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In-Cylinder Optical Imaging for Combustion Research in Natural Gas Engines

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Program Manager: Kevin Stork

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Combustion Research Facility of Sandia National Laboratories in Livermore, CA

Mission: Provide the combustion and emission science-base needed by industry to develop high-efficiency, clean engines for future fuels.

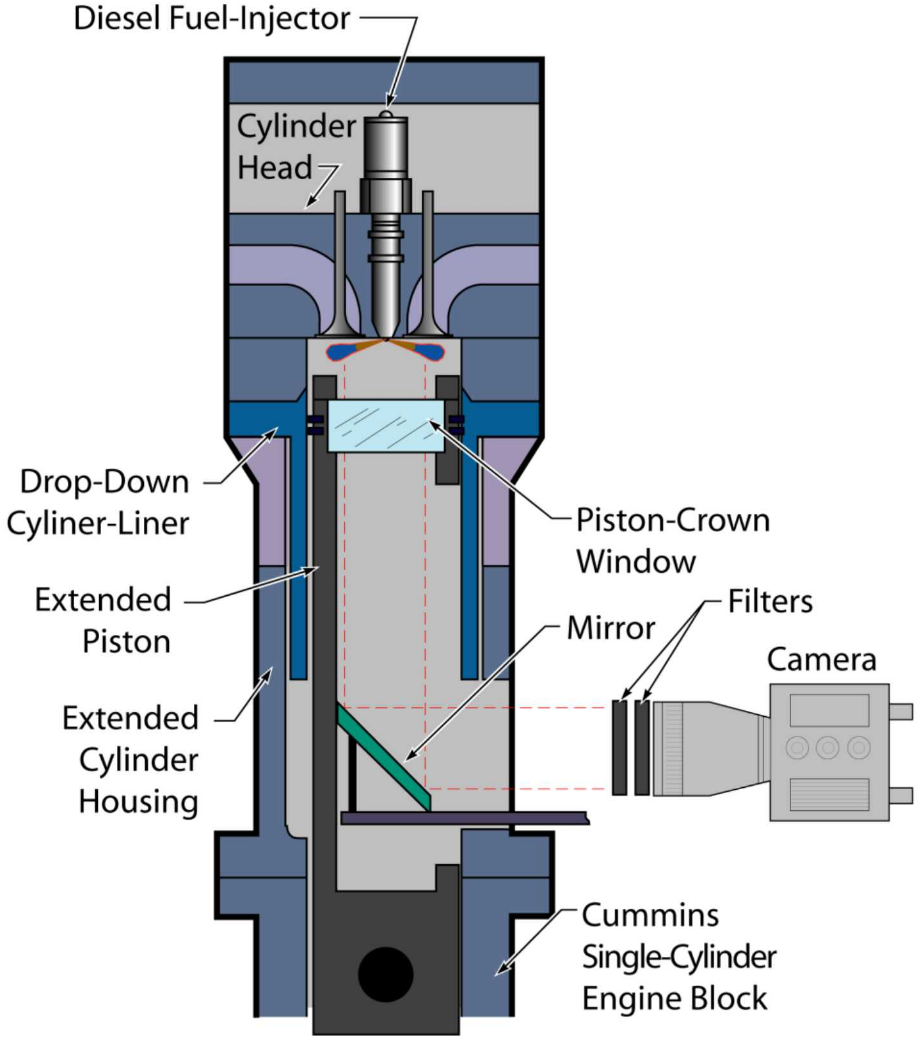
Sponsor: DOE Office of Vehicle Technologies

- Facility built in 1980
- 100 full-time employees
- 100 visitors per year
  - Post-docs
  - University faculty
  - Undergraduate interns
  - Graduate students
  - Industrial collaborators

Visitors bring technical knowledge and skills. The CRF provides access to facility equipment, resources, and a knowledge base of combustion

crf.sandia.gov or Google "Combustion Research Facility"

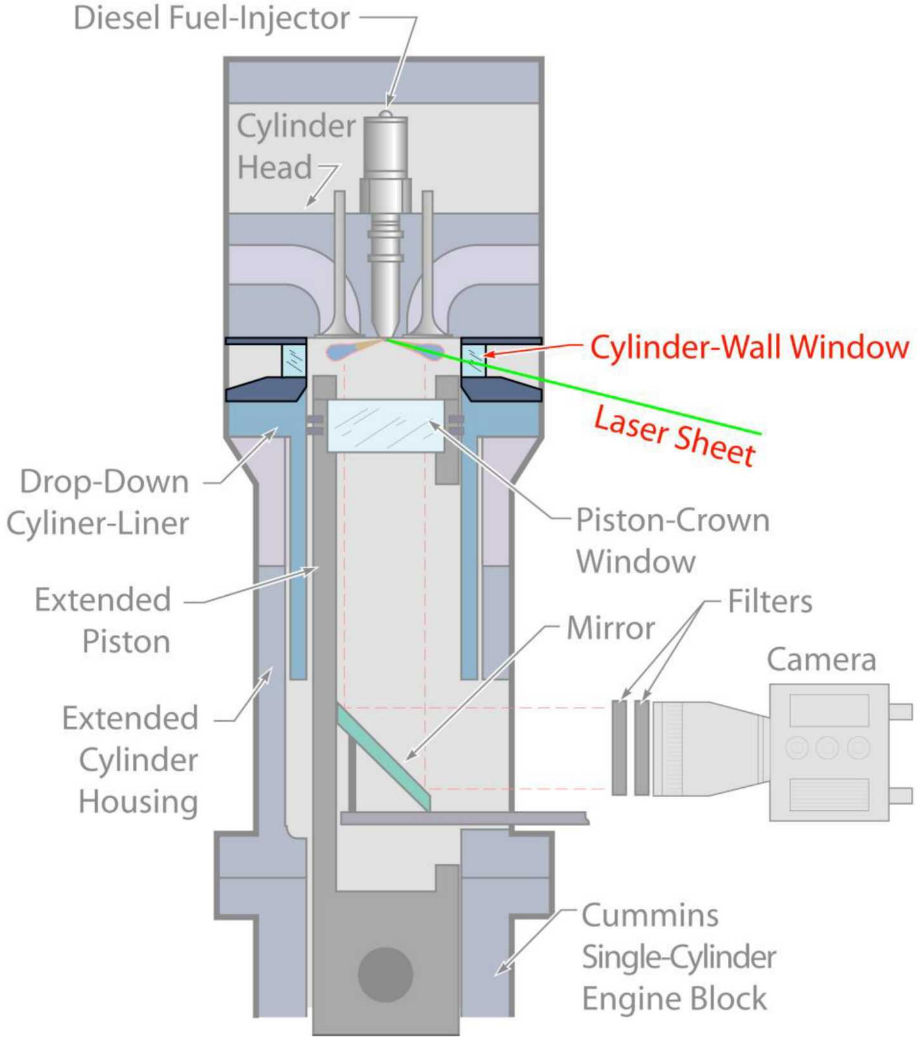
Heavy-duty diesel engine modified for optical imaging of in-cylinder combustion

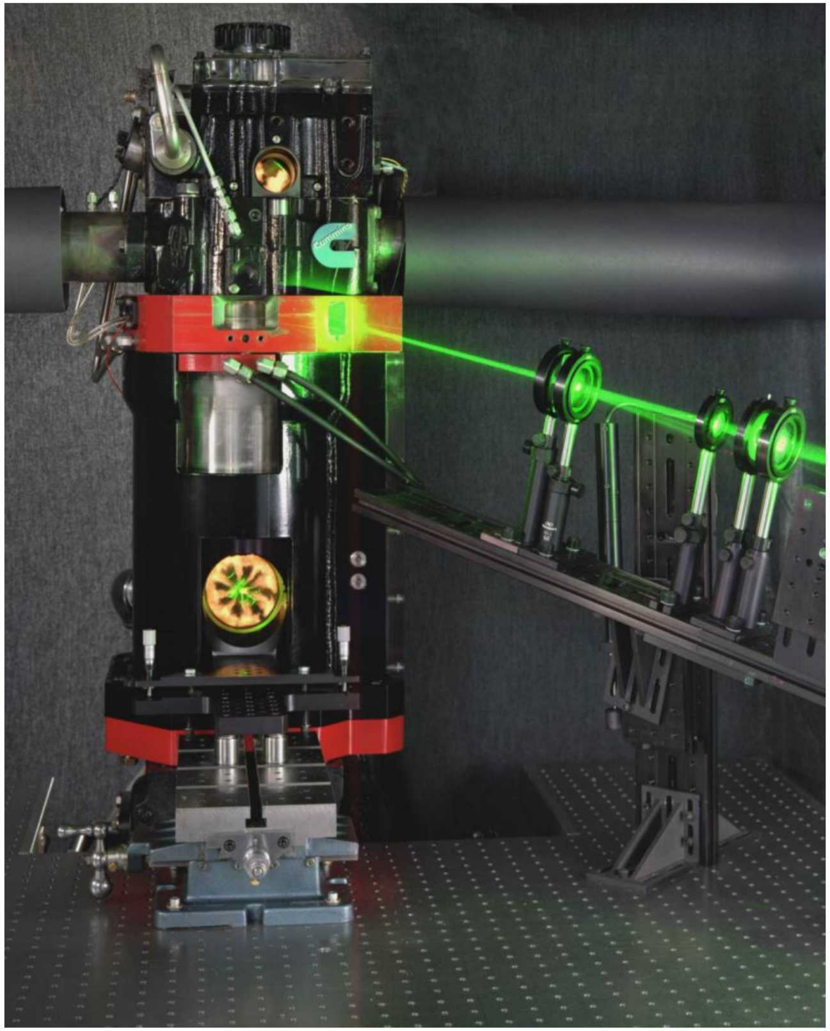


<u>Conventional Diesel Combustion</u>

- Natural luminosity imaging
  - Hot soot glows bright yellow
  - Also reflects off liquid fuel sprays in center of images

Optical engine also equipped with cylinder-wall windows to transmit laser beams into cylinder

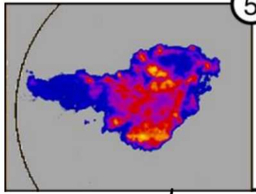




Multiple optical/laser diagnostics characterize and quantify in-cylinder processes of diesel combustion

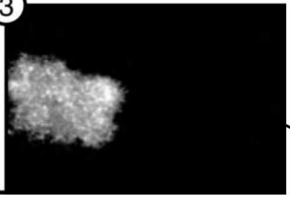
O_2 = 21% (no EGR)
SOI = 10 BTDC
P_{inj} = 1000 Bar

4 PAH PLIF: Soot Precursors
As hot ignition reactions increase the temperature in the jet, fuel fragments are formed into chemical building blocks for soot.

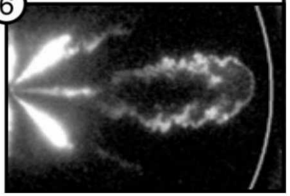


5 LII: Soot Concentration
Shortly after the premixed fuel burns, soot is formed in the hot, fuel-rich region throughout the jet cross-section.

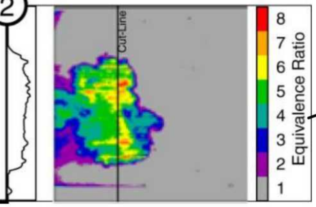
3 Chemiluminescence: Ignition
Spontaneous ignition reactions occur in the hot mixture of fuel and air throughout the leading portions of the jet.

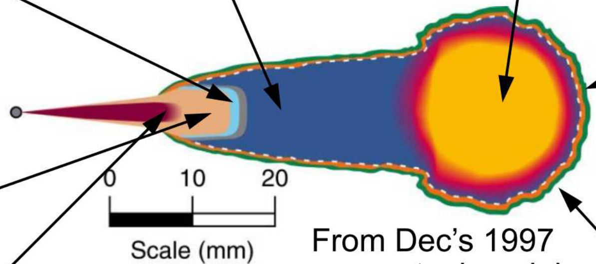


6 OH PLIF: Diffusion Flame
Shortly after the premixed fuel burns, a thin diffusion flame forms on the jet periphery, surrounding the interior soot cloud.



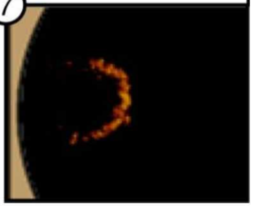
2 Rayleigh Scatter: Vapor Fuel
The vaporized fuel-air mixture downstream of the liquid is relatively uniform and fuel-rich (Φ = 2-4).



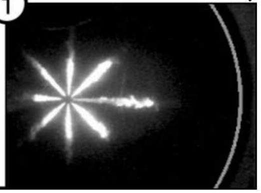


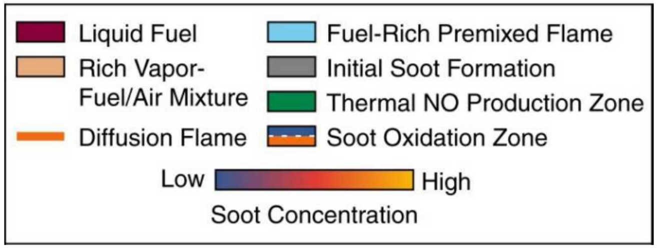
From Dec's 1997 conceptual model (SAE 970873)

7 NO PLIF: Thermal NO
NO forms on the periphery of the jet in the hot diffusion-flame products.

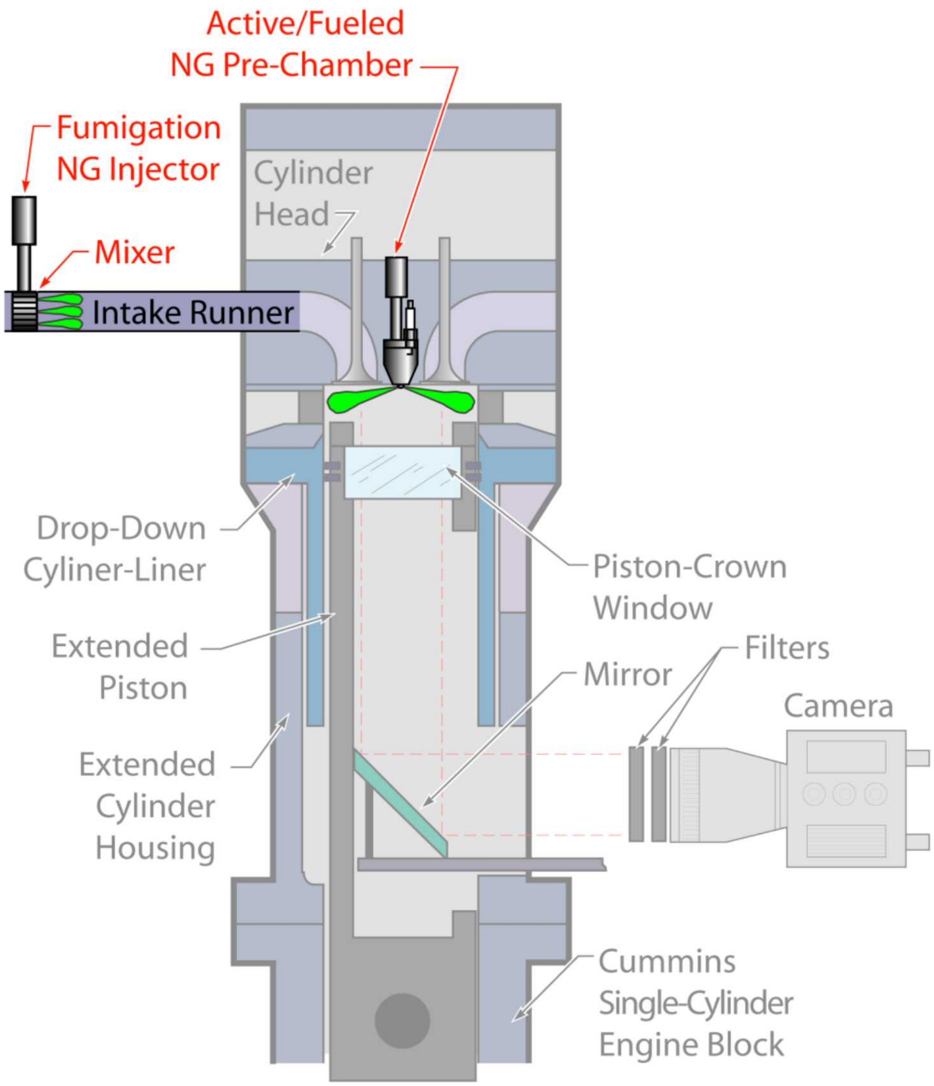


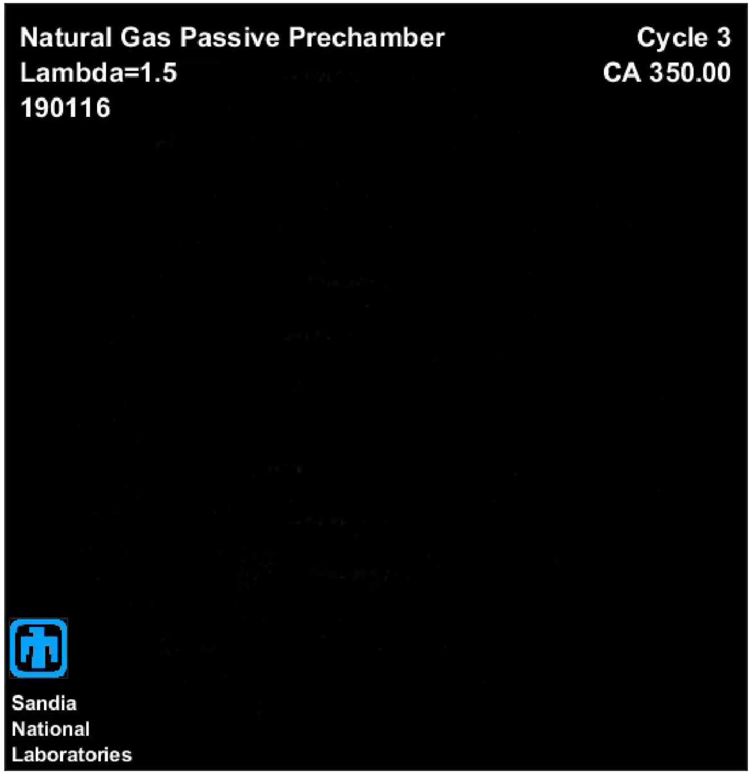
1 Mie Scatter: Liquid Fuel
After penetrating approx. 25 mm, the hot, entrained gases completely vaporize the liquid fuel.





Heavy-duty optical engine modified for multiple means of natural gas fueling and ignition

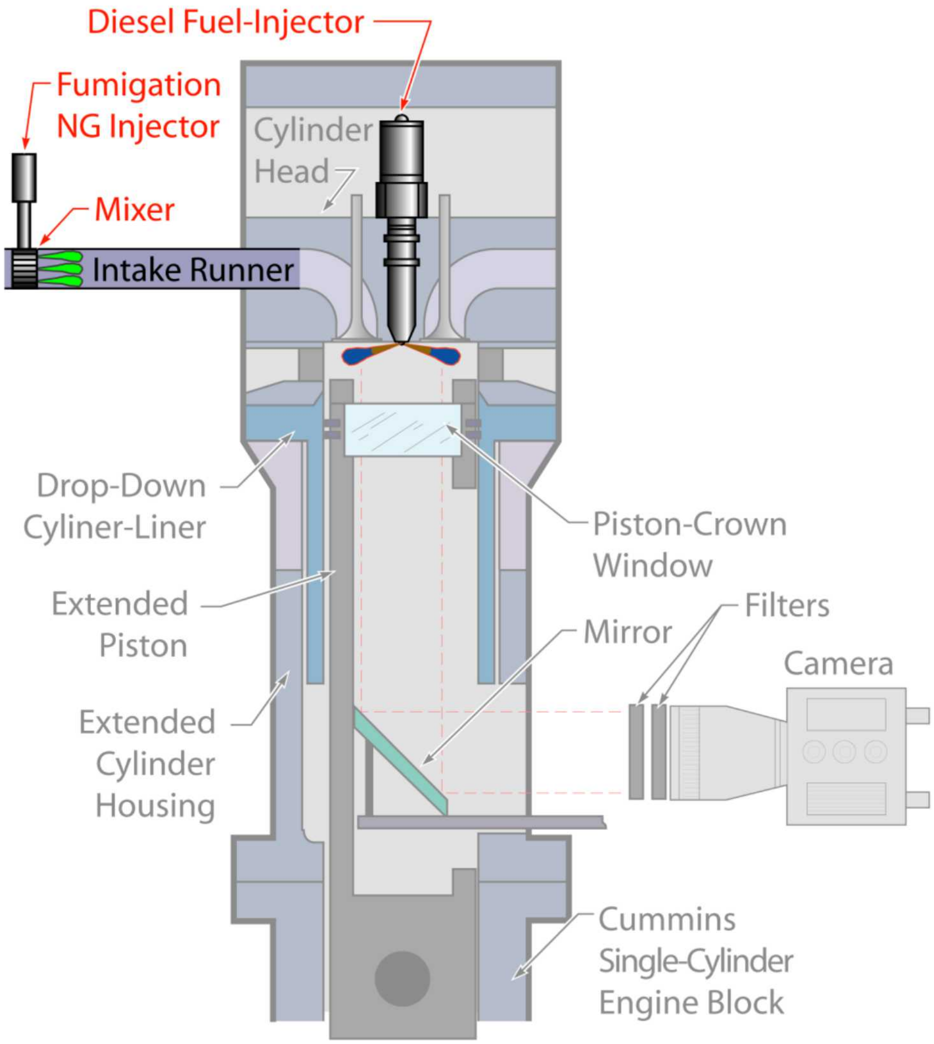




Natural Gas Pre-Chamber Ignition

- Engine can run more fuel-lean than spark ignition: higher efficiency
- Flame chemiluminescence imaging
  - Blue pre-chamber jets ignite NG

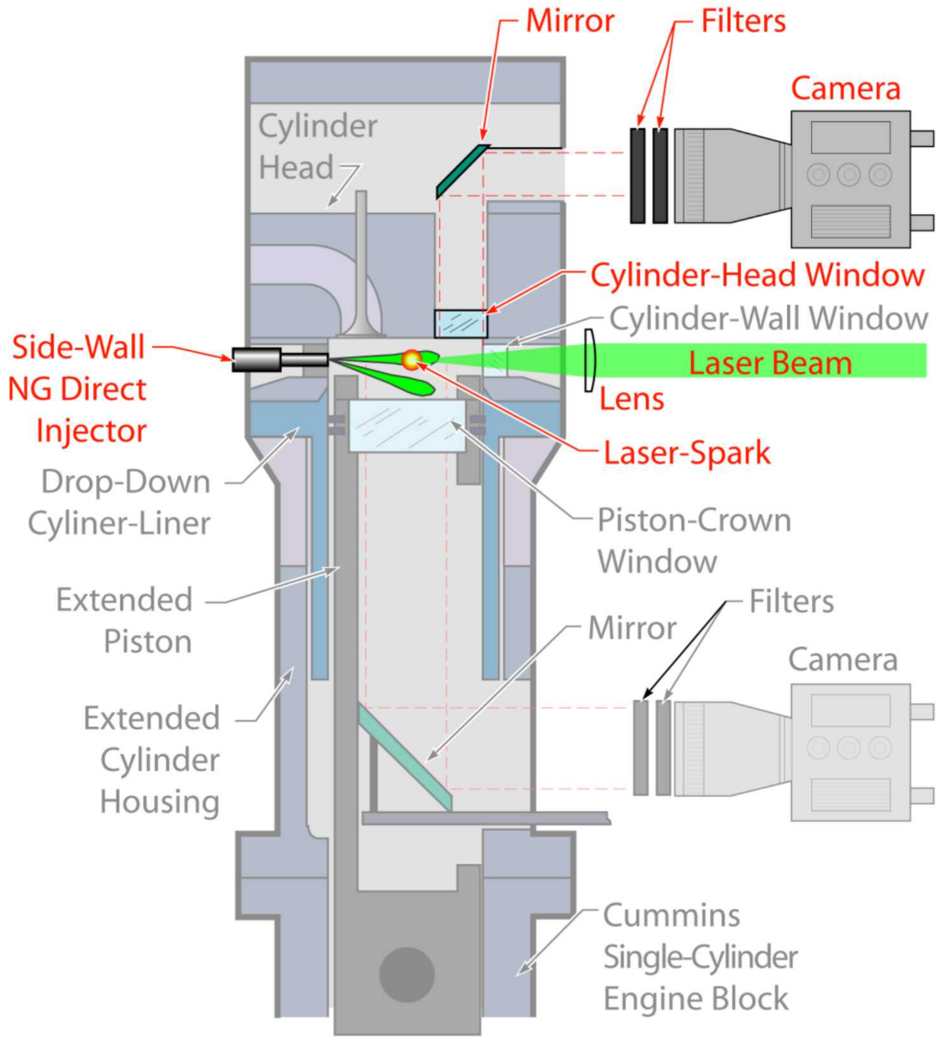
Diesel fuel injection can ignite premixed natural gas for dual-fuel combustion research

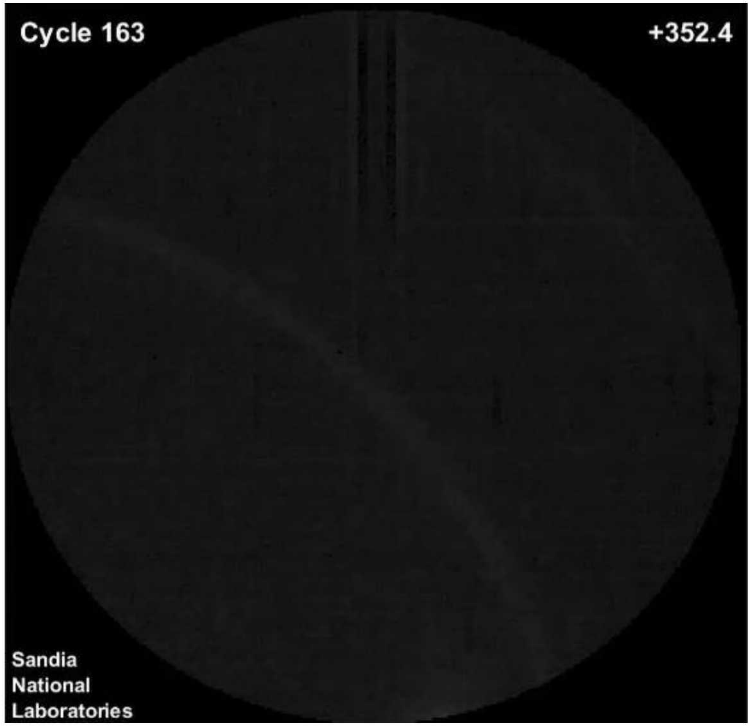


<u>OH* Chemiluminescence Imaging</u>

- Small diesel pilot of fuel-lean natural gas for high efficiency
- Complements pre-chamber work
  - Isolates ignition by fuel radicals

Optical imaging of spark-ignition end-gas auto-ignition (knock) that limits efficient engine design

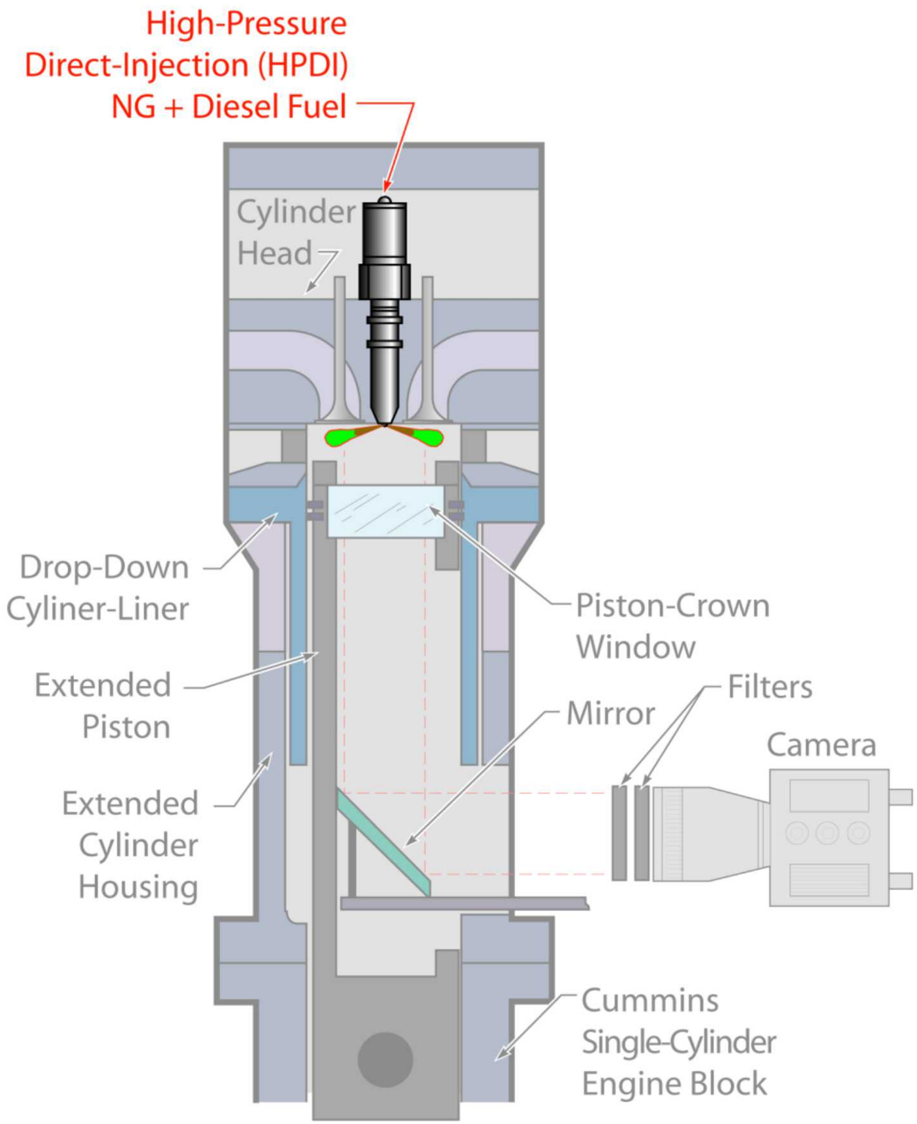




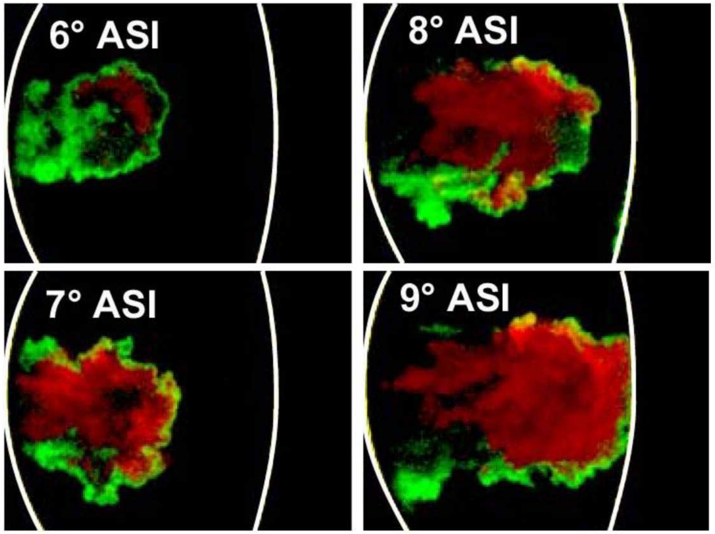
<u>OH* Chemiluminescence Imaging</u>

- Direct injection of natural gas
- Laser-spark at various locations
- Top-view through cylinder head
- Chem. kinetics sim. predicts knock

High-pressure direct-injection (HPDI) capabilities for high-efficiency mixing-controlled NG combustion



Diesel: Simultaneous laser-induced incandescence of soot (red) and laser-induced fluorescence of OH (green)

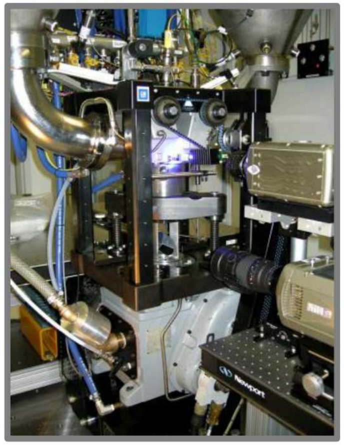


Diesel-ignited natural gas jets

- NG injection pressure up to 600 bar
- High-efficiency compression-ignition
- Diesel-like emissions (soot, NOx)
  - –Laser diagnostics for science base

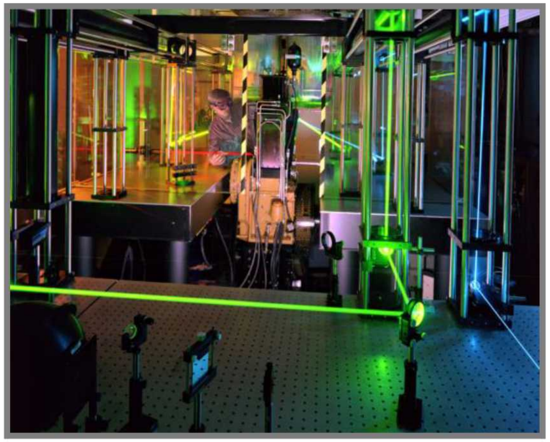
Engine combustion research capabilities span multiple approaches and engine size-classes

Low-temperature gasoline combustion
PI – John Dec

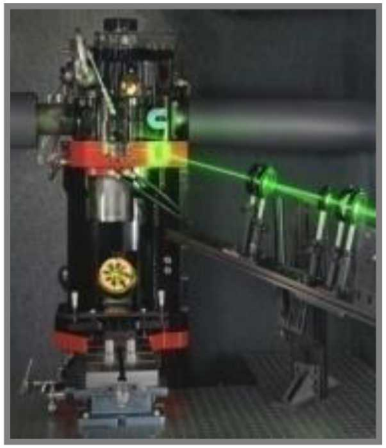


Alternative fuels – light-duty DISI
PI – Magnus Sjoberg

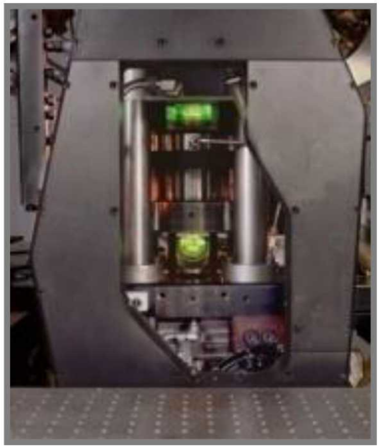
SI ignition & com-bustion fundamentals
PI –Isaac Ekoto



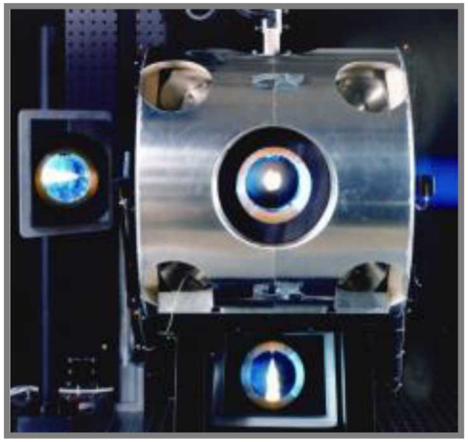
Alternative fuels – Heavy-duty CI:
PI – Chuck Mueller



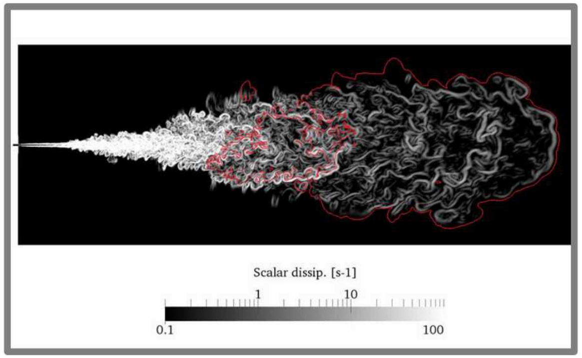
HD Diesel/gaseous-fuel combustion
PI – Mark Musculus



MD Diesel/low-temp. combustion
PI – Steve Busch



Spray Combustion & Soot
PI – Lyle Pickett



Combustion Modeling & Simulation
PIs – Jacqueline Chen and Marco Arienti