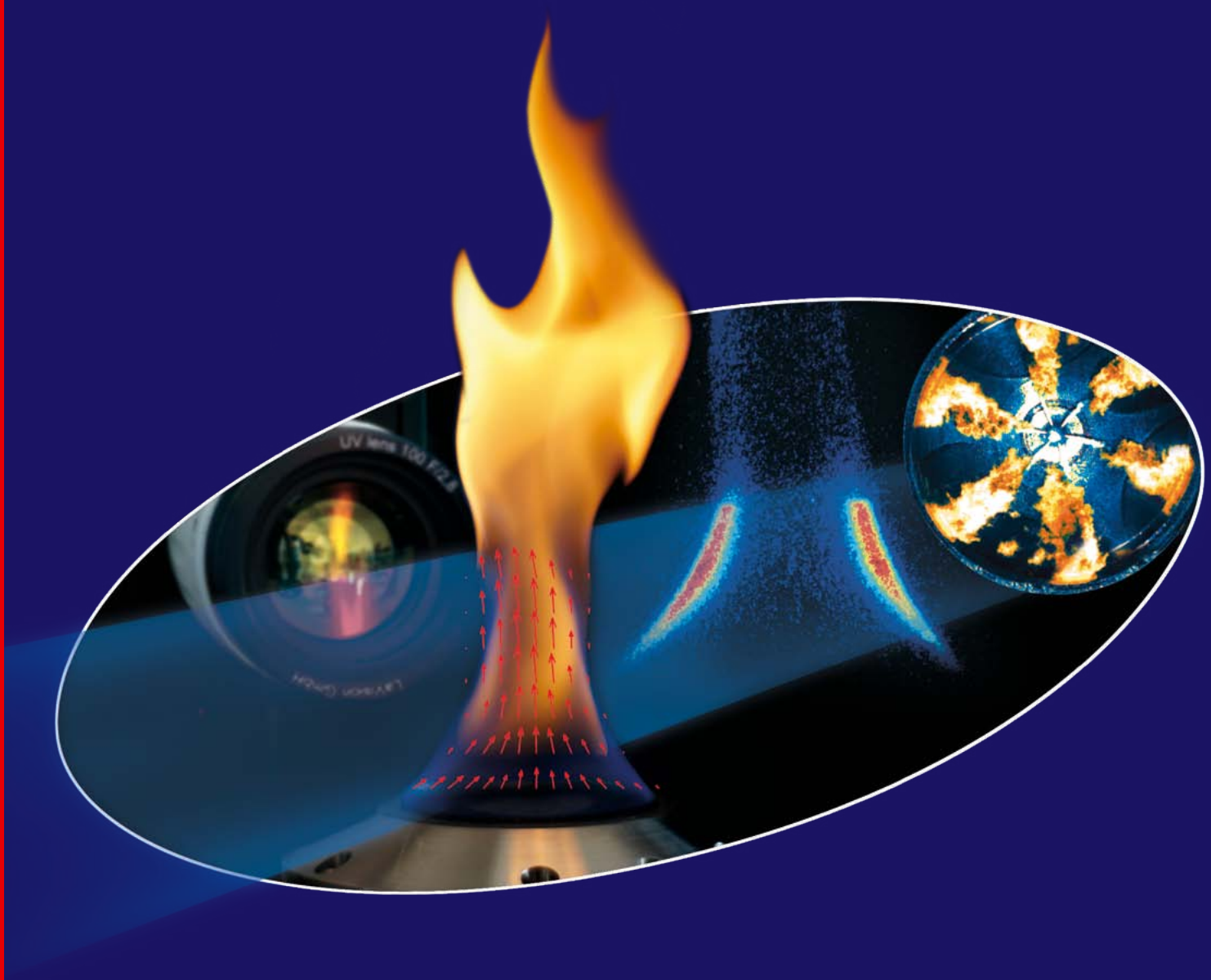


Focus on Combustion

Optical Measurement Solutions

LaVision

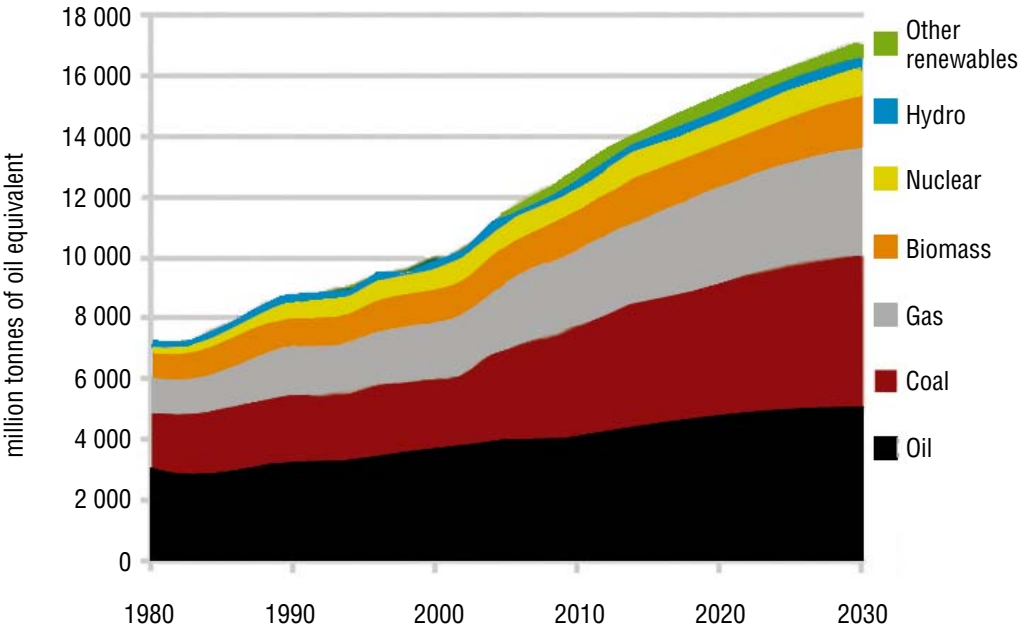
FOCUS ON IMAGING

Energy Challenges of Today

Developing industries and quickly increasing markets worldwide are continuously demanding an increased primary energy supply, reliable domestic production and flexible public transportation. Even though alternative technologies are a growing market and will gain relevance, conventional power generation from combustion will continue to hold a strong share of the energy mix for the next decades (see „world energy outlook“ below).

The diversity of fuels for power and heat generation with the stronger impact of renewable sources has been massively extended. Furthermore, requirements for energy efficiency and legislation on combustion generated pollutants have tightened. With a detailed understanding of the complex processes in combustion advances in combined measurement technologies are helping to meet the challenges of today and to develop the technology for the future.

World Energy Outlook



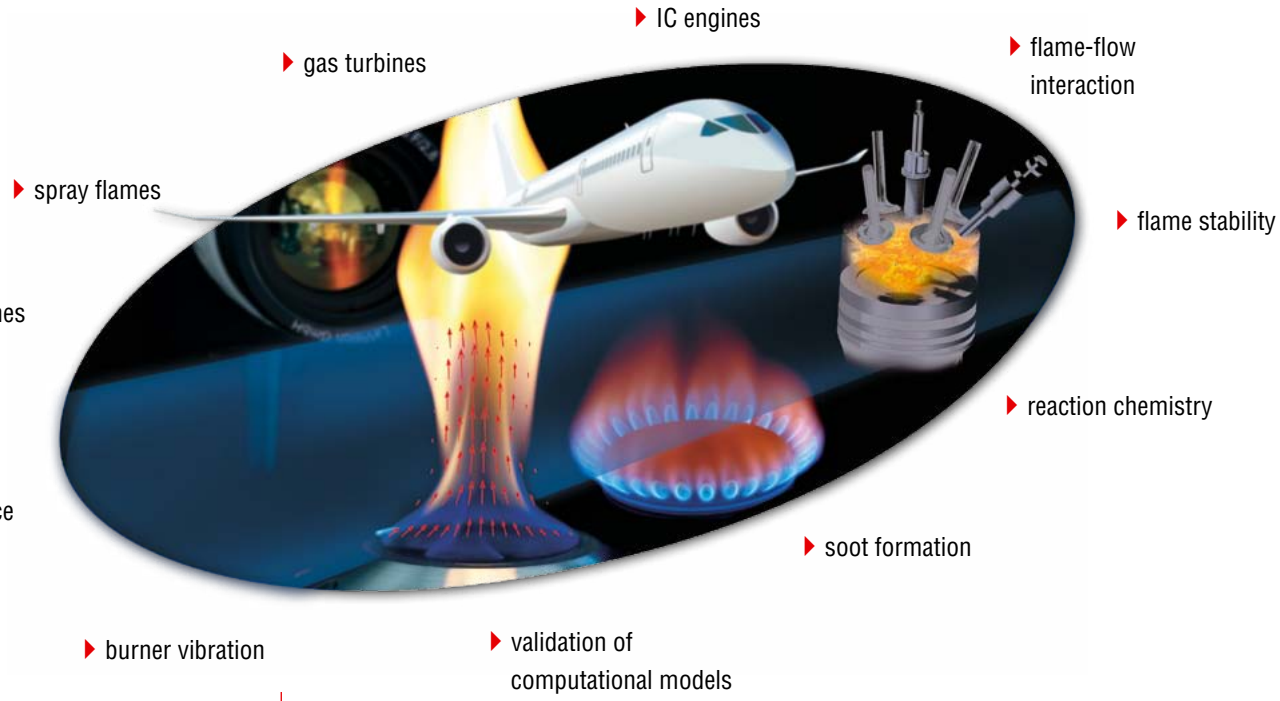
Prediction of future energy supply sources
© OECD/ IEA 2008

Advanced Combustion Diagnostics

Due to their non-intrusive nature, optical diagnostics offer unique capabilities for in-situ multi-parameter reactive flow field measurements even in the harsh environment of practical combustion systems. These can not be achieved using conventional, i.e. non-optical probe techniques. Optical diagnostics contribute significantly to the reduction of combustion generated pollution, particularly the greenhouse gases CO_2, CH_4 and H_2O.

LaVision's Expertise

LaVision has 30 years of **expertise** and experience in the field of combustion diagnostics.
Our **competence** is in offering the knowledge and the most modern technology of optical diagnostic tools. Our **strength** is the flexibility and the motivation to satisfy our customer's needs by providing the best measurement solution.

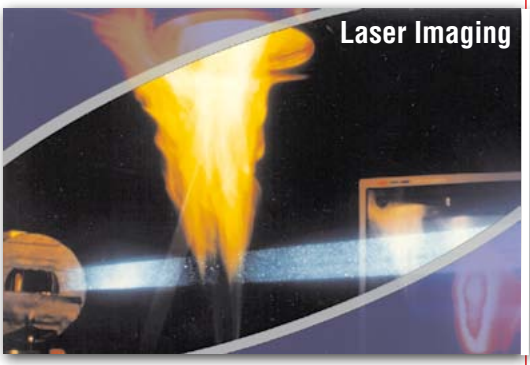


Advantages of LaVision's Laser-based Measurement Instruments

- in-situ
- nonintrusive
- instantaneous with high spatial and temporal resolution
- 1D, 2D or 3D imaging
- highly integrated (laser) imaging systems
- modular and flexible system setups for multi-parameter measurements

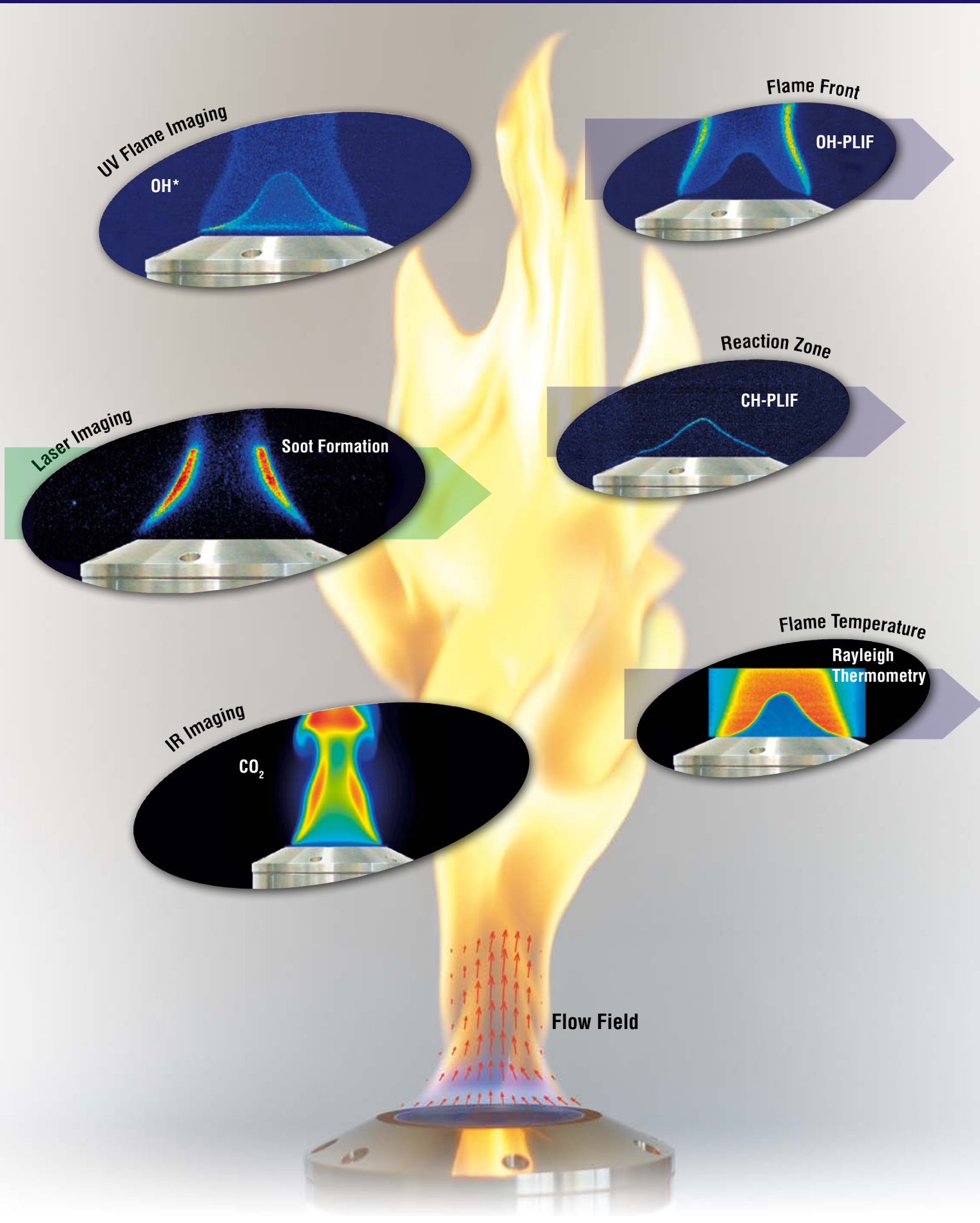
Imaging and Absorption Techniques

The realization of efficient and optimal combustion systems requires in-situ measurements and detailed understanding of complex gas dynamical processes. Laser imaging techniques such as Laser Induced Fluorescence (LIF), Laser Induced Incandescence (LII), Particle Image Velocimetry (PIV), Mie- and Rayleigh Scattering (RS), Spontaneous Raman Scattering (SRS) as well as Emission and Absorption Spectroscopy are well suited for this purpose allowing multi-parameter measurements with high spatial and temporal resolution in technical combustion systems.



Characteristics	Laser Imaging on Light Sheets	Flame Imaging Line-of-Sight	Absorption Path Integrated
(Multi-Phase) Flow Field	PIV		
Mixture Preparation	Fuel & Tracer PLIF		IR-Absorption
Flame Radicals	PLIF (OH, CH, NO ..)	Flame Emission	
Flame Temperature	Rayleigh, Raman, PLIF	IR-Thermography	IR-Absorption
Soot & Particulates	LII, Mie	Pyrometry	
Exhaust Gas (H_2O, CO_2)	Raman	IR-Imaging	IR-Absorption

LIF imaging= Planar LIF= PLIF


UV Flame Imaging
OH*
Flame Front
OH-PLIF
Reaction Zone
CH-PLIF
Laser Imaging
Soot Formation
Flame Temperature
Rayleigh
Thermometry
IR Imaging
CO_2
Flow Field

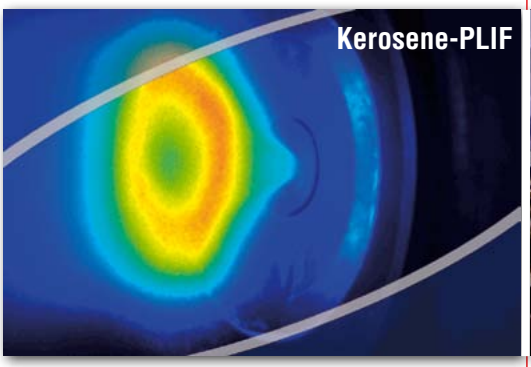
Resolving Mixing Processes

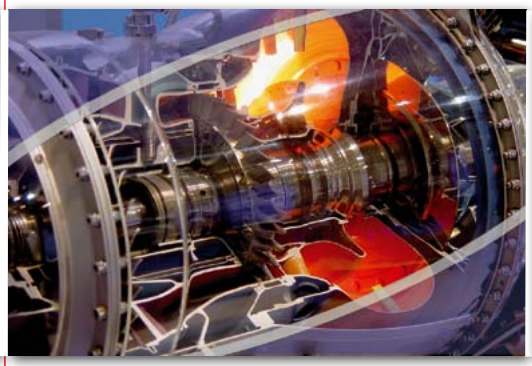
Liquid and Gaseous Fuel Distribution

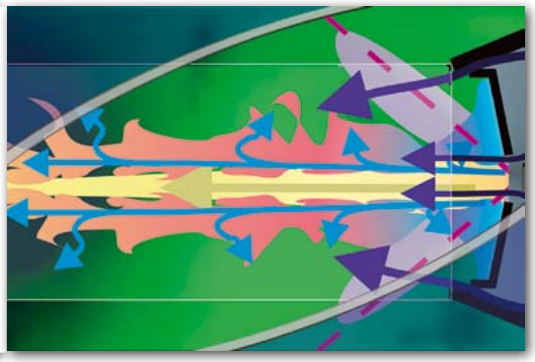
Driven by the continuous demand for increased fuel efficiency and improved performance the design of combustion devices requires detailed knowledge about the fuel preparation and mixing processes. A thorough analysis necessitates the use of advanced diagnostic tools which have to be capable of resolving the liquid and gaseous fuel distribution in a harsh environment sustaining highly transient flow and transport phenomena. Researchers and industries rely on the imaging systems from LaVision that enable versatile diagnostic applications: fuel distribution, mixture fraction, temperature and flow fields of liquid and gaseous fluids.

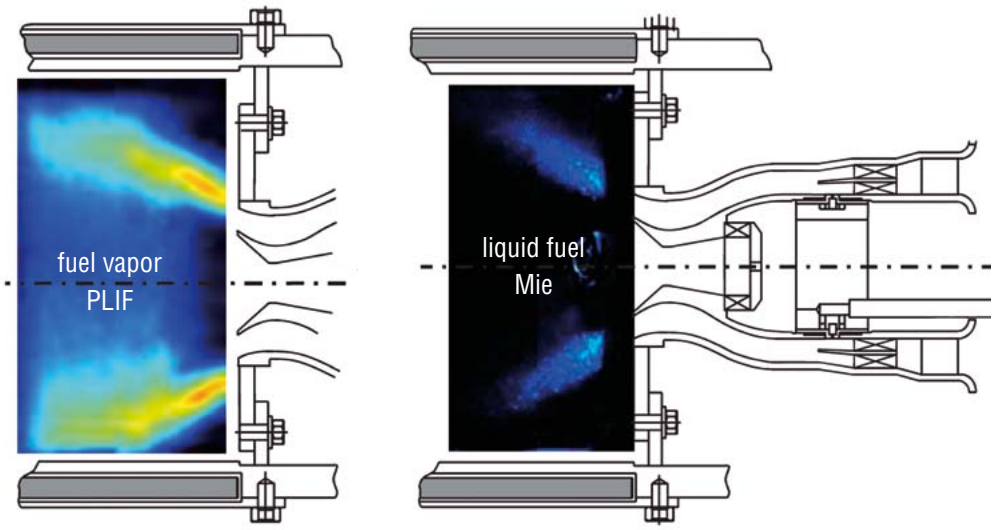
Features

- quantitative air-fuel mixing
- fuel injector patternation
- **heat transfer** in thermal flows
- fuel spray imaging and evaporation
- flow field in multi-phase flows









Courtesy of R. Fink et al., Technical University Munich, TUM

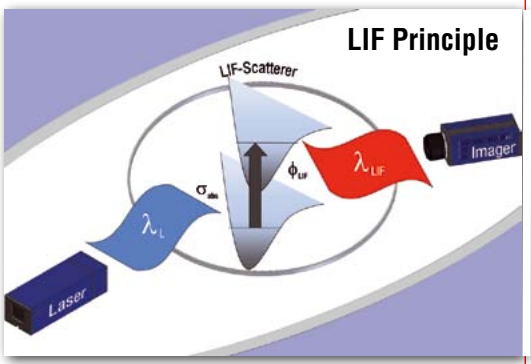
Fuel distribution inside a lean premixed prevaporized gas turbine combustor at 4 bar

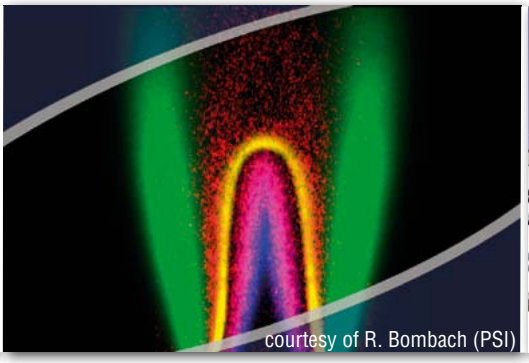
Energy Transformation

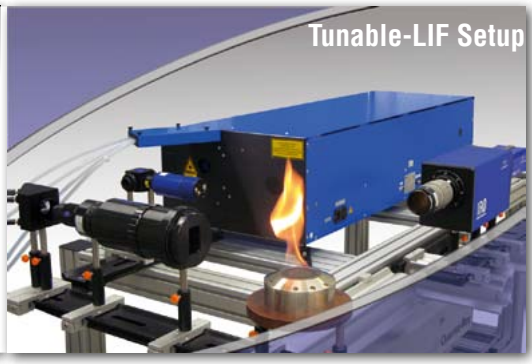
LaVision offers diagnostic solutions for the detection of reactive species. These systems can characterize the conditions inside the reaction zone of laminar and turbulent flames. The location of initial flame kernels and precursor species is identified via species selective detection of the chemiluminescence. Advanced diagnostics such as LIF enable instantaneous 2D imaging of important intermediate species in reaction kinetics like H_2CO, CH and OH.
LaVision's diagnostic tools furthermore utilize processes like spontaneous Raman scattering and Rayleigh scattering for simultaneous and quantitative measurement of temperature and all major species inside and outside the flame structure.

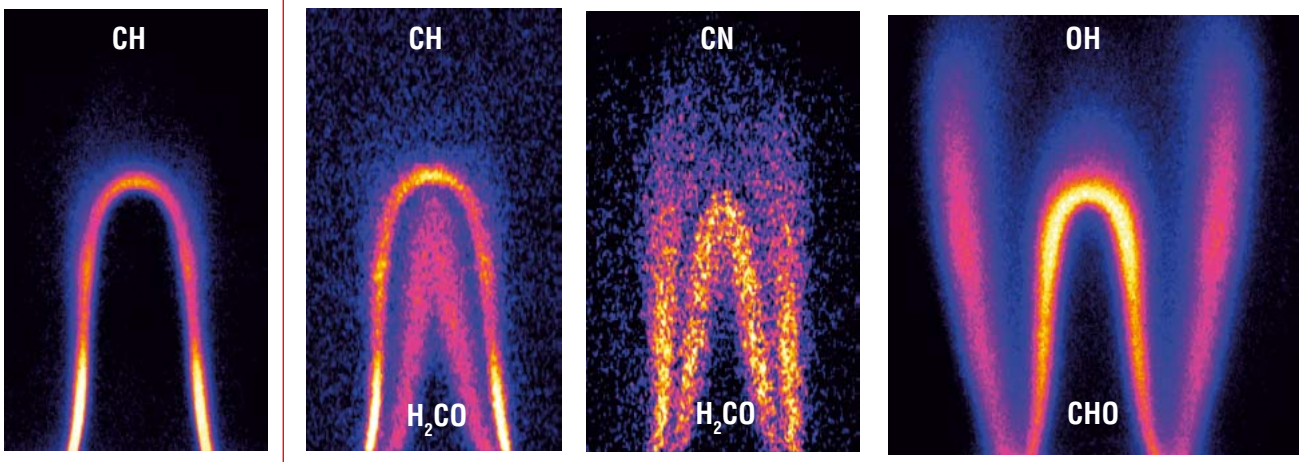
Features

- species selectivity and sensitivity in the lower ppm range
- instantaneous temperature fields
- identification of hot spots and reaction zone
- characterization of flame structure and stability









PLIF imaging of flame species in a Wolfard-Parker-Burner

Courtesy of Rolf Bombach,
Paul Scherrer Institut, Switzerland,
Appl. Phys. B 68, 1999

Analysis of Pollutant Formation

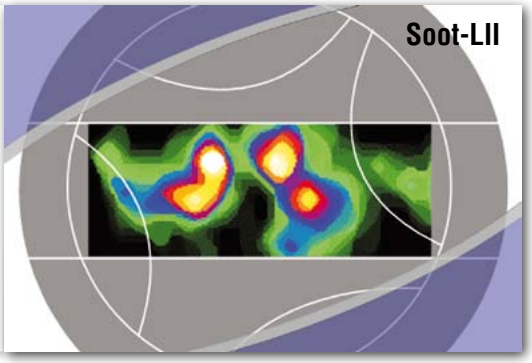
In-situ Imaging of Pollutants

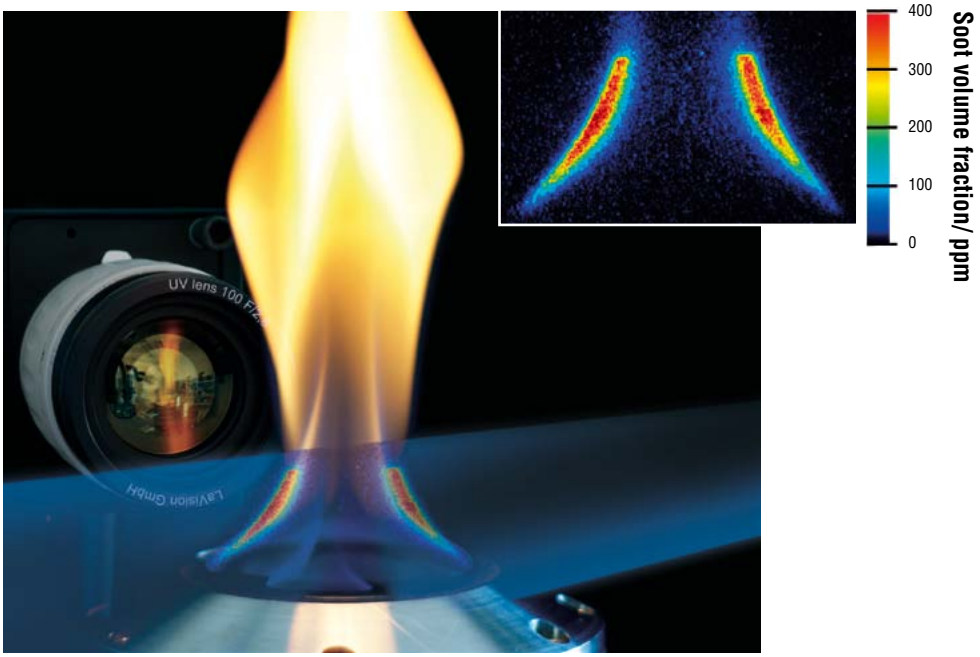
Combustion research must face the challenges of future legislation. A thorough understanding of reaction chemistry for the related post-combustion processes and the mechanisms of flame quenching is essential to reduce pollutant emissions.
LaVision offers laser based techniques that are able to resolve the distribution of prominent pollutants like NO, CO or SO_2 as well as particulate matter. Self-emission of a sooting flame is utilized to determine particle temperatures applying **pyrometry**. Advanced diagnostics like Laser Induced Incandescence are capable to quantify the size and volume fraction distribution of soot particles in both, the hot flame front and in the cold exhaust gas.

Features

- details on NO formation
- soot distribution (soot volume fraction) and primary particle size
- soot temperature


courtesy of K. Geigle (DLR)





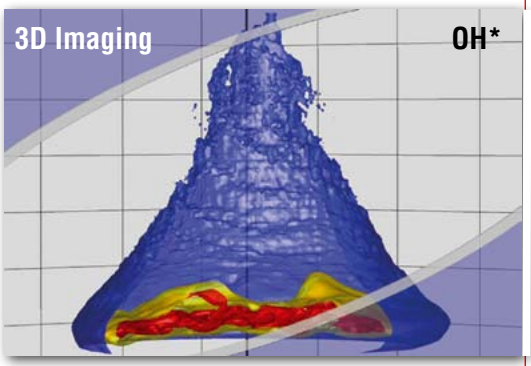
Distribution of soot volume fraction in a laminar diffusion flame

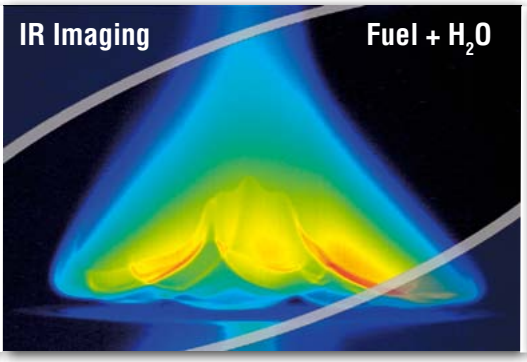
IR Imaging

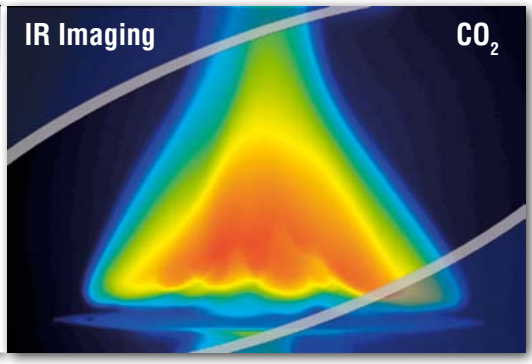
Besides the insight into the details of reaction kinetics in combustion it is the integral view that contributes to the understanding on important features like ignition, flame structure and stability. LaVision is offering this global view on combustion via infrared (IR) imaging of the major relevant species, such as CO_2, H_20 and hydrocarbon based fuels. Furthermore, IR imaging introduces the capabilities of **thermal imaging** and active **IR absorption**.
By providing IR technology to the scientific community and industrial partners, LaVision maintains the same system integration and performance as for standard imaging systems.

Features

- detection of major combustion species
- thermal imaging of gases, particulate matter and combustor surfaces
- dynamic and flexible image synchronization on external events



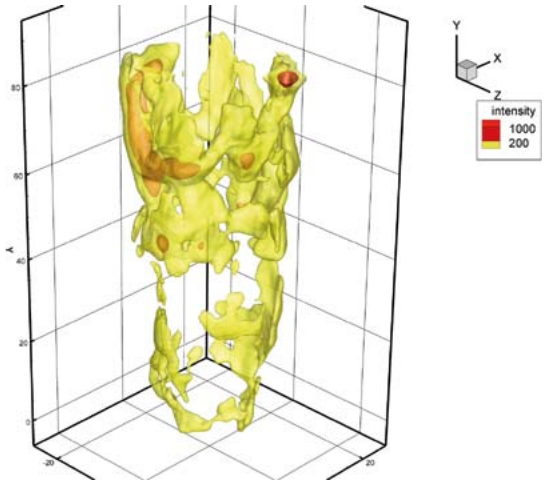




3D Flame Imaging

Volumetric flame imaging based on **tomographic reconstruction** gives insights into the complex 3D-distribution of flame species. While multi-cameras are used in parallel to reconstruct the instantaneous 3D flame structure, time-averaged 3D flame imaging is possible with only one camera collecting consecutively the flame emission from multiple views.

Courtesy of Weinkauff et al., TU-Darmstadt, 17th Int. Symp. on Applications of Laser Techniques, Lisbon, 2014



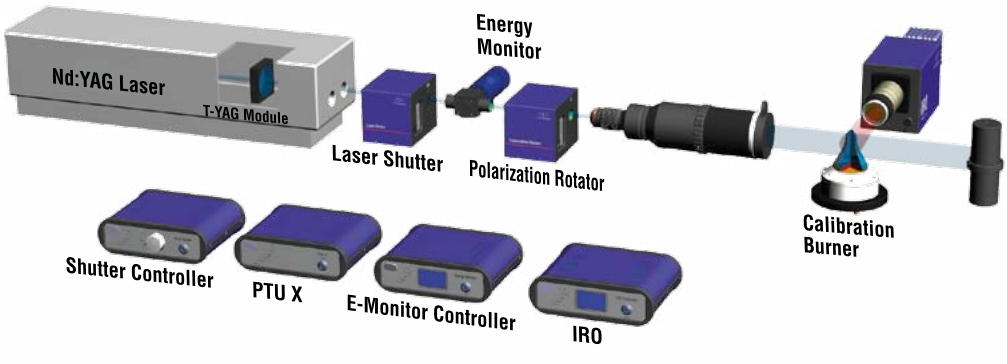
movie and more

Features

- 3D-flame structure in all details
- volumetric distribution of the flame radicals OH*, CH*, …

Modular and Upgradable Laser Imaging Solutions for Combustion Research

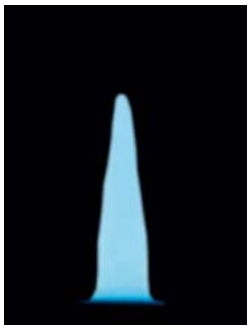
LaVision's **FlameMaster** laser imaging systems are designed for multi-parameter measurements with high spatial and temporal resolution in flames. The systems provide in-situ and online flame imaging as well as quantitative information about species (particle) concentration, gas composition and flame temperature.



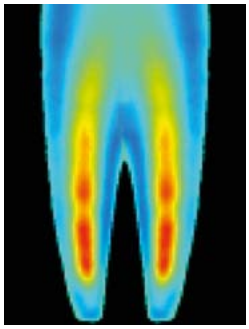
FlameMaster Multifunctional

system supporting the following flame imaging applications:

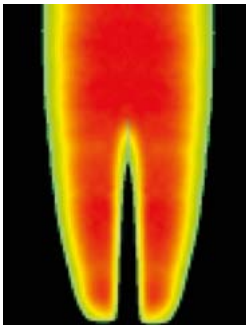
***CH_4**-air flame*



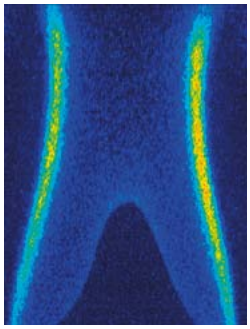
***CH_4** with Tracer-LIF*



***OH-LIF** with T-YAG™*



***Temperature** with Rayleigh*



***Soot** with LII*

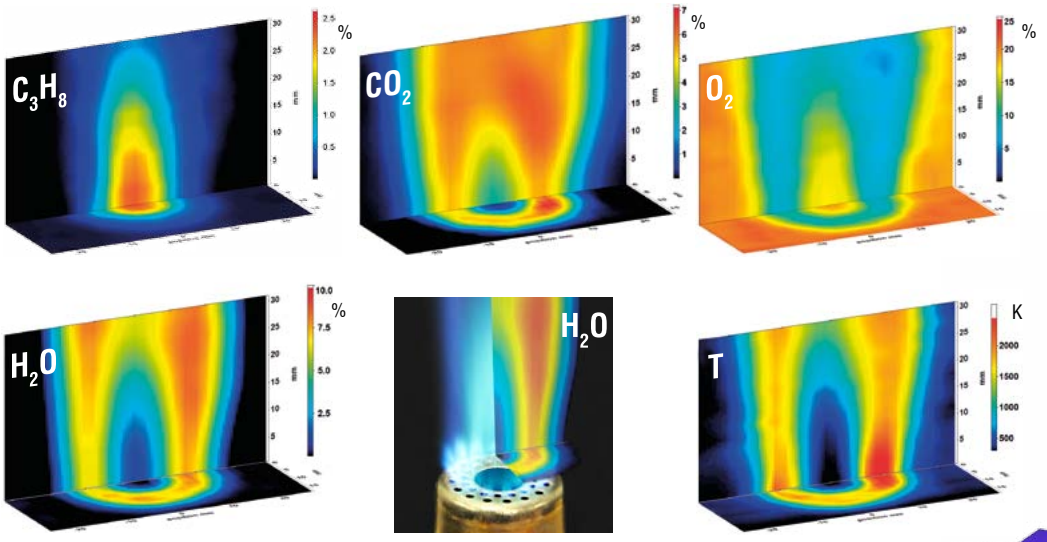
FlameMaster Application Matrix

The **FlameMaster** application matrix shows the imaged combustion parameter in combination with the applied laser imaging technique and **FlameMaster** system setup. For each application a dedicated set of hardware and software modules is provided allowing straightforward imaging upgrades for different flame imaging applications.
The intelligence of the **FlameMaster** laser imaging systems is concentrated in LaVision's powerful timing and synchronization unit **PTU X** and the versatile software platform **DaVis**.

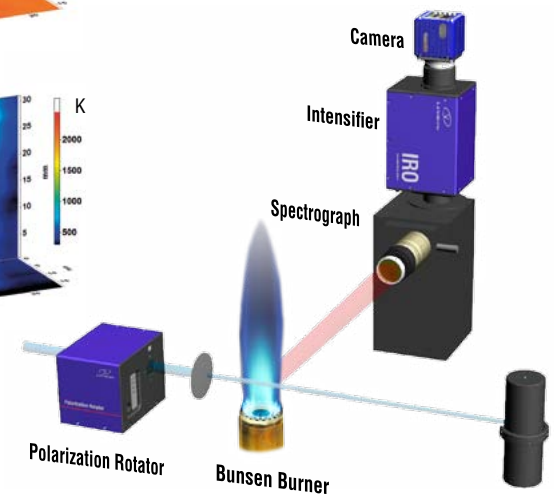
Tunable LIF	Flame Species: OH, NO, CH.....with LIF
Raman	Flame Composition Flame Temperature
Multifunctional	Fuel (Tracer) LIF Formaldehyde LIF OH-PLIF with T-YAG Rayleigh Thermometry Soot with LII

FlameMaster Raman

LaVision's **FlameMaster** Raman system measures simultaneously all major species concentrations together with flame temperature along a line focus (1D). Scanning the line focus through the flame generates 2D or even 3D views of the flame composition.

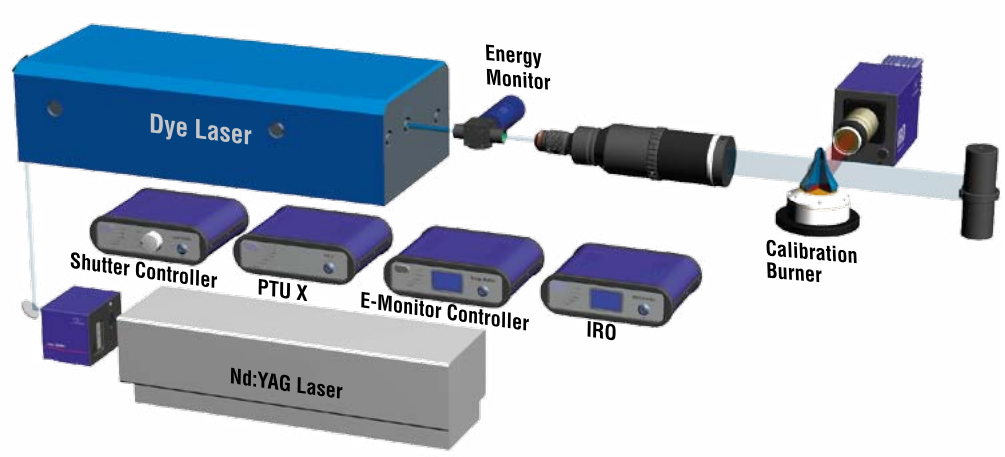


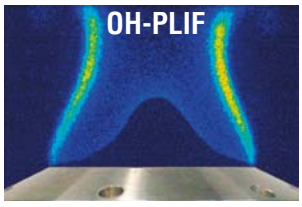
Raman imaging setup

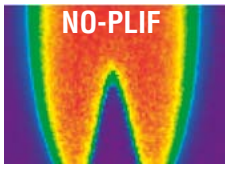


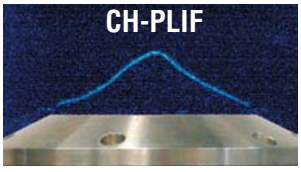
FlameMaster Tunable LIF

system setup for flame species and radicals.









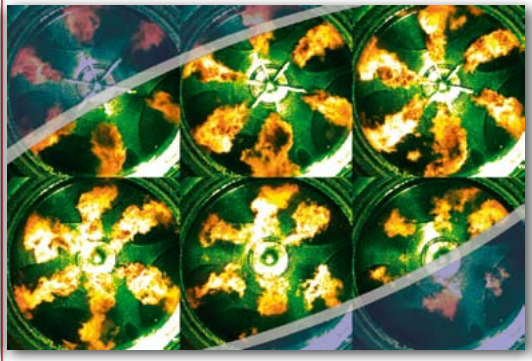
For the detection of all LIF-active diatomic flame species such as OH, NO, CH, CN, CO a dye laser is added to the multifunctional **FlameMaster** system. The precise dye-laser wavelength tuning for the selected diatomic molecule is under **DaVis** control. For concentration calibration of the LIF signals a calibration burner is used.

Time-resolved (Laser) Imaging

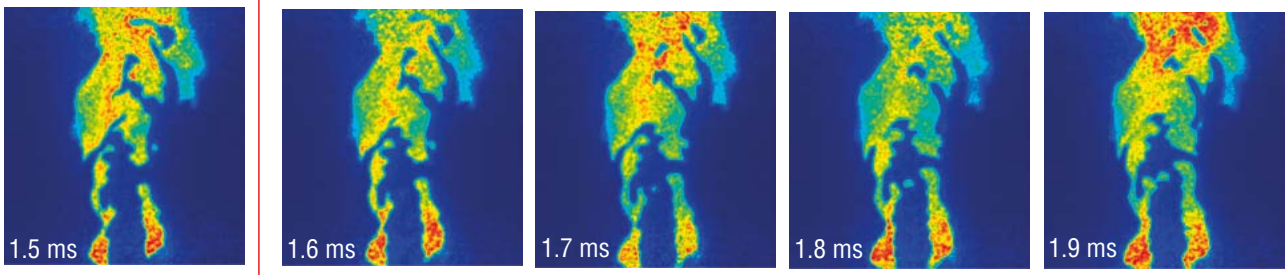
Most mixing and combustion phenomena are highly turbulent processes where diagnostic tools require high spatial and temporal resolution. Truly time-resolved laser imaging requires repetition rates in the kHz-range to visualize the development of unsteady or statistical phenomena such as flame vibrations. These diagnostic tools have become available with the development of powerful laser sources and sensitive detection units, like intensified CMOS cameras.

Features

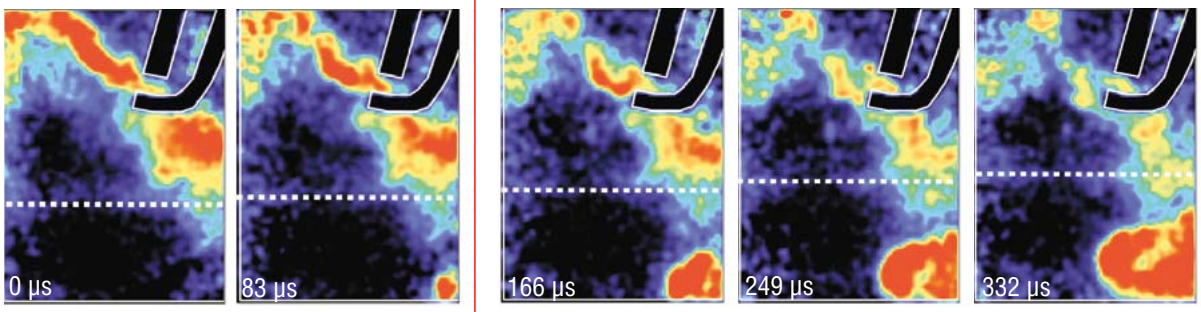
- modular image intensifiers: The modular design adds UV-sensitivity and short exposure times (fast gating) to the CMOS camera. Weak signals of LIF processes are substantially enhanced
- state-of-the-art tunable dye laser for highest repetition rates



High repetition rate (kHz) laser imaging allows the investigation of transient combustion phenomena like flame ignition or local flame extinction.



High-speed (10 kHz) OH-LIF imaging



Courtesy of V. Sick et al., University of Michigan

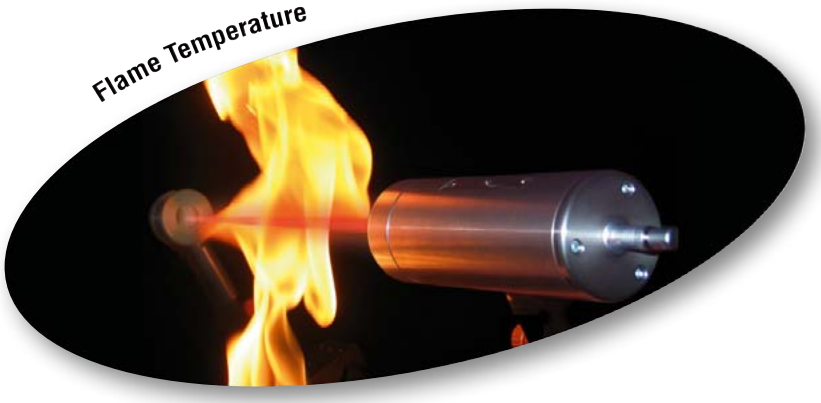
High-speed (12 kHz) fuel LIF imaging at spark plug

LaVision's Optical Sensor Systems

LaVision offers three types of optical sensor systems for combustion diagnostics. They are capable of time resolved (real-time) point measurements for mixture characterization in internal combustion (IC-) engines, flame temperature and sensitive soot detection:

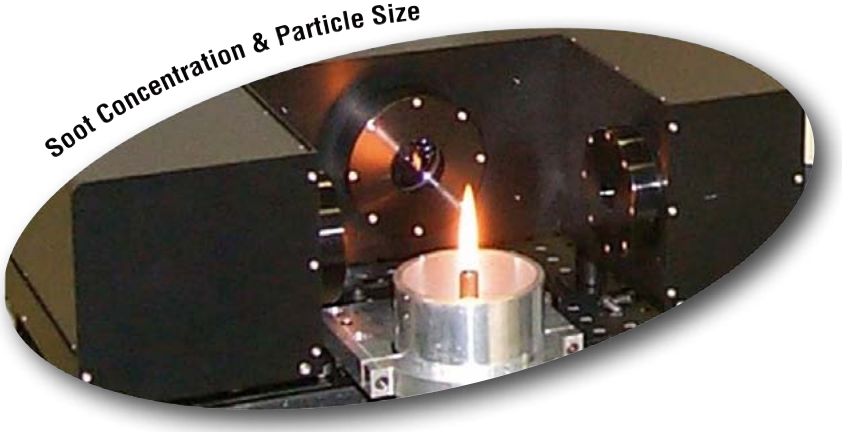
- The ICOS and TDLAS sensors are keyhole detection devices based on IR-absorption allowing in-situ measurement of concentration and temperature at high data rates.
- The LII soot sensor measures soot volume fraction and primary particle size in-situ as well as in the exhaust line for continuous emission control.

Internal Combustion Optical Sensor (**ICOS**) systems for ultra fast crank angle resolved measurements of fuel and exhaust gas concentration or gas temperature together with engine pressure indication at kilohertz data rates.

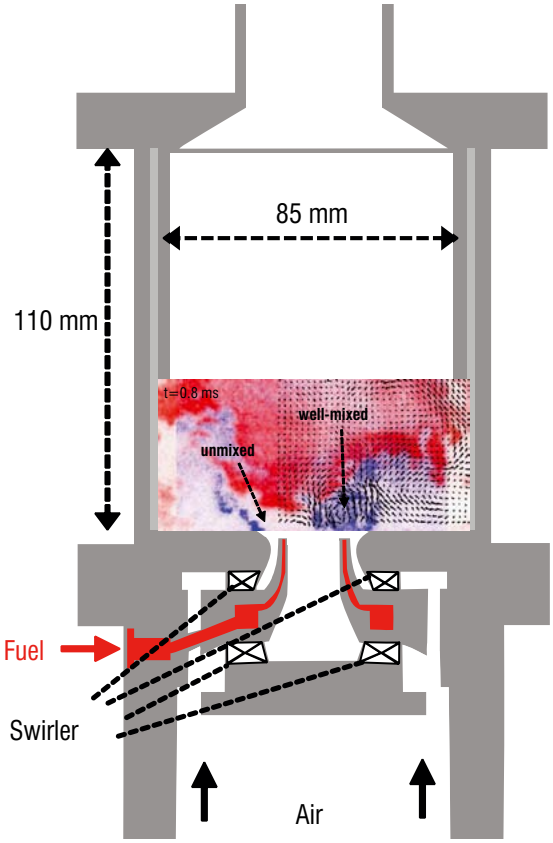


Flame temperature sensor based on tunable diode laser absorption spectroscopy (**TDLAS**) of water. Flame temperatures up to 2200°C are measured in-situ at a sampling rate of 200 Hz.

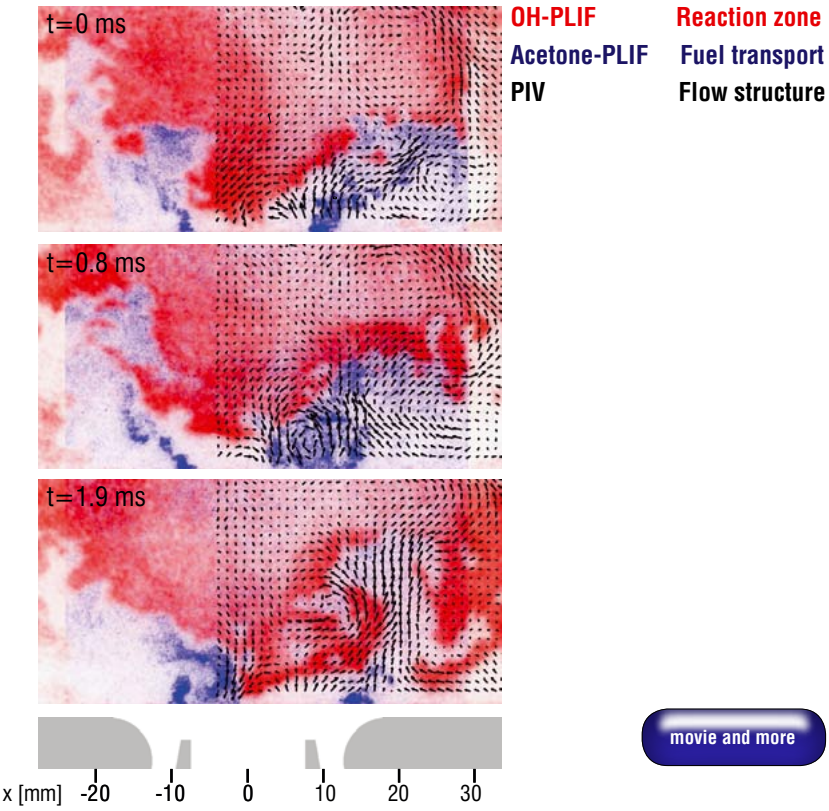
Most advanced Laser Induced Incandescence instrument (**LII-300/ 200**) for particulate matter measurements. Specifically designed for accurate, non-intrusive, and temporally resolved in-situ measurements of soot concentration, specific surface area, and primary particle diameter in the exhaust gas stream.



Time-resolved laser imaging of fuel-air mixing, reaction zone visualization and flow field in a turbulent swirl flame inside a gas turbine model combustor



Simultaneous high-speed (10 kHz) laser imaging:



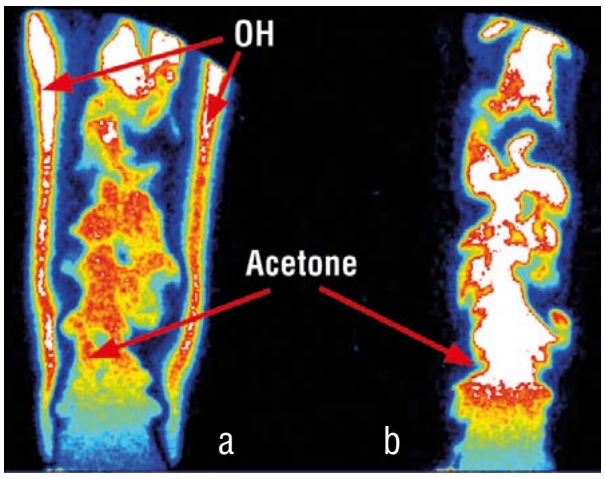
Courtesy of M. Stöhr et al., German Aerospace Center (DLR), Proc. Combust. Inst. (2014)

Simultaneous imaging of fuel and reaction zone using FlameMaster multifunctional system

A standard Nd:YAG laser upgraded with an intra-cavity tuning device (**T-YAG™-module**) allows the simultaneous detection of fuel (acetone) LIF and OH-LIF. One intensified camera allows the imaging of both LIF signals at different locations in the flame.

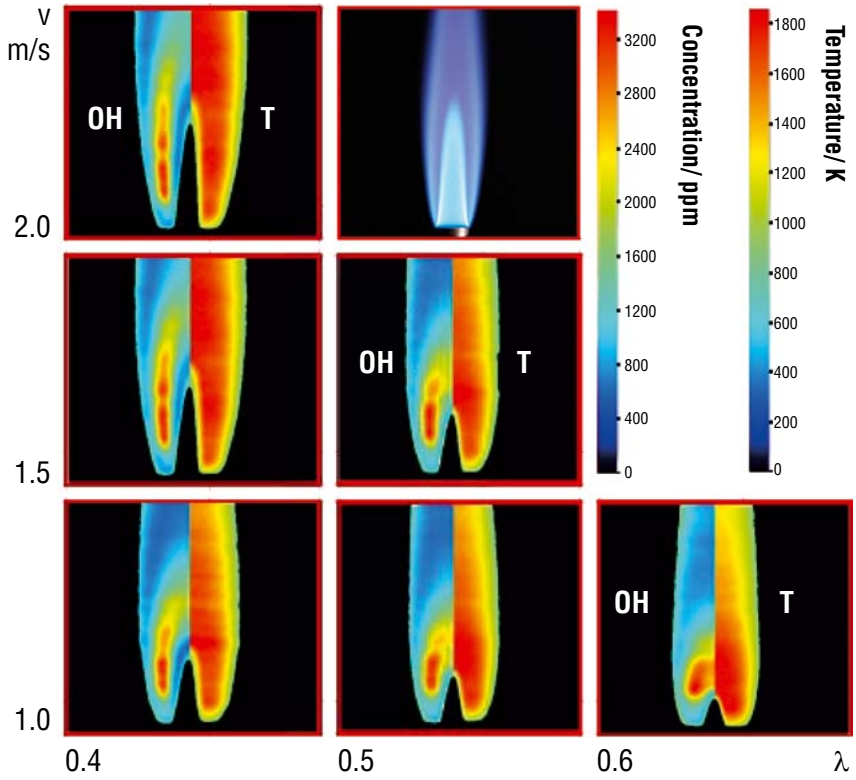
Single-shot distribution of OH-radicals and acetone in a turbulent Bunsen burner flame.

Picture a shows the combined OH and acetone LIF signals, while in picture b the laser was tuned away from the OH-line and thus only the acetone signals are produced.



Courtesy of V. Sick et al, University of Michigan, Appl. Phys. B 79, 2004

OH concentration and flame temperature in a rich methane-air flame

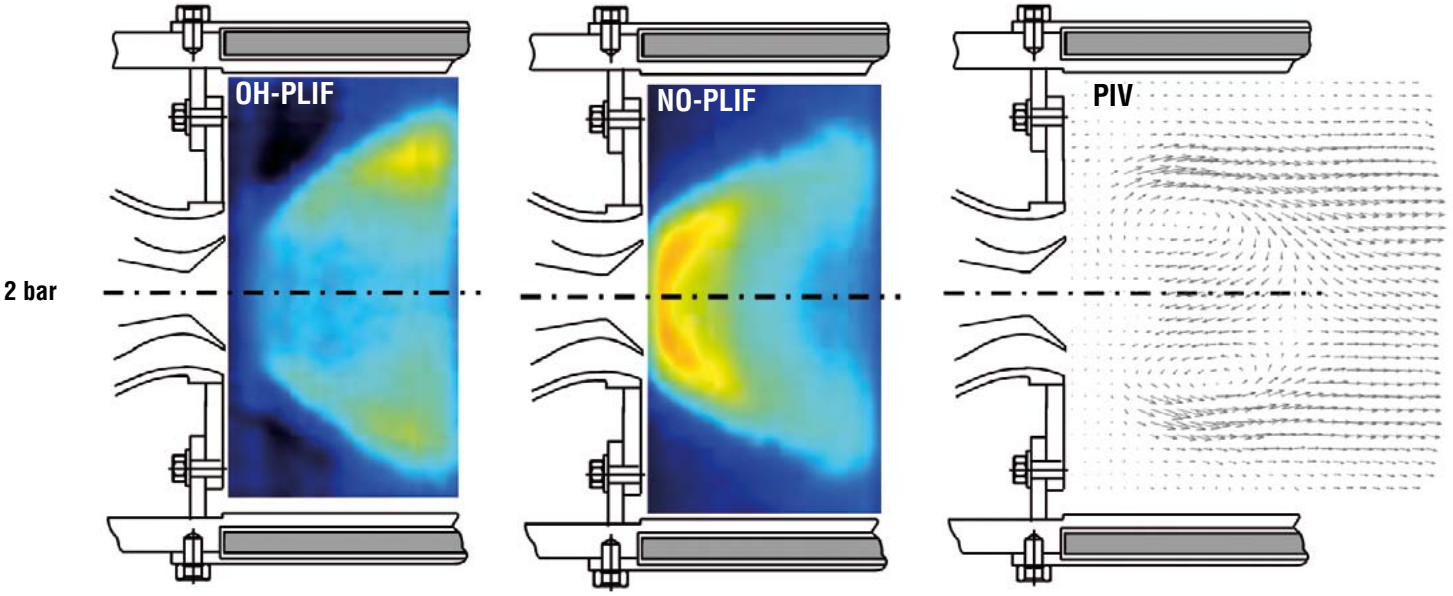


Courtesy of S. Marengo et al., SSC, Italy

OH concentration (left side) and flame temperature T (right side) for different stoichiometries and flow velocities of a methane-air diffusion flame.

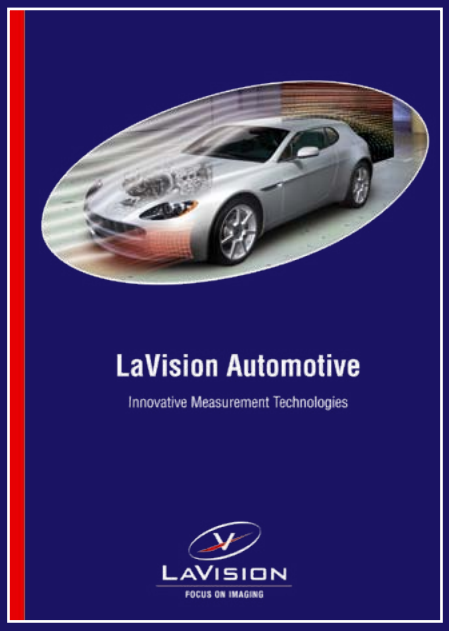
A tunable Nd:YAG laser (T-YAG™) was used for UV Rayleigh thermometry and OH-PLIF imaging.

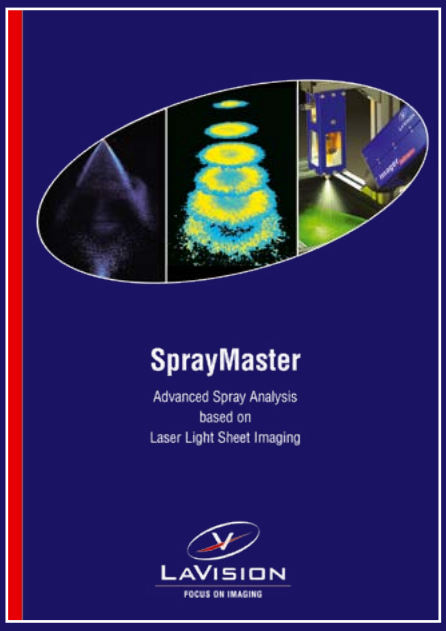
Multi-parameter laser imaging inside a gas turbine combustor

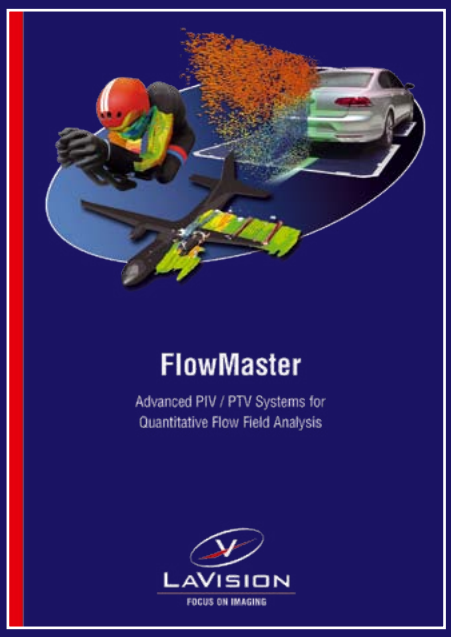


Courtesy of R. Fink et al.,
Technical University Munich, TUM

Related Product Information







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