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للعلوم والتقنية
King Abdullah University of
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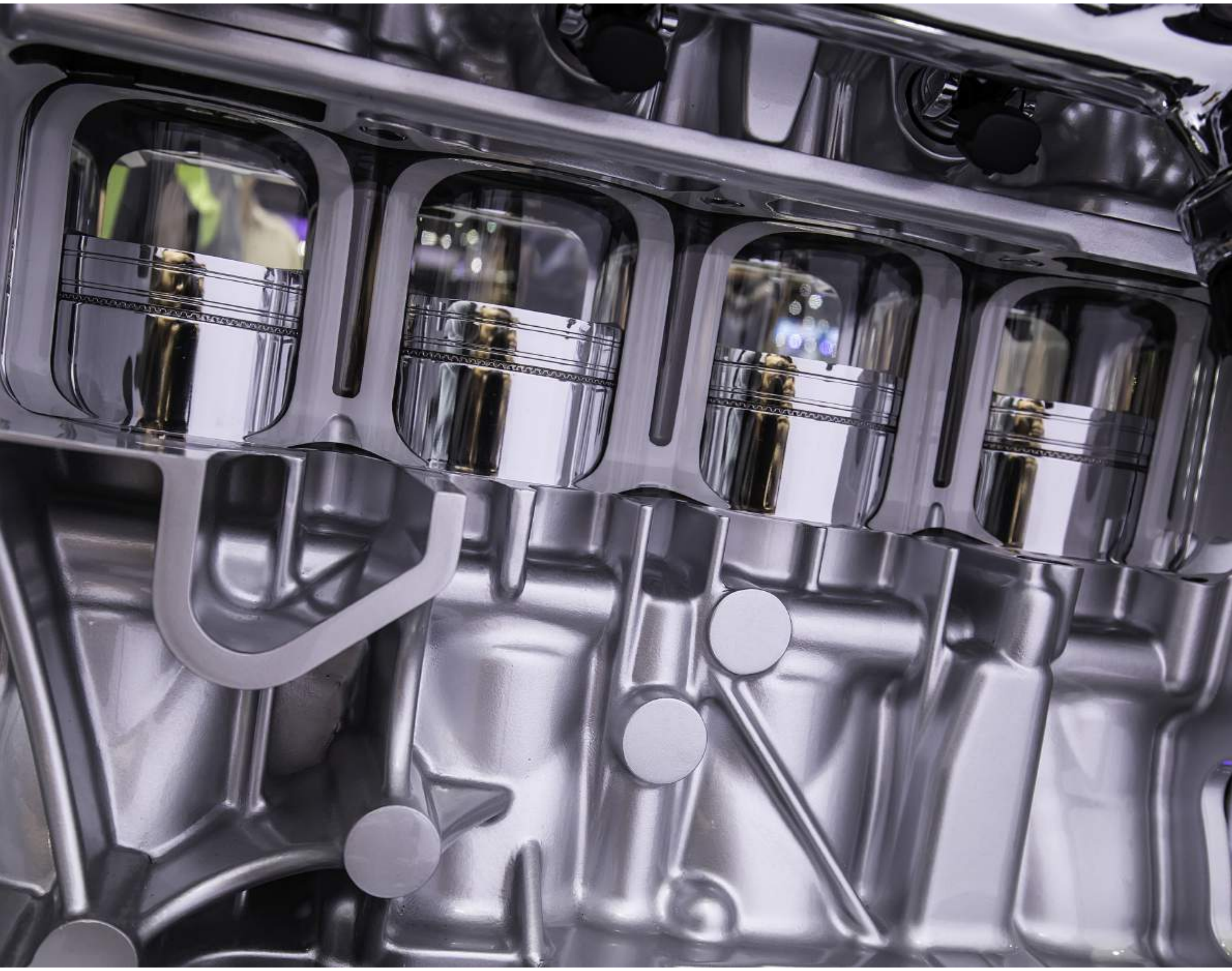
KAUST



SPRING 2016

CCRC Clean Combustion Research Center

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From the Director:

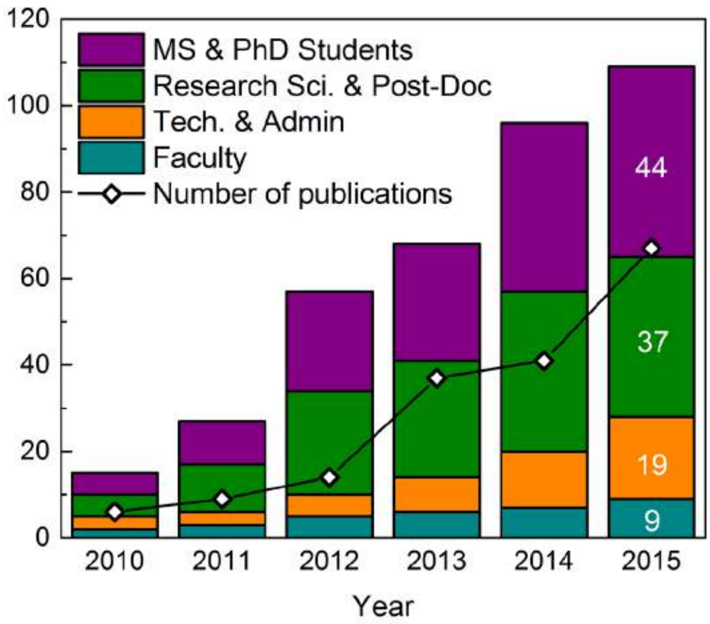
The Clean Combustion Research Center Newsletter has been initiated for the purpose of sharing the activities and opportunities of the Center with colleagues and students of combustion research. The Center is one of eleven facilities within KAUST that broadly research food, water, energy and the environment. CCRC research focuses on chemical kinetics experiments and modeling, high fidelity numerical simulations, development of diagnostics, soot formation, high pressure combustion, plasma-assisted combustion and fuels and surrogates. We are also enjoying rapidly growing expertise in internal combustion engine research.

The Kingdom of Saudi Arabia relies on the export of crude oil as its primary source of revenue. However, due in large part to energy intensive demands for air conditioning and desalinated seawater, the Kingdom internally consumes approximately a third of the ten million barrels produced daily. One of the most important research objectives of the Center is to maximize the efficiency of power generation utilities and minimize emission of pollutants, including NOx, SOx, and particulate matter.

We are working closely with Saudi Aramco on liquid transportation fuels for next generation IC engines, focusing primarily on straight-run naphthas for use in advanced compression ignition engines. These studies include everything from mechanism development and validation and surrogate formulation to single cylinder research engines operating in various partially premixed combustion modes. In conjunction with Saudi Aramco, we are also investigating gasoline compression ignition engines and pre-ignition prevention in boosted GDI engines. Industrial projects on flame quenching are being conducted with Boeing; with GE we are investigating high pressure oxidation characteristics of light Arabian crudes; and the formation of cenospheres from burning heavy fuel oil is an ongoing study with Alstom and the Saudi Electric Company.

The Clean Combustion Research Center was established in 2009, with Professor SukHo Chung as its inaugural Director. In just over five years, Prof. Chung designed and outfitted more than 2000 m^2 of lab space and recruited six faculty members. Today the Center has nine faculty members and over 50 graduate students.

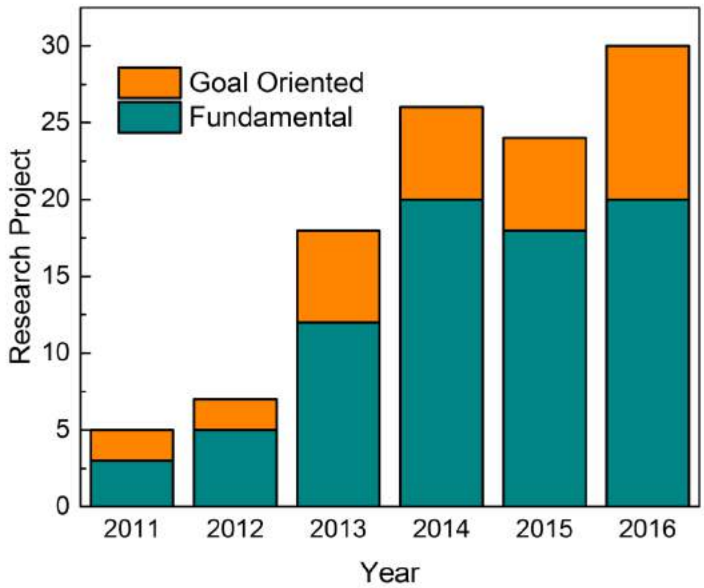
William L. Roberts



CCRC Personnel Statistics Since 2010

OVERVIEW

The Clean Combustion Research Center (CCRC) was founded in September 2009 with two faculty members, four technicians, three research fellows, and three PhD students. Today, the CCRC has grown to include more than 100 people. During these six years, the CCRC conducted two meetings of the Saudi Arabian Section of the Combustion Institute (SAS-CI), an inaugural workshop, and a workshop on turbulent combustion. The number of its journal publications per year increased from six in 2010 to 67 in 2015. Two thirds of our projects are in fundamental research, while the amount of our goal-oriented research is continuously broadening in size and scope.

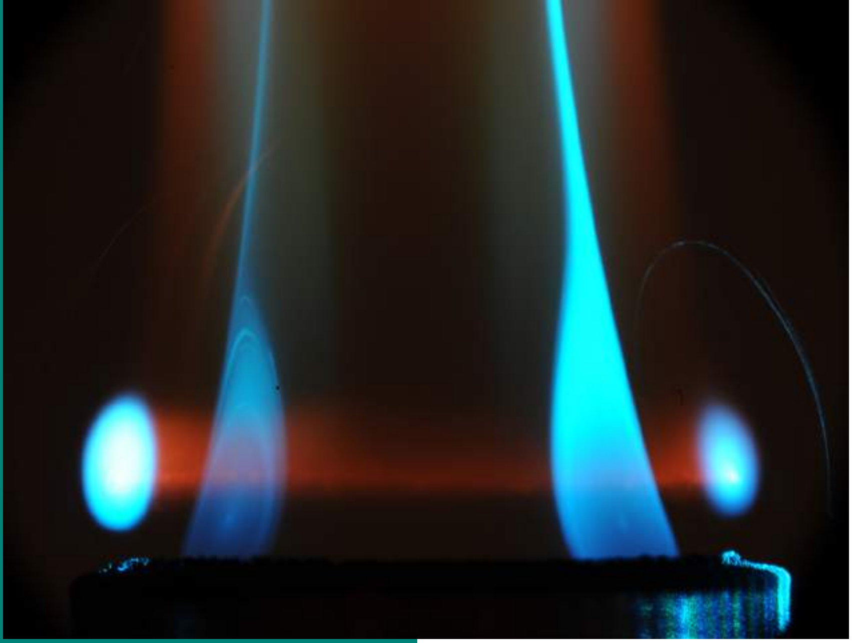


CCRC Research Projects Since 2010

CCRC FACILITIES

The CCRC has experimental and computational facilities to study a range of fundamental and applied combustion problems, including:

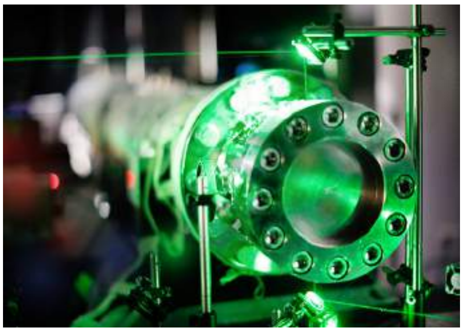
- Chemical kinetics and combustion chemistry
- Flames, plasmas and new concepts
- High pressure and turbulent combustion
- Engines and fuels
- High fidelity combustion simulation



Electrically Generated Vortices in a Laminar Jet Diffusion Flame

CHEMICAL KINETICS AND COMBUSTION CHEMISTRY

Fundamental research on chemical kinetics and reaction mechanisms is conducted in two laboratories in the CCRC. Current emphasis is on development of chemical kinetics mechanisms for transportation fuels using well characterized experiments. Experiments include measurement of ignition delay times, elementary reaction rates and speciation profiles. These laboratories feature both low and high pressure shock tubes and a rapid compression machine; combined, these facilities can probe the operating conditions of many practical energy conversion systems.



Laser Absorption Spectroscopy for Species Measurement in a Shock Tube

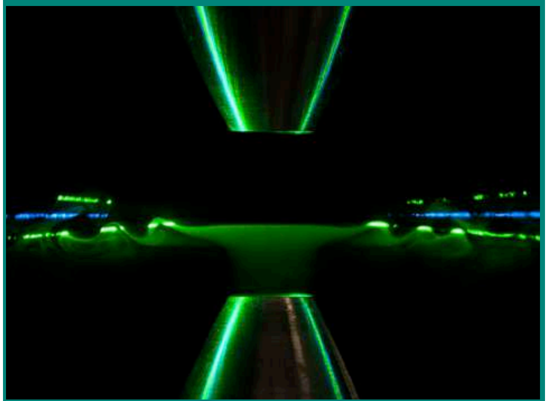
Jet stirred and micro flow reactor studies are also employed to probe combustion chemistry and pyrolysis of hydrocarbon and oxygenated fuels. These instruments can be coupled with state of the art laser diagnostics that cover a wide range of spectra (UV to mid-IR); they are also compatible with sampling apparatuses such as molecular beam (MB), time of flight (TOF), mass spectrometers. Our combustion chemistry research is also conducted at various synchrotron light sources by way of collaborative beamtime with researchers in the US, Europe and China.

FLAMES, PLASMAS AND NEW CONCEPTS

The CCRC has diverse experimental facilities focusing on multiple challenges in laminar and turbulent combustion. Investigations focus mainly on the dynamics of flame response within laminar or turbulent flow fields in order to examine interactions between flame chemistry and dynamics of the surrounding flow field.

Experiments are designed to investigate different aspects of laminar and turbulent flame characteristics from a fundamental standpoint. For instance, high pressure laminar and turbulent burning characteristics are studied within a constant volume combustion vessel. Additionally, various burner configurations (e.g., Coanda, coflow and counterflow), are employed to explore flame attributes for diverse applications corresponding to jet flames, diffusion flames and nanomaterial synthesis. Another major area of focus is the study of combustion instabilities and effects of AC electric field and non-thermal plasmas on flame dynamics and soot formation.

These experiments are integrated with state of the art laser diagnostics, including a high speed PIV-OH system for characterizing chemistry-flow field interaction. Furthermore, optical diagnostics such as as two color planar induced fluorescence (PLIF) of OH and coherent anti-stokes Raman spectrospoy (CARS) are used to gain more insight into flame dynamics.



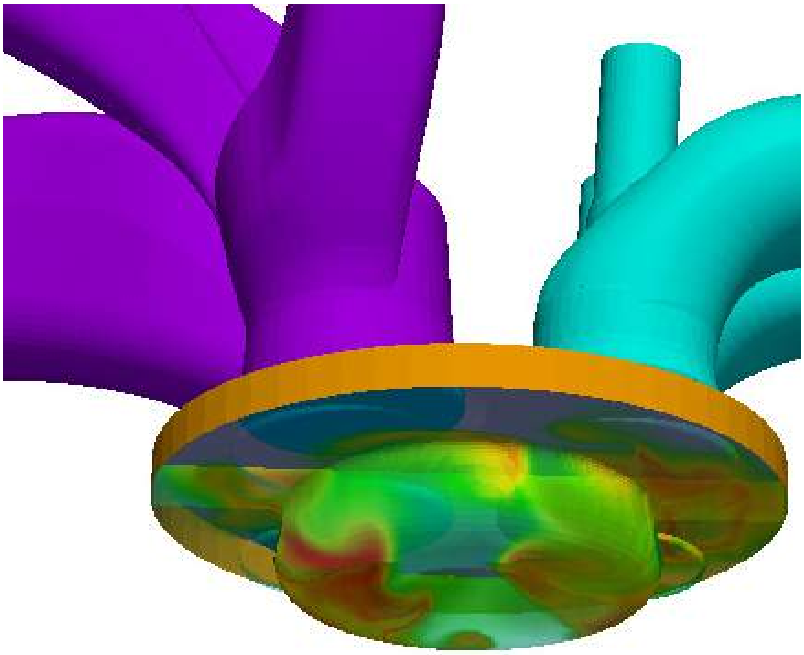
Flow Field Visualization in a Laminar Counterflow Burner

HIGH PRESSURE AND TURBULENT COMBUSTION

Our high pressure and turbulent combustion laboratories are equipped to develop understanding of fundamental combustion behavior and pollutant formation kinetics at higher pressures and Reynolds numbers, relevant to internal combustion engines and gas turbines. The labs are designed for large scale approximation of practical combustor operation with very high Reynolds number flames.

Exceptional diagnostic capabilities are available for the study of reactive species, soot formation, temperature, and heat release rates at high pressures (up to 45 bar), and high air flow rates (up to 0.16 Kg/s). Current experiments investigate diverse aspects of combustion, and new equipment can be easily accommodated by the flexible design of the lab. Present research is examining a range of conditions at higher pressures, including the interaction of turbulence and chemistry in diffusion flames, with a focus on soot formation. Additional experiments include autoignition and combustion instabilities at very high pressures.

Laser Based Soot Measurement in a High Pressure Ethylene Coflow Diffusion Flame



High Fidelity Simulation of Fuel Combustion in a Partially Premixed Compression Ignition Engine

COMPUTATIONAL FACILITIES

CCRC researchers have access to a number of computational facilities, including workstations, computer clusters and Shaheen II, KAUST's new Cray XC40 system; the International Supercomputing Conference (Frankfurt, Germany) named it the seventh fastest supercomputer in the world. This unique facility features nearly 200,000 processor cores, 17.6 petabytes of disk storage, and more than 790 terabytes of memory.

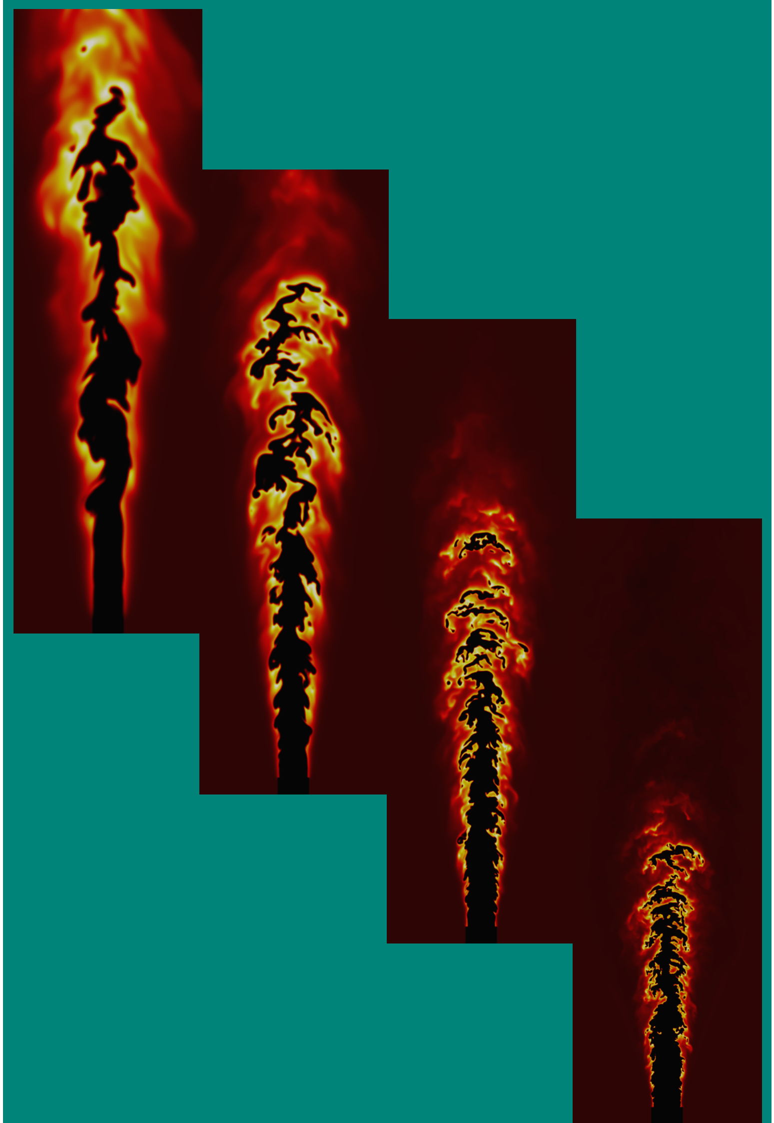
Shaheen II performs large simulations which have been unattainable in the past for combustion problems ranging from turbulent premixed flames at large Reynolds number to soot formation in nonpremixed flames, engine simulations, quantum chemical kinetic rate calculations, and uncertainty quantification for combustion.

ENGINES AND FUELS

Laboratories for studying engines and fuels are equipped with state of the art engine technology from AVL. A variety of engine test equipment includes research engines, dynamometers, engine controllers, emission analyzers, diagnostic equipment and exhaust measurement systems. The laboratory boasts a wide range of crank-angle resolved exhaust gas analyzers, a high-end emission bench for both certification and R&D emissions tests, a smoke meter for combustion particulates from internal combustion engines, a soot sensor for continuous measurement of low soot concentrations in diluted exhaust gas, a gravimetric measurement of combustion particulates, an FTIR system for measuring a range of exhaust gas species, and a CO/CO_2 analyzer.

Four single cylinder research engines are available in the engines and fuels laboratories. Two metal engines and two optical engines are dedicated to spark ignition (SI) and compression ignition (CI) engine research. All engines can be boosted to run under high intake pressures to simulate real turbocharging conditions. The engines are also equipped with a VisioScope, which incorporates the latest camera technology with extended image processing software for enhanced optical diagnosis of combustion and injection phenomena.

The KAUST cooperative fuels research engine (CFR) is a versatile system that measures the knocking index of gasoline fuel (i.e., RON [research octane] and MON [motor octane] numbers). It operates with a wide range of fuels such as gasoline, jet and diesel fuels under multiple combustion modes. The standard configuration has been modified to allow rapid testing of various fuels and for measuring in-cylinder species as a function of engine crank angle. Successful trials have also been conducted with blends of liquid and gaseous fuels to study dual fuel blends. These unique features allow our researchers to study a host of fuels under various combustion modes.



Direct Numerical Simulation of a Turbulent Premixed Methane/Air Flame

The FUTURE FUELS WORKSHOP encompasses a wide spectrum of cutting edge technologies relevant to fuel production, utilization and global sustainability issues with an emphasis on low-grade and alternative fuels for transportation and stationary power generation.

TRIBUTE TO DR. NORBERT PETERS

by Fabrizio Bisetti

Dr. Norbert Peters, Distinguished Professor at RWTH Aachen University, died unexpectedly on July 4, 2015. In late March of the same year, he delivered the opening keynote lecture at the High-Pressure High Reynolds Combustion Workshop on turbulent combustion, held at KAUST under the auspicies of the Clean Combustion Research Center.

Norbert spoke about recent trends in combustion technology, in which increasing operating pressures have brought about higher Reynolds numbers. He explored the implications of increasing pressure on the propagation of turbulent premixed flames in internal combustion engines and combustors for power generation. With his well-known regime diagram in the background, Norbert discussed the effect of pressure on the scaling of turbulent premixed flames; he then postulated that flame stretching, followed by extinction, could play a growing role in increasing pressure. In his closing, Norbert shared a novel theory about the role of turbulent mixing and scalar dissipation rate in promoting rare ``super-knock'' events, which have been observed in turbo-charged spark-ignition engines.

To those of us fortunate enough to be in attendance, Nobert's lecture stands as another example of his stature as a giant in the field of combustion science and technology, a testament to his clarity of thought, and a reminder of his constant efforts to pursue innovative and creative ideas outside the beaten paths. Norbert's work in chemical kinetics, laminar flames, turbulent flames, and not to forget--fundamental turbulence and turbulent mixing--constitutes the standard and the legacy of a true scientist who solved practical problems with dedicated scientific rigor.