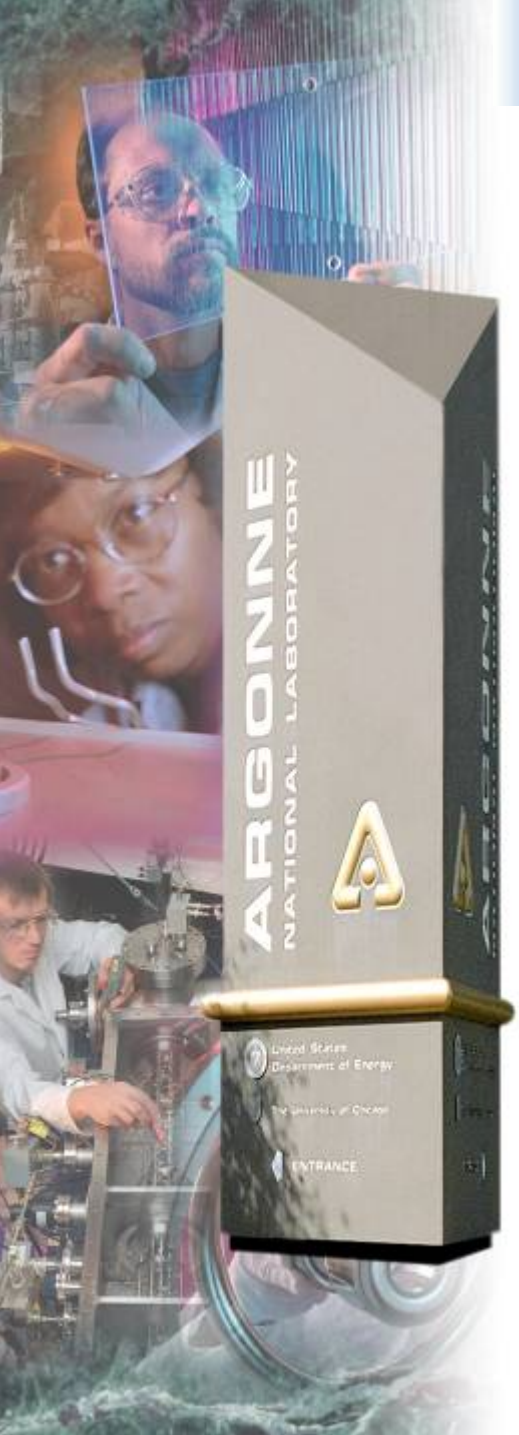

ARGONNE NATIONAL LABORATORY

Comparing the Performance of SunDiesel™ and Conventional Diesel in a LD Vehicle and Engines

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THE UNIVERSITY OF CHICAGO

Argonne National Laboratory is managed by The University of Chicago for the U.S. Department of Energy

Acknowledgments

- Stephen Goguen and Kevin Stork of DOE for their support and guidance
- CHOREN (Carbon Hydrogen Oxygen and Renewable) of Germany for the SunDiesel™ fuel
- Roger Cole, Geoffrey Amann, and Gregory Hillman of Argonne

SunDiesel™ Fuel: Fuel Properties and Engine Performance Results

Research Objectives

- To investigate and compare SunDiesel™ with conventional diesel fuel both on road and in the lab
- To provide DOE and fuel producers with key emissions and detailed combustion data

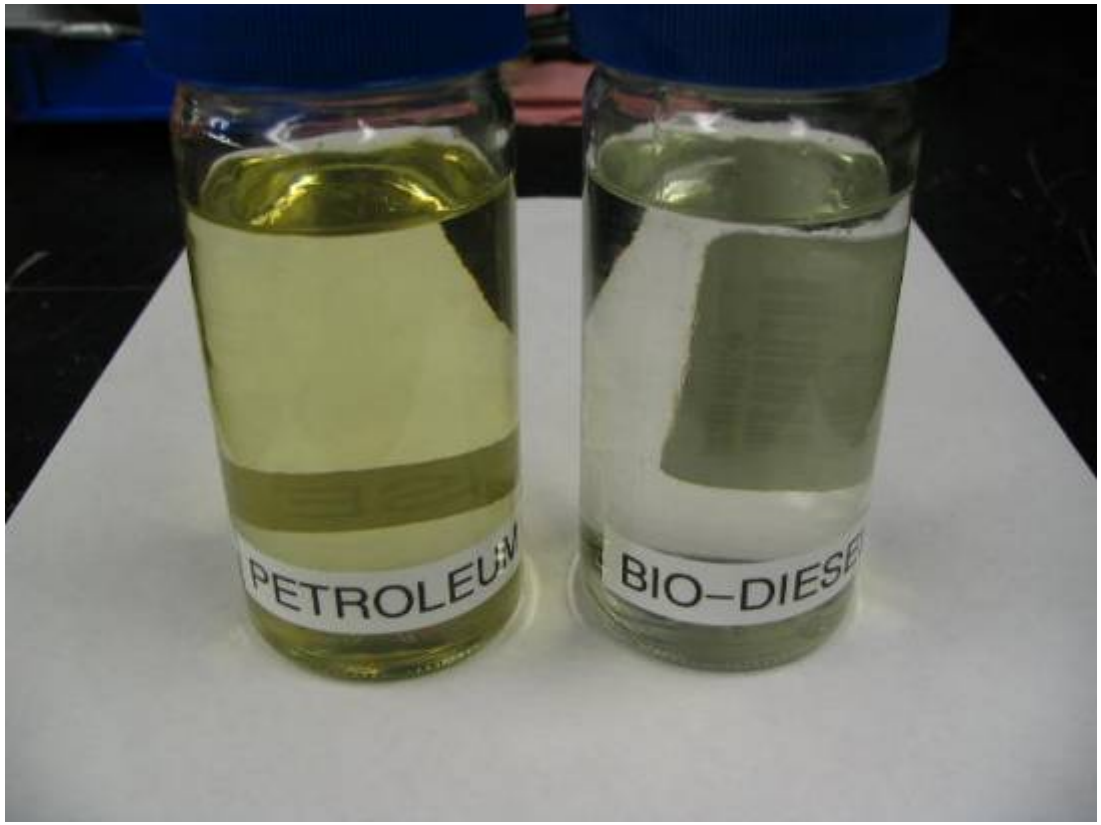
Tasks Undertaken

- Fuel chemical analysis subcontracted to Phoenix Chemical Lab
- On-road and 4-wheel chassis dynamometer testing
- Single-cylinder HD and 4-cylinder LD engine combustion analysis

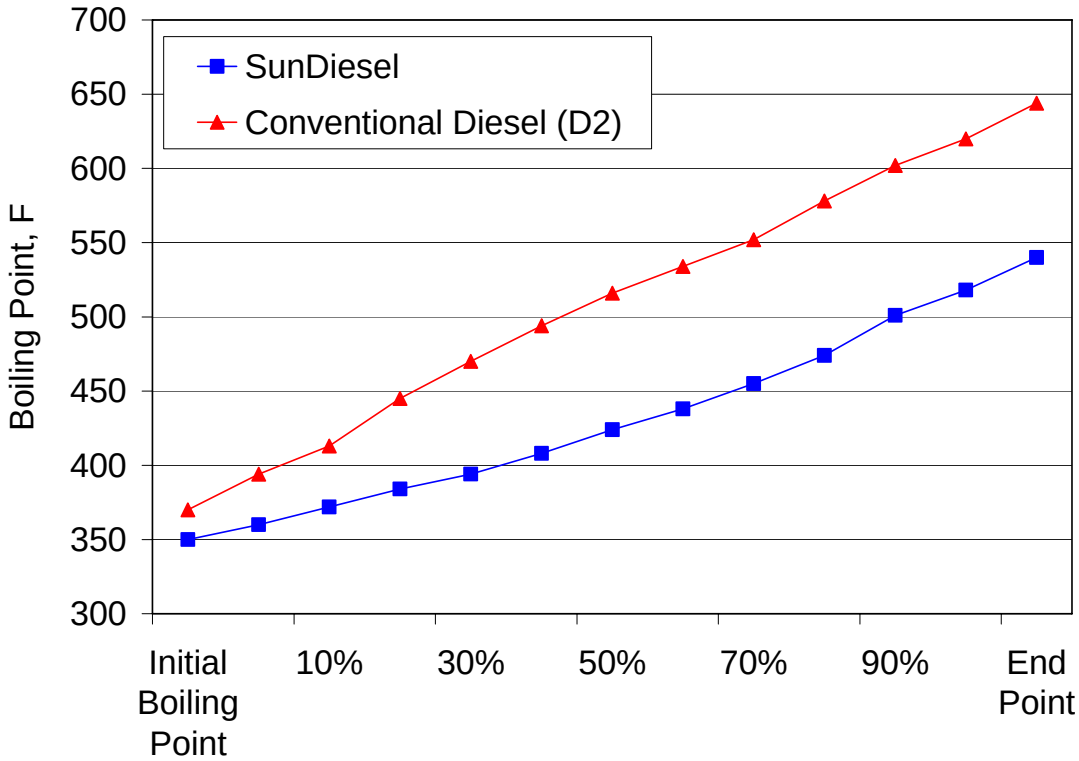
What is SunDiesel™?

- The fuel is derived from wood chips that are first gasified and subsequently go through the Fischer-Tropsch process to produce SunDiesel™.
- CHOREN projects production of 1 million tons/year by 2010.
- SunDiesel™ is now used to blend German fuel.

Compared to Conventional Diesel Fuel, SunDiesel™ Is Clear and Odor Free.



SunDiesel™ Has Lower Boiling Points than Conventional Diesel.



Chemical Characteristics

Hydrocarbon Types (ASTM D1319)

	Conventional Diesel %	SunDiesel™ %
Saturates	67.2	91.8
Olefins	2.6	5
Aromatics	**30.2**	**3.2**
Carbon	**86.59**	**85.79**
Hydrogen	**12.67**	**12.54**

Trace Sulfur (ASTM D5453)	**311 ppm**	**0.3 ppm**

Fuel Comparison by Phoenix Chemical Lab

Characteristic	California Diesel	SunDiesel™
Heat of Combustion		
Gross	19633 Btu/lb	20312 Btu/lb
Net	18477 Btu/lb	19168 Btu/lb
Specific Gravity (ASTM D287)	**0.8514**	**0.7612**
Pour Point (ASTM D97)	-5°F	-5°F
Cloud Point (ASTM 2500)	4°F	4°F
Viscosity (ASTM D445)	2.95 cSt	1.55 cSt
Odor (Subjective)	Unpleasant	Pleasant

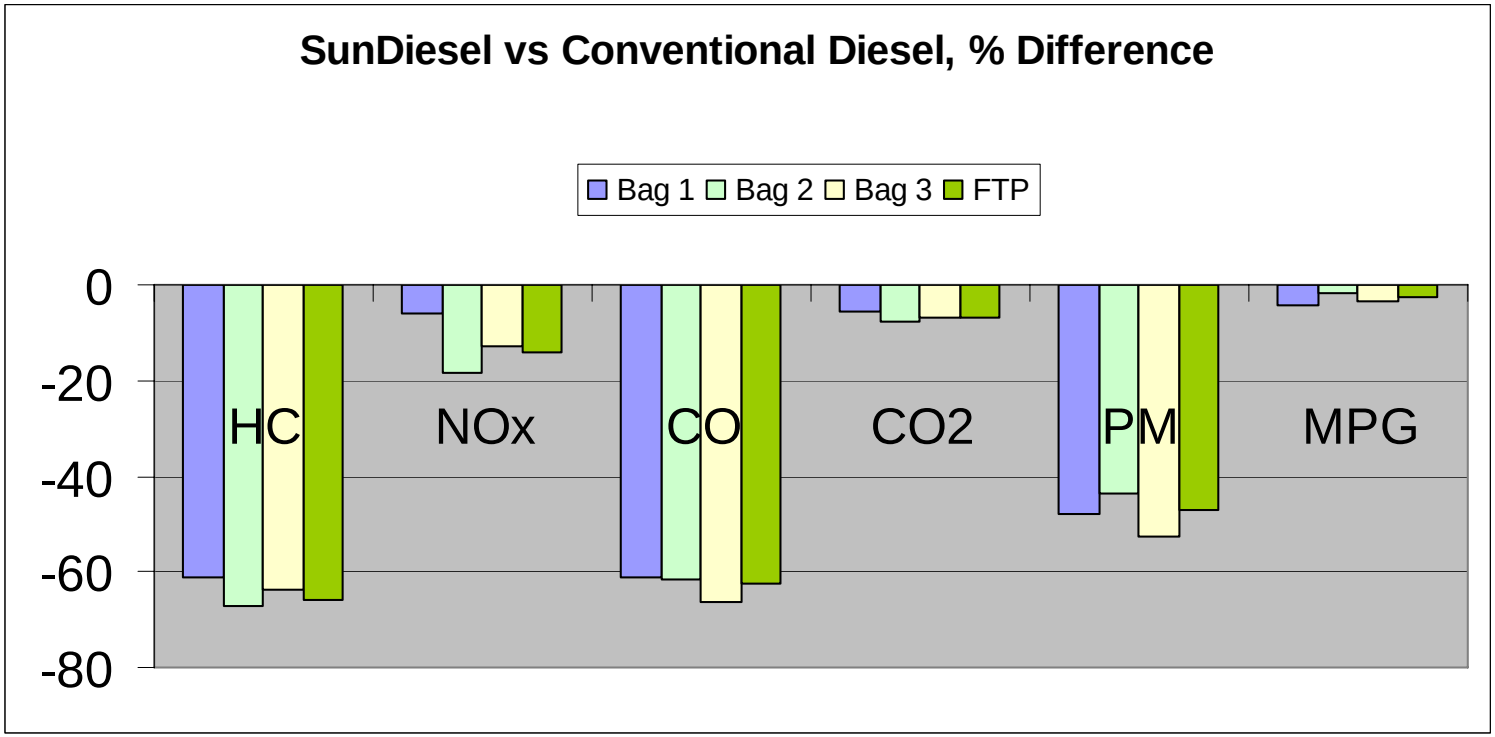
SunDiesel™ Tested with a Mercedes A-170

- Initial testing was performed on a 1999 Mercedes A-170 with a 1.7- liter diesel engine.
- Tests were conducted included both on the road and in ANL's Advanced Powertrain Research Facility (APRF).
- Emission and fuel economy data were collected back-to-back with both fuels.

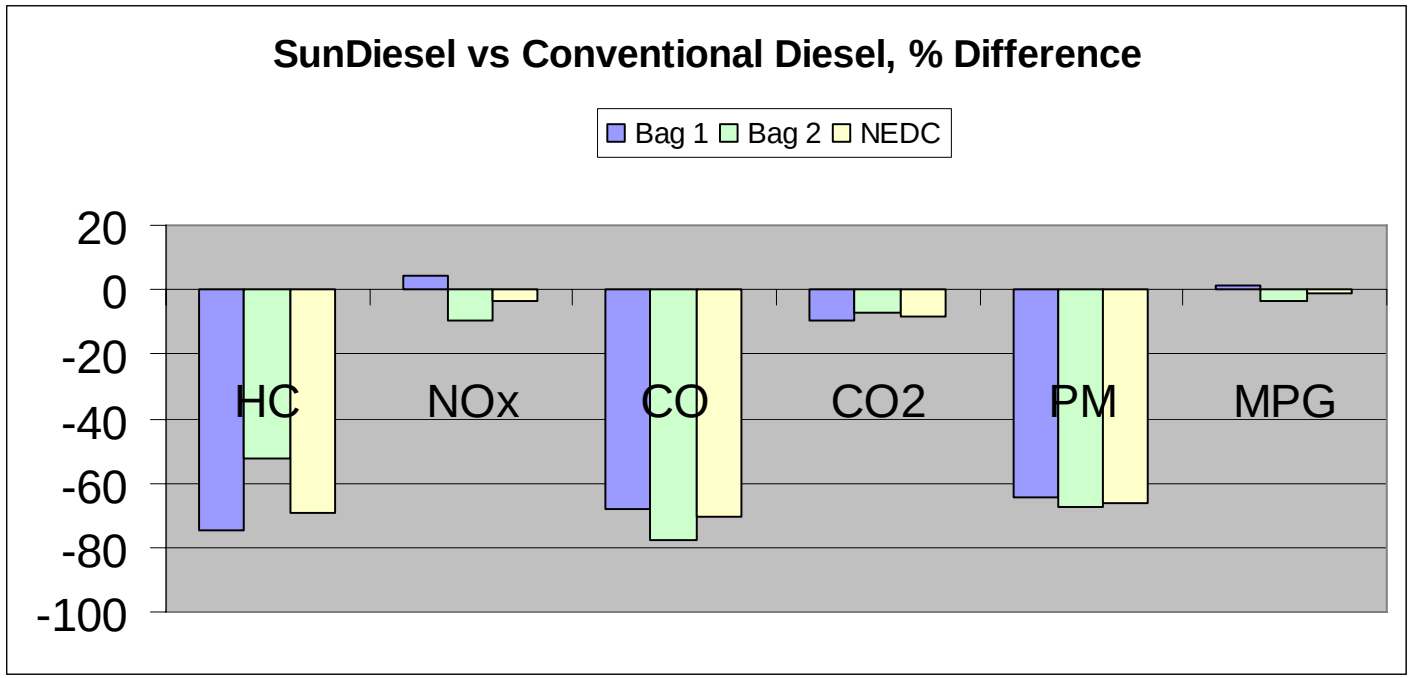
Summary of SunDiesel™ Vehicle Tests

- SunDiesel™ was tested in the Mercedes A class diesel; improved drivability was noted, while the characteristic diesel exhaust odor was absent.
- Both cold FTP-75 and NEDC (New European Drive Cycle) were run at Argonne.
- THC, CO, PM, and NO_x emissions were significantly lower than conventional diesel fuel.
- Total CO_2 emission rate was 10% lower than the base fuel -- less fuel mass consumed.

Significant Improvement in FTP-75



NEDC Improvement Is Similar to Results from FTP-75.



SunDiesel™ Has Lower NO_x Emissions than U.S. Biodiesel

AVERAGE BIODIESEL EMISSIONS COMPARED TO CONVENTIONAL DIESEL, ACCORDING TO EPA		
Emission Type	**B100**	**B20**
Regulated		
Total Unburned Hydrocarbons	-67%	-20%
Carbon Monoxide	-48%	-12%
Particulate Matter	-47%	-12%
Nox	+10%	+2%
Non-Regulated		
Sulfates	-100%	-20%*
PAH (Polycyclic Aromatic Hydrocarbons)**	-80%	-13%
nPAH (nitrated PAH's)**	-90%	-50%***
Ozone potential of speciated HC	-50%	-10%

*** Estimated from B100 result**
**** Average reduction across all compounds measured**
***** 2-nitroflourine results were within test method variability**

(more)

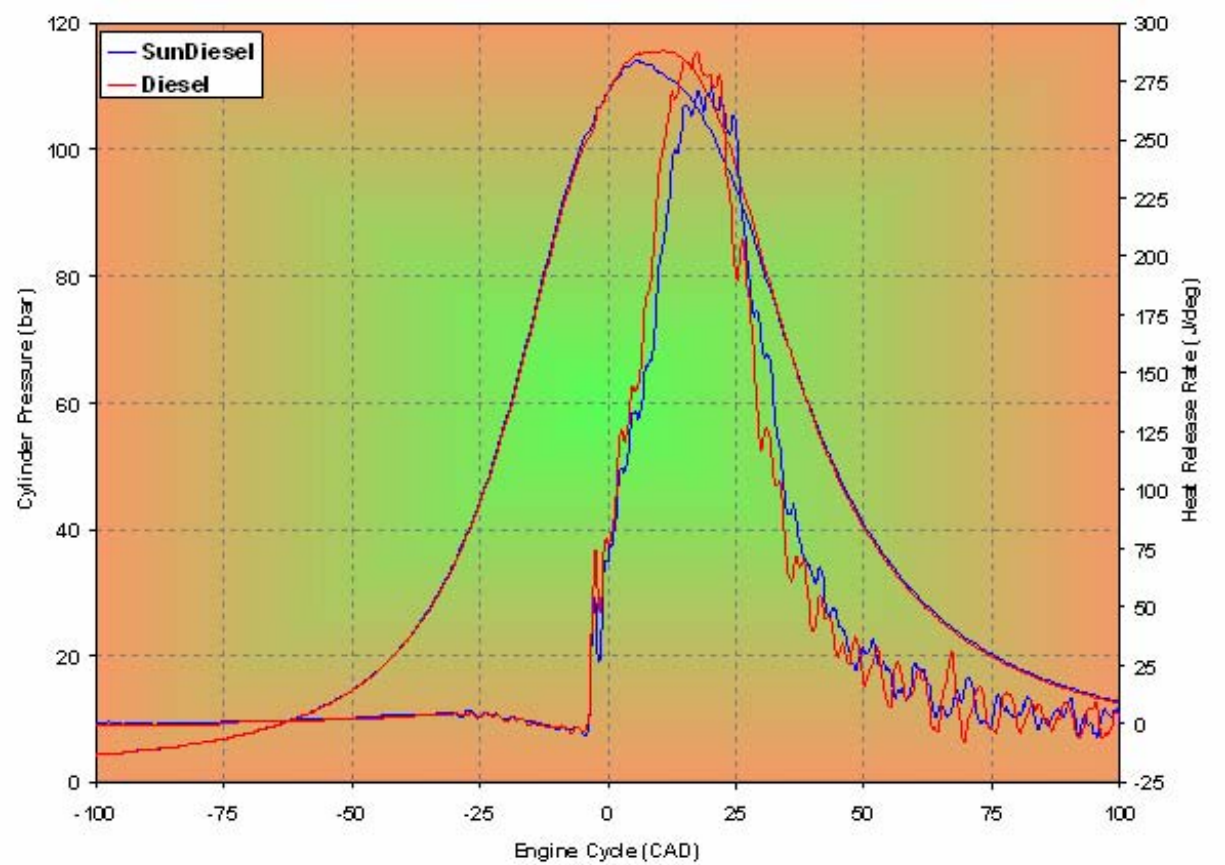
Additional Engine Combustion Research on SunDiesel™ Characteristics

- Utilizing a single-cylinder Caterpillar engine to learn more about the SunDiesel™ combustion process and emissions
- Performing PM measurements with mini-dilution tunnel and SMPS(Scanning Mobility Particle Sizer)
- Applying in-cylinder diagnostics (VisioScope) to gain further insight of the differences in combustion using the conventional and SunDiesel™ fuels with a Mercedes A-class, 4-cylinder 1.7-L engine

Caterpillar Single-Cylinder Diesel Engine Used for Testing

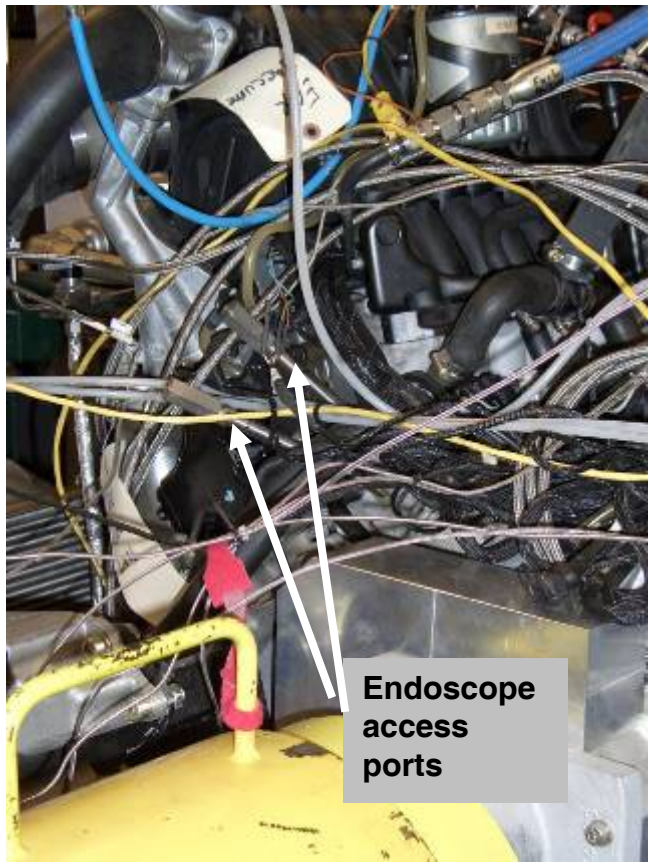
- Single-cylinder Caterpillar engine is ideal for fuels and lubricants research.
- Calibration tests have been run to compare a wide range of fuels.
- Extensive data has been collected to correlate the results of heavy-duty engine performance in the past.

SunDiesel™ Has Less Pre-mixed Burning than Conventional Diesel in a Caterpillar Heavy-Duty Engine.



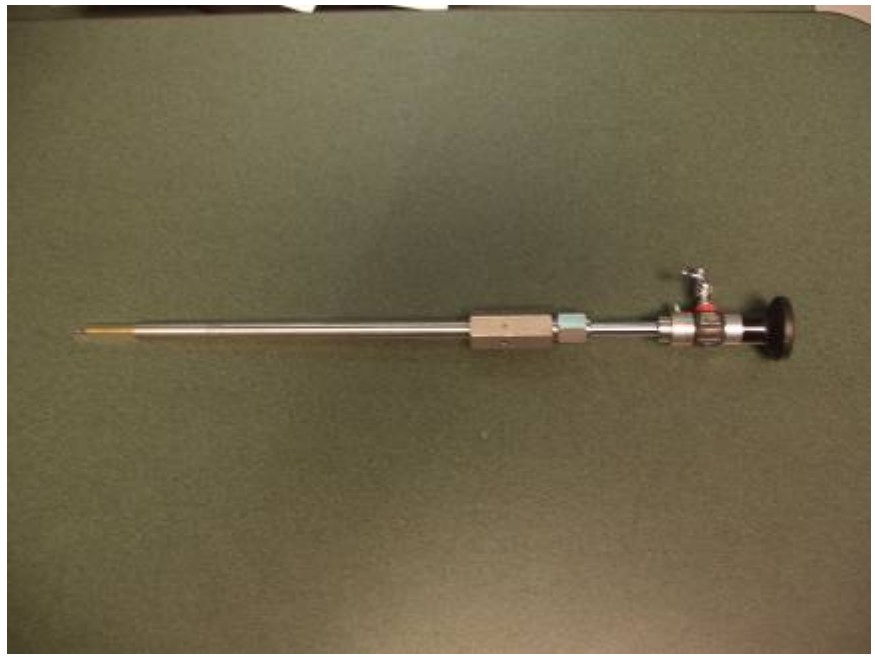
VisioScope Was Used to Study Combustion of SunDiesel™ in a 4-Cylinder, LD Engine.

- Slight modification to engine provides access.
- Engine can be operated full speed/full load – all conditions.
  - 4000 RPM, 100% Load
- Other tools can be used simultaneously.
  - Emissions measurements
  - Pressure measurements
- Illumination capability is available (2nd access port).
  - Spray/mixture formation in pre-combustion phase
  - Part of next experiment matrix



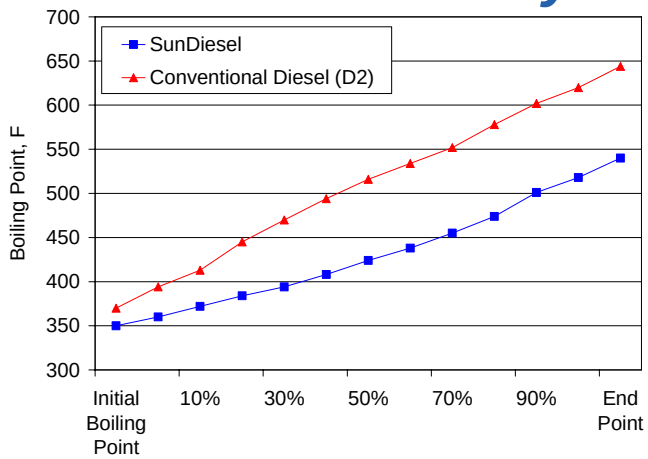
Endoscopes provide low-intrusion optical access.

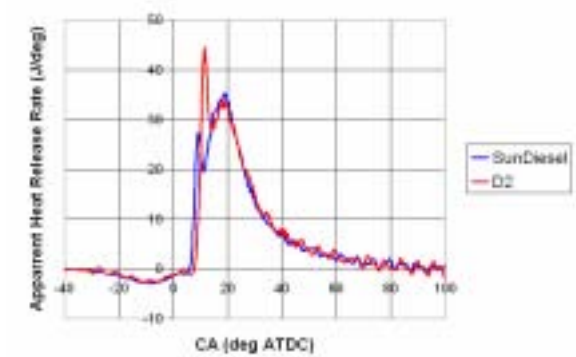
- Endoscopes are cooled to maintain optical quality and durability.
  - No fiber-optic bundles – one-piece construction
  - Excellent optical quality
  - 2.5 consecutive hours during low soot conditions
- Small quartz window exposed to combustion gas
- Variety of cameras can be used.
  - 12-bit Video Graphics Array (VGA) camera currently used
    - *One image per cycle – excellent resolution (640X480)*
  - High-speed camera can also be used.



SunDiesel™ and D2 Show Different Combustion Characteristics Based on In-cylinder Pressure Analysis.

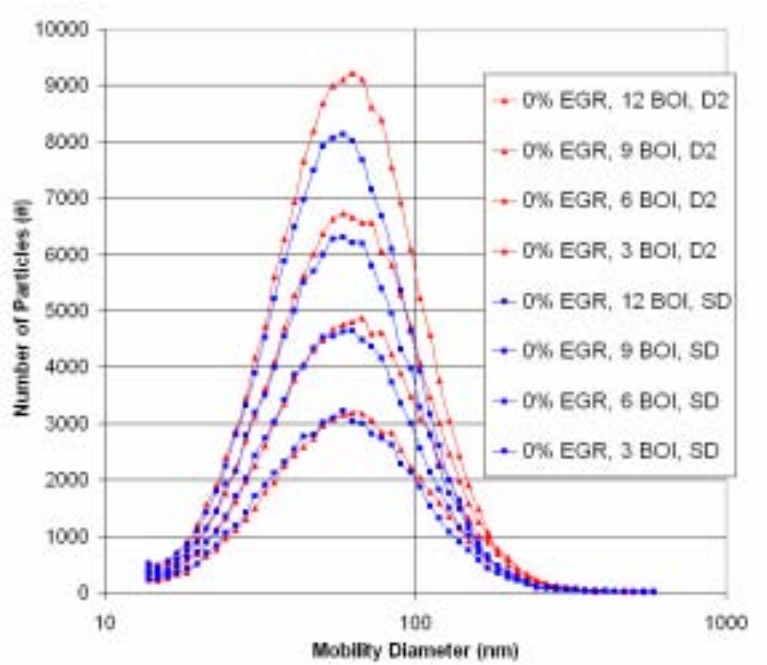
- Distillation curves show SunDiesel™ evaporates more easily than conventional diesel.
- Heat release curves show different combustion characteristics.
  - Lower “premixed burn” portion for SunDiesel™
  - Advanced combustion timing for SunDiesel™

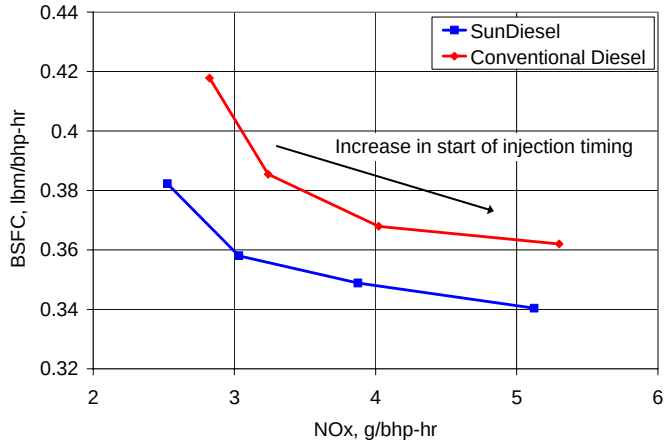


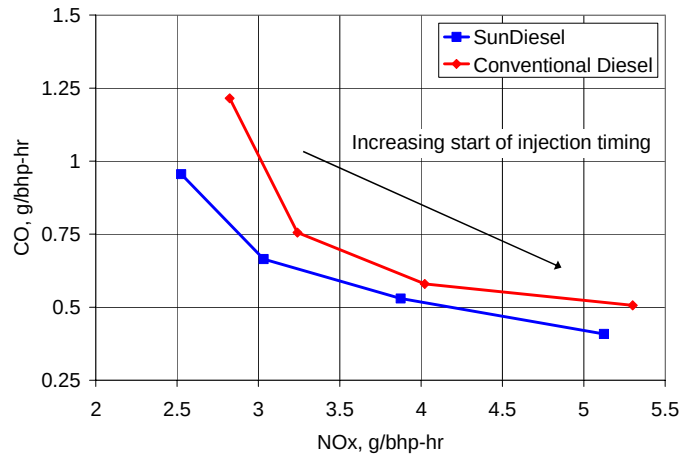


Emissions Results Show Advantages of SunDiesel™ .

- Significantly reduced PM, NO_x, CO,and BSFC

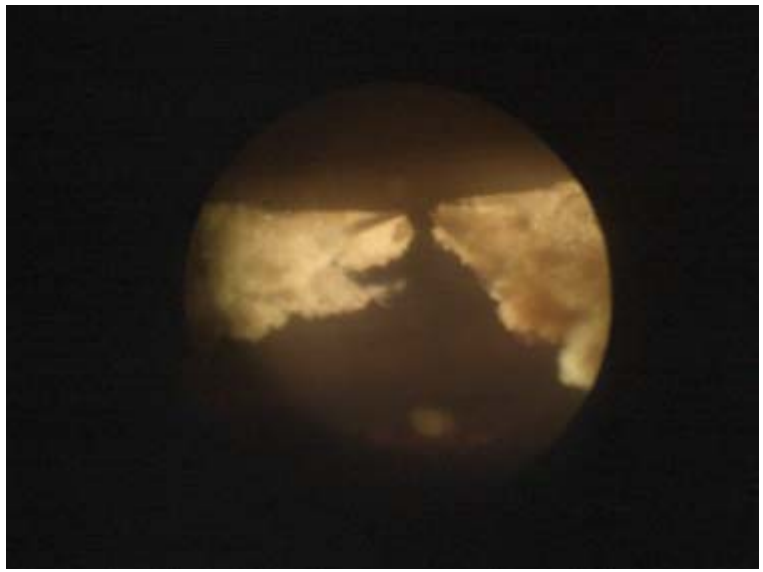


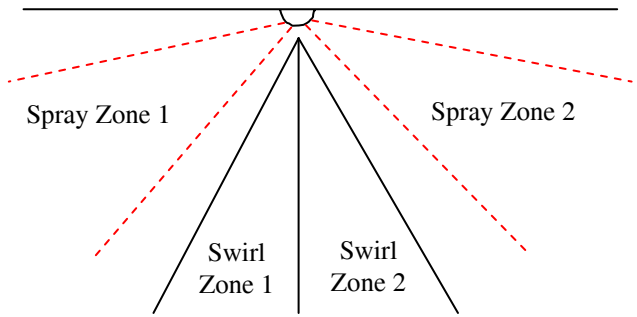




Valuable VisioScope Pictures Were Obtained at 2500 RPM and 50% Load.

- Automotive “cruise” point
- Consistent test conditions
  - 705 bar injection pressure
  - 26.16 µs injection duration
  - Injection timing set at 3, 6, 9, and 12 deg BTDC
  - Allow load to “float” with timing change or fuel change
- Example of optical access shown
- Injector rotated to maintain window cleanliness

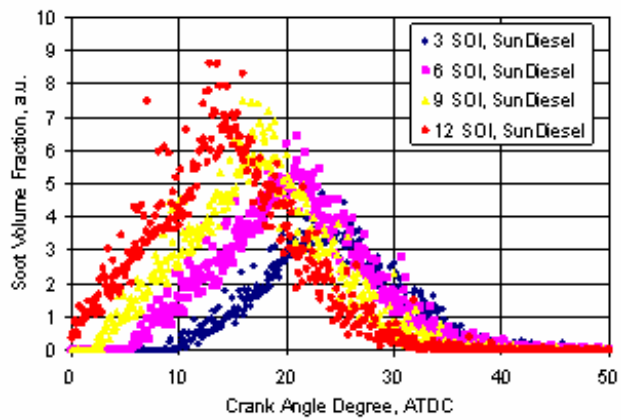




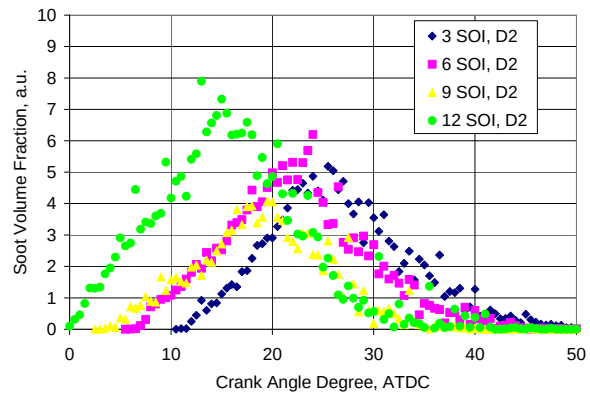
VisioScope SunDiesel™ Results Show Significant Combustion Differences.

- Higher volatility, shorter premixed burn for SunDiesel™
  - Shorter time for mixing
  - Generally increases soot
  - *However, engine-out soot decreases!*
- Graphs on right are statistical representation of images.
- Between 30 and 40 deg ATDC, D2 Soot Volume Fraction (SVF) is higher than for SunDiesel™ .

SunDiesel™

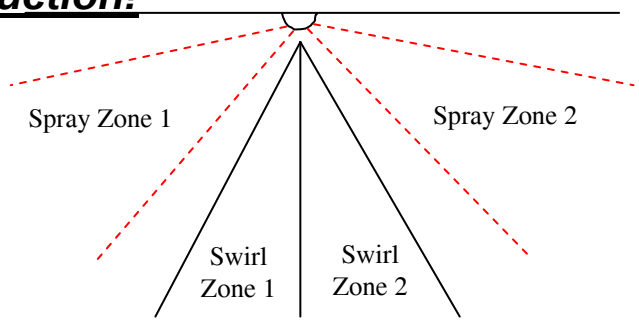


Diesel Fuel

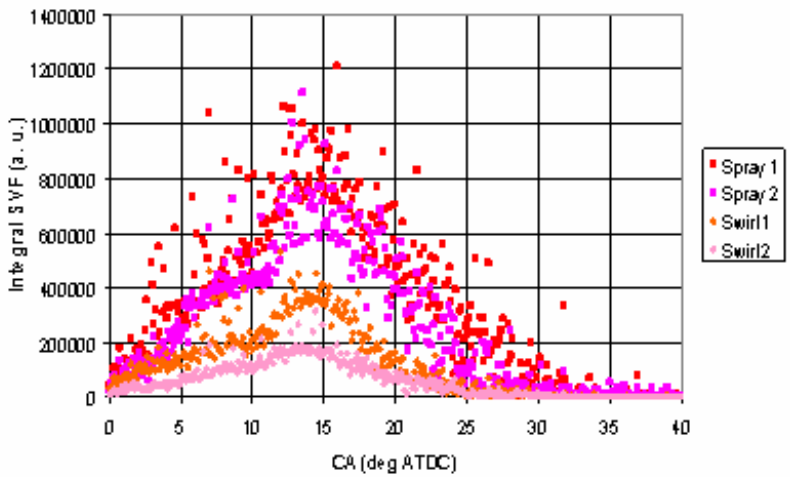


Detailed Image Analysis Sheds Light Upon Soot Mechanisms.

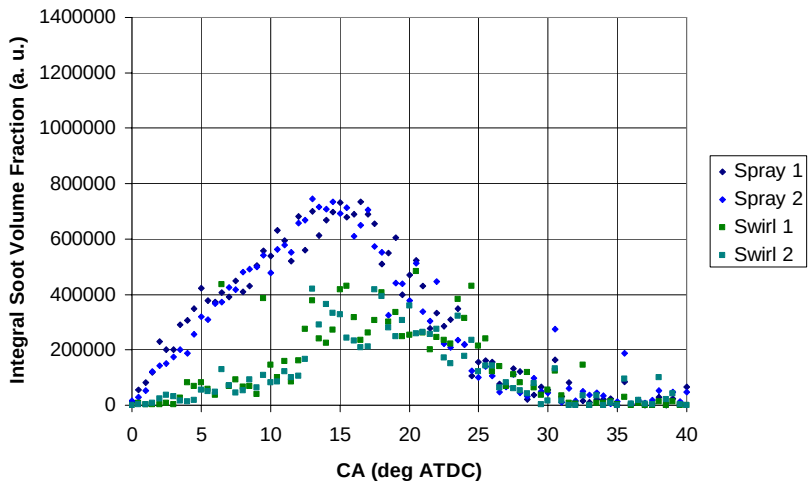
- 2-D details from imaging show where soot is formed/oxidized.
- Soot formation is actually higher for SunDiesel™ .
  - Shorter premixed burn
    - *Poor mixing*
    - *High soot production*
- Soot oxidation is more rapid for SunDiesel™ .
  - Different soot characteristics
    - *Low sulfur, low aromatic*
- ***Chemistry mechanisms dominate fluid mechanics for overall soot reduction!***



SunDiesel™



Diesel Fuel



Points of Interest and Observations

- The full potential of SunDiesel™ has not been explored (i.e. high cetane engine optimization); further testing will be necessary to determine the full extent of SunDiesel™ capabilities.
- Blending with U.S. conventional diesel may produce a fuel that has both lower criteria emissions, especially NO_x, and greenhouse gases.
- Our continuing research encompassing vehicles, engines, and state-of-the-art measurements will provide needed emissions and combustion data to DOE so the potential of the fuel can be evaluated.
- The testing has gained the attention of OEMs and government entities.
  - U.S. Postal Service has requested SunDiesel™ testing of their medium-haul fleet vehicles.
  - BMW and DaimlerChrysler have requested test results and data.