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Status Update on Ducted Fuel Injection

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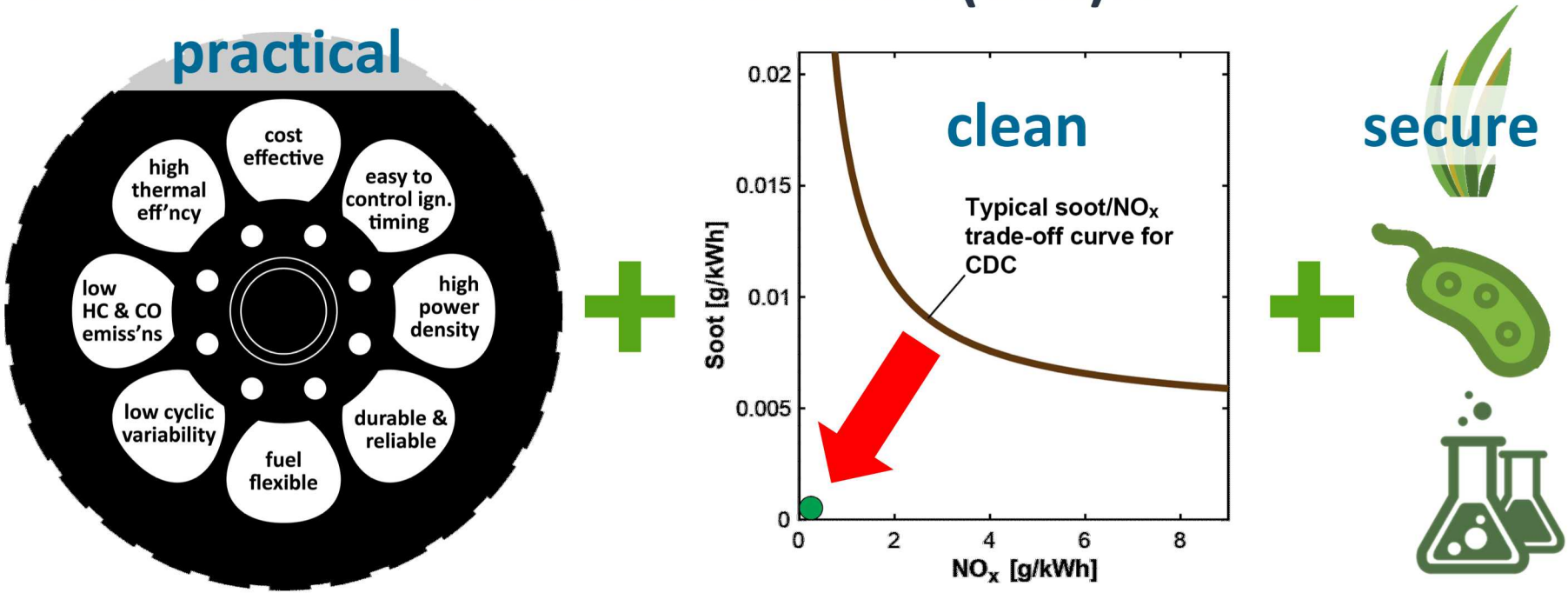
Objective: Maintain all the desirable attributes of conventional diesel combustion (CDC)…

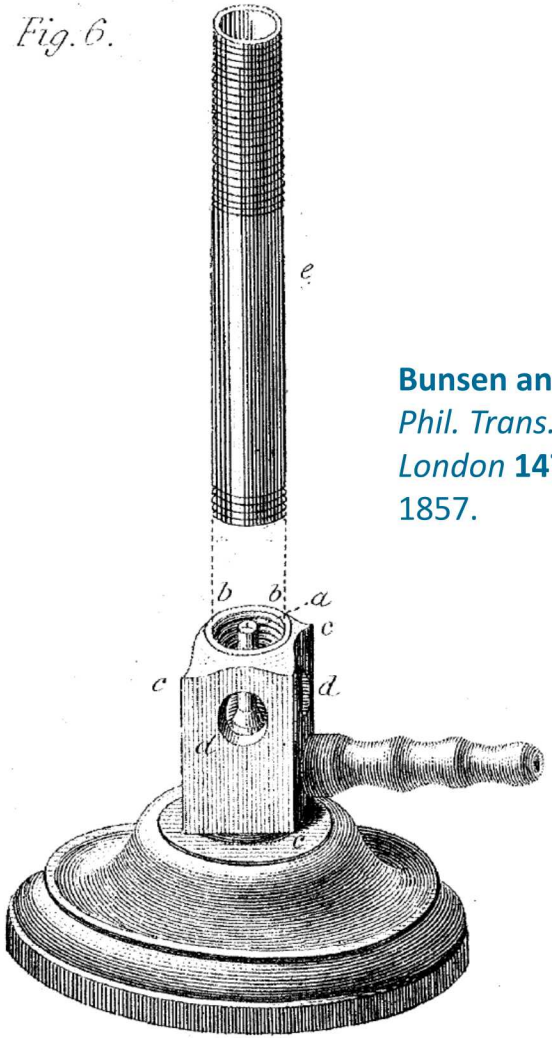


…with 10X – 100X lower soot & nitrogen oxides (NO_x) emissions

…while harnessing synergies with sustainable, home-grown fuels.

Ducted fuel injection (DFI) shows promise for achieving this vision.

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

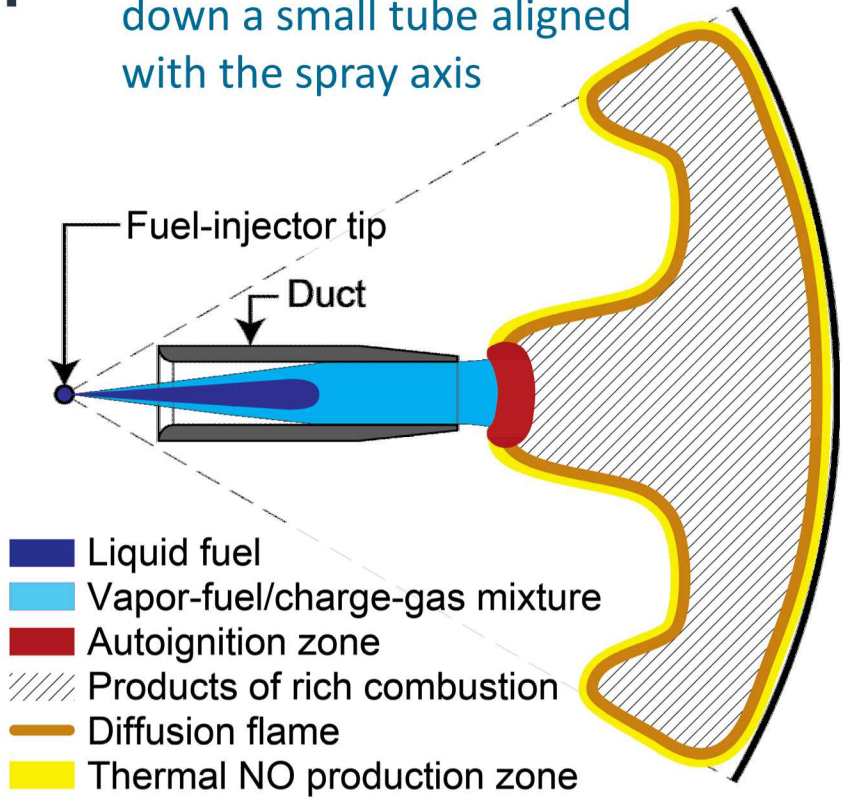


Bunsen and Roscoe, *Phil. Trans. Royal Soc. London* **147**:355-380, 1857.

Ducted fuel injection (DFI) shows promise for achieving this vision

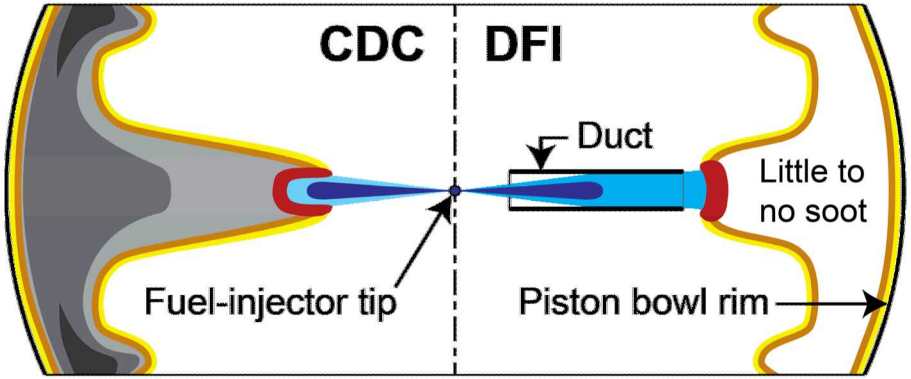
- **DFI is a simple, mechanical approach for improving diesel combustion**
  - Motivated by Bunsen burner concept
  - A refinement of CDC → behaves similarly
- **Recent engine exp'ts have shown DFI:**
  1. Is effective at curtailing/eliminating soot
  2. Can break the soot/NO_x trade-off with dilution
  3. Is synergistic with dilution for emis'ns & effic'cy
  4. Is both compatible with current diesel fuel & synergistic with oxygenated sustainable fuels
  5. Is easy to control
  6. Performs well across a range of loads
  7. Outperforms CDC under cold-start conditions

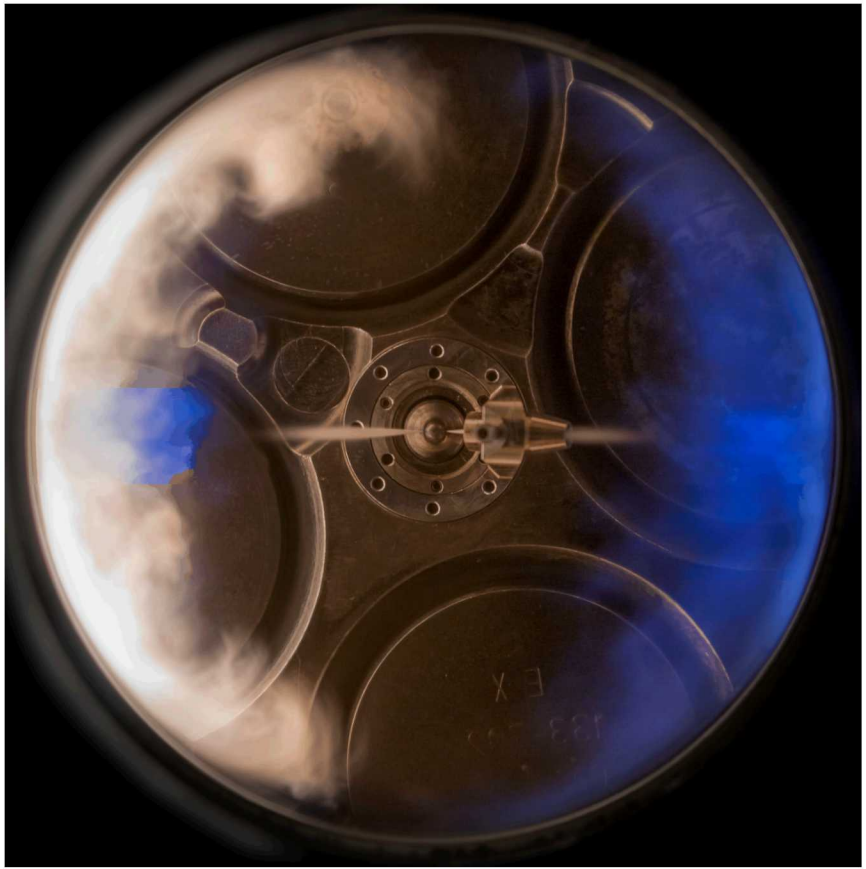
Basic idea: inject the fuel spray down a small tube aligned with the spray axis



Mueller et al., doi:10.1016/j.apenergy.2017.07.001

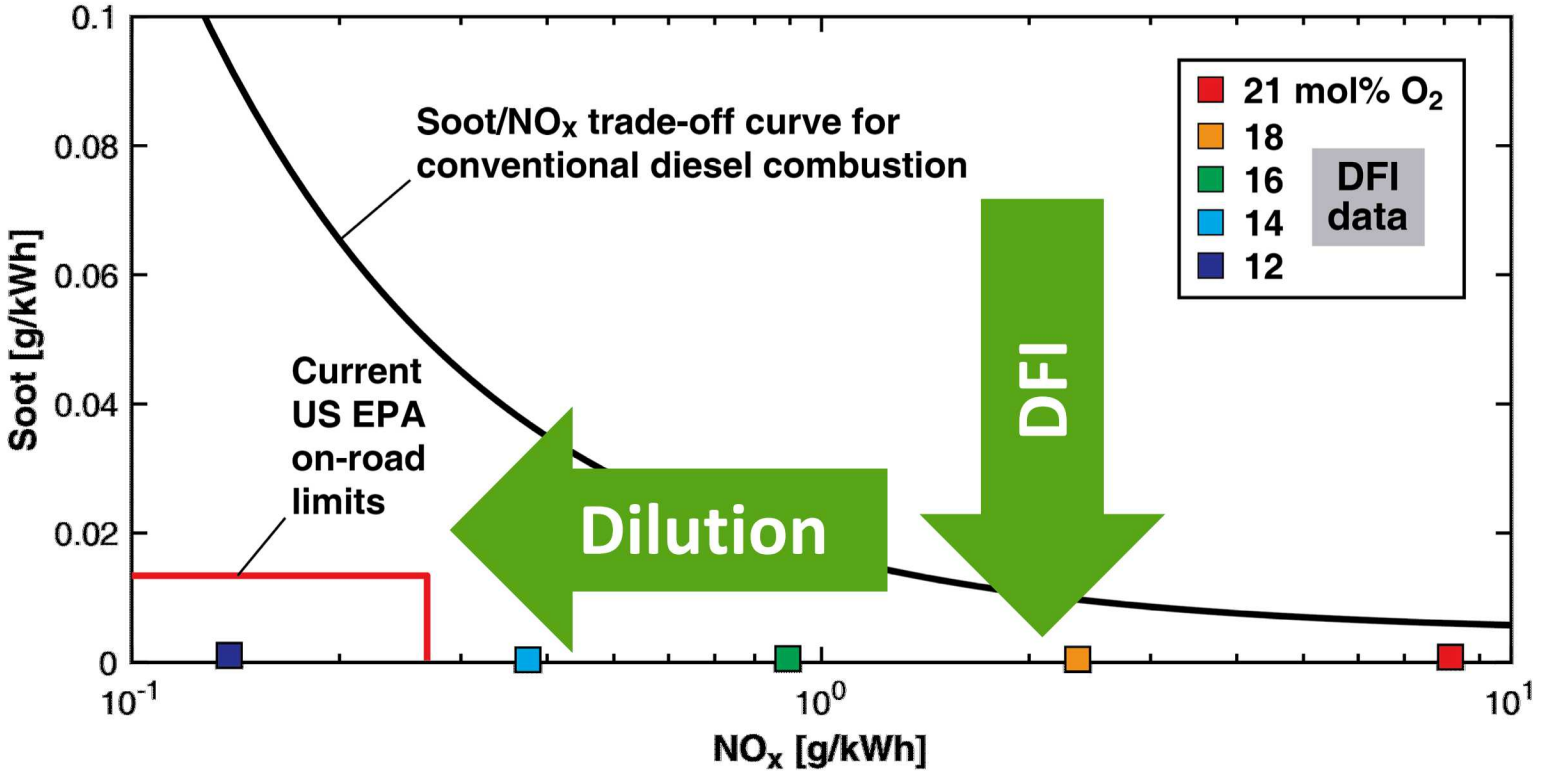
1. DFI dramatically curtails soot production in engine experiments.





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

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



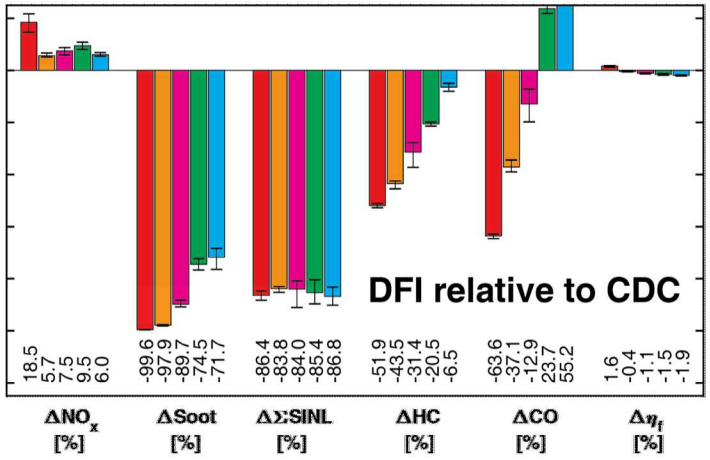
3. DFI is synergistic with dilution.

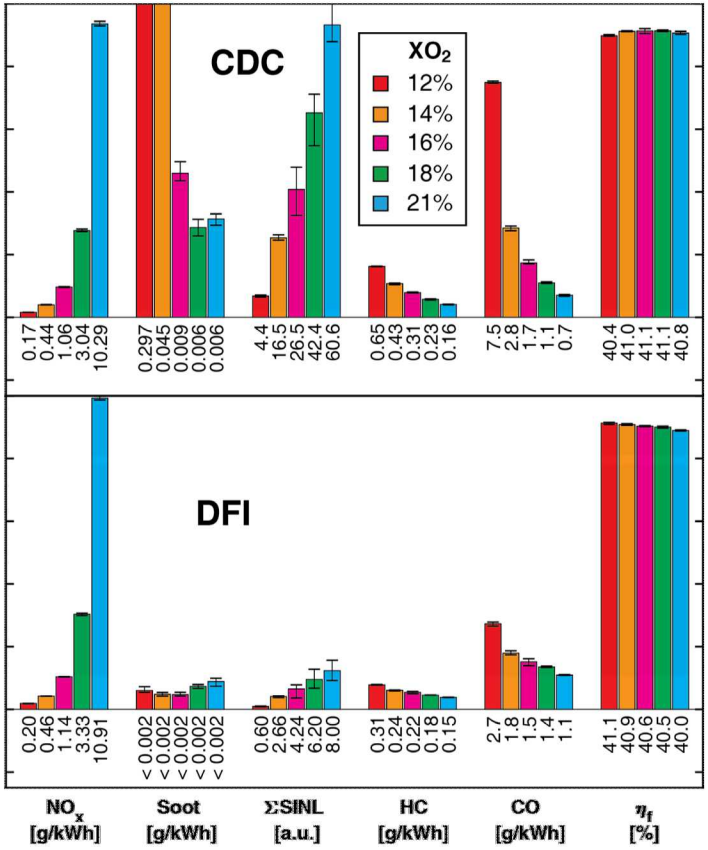
- **DFI shows generally lower emissions & higher efficiencies vs. CDC as dilution ↑. DFI has:**
  - Lower soot, HC, & CO emiss. at const. $XO_2 \leq 16\%$
  - Lower NO_x at minimum feasible XO_2 level
  - Higher fuel-conversion efficiency as XO_2 level ↓

XO_2 = intake-oxygen mole fraction

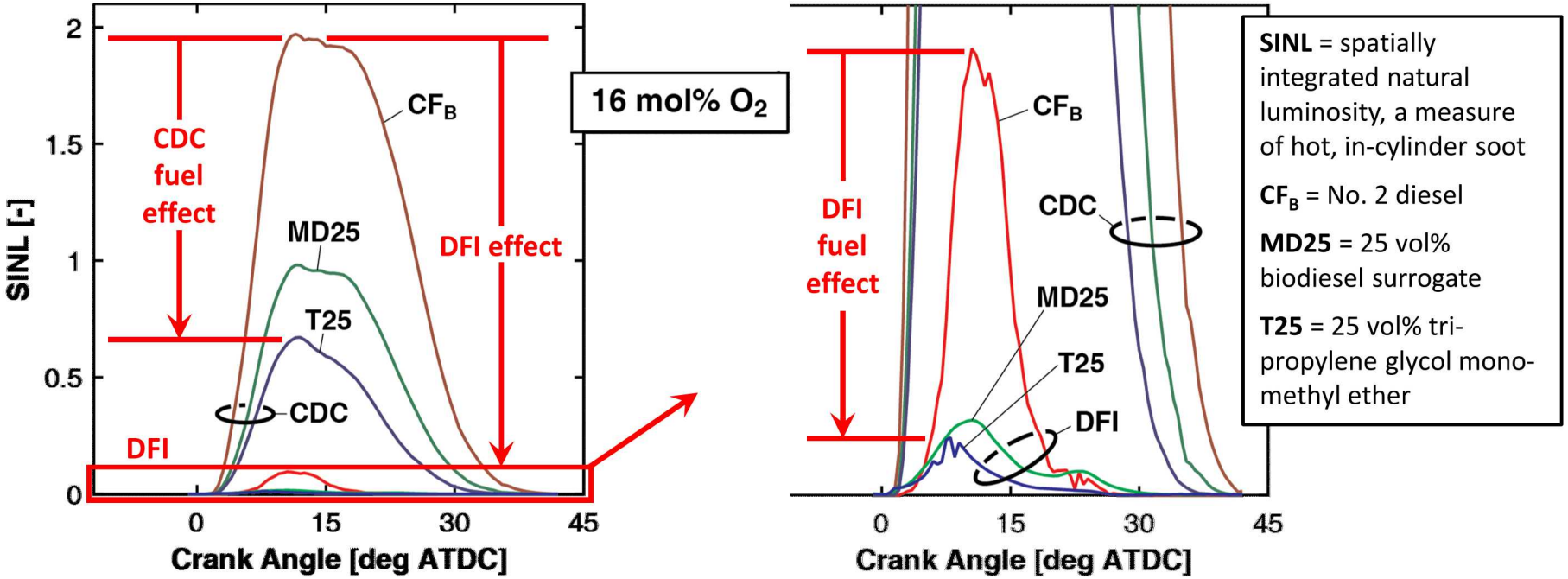
η_f = fuel-conversion efficiency

Four-duct config.,
1200 rpm,
~6.7 bar $IMEP_g$



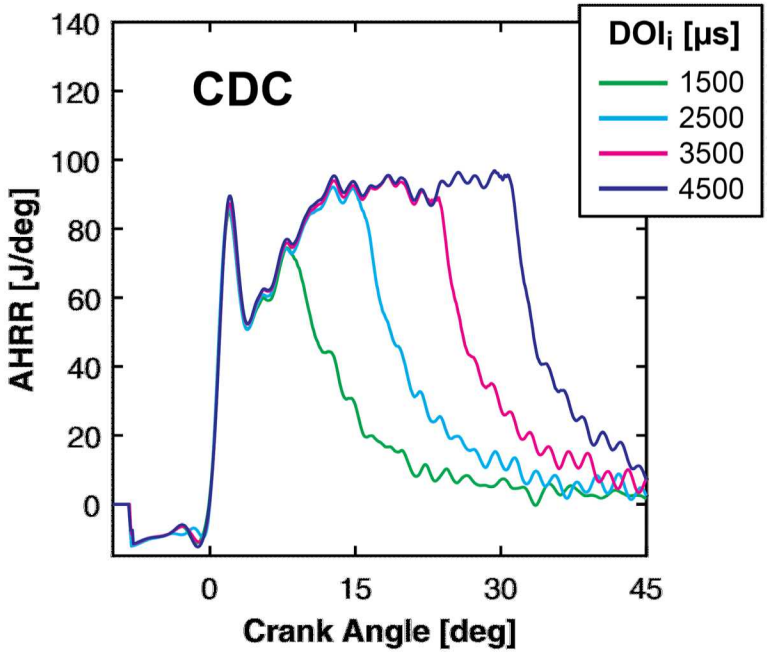


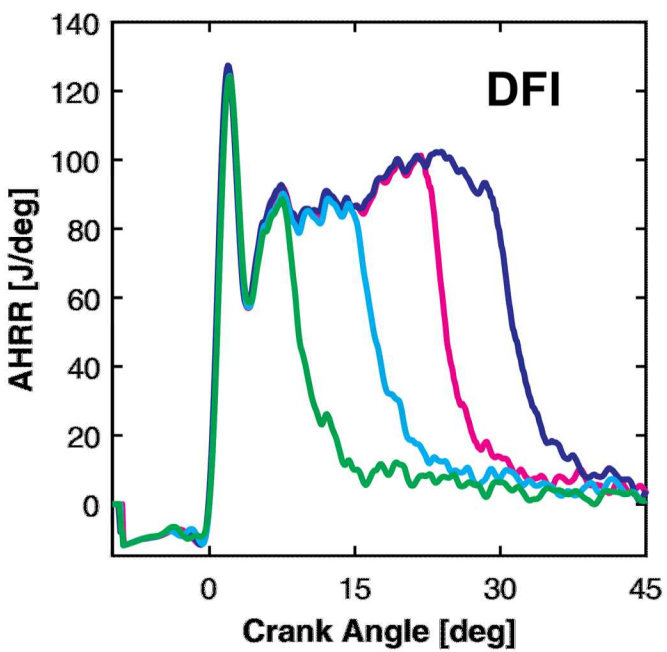
4. DFI is synergistic with oxygenated renewable fuels, lowering SINL by another 10X relative to petro-diesel.



- Changing from CDC to DFI lowers SINL more than adding 25 vol% of either oxy.
- Fuel effect is larger for DFI than for CDC (on a percentage basis)

5. DFI is easy to control; its heat release is similar to CDC.





DOI$_i$ = indicated (i.e., commanded) duration of inj'n

Four-duct config., 1200 rpm, 2.4 - 8.7 bar IMEP$_g$

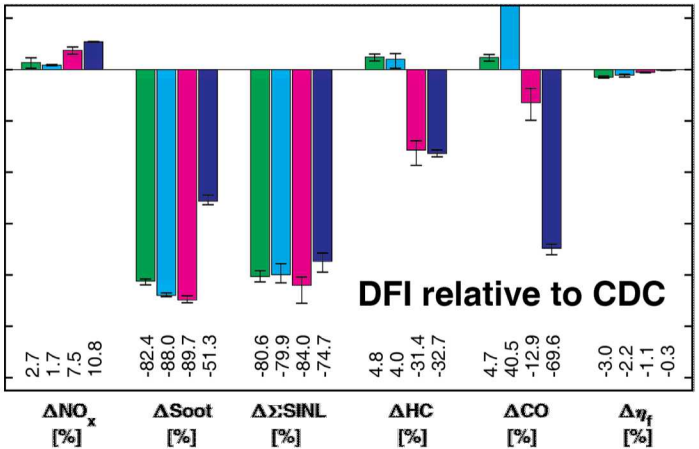
IMEP$_g$ = gross indicated mean effective pressure

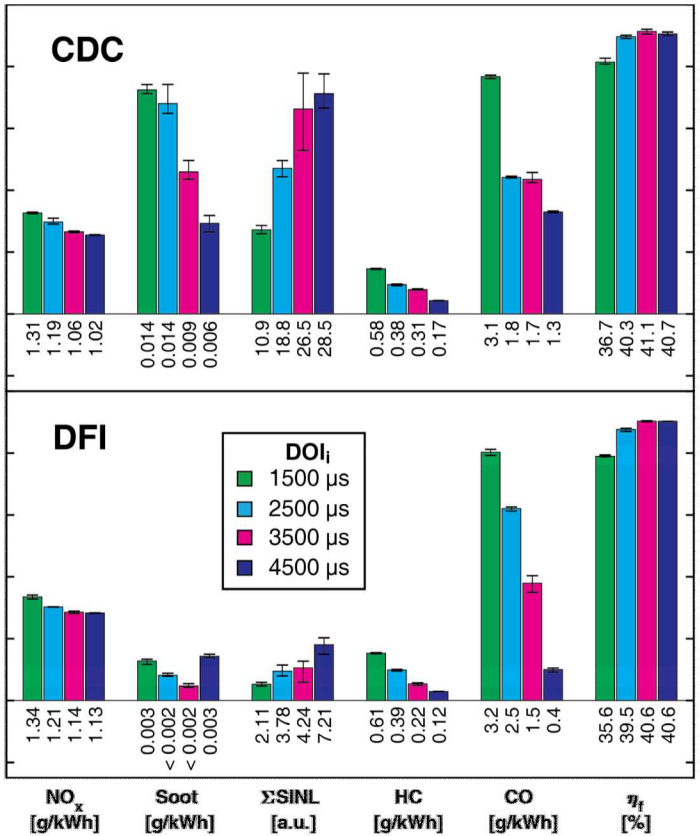
- Ignition timing & load are easily controlled by changing injection timing
- DFI has larger premixed burns & shorter combustion durations than CDC

6. DFI performs well across a range of loads.

- Soot is 50 - 90% ↓ for DFI across the sweep
- NO_x is 2 - 11% ↑ & η_f is 0.3 – 3.0% ↓ for DFI
  - Both can be improved via dilution
- HC & CO are lower for DFI when DOI_i is longer
- DFI performance generally ↑ with longer DOI_i

Four-duct config.,
1200 rpm,
2.4 - 8.7 bar $IMEP_g$,
16% XO_2

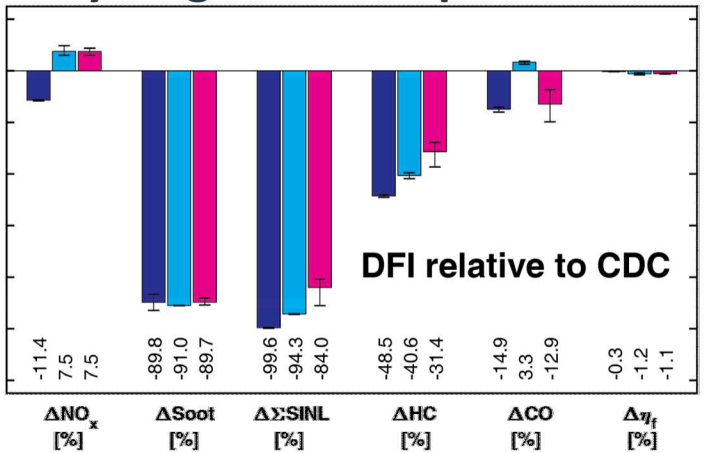


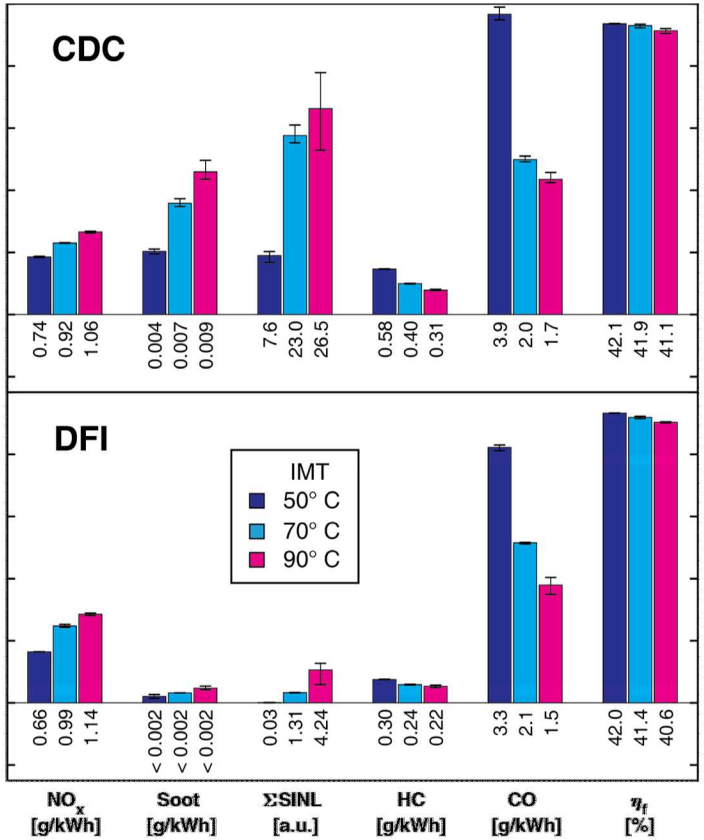


7. DFI outperforms CDC at simulated cold-start cond's.

- **Emissions & efficiency. DFI has:**
  - Lower soot, HC, & lower/similar CO
  - Lower NO_x at min. intake-manifold temp. (IMT)
  - Similar η_f vs. CDC
- **DFI should work well for cold-starts & at cond's below catalyst light-off temp.**

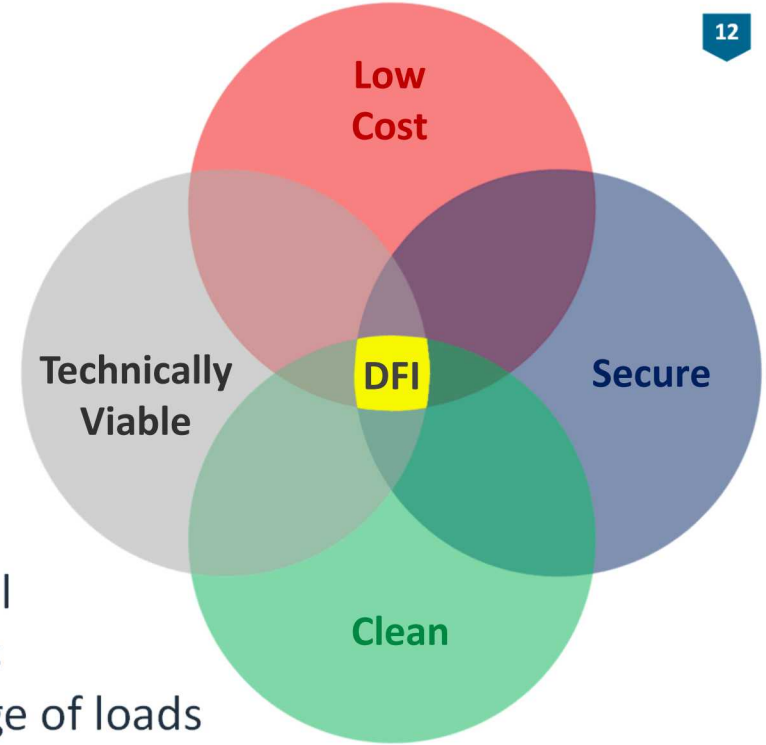
Four-duct config.,
1200 rpm
6.7 – 7.0 bar $IMEP_g$
16% XO_2





Summary & conclusion

- **Ducted fuel injection (DFI):**
  - Is conceptually simple
  - Is effective at curtailing/eliminating soot
  - Can break the soot/NO_x trade-off with dilution
  - Emissions & efficiency improve with dilution
  - Is fully compatible with conventional diesel fuel
  - Is synergistic with oxygenated sustainable fuels
  - Is easy to control & performs well across a range of loads
  - Outperforms CDC under cold-start conditions



DFI with oxygenated, sustainable fuels provides a promising potential path to practical, clean, and sustainable vehicles and machines for the future.

Additional information on Sandia DFI research

- 1st paper in *Applied Energy*: https://www.sciencedirect.com/science/article/pii/S0306261917308644
- 2nd paper in *Applied Energy*: https://www.sciencedirect.com/science/article/pii/S0306261918307888
- 1st results from DFI engine experiments (two-duct configuration): https://saemobilus.sae.org/content/03-12-03-0021/
- YouTube video for R&D 100 Special Recognition Silver Medal in "Green Tech": https://youtu.be/1dijtRUZeLw
- *Scientific American* article: https://www.scientificamerican.com/article/can-diesel-finally-come-clean/
- Results from most-recent DFI engine experiments (four-duct configuration): https://saemobilus.sae.org/content/03-13-03-0023/