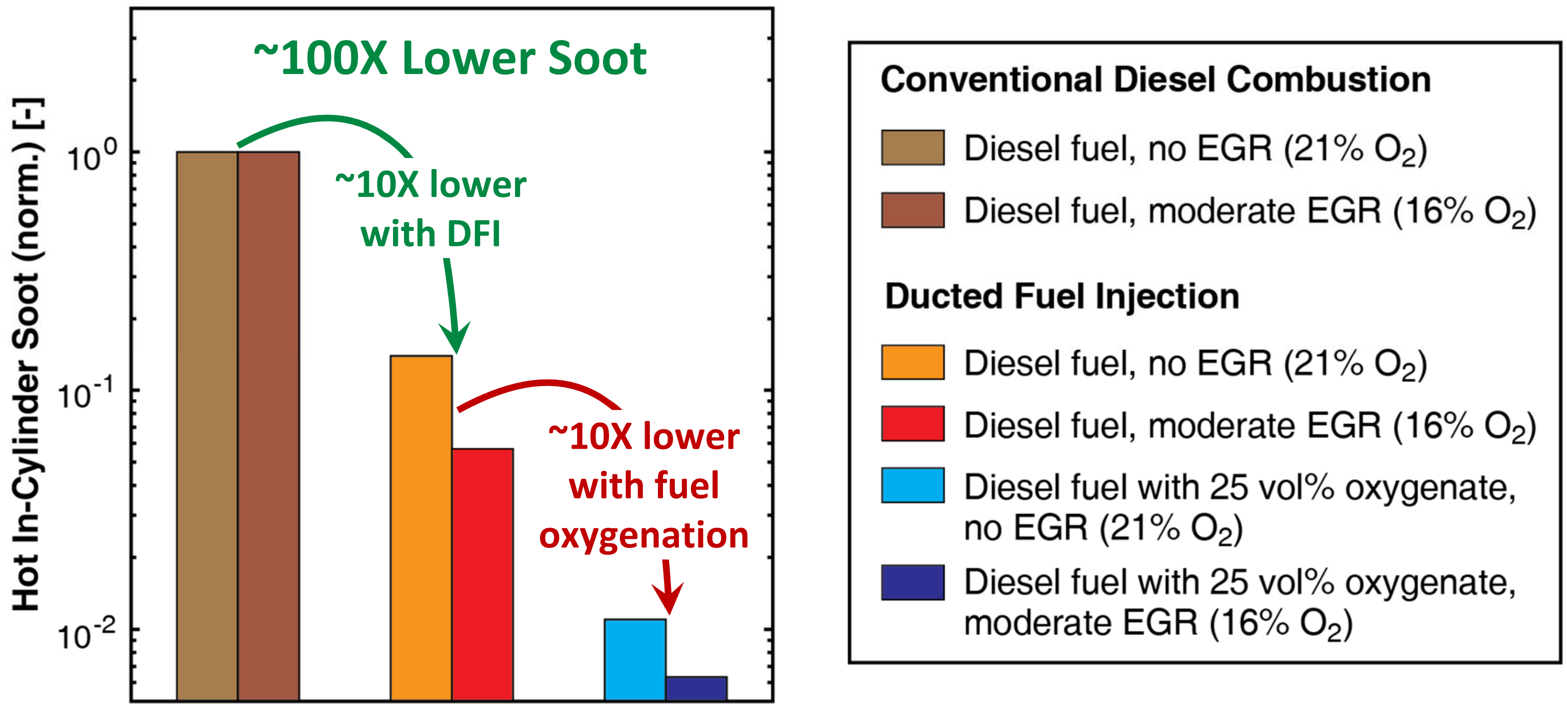
S. Ashley, https://www.scientificamerican.com/article/can-diesel-finally-come-clean/

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



*Optical-engine results for ~2.6 bar gross indicated mean effective pressure, 1200 rpm, steady state, 2-hole injector, No. 2 diesel fuel

In addition, DFI is synergistic with low-net-carbon, oxygenated fuels like biodiesel.



doi: 10.1016/j.jaecs.2021.100024

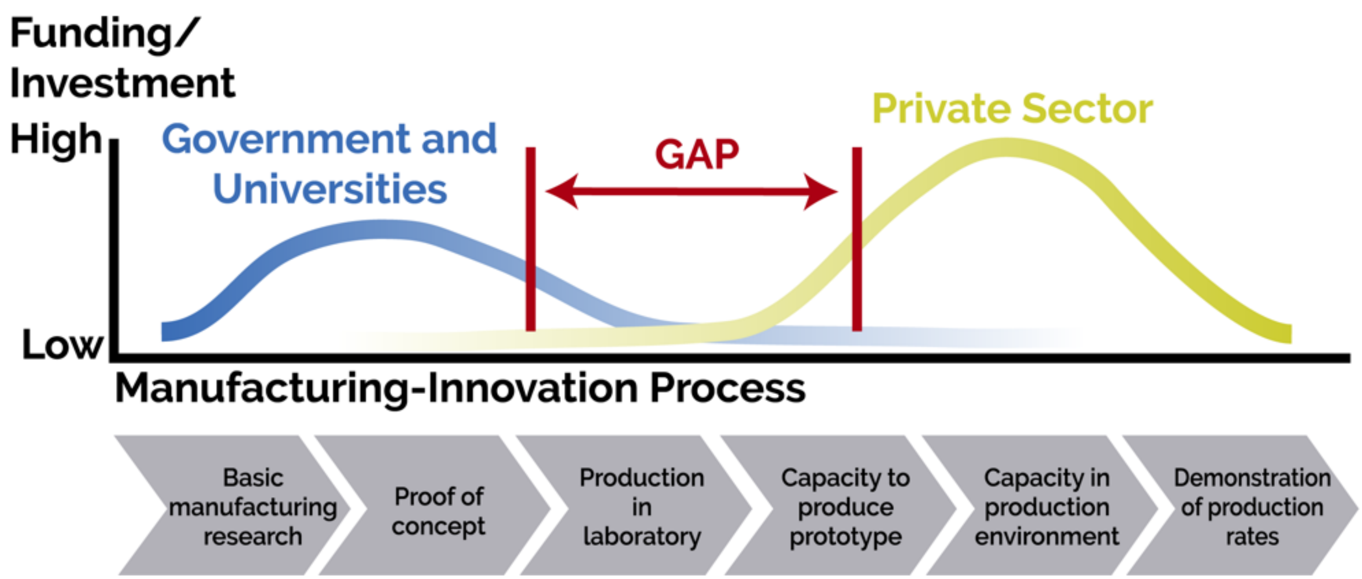
*Optical-engine results for ~2.6 bar gross indicated mean effective pressure, 1200 rpm, steady state, 2-hole injector

DFI Development Effort (DFIDE): Mission

Develop & deploy DFI to enable practical, clean, & sustainable engines & fuels for heavy-duty applications.

Scope of work

- Includes fundamental through applied tasks to bridge the “valley of death”
- Fundamental tasks are DOE-funded
- Applied tasks are industry-funded



Potential participants by sector

- **Engine, vehicle, & machine OEMs**
  - Agriculture, construction, forestry, marine, military, mining, power, pumping, rail, trucking
- **Energy companies & fuel suppliers**
- **Fuel-injection equipment OEMs**
- **Software companies**
- **Component suppliers: EGR, turbos, aftertreatment systems**
- **Armed services**
- **Academia**

DFIDE goals

1. Implement DFI in a multi-cylinder engine with production-viable hardware, showing an average of at least 80% lower engine-out soot & NO_x emissions without an efficiency penalty over a test cycle of interest vs. conventional diesel operation.

2. Demonstrate the potential to achieve the above goal while simultaneously reducing net-CO_2 emissions by at least 80% vs. petroleum diesel fuel.

3. Provide validated DFI modeling tools to DFIDE partners for in-house product-development efforts.

Key barriers to the commercialization of DFI

1. Unquantified sensitivity of DFI performance to operating/fuel parameters (e.g., full load, spray/duct misalignment, duct temperature, fuel ign. quality)
2. Unknown relationships for scaling DFI to engines of different sizes
3. Lack of validated computational tools for optimizing DFI for specific engines
4. Unknown requirements & methods for cost-effective duct fabrication
5. Paucity of analysis & data regarding duct durability
6. Lack of low-net-carbon fuels vetted for use with DFI
7. No multi-cylinder engine results with DFI & low-net-carbon fuels over legislated test cycles, including transient operation

Further elucidating barriers via participation in Energy I-Corps program

What could DFIDE enable?

- **Lower net-CO_2 emissions** due to biodiesel use
- **Lower engine-out PM** due to synergies between DFI & biodiesel
- **More cost-effective NO_x control** via higher EGR levels & hence lower DEF consumption
- **Lower capex and opex** due to possible removal of the DPF
- **Higher efficiency**
  - Due to lower backpressure: less soot & ash loading of DPF – *or no DPF!*
  - Fewer/no DPF regenerations
- **Longer oil-change intervals** due to lower in-cylinder soot levels
- **Domestic/local fuel production**

Next steps

- Sandia is collecting sponsors and funding for this work now. If interested, please let us know.
- Sandia will ideally identify all founding sponsors by December 2021.
- DFIDE kick-off meeting in January 2022.

Thank you for listening! What are your thoughts?

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
12. Co-Optima capstone webinar: (DFI overview begins at ~24:00): https://www.energy.gov/eere/bioenergy/how-can-fuels-and-combustion-reduce-pollutants-future-diesel-engines