Quantitative Characterization of Diesel Particulates: Development of the Self-Calibrating Laser-Induced Incandescence Technique

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NRC·CNRC Institute for Chemical Process and Environmental Technology

Artium Technologies Inc.

Outline

- Introduction
- LII Method
- LII Applications
  - heavy-duty diesel engine
  - light-duty diesel engine
  - direct injection spark ignition vehicle
- Summary
- Future Work
- Acknowledgements

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Introduction - I

- diesel particulate matter (PM) is composed of elemental carbon (soot), adsorbed organic compounds, sulphates, nitrates, metals and other trace elements
- current diesel emission regulations only deal with total PM mass
- evidence suggests that the ***number***, ***size,*** and ***composition*** of particles may be important from a human health perspective

Is PM mass the most appropriate parameter to correlate with human health effects?

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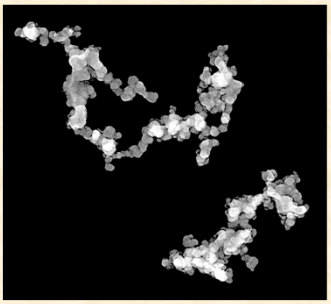
Introduction - II

What other parameters may be important for characterizing PM emissions?

- primary particle size
- surface area
- aggregate size
- organic fraction



NRC/Sandia are developing HELD* methods to more fully characterize PM emissions in real-time

** high energy laser diagnostics*

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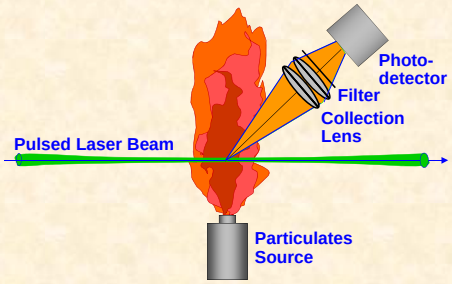
LII Concept

- pulsed laser beam
- rapidly heat soot to ~4000 K (<T_{sub})
- soot radiates incandescence as it cools to T_{amb}



- incandescence signal is analyzed to determine soot volume fraction and primary particle size
- potential to also provide soot morphology info (aggregate size, distribution) with scattering

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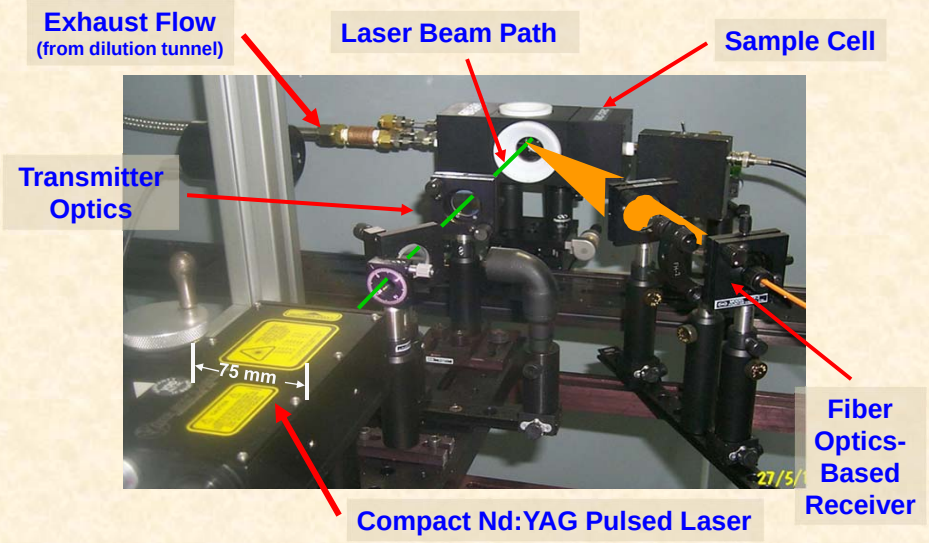
Compact LII System and Sample Cell



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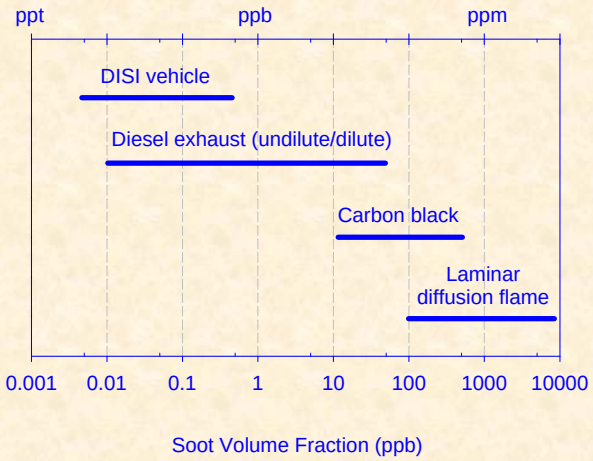
Demonstrated LII Measurements



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Key NRC Innovations

- Absolute intensity self-calibration
  - NIST traceable
  - not susceptible to fluctuations in laser fluence, attenuation, condensed organic matter on particles
  - don't need T_{amb} to determine concentration
- Two-color pyrometry
  - particle temperature measured throughout event
- Low fluence LII
  - minimize vaporization of soot
- Relay-imaging of apertured beam
  - top-hat laser spatial profile (uniform particle heating)

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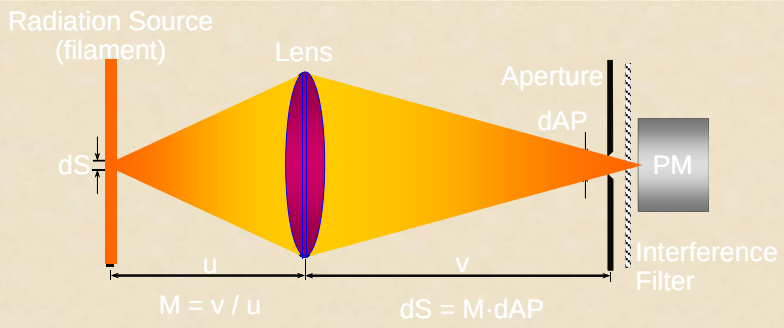
LII Absolute Intensity Self-Calibration



- use two-color pyrometry to determine the filament temperature
- use known filament radiant power incident on the aperture to calibrate the detection system

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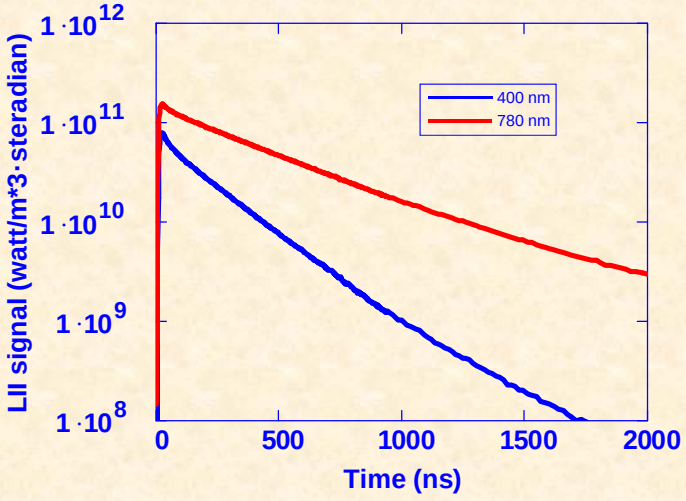
LII Signal - Laminar Diffusion Flame



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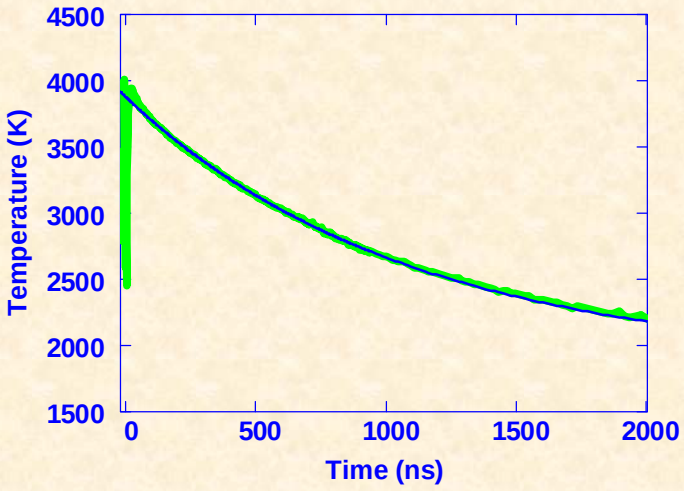
Soot Temperature History



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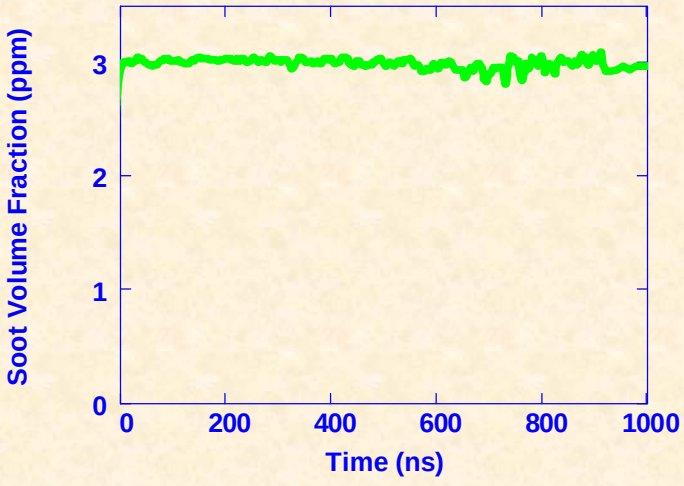
Soot Volume Fraction



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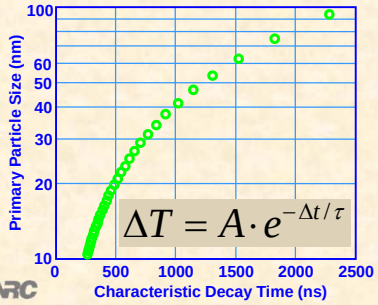
Soot Volume Fraction

- soot volume fraction calculated from LII signal and particle temperature

$$f_v = \frac{V_{EXP}(\lambda)}{\eta(\lambda) w_b} \frac{\lambda^6 \left(e^{\frac{hc}{k\lambda T}} - 1\right)}{12\pi c^2 h E(m_\lambda)}$$

- primary particle size obtained from time constant of temperature decay during conduction phase



$$d_p = \frac{12 k_g \alpha \tau}{G \lambda_{MFP} c_p \rho_p}$$

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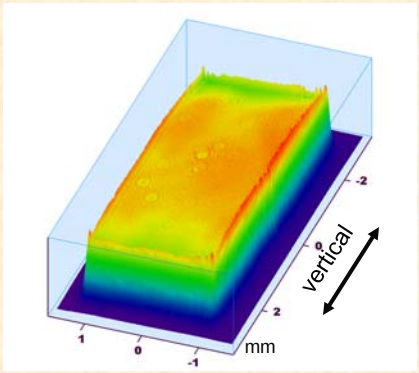
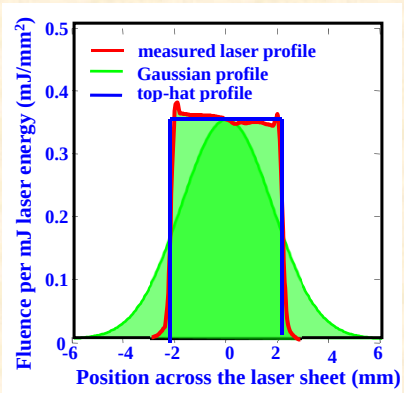
Uniform Soot Particle Heating





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Heavy-Duty Diesel Engine

Caterpillar 3401E
(NRC Prototype 2004)

Cylinders	1
Volume	2.44 liters
Comp. Ratio	16.25:1
Peak Power	74.6 kW (1800 rpm)
Valves	4
Injection	EUI
EGR	Cooled

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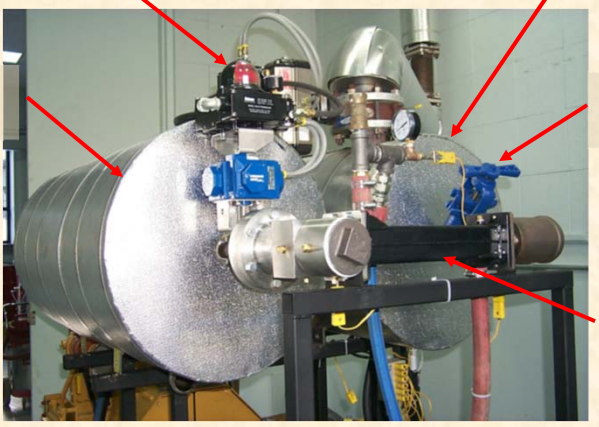
Prototype Cooled EGR System



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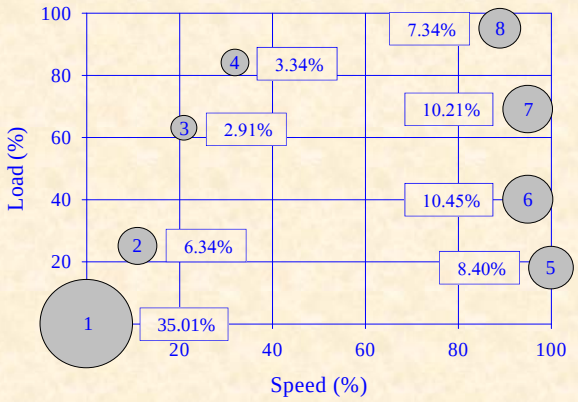
AVL 8-Mode Steady-State Test



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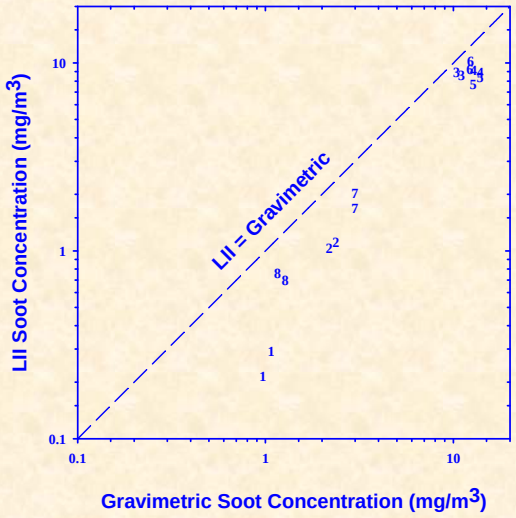
LII Soot vs. Gravimetric Soot (no EGR)



- gravimetric method measures solid carbon (soot), condensed soluble organic (SOF) and sulfate fractions
- SOF portion of PM extracted from filters
- sulphate fraction small - fuel sulphur content <10 ppm
- LII method measures soot volume fraction - soot density of 1.9 g/cm^3 assumed

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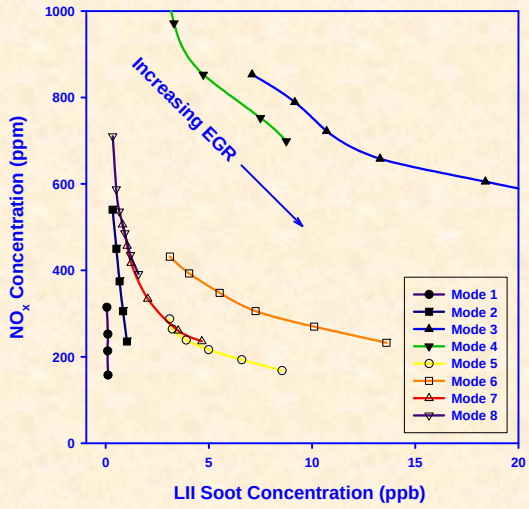
NO_x vs. LII Soot Tradeoff



- LII used to rapidly measure soot concentrations over wide range of EGR rates at 8 modes
- LII measurements taken from dilute exhaust gas in this case, however, method works equally well with undilute gases

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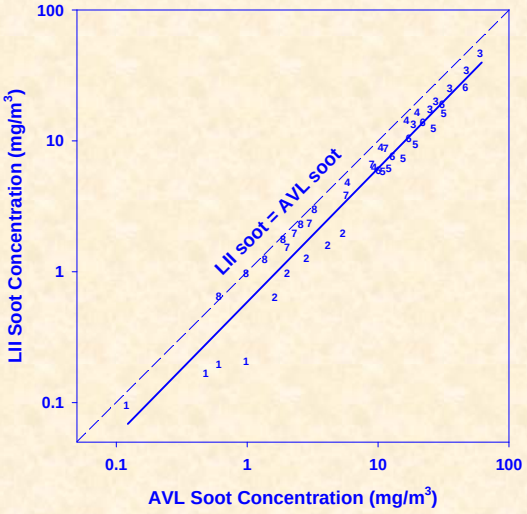
LII Soot vs. AVL Soot (EGR)



- AVL Smoke Meter determines soot concentration from reflectance of soot sample collected on filter paper
- soot concentrations from AVL Smoke Meter are ~50% higher on average
- evidence suggests that SOF plays a role, particularly at mode 1

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Light-Duty TDI Diesel Engine

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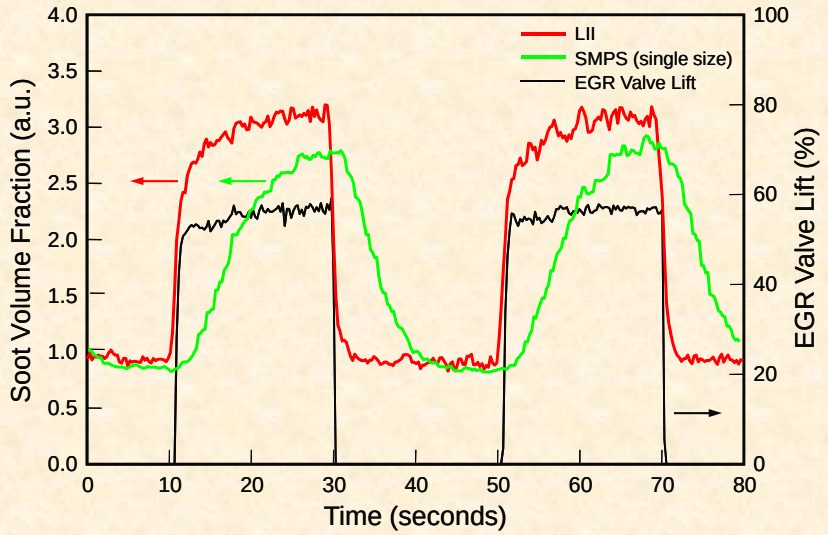
LD Diesel EGR transient



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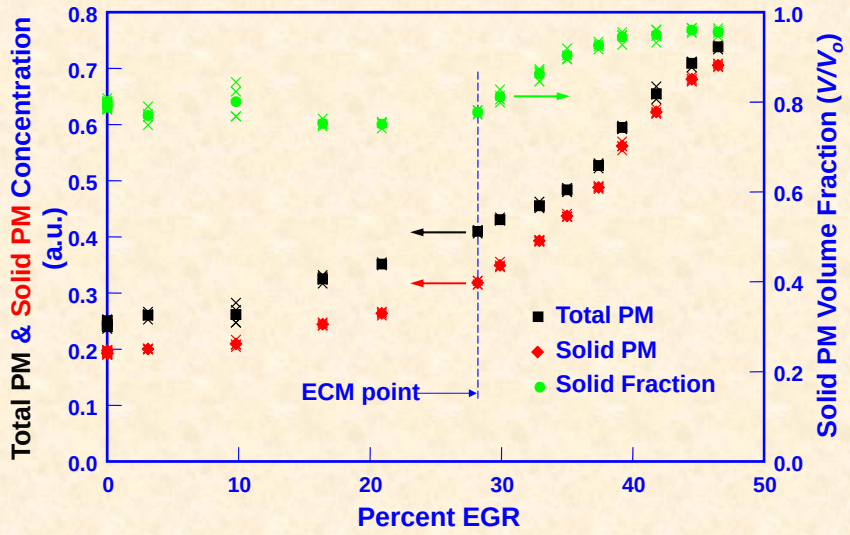
Double-pulse LIDELS for EGR Sweep



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Production DISI Vehicle

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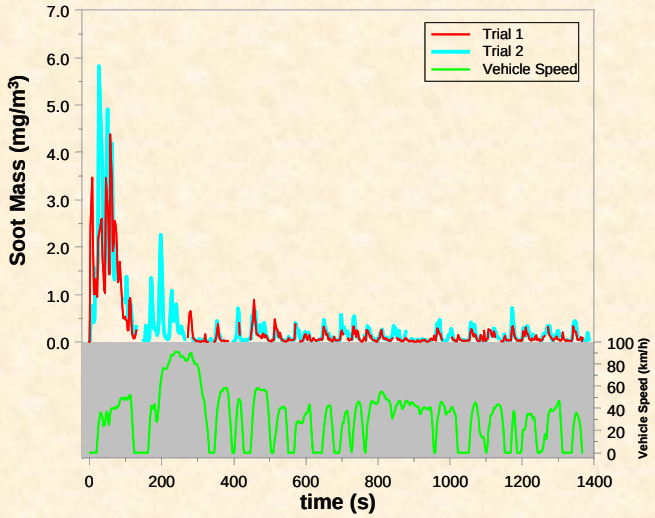
LII LA4 Cold Start Cycle



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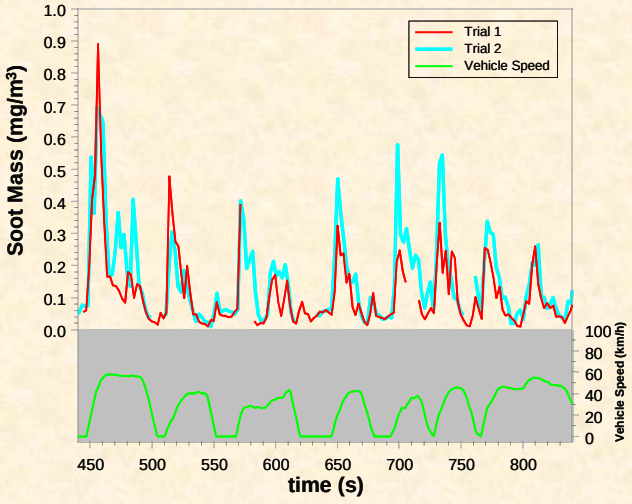
LII LA4 Cold Start Cycle (Detail)



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Summary

- LII is a potential standard method for taking in-situ real-time soot concentration measurements
  - LII has a large measurement range and sensitivity even at very low soot concentrations
  - LII has very high precision (excellent repeatability)
  - NRC has developed a NIST-traceable self-calibration method for LII (good accuracy)
  - LII measures transient soot emissions (excellent temporal resolution)
  - LII measurements can be made with/without dilution
- HELD methods have the potential to more fully characterize PM emissions in real-time
  - aggregate size, surface area, organic fraction

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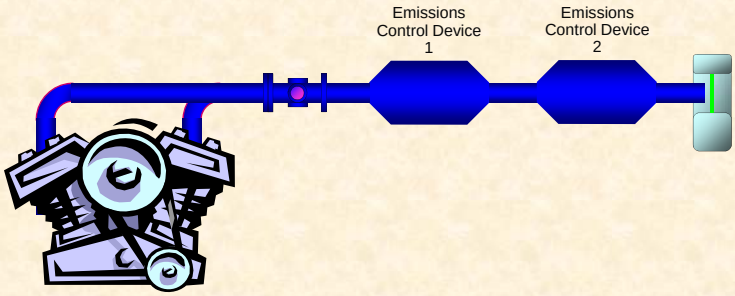
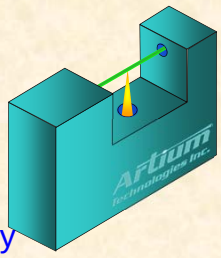
Future Work: LII for Emissions Control Performance



- LII provides sensitivity for post-2007 regulations
- Ideal for measuring engine-out / emissions-control-systems-in particulate levels
- Evaluate emissions control system efficiency



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Acknowledgements

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- Sandia National Laboratories
  - *Dr. Peter O. Witze*
- Environment Canada
  - *Lisa Graham*

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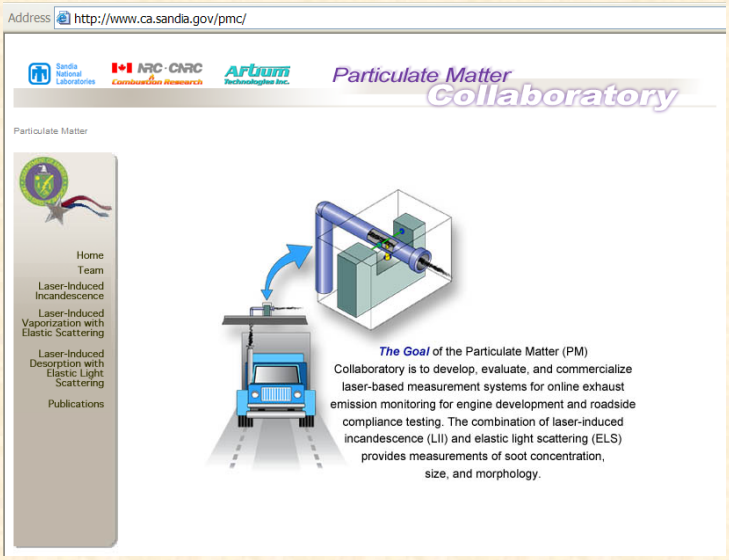
Additional Information



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