Current Research in Combustion

A Forum for Research Students and Early Career Researchers

25 September 2025

University of Cambridge, Cambridge, UK

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Current Research in Combustion: A Forum for Research Students and Early Career Researchers

Programme Thursday 25 September 2025

9:00 AM - 10:00 AM	Registration and Welcome Refreshments
10:00 AM - 10:10 AM	**Introduction by the Chair of the IOP Combustion Physics Group** **Prof. Ramanarayanan Balachandran**, University College London, UK
10:10 AM - 11:00 AM	**Morning Technical Session 1** **10:10 AM - 10:35 AM Jiajun Qiu**: Sectional modelling of TiO2 particle size distribution and crystallinity in burner-stabilised stagnation flames **10:35 AM - 11:00 AM Weiyue Liu**: LES of Dual-swirl Non-premixed H2 Turbulent Flames Using Eulerian Stochastic Fields
11:00 AM - 11:30 AM	Morning Break and Poster Session
11:30 AM - 12:45 PM	**Morning Technical Session 2** **11:30 AM - 11:55 AM Fatemeh Khodaparastan**: Oxygen Dynamics in Applied Smouldering: Impacts on Reaction Zone **11:55 AM - 12:20 PM James Harman-Thomas**: The conversion of aeroderivative gas turbines from fuel oil to hydrotreated vegetable oil **12:20 PM - 12:45 PM Caleb J. Li**: Partially premixed hydrogen-air flames in lean-direct-injection combustor
12:45 PM - 1:45 PM	Lunch and Poster Session
1:45 PM - 2:15 PM	**Combustion Institute AGM**
2:15 PM - 3:30 PM	**Afternoon Technical Session** **2:15 PM - 2:40 PM Ben Cosway**: Dynamic Response and Flame Structure of Acoustically Forced Ammonia/Hydrogen Flames **2:40 PM - 3:05 PM Yujia Wang**: Igniting hydrogen bubbles: unveiling combustion dynamics in a fluidised bed of silica sand **3:05 PM - 3:30 PM Hazem Awad**: Predicting flame blow-off in realistic configurations using low-order extinction modelling
3:30 PM - 4:00 PM	Afternoon Break and Poster Session
4:00 PM - 4:45 PM	**2025 'Huw Edwards Award' Lecture by Dr David Abbott** What exactly is a flame?
4:45 PM - 5:00 PM	**Presentation of Prizes and Close**
6:00 PM - 9:00 PM	**Dinner to honour Dr David Abbott (pre-registered only)** Browns Brasserie and Bar, 23 Trumpington Street, Cambridge, CB2 1QA

2025 ‘Huw Edwards Award’ Lecture

What exactly is a flame?

Dr. David Abbott[1]
[1]*Uniper (technical consultant) and Cranfield University (visiting fellow), United Kingdom*

2025 ‘Huw Edwards Award’ Lecture by Dr David Abbott, September 25, 2025, 16:00 - 16:45

Coincidentally, I was asked the question “What exactly is a flame?” within a few days of each other by two people from very different backgrounds. This led me to consider importance of asking questions and how the answers are presented.

Trying to determine “exactly” what a flame is leads to a multitude of other questions. This lecture reflects on my career in combustion and considers some of the questions I have asked, and some I have been asked, regarding flames and their interactions with their environment. These range from queries about the droplet size distribution in fuel sprays to acoustic-flame-structure interactions and the impact of fuel composition of combustion behaviour.

Inevitably in research, as we look for answers, we find even more questions. The question “What exactly is a flame?” continues to be an important and interesting area of research now and in the future.

Oral Presentations

Predicting flame blow-off in realistic configurations using low-order extinction modelling

Hazem Awad[1], Baijun Luo[1], Savvas Gkantonas[1], Epaminondas Mastorakos[1]
[1]*University of Cambridge, United Kingdom*

Afternoon Technical Session, September 25, 2025, 14:15 - 15:30

Capturing flame blow-off (BO) or extinction limits early in the combustor design process is essential for ensuring reliable aero-engine performance and reducing development time and cost. While high-fidelity methods such as Large Eddy Simulation (LES) can predict extinction limits, their high computational cost makes them impractical for exploring wide parametric spaces or screening multiple injector geometries. This study investigates the applicability of a low-order extinction prediction model based on a stochastic formulation of the Imperfectly Stirred Reactor (sISR) approach to rank different realistic Rolls-Royce injector designs according to their blow-off behaviour. The model relies on flow and mixing statistics extracted from CFD simulations, obtained using the Reynolds-Averaged Navier–Stokes (RANS) framework with the Flamelet Generated Manifold (FGM) combustion model. These statistics are used to construct extinction probability maps, which are then utilised to predict the Air/Fuel ratio at blow-off for each injector configuration. Two CFD datasets were evaluated: one corresponding to operating conditions far from blow-off, and another closer to the extinction limit. The former was able to capture the general trends in blow-off behaviour across injector designs but exhibited discrepancies in the predicted magnitudes. The latter, being closer to experimental blow-off conditions, showed improved agreement in both trends and absolute values. Overall, the results demonstrate that the sISR model provides a reliable and computationally efficient method for ranking injector designs based on blow-off behaviour, offering a fast and practical tool for quantifying combustor operability during the early stages of design.

Dynamic Response and Flame Structure of Acoustically Forced Ammonia/Hydrogen Flames

Dr Ben Cosway[1], Midhat Talibi[1], Ramanarayanan Balachandran[1]
[1]*University College London, United Kingdom*

Afternoon Technical Session, September 25, 2025, 14:15 - 15:30

Ammonia/hydrogen (NH_3/H_2) mixtures have emerged as promising alternatives to natural gas for gas turbines, offering similar combustion properties without producing carbon emissions. However, concerns remain over NOx emissions and knowledge is limited about their thermoacoustic stability. In particular, the non-linearity of the flame response to high amplitudes of acoustic excitation has not been studied before for ammonia/hydrogen flames, which is crucial for mitigating limit cycle behavior in gas turbines. This work evaluates the non-linear response of different NH_3/H_2 flames to acoustic forcing and investigates its relationship to NO formation. This was achieved by employing phase-locked, simultaneous OH and NO planar laser-induced fluorescence (PLIF) imaging, for the first time, to investigate the flame surface evolution of NH_3/H_2 flames under acoustically forced conditions. The study was conducted on a bluff-body burner, with ammonia premixed with air, and hydrogen injected 50 mm upstream of the dump plane, resulting in an imperfectly premixed mixture. Loudspeakers induced velocity perturbations in the flow, while pressure transducers and a photomultiplier tube (PMT) were used to measure flow velocity and estimate global heat release fluctuations (using OH* chemiluminescence), respectively. All the flames showed non-linearity in their heat release response at higher amplitudes due to strong vortex-flame interactions. For a lean 60/40 NH_3/H_2 mixture, these strong vortex-flame interactions resulted in a reduction of the flame response within the non-linear region. This was attributed to flame elements formed inside the outer shear layer interfering with the vortex shedding later in the cycle. Opposite trends in the NO distribution were seen in the axial direction compared to the unforced flames, due to increased fuel entrainment into the central recirculation zone. High NO concentrations were detected in the outer shear layer without OH, due to recirculated hot combustion products. These findings provide crucial insights into ammonia/hydrogen combustion relevant to gas turbine applications.

The conversion of aeroderivative gas turbines from fuel oil to hydrotreated vegetable oil

Dr James Harman-Thomas[1], Jon Runyon[1], Stu James
[1]*Uniper Technologies, United Kingdom*

Morning Technical Session 2, September 25, 2025, 11:30 - 12:45

Since Uniper performed the world's first demonstration of an industrial gas turbine operating on hydrotreated vegetable oil (HVO) in Malmö in 2021, the company has made great strides in the decarbonisation of dispatchable power. HVO is a renewable fuel produced from waste, originally intended to act as a drop-in replacement for fossil diesel in the transport sector. Due to the similarities between fuel oil and HVO in terms of chemical composition, converting existing gas turbines operating on liquid fuel oil requires minimal modifications to the fuel delivery and combustion systems. This has allowed for the rapid decarbonisation of Uniper's open cycle gas turbine assets in Sweden.

In December 2024 and May 2025, Uniper converted its gas turbines at Karlshamnsverket (KVT) and Barsebäcksverket (BVT), respectively, from fuel oil to HVO. Each site operates aeroderivative gas turbines. KVT operates two Rolls-Royce Olympus gas turbines in a single unit, and BVT operates two gas turbine units, each comprising two Pratt and Whitney JT4A-11 (or FT4) gas turbines. To the best of the authors' knowledge, the trials and commissioning associated with the conversion of these sites is the only experience of these gas turbines operating on HVO.

This presentation analyses the difference in combustion performance of both gas turbine types operating on HVO compared with typical fuel oil operation. Whilst the instrumentation on these legacy gas turbines is limited, key industrially relevant parameters such as the power output, efficiency, exhaust gas temperature and emissions are considered. Alongside the 80-90% life cycle reduction in CO2 emissions operating on HVO, there was also a significant reduction in SO2 emissions (94.2%), dust emissions (49.4%),and CO emissions (22.4%) at baseload. This highlights the positive impact that converting fossil liquid fuel assets to HVO can have environmentally, with limited impact on gas turbine performance and minimal capital investment.

Oxygen Dynamics in Applied Smouldering: Impacts on Reaction Zone

Fatemeh Khodaparastan[1], James Bowen[1], Fatemeh Switzer[2], Gavin P. Grant[3], Joshua K. Brown[3], Marco A.B. Zanoni[4], Tarek Rashwan[5]

[1]School of Engineering & Innovation, The Open University, United Kingdom, [2]Department of Civil and Environmental Engineering, University of Strathclyde, United Kingdom, [3]Savron , Canada, [4]Hydrogen Technologies Branch, Canadian Nuclear Laboratories, Canada, [5]Faculty of Engineering, The University of Nottingham, United Kingdom

Morning Technical Session 2, September 25, 2025, 11:30 - 12:45

Smouldering combustion is a slow, low-temperature, flameless combustion process driven by the interplay between competing pyrolysis and oxidation chemical reactions alongside physical heat and mass transport processes within porous media. Applied smouldering has been demonstrated as a cost-effective technology for soil remediation and waste treatment, and a few studies have shown it can also be tuned to produce valuable products such as syngas, bio-oil, and biochar. However, the influence of oxygen (O_2) concentration on reaction zone dynamics and its interplay with oxidation and pyrolysis reactions in applied systems remains poorly understood. This study addresses this knowledge gap by examining the sensitivity of smouldering dynamics to inflow oxygen concentration in forward smouldering experiments. Experiments were conducted with inflow O_2 concentrations of 21%, 10%, 5%, 4%, 3%, and 2% (volume basis) by mixing air and nitrogen with a constant total Darcy air velocity of 5 cm s^{-1}. The fuel bed was a mixture of crushed walnut shells and sand, with a 1:10 (walnut: sand) mass ratio. Smouldering was self-sustained with inflow O_2 concentrations of 3% and higher, while the average smouldering velocity increased from 0.24 to 0.81 cm min^{-1} with 3% to 21% O_2, respectively. The temperature profiles evolved differently across various O_2 concentrations. The average peak temperature stabilised between 823 – 930°C at O_2 levels at 4% and above, indicating robust self-sustained smouldering, whereas the peak temperature dropped to 400°C at 3% O_2 due to reduced oxidation reactions, which signals the onset of weak smouldering. High O_2 concentrations created narrow reaction zones with high heating rates, while low O_2 concentrations created broad reaction zones with slow heating rates. These findings reveal how O_2 influences key parameters such as smouldering velocity, temperature profile evolution, and heating rates. Altogether, this study provides new insight into reaction zone dynamics in applied smouldering systems.

Partially premixed hydrogen-air flames in lean-direct-injection combustor

Caleb J. Li[1], James C. Massey[1], Rojhat Dera[2], Christoph D. K. Schumann[1], Chinonso Ezenwajiaku[2], Midhat Talibi[2], Ramanarayanan Balachandran[2], Yusuke Tanaka[3], Nedunchezhian Swaminathan[1]

[1]University of Cambridge, United Kingdom, [2] University College London, United Kingdom, [3]Mitsubishi Heavy Industries, Japan

Morning Technical Session 2, September 25, 2025, 11:30 - 12:45

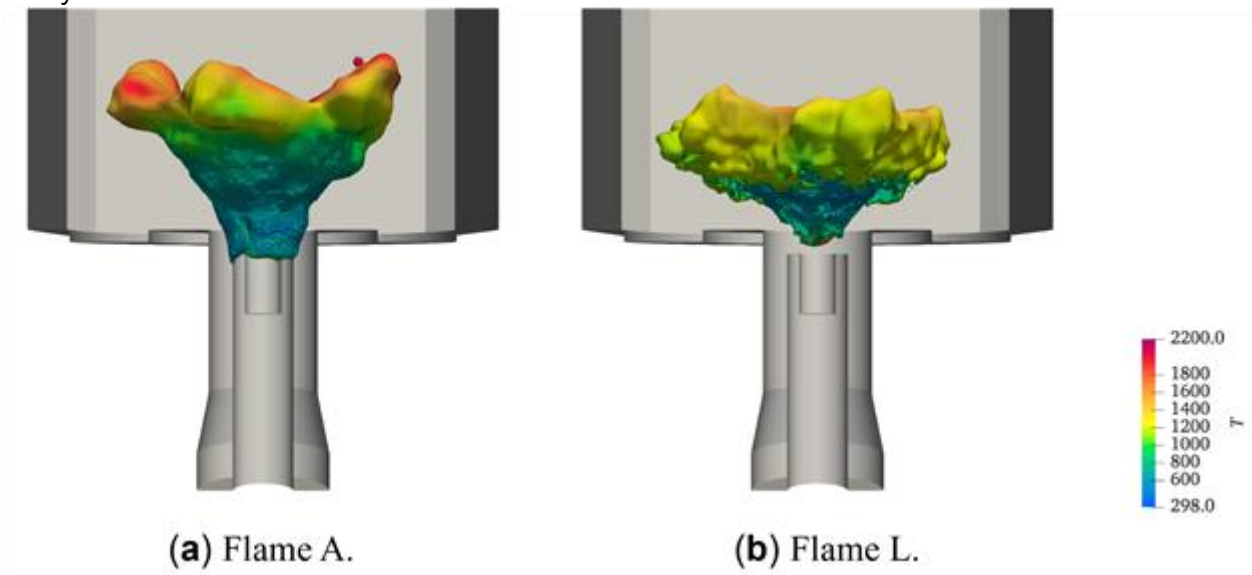
Hydrogen is a promising zero-carbon energy carrier to achieve decarbonisation targets. Its broad flammability range compared to conventional hydrocarbons allows for fuel-leaner operations, which can lower thermal Nox emissions. Moreover, using the Lean-Direct-Injection (LDI) concept can reduce the risk of flashback, which is important from the safety perspective. In the LDI configuration used in the present study, hydrogen is injected transversely through multiple, oppositely oriented circumferential orifices into the air stream, with the main flame stabilised by pilot flames. By varying the global hydrogen–air equivalence ratio at a fixed air bulk velocity, distinct flame regimes were observed, including lifted, attached, and unstable lean blow-off (LBO) conditions. Large-eddy simulations (LES) of the LDI combustor were performed, and results were validated using particle image velocimetry (PIV) for the non-reacting flow and OH∗ chemiluminescence for the reacting field. The LES results provide detailed insights into flame stabilisation mechanisms across the different regimes, with the flame dynamics at LBO conditions also accurately captured. The findings indicate that the jet (hydrogen)–to–crossflow (air) momentum flux ratio is the key parameter governing the global flame behaviour in the LDI combustor.

LES of Dual-swirl Non-premixed H2 Turbulent Flames Using Eulerian Stochastic Fields

Weiyue Liu[1], William P. Jones[1]
[1]*Imperial College London, United Kingdom*

Morning Technical Session 1, September 25, 2025, 10:10 - 11:00

Hydrogen is a `zero-carbon' fuel and sustainable energy carrier with great potential within the context of combustion decarbonisation. The present work describes the compressible Large Eddy Simulation (LES) of an injector lip-attached (Flame A) and a fully-lifted (Flame L) H2-air non-premixed dual-swirling flame, see the figure, in the HYdrogen-LOw-Nox (HYLON) injector. Both flames form non-premixed/partially-premixed combustion regimes along with spatio-temporal varying mixing and burning processes and complicated dual-swirling flow fields, which pose challenges to many LES flame models. Considering this, the Eulerian stochastic field method is adopted in the present work to describe the subgrid-scale chemistry-turbulence interactions and the resulting solutions are compared with the experimental measurements. The results suggest that the Eulerian stochastic field method is capable of accurately reproducing the multi-regime hydrogen flames in terms of velocity fields, flame and temperature fields. None of model parameters are tuned and no ad-hoc treatment is needed during the simulations, showing the good robustness of the flame model. Three different chemical kinetic mechanisms are additionally compared and an inlet temperature sensitivity study is carried out.



(**a**) Flame A. (**b**) Flame L.

Sectional modelling of TiO2 particle size distribution and crystallinity in burner-stabilised stagnation flames

Jiajun Qiu[1], Lu Tian[1,2], Adrian Spencer[1], Peter Lindstedt[2]
[1]*Loughborough University, United Kingdom,* [2]*Imperial College London, United Kingdom*

Morning Technical Session 1, September 25, 2025, 10:10 - 11:00

Flame synthesis of nanoparticles has gained significant attention due to their one-step, high-throughput nature and the absence of liquid by-products compared to traditional wet chemistry methods. Titanium nanoparticles, such as, Titanium Dioxide (TiO2), have been widely used as photocatalysts for solar cells and semiconductors for gas sensors. Macroscopic properties of the produced TiO2 are directly influenced by nanoscale characteristics of particles, such as, Particle Size Distributions (PSDs) and phase composition. Accurate modelling characteristics of nanoparticles is vital for the production of high-quality nanomaterial in the industrial applications. A mass and number density preserving sectional method, originally developed to predict soot PSDs, is here extended to compute titanium dioxide nanoparticle size distributions. The gas phase chemistry combines a detailed C/H/N/O mechanism with a Titanium Tetra-Iso-Propoxide (TTIP) decomposition mechanism which leads to the incipient species Ti(OH)4. Coagulation and aggregation using fixed and varying collision efficiencies are explored and surface growth is assumed via condensation of Ti(OH)4 molecules on the particle surface. Crystalline phase transport equations are proposed and integrated with the sectional model with two distinct phase identification models. It is the first time to use a sectional model for direct modelling of TiO2 PSDs and crystalline phases, which allows implementation in turbulent flames. The methodology is applied to the formation of TiO2 in three sets of laminar, premixed, ethylene-oxygen-argon stagnation flame experimentally studied by Tolmachoff et al. (Proc. Combust. Inst., 2009) and Manuputty et al. (Combust. Flame, 2021 and J. Aerosol Sci, 2019). Results are compared with experimental data for PSDs of TiO2 and phase composition with TTIP loading in the range of 306 ppm to 1454 ppm. Satisfactory results are obtained for all data sets for both fuel lean and rich conditions supporting the applicability of the augmented sectional model for providing both PSDs and crystalline phases.

Igniting hydrogen bubbles: unveiling combustion dynamics in a fluidised bed of silica sand

Yujia Wang[1], Ewa Marek[1]
[1]*Department of Chemical Engineering and Biotechnology, University of Cambridge, United Kingdom*

Afternoon Technical Session, September 25, 2025, 14:15 - 15:30

Hydrogen, as a promising net-zero fuel for the green future, is dangerous during conventional combustion in flames. Fluidised beds (FBs) have been used to gain control over combustion of various solid and gaseous fuels, improving heat transfer and introducing quenching mechanisms on particles. Yet, their application to hydrogen combustion remains unexplored and little to no information about ignition and combustion mechanism of H2 in FBs is available. This study investigates the ignition of 5vol% H2/N2 bubbles injected through a centrally located orifice into a bed of silica sand, 250-300 µm, fluidised by 5vol% O2/N2 at minimum fluidisation velocity. Then, the reaction between H2 and O2 was monitored by measuring the concentration of H2, O2, or H2O in the gas extracted by a sampling tube. The locations of combustion – in the freeboard or inside the bed – were determined by mapping the off-gas composition and temperature profiles vertically. Combustion below the normal lower flammability limit (LFL) of hydrogen (4vol%) was realised between 500 and 700 °C, resembling moderate or intense low-reactant dilution (MILD) combustion or flameless combustion (FLC). The results revealed three different modes of combustion in fluidised beds – slow oxidation, transition, and quick combustion, corresponding to small, medium, and large bubbles. Two critical criteria for in-bed combustion were identified – bed temperature and bubble size. Preignition in freeboard was found to be beneficial in lowering the temperature requirements for sustaining combustion in the bed by 100 °C. The work provides experimental insight into the combustion behaviour of hydrogen in fluidised bed media. The ongoing work focuses on establishing a new crossflow factor to describe the gas exchange between hydrogen and oxygen bubbles and the particulate phase. The overall aim is to develop a phenomenological model to fully map the range of conditions favourable for H2 combustion in fluidising beds.

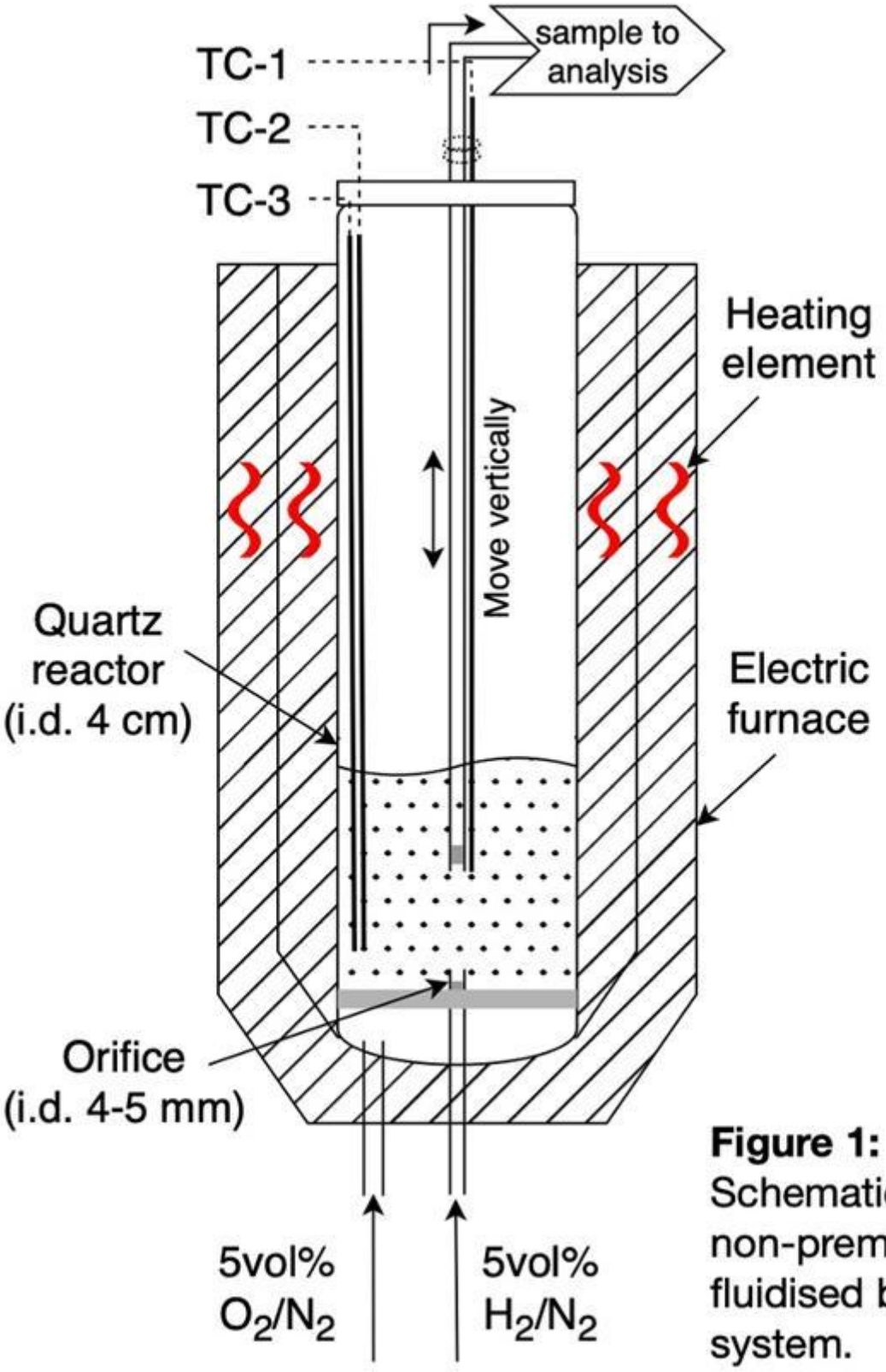


Figure 1: Schematic of the non-premixed fluidised bed system.

Poster Presentations

Experimental study of flame structure and NO formation in laminar flames of ammonia-hydrogen blends with nitrogen dilution

Mayokun Afolabi[1], Ben Cosway, Midhat Talibi, Ramanarayanan Balachandran
[1]*University College London (UCL), United Kingdom*

Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

Ammonia (NH3) is increasingly being recognised as a viable solution for decarbonising the power generation and transportation sectors, serving either as a direct energy vector or a hydrogen carrier. However, its low reactivity and higher nitrogen oxide (NOx) emissions compared to conventional hydrocarbons pose challenges for practical implementation. Partial ammonia cracking is a promising strategy to counter these challenges, as it produces hydrogen, which significantly improves reactivity and widens the flammability range. However, the effect of the nitrogen byproduct on the combustion characteristics is not well understood and needs further study. This study explores the flame characteristics and NO formation in laminar flames using ammonia/hydrogen (NH3/H2) and NH3/H2/N2 blends, the latter simulating partially cracked ammonia. Experiments were conducted on premixed laminar flames at five equivalence ratios ranging from lean to rich. The theoretical adiabatic flame temperatures were kept constant for each equivalence ratio, while nitrogen dilution were varied, thereby allowing investigation of impact on important chemical reactions. Measurements of NH*, NH2*, and OH* chemiluminescence, and NO PLIF were performed and compared against results from 1-D simulation using four reaction mechanisms relevant to NH3/H2 flames. The experimental results broadly captured the trends in NO formation and heat release rate markers related to effect of variation in equivalence ratio and nitrogen dilution. Formation rates were higher for all chemiluminescence species in the majority of NH3/H2 cases compared to NH3/H2/N2, with a consistent reduction from lean to rich, in line with computational trends. However, NO levels remained lower up to stoichiometric conditions in the NH3/H2/N2 flames and higher in the rich, showing that N2 dilution reduces the sensitivity of NO to the equivalence ratio. Results suggest further research into role of N2 dilution and its impact on reaction dynamics and chemical pathways are required to fully evaluate combustion behaviour of cracked ammonia blends.

Experimental Investigation of Hydrogen Air Mixtures

Rawan Alkandari[1], Derek Bradley[1], Junfeng Yang[1]
[1]*University of Leeds, United Kingdom*

Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

An experimental study using laser technique, particle image velocimetry (PIV) was conducted to investigate the complex turbulent flow fields in premixed flame. All measurements were performed in a controlled confined vessel, for hydrogen/air mixtures. Turbulence was generated using four fans, producing near-uniform, isotropic rms turbulent velocities, u'. A high-speed camera was used to capture the flame front propagation. The PIV measurement provided detail information on the velocity field in the unburned region. The PIV also revealed information about the mean radial velocity and the spatial rms turbulent velocity, u's. Any additional turbulence generated by the velocity field ahead of the flame can be revealed by measuring the spatial rms turbulent velocity u's. The two-dimension velocity field show disturbance in the unburned region. Higher disturbance is seen in case of higher rms turbulent velocities. At the onset of ignition, the u's was high this is due to the spark ignition, as the flame propagates the u's increases as a result of the flame wrinkling. This flame wrinkle acceleration depends on how strong the burning velocity and flame expansions. The study was carried for different equivalence ratio at atmospheric conditions and revealed that the u's increases with stronger burning velocity and flame expansions.

Historical Investigation into the First Burning Model of a Solid Fuel and the Origin of the Crank-Nicolson Numerical Method

Mr Alexander Castagna[1]
[1]*Imperial College London, United Kingdom*

Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

Models for the burning of solids have a complex formulation that reflects the intricate physics and chemistry involved, with a common mathematical structure which can be traced back to the first model of solid burning which was applied to wood burning. We investigate the origins, formulation and historical context of this model. Developed during the Second World War, it brought together a team of five scientists - Phyllis Nicolson, John Crank, Douglas Hartree, Clement Bamford and David Malan - from the University of Manchester, the University of Cambridge, and the Special Operations Executive, a British espionage and sabotage organisation, tasked to produce incendiary devices to be used offensively as part of the war effort. The model consists of the heat diffusion equation with a source term accounting for an Arrhenius-type reaction for pyrolysis [1,2]. The stiffness of the resulting partial differential equations leads to the development of second-order accurate semi-implicit Crank-Nicolson numerical method [3] which has enabled the development of computational fluid dynamics and heat transfer. Overall, we explore the historical context of the first solid fuel burning model and demonstrate the relevance it has had in the development of modern models and computational methods.

We reconstruct the model of Nicolson et al. and compare it to the original one, as well as to the state of the art, Gpyro, by operating a complexity reduction (Figure 1). Results show a 10% discrepancy, attributable to the difference in numerical precision and computational resources of the time. Despite this, we show that current pyrolysis models retain the same foundational formulation.

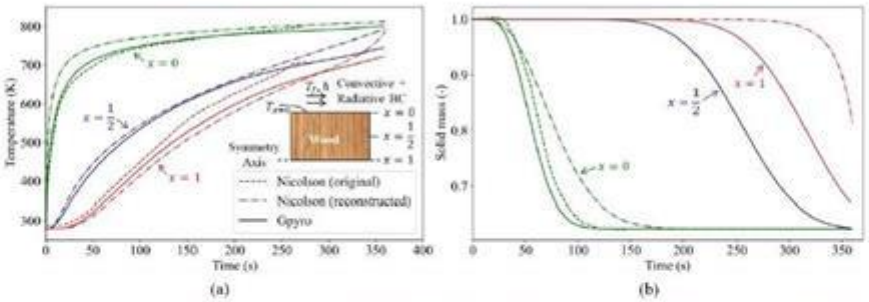


Figure 1: Temperature (a) and mass loss (b) over time: original solution of Nicolson, the reconstructed one, and the one reproduced with Gpyro.

References

[1] P. Nicolson, Three problems in theoretical physics, *Ph.D. thesis*, University of Manchester, Manchester, UK, 1946.

[2] C. Bamford, J. Crank, D. Malan, *Math. Proc. Camb. Philos. Soc.* 42 (1946) 166–182

[3] J. Crank, P. Nicolson, *Math. Proc. Camb. Philos. Soc.* 43 (1947) 50–67

Investigation of Novel Architectures For Hydrogen Lean Direct Injection (LDI) Combustors

Rojhat Dere[1], Yashvir Jugduth[1], Dr. Ben Cosway[1], Prof. Ramanarayanan Balachandran[1], Dr. Midhat Talibi[1]

[1]*Mechanical Engineering, University College London, United Kingdom*

Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

Hydrogen is increasingly being recognised as a promising carbon-free energy carrier in the global transition toward decarbonised energy systems. This study presents the development and analysis of different piloted single-nozzle burners designed for 100% hydrogen combustion, employing a jet-in-crossflow configuration to inject hydrogen close to the combustor inlet, creating a partially premixed mixture while minimising flashback risk. The burners differed in premixing distance, fuel-injection angle, and piloting strategy. The impact of premixing geometry and injection strategy on flame stabilisation and dynamics was systematically evaluated.

Experiments were conducted across a range of main air bulk velocities (30–90 m/s) and global equivalence ratios (ϕg = 0.2–0.6), with the pilot flow rate held constant. Flame structure was characterised using OH* chemiluminescence imaging (captured with a high-speed intensified CMOS camera), flame dynamic behaviour was studied from integrated OH* chemiluminescence and acoustic measurements were measured using dynamic pressure transducers. Additionally, LIBS and both reacting and non-reacting PIV were employed to investigate fuel distribution and flow field characteristics. Results showed that varying the premixing distance had minimal influence on flame dynamics. This suggests that shorter premixing lengths can help prevent flashback without compromising combustion performance.

The fuel injection angle was observed to significantly influence flame behaviour: upstream angled injection promoted a more uniform fuel-air mixture, reduced acoustic oscillations, and attached flames. Whereas, downstream-angled injection resulted in shorter flame root heights and lower exhaust NOx emissions, although the flames were not fully attached. Preliminary experiments on a multi-burner nozzle with angled fuel injection under heated-air conditions show that increasing the inlet air temperature from ambient to 500 K significantly lowers the lean blow-off limit. These findings provide valuable insight into the coupling between injection strategy and flame stabilisation in lean direct injection (LDI) hydrogen systems, offering guidance for the development of stable, low-emission hydrogen combustion technologies.

An analytical solution to a one-dimensional thermoacoustic eigenvalue problem

Dr Ankit Dilip Kumar[1,2]
[1]Department of Engineering, University Of Cambridge, United Kingdom, [2]Robinson college, University of Cambridge, United Kingdom

Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

Gas turbine (GT) combustors often operate near the threshold of thermoacoustic instability to minimize noxious emissions. Safe GT operation demands that these instability limits are accurately determined, whether through experimental testing, computational fluid dynamics simulations, or low-order modelling. Of these, low-order models are the most cost-effective, typically reducing the problem to solving a one-dimensional (1D) nonlinear eigenvalue problem (NLEVP). Fully mapping the stability margins is challenging, requiring up to $O(10^8)$ eigenvalue evaluations. Recent interest in CH4-H2 combustion has elevated this challenge by widening the range of operating regimes to be explored. It is then imperative that these solutions must be obtained in a computationally efficient manner. Existing approaches for solving NLEVPs are computationally inefficient, yield spurious solutions or fail to capture eigenvalues with narrow basins of attraction. In this study, an analytical eigenvalue solver that overcomes these limitations and is computationally efficient is proposed. The eigenvalue problem is derived from the 1D linearised Euler equations, using Crocco's n-τ model for flame response as an illustrative case. The resulting dispersion relations are reformulated to express the interaction index n and time delay τ as functions of frequency. Eigenvalues are then identified as the intersections of iso-contours of n and τ in the eigenspace. The proposed solver is significantly faster than current methods, computing $O(10^6)$ eigenvalues in the time that the next-best technique, Beyn contour integration, computes only O(10).

Predicting non-premixed hydrogen jet flames using Eulerian Stochastic Fields with prescribed inlet turbulence

Jan Dobrzycki[1], Hao Xia[1], Daniel Butcher[1], Ivan Langella[2]
[1]Loughborough University, United Kingdom, [2]Technical University Delft, Netherlands

Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

Combustion simulations have a recurring difficulty of modeling turbulence-chemistry interactions. These processes occur at microscopic scales, which are challenging to simulate with CFD due to mesh resolution limitations [1]. Combustion models aim to predict these effects with different solution strategies. In this study, we consider a modern version of the Eulerian Stochastic Fields (ESF), transport-PDF method [2]. In essence, the model transports full chemistry in conjunction with a detailed chemical mechanism. This allows for the simulation of complex combustion configurations dominated by finite-rate chemistry effects, such as non-premixed turbulent flames [3].

As part of our research, ESF based LES is applied to the DLR hydrogen jet flame case under the H3 flame configuration presented at the TNF workshop [4]. In this case, we found that accurately described inlet turbulent conditions play a crucial role in predicting the breakdown of the shear layer. Instantaneous contours (Fig 1a) show how the turbulent shear-layer immediately mixes the jet and co-flow streams allowing for stable combustion (Fig 1b). Quantitative investigation of velocity at a downstream location of $x/D=5$ shows that the evolution of turbulence from the inlet is able to correctly match the experimental results which is a challenge noted in other studies [5-7]. Finally, transport profiles of key species show that the adopted ESF method is able to accurately account for the mixing and chemical reactions (Fig 1d).

In summary, by combining the strength of the ESF method with finely prescribed inlet turbulent profiles, we achieve validation against DLR's H3 jet experiment. We believe similar practices could have wider interests and will be applied in our future studies.

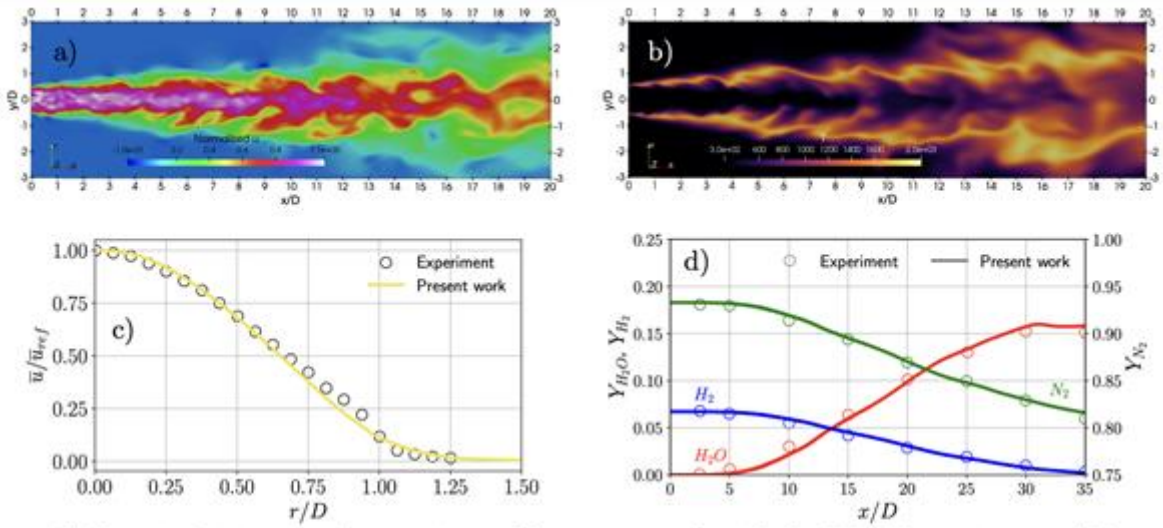


Figure 1: Key visualisations and comparisons of the present work with the DLR H3 experiment: a) Instantaneous normalised u contour; b) Instantaneous temperature contour; c) radial profile of normalised u at $x/D = 5$; d) species mass fraction distribution along the centreline

References

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Fundamental investigation on the micro-explosion of iron-carbon alloy particle: Insights gained from molecular dynamics simulation

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Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

Micron-sized iron particles have recently emerged as promising carbon-free fuels, offering stable and clean energy release through combustion. During burning, a distinct phenomenon known as micro-explosion, an individual particle fragments into smaller pieces. Previous experimental studies on iron particles with different carbon impurity revealed that carbon significantly influences the position and intensity of micro-explosions[1]. While such effects have been observed experimentally, the underlying mechanisms remain insufficiently understood. In this study, the reactive molecular dynamics (RMD) simulations were performed to comprehensively capture the micro-explosion sequence of Fe-C alloy particles under similar conditions performed in the previous experimental study.

The different ReaxFF parameterizations were systematically evaluated by comparing simulation results with density functional theory (DFT) data and experimental bond length and bond angle distributions of iron oxides and iron carbides. The analysis comprehensively indicates that ReaxFF2016 provides the most reliable description of Fe–C–O interactions for the current system. Furthermore, the simulations reveal that oxygen molecules initially absorb on the particle surface and subsequently penetrate the particle interior, forming bonds with both iron and carbon atoms. This process is accompanied by structural changes, including variations in particle size and shape.

Future work will focus on identifying the microscopic origins of micro-explosions. We will investigate whether the formation of internal gas clusters, such as CO_2, contributes to particle fragmentation, as previously hypothesized in experimental studies. Further analysis will explore how varying carbon concentrations affect the generation rate of such gaseous species, as well as the resulting internal expansion stresses within the particle. This study will provide atomistic insight into the micro-explosion behavior of carbon-containing iron particles.

Keywords: micro-explosion, iron particle, molecular dynamics

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A laser-induced breakdown spectroscopy (LIBS) methodology for quantitative measurement of potassium in biomass thermal processing

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Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

The release of potassium during the combustion of biomass in power plants leads to ash deposition on the furnace walls leading to surface corrosion and clogging of transport pipelines reducing significantly the thermal efficiency of the plant. Therefore, estimating the release trends of these species is crucial. Laser-induced breakdown spectroscopy has been used previously to quantify the total elemental concentration of alkali metals in flames. Here we comprehensively investigate this technique by studying the time-evolution of LIBS spectra. As well as calibration through the established approach of seeding known amounts of potassium to a stable laminar flat flame, we also discuss the feasibility of absolute quantification through measurement of the plasma temperature and radiometric calibration of the detector. We also apply the technique to determine release trend of elemental potassium from a burning biomass pellet.

A pulsed Nd:YAG laser beam was focussed to a small spot to form a plasma in the flame and the resulting emission was imaged onto a spectrometer to obtain the LIBS spectrum. Both a miniature fibre-coupled spectrometer and a spectrograph coupled with a short-gated, intensified camera were used to compare the outcomes of various detection approaches and gate delays. A methane-air, premixed, fuel rich, laminar flame was seeded homogeneously with different concentrations of KCl using a pneumatic nebuliser to obtain the calibration plot.

A calibration plot was obtained by seeding known amounts of elemental potassium to the flame ranging from 0.7 ppm to 73 ppm. We compare the optimum choice of detection gate delay for the two spectrometers used. Spectral simulation has been used to investigate the evaluation of plasma temperature from short-gated emission spectra. Together with radiometric calibration of the collection efficiency using a well-characterised integrating sphere light source, this leads to an alternative means of quantifying total elemental concentration.

Using external electric fields to control the trajectory of charged droplets in a crossflow

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Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

The atomisation of bulk fuel into droplets and sprays plays a critical role in the combustion process. Electrostatic atomisation uses electric fields to produce small, monodisperse charged droplets. Conventional electrospray atomisers consist of a nozzle electrode connected to a high voltage and positioned perpendicular to a grounded electrode. The resulting potential difference generates an electric field. At certain field strengths, as an ionic liquid exits the nozzle, positive ions are repelled toward the liquid/air interface, opposing the surface tension and deforming the fluid interface into a Taylor cone [1]. The tip of the Taylor cone elongates into a ligament that eventually breaks up into individual charged droplets [1]. The electric field influences the charge and motion of the produced droplets and, for a given liquid, is primarily determined by the electrode voltages and the spacing between them [2]. The effect of these parameters on droplet sizing and charge is well researched [2]; however, as electrostatic atomisation traditionally occurs in quiescent air, research pertaining to the dynamics of charged droplets in a convective flow is limited [3].

The ability to control the droplets' trajectory in a convective flow can enhance penetration length, residence time, and overall mixing of fuel, all of which are important factors for sustainable combustion technologies [3]. In this work, charged droplets are injected into a convective flow in the presence of an electric field. The charged droplets experience a force in the direction of the electric field, altering the resultant force vectors and, therefore, the droplets' trajectory [3]. Variations in grounding geometry induce significant spatial variations in the electric field and, therefore, strongly influence droplet trajectories. This research investigation elaborates on the controlling parameters for the charged droplet trajectory and introduces a non-dimensional length scale with predictive capabilities for droplet motion.

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E-Methanol Combustion in a Lab-Scale Gas Turbine Jet Combustor

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Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

Gas turbines (GTs) are essential to the global energy infrastructure but are responsible for an estimated 7–10% of global CO_2 emissions due to their widespread use in power generation, aviation, and marine propulsion. As the transition to zero-carbon fuels like hydrogen faces technological and infrastructural challenges, e-methanol emerges as a promising near-term alternative to reduce carbon emissions in GT engines. Whilst extensively studied as an additive in internal combustion engines, methanol's combustion behaviour under conditions relevant to GT operation remains experimentally underexplored. This research aims to address this gap through a three-phase experimental campaign, spanning across fundamental scientific investigations to applied engineering solutions. In the first phase, a laminar combustion regime is studied using an inverse diffusion flame (IDF) burner, employing advanced laser diagnostics such as Phase Doppler Particle Analysis (PDPA) to characterise the non-reacting atomised fuel droplet size distribution and Planar Laser-Induced Fluorescence (PLIF) to capture the flame structure and the droplet-flame interactions. These insights will not only help refine and validate existing combustion models but also inform practical design considerations to implement a methanol injection system in a larger scale jet combustor for the second phase of this project. The latter will investigate turbulent methanol spray combustion under more realistic GT operating conditions. Finally, phase three will explore methanol-hydrogen co-combustion across various turbulent conditions, yielding critical data to inform the retrofitting and optimisation of current liquid-fuelled GTs. Collectively, this research will provide foundational knowledge to integrate methanol as a low-carbon fuel for GT applications, while paving the way for a smoother transition to fully decarbonised fuel systems in the long term.

Analysis of the Influence of Chemical Mechanism Choice on Direct Numerical Simulations of NH_3/H_2 Turbulent Premixed Flames

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Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

The growing need to reduce greenhouse gas emissions has created an interest in carbon-free fuels. Hydrogen (H_2) presents difficulties, such as its wide flammability range, high reactivity, and storage challenges. In contrast, ammonia (NH_3) offers a higher potential due to its higher volumetric density and manageable storage. However, NH_3-air mixtures are considerably less reactive than H_2-air mixtures due to the narrower flammability limits and lower laminar burning velocities, making NH_3 prone to blowout and harder to stabilise in practical combustion systems. A potential solution is blending ammonia with hydrogen. The addition of hydrogen enhances the mixture's burning velocity, mitigating the inherently low reactivity of NH_3. Given that NH_3 is a recent candidate for combustion, it is important to evaluate how the choice of skeletal chemical mechanisms affects high-fidelity simulations. To explore this, Direct Numerical Simulations (DNS) were performed for a statistically planar turbulent premixed flames consisting of a fuel blend of $NH_3/H_2/N_2$ in a 40:45:15 molar ratio for equivalence ratios 0.8 and 1.1. Two chemical mechanisms were used: the first, developed by Stagni et al. [1], includes 31 species and 203 reactions; the second, by Greenblatt et al. [2], contains 22 species and 104 reactions. The DNS results examined flame characteristics such as surface area, turbulent burning velocity, combustion regime, heat release, and NOX formation. This aims to determine whether the improved accuracy from using more detailed mechanisms justifies the computational cost in comparison to a less detailed mechanism.

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Uncovering sensitivities in applied smouldering systems

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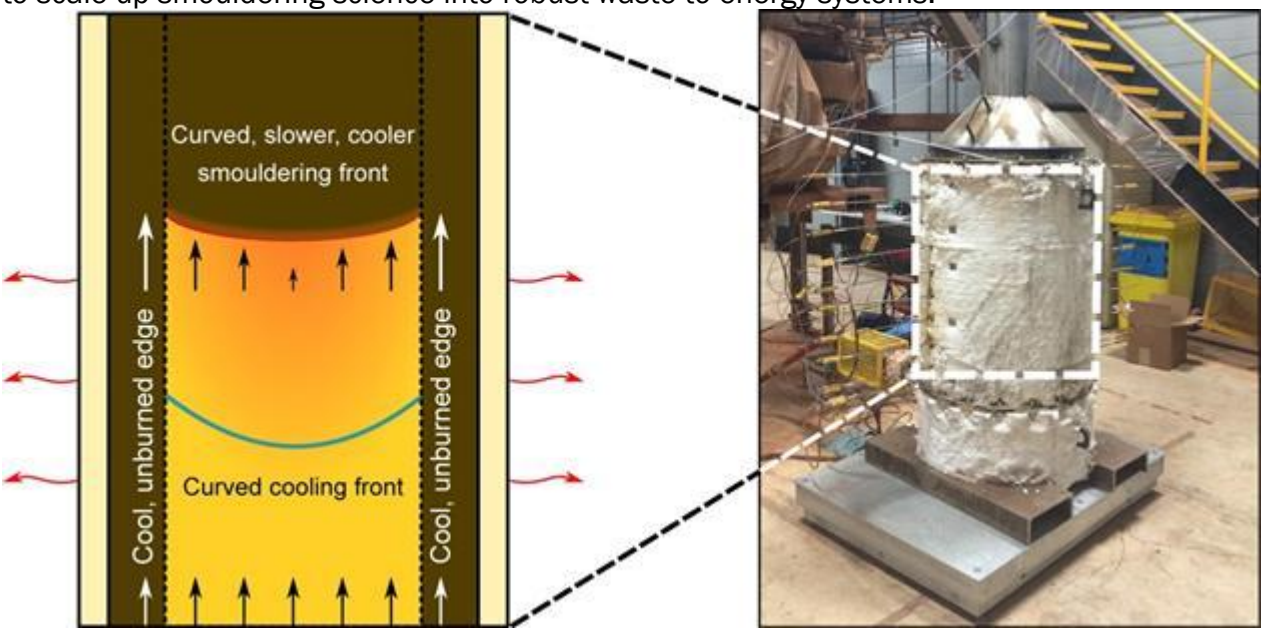
Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

Applied smouldering combustion systems are emerging useful for a range of waste treatment purposes. These systems provide unique benefits over other thermal treatment systems due to their wide self-sustaining limits offered by smouldering's resilient combustion characteristics. Therefore, smouldering systems can treat traditionally problematic wastes – e.g., those with high moisture contents or low fuel volatilities. However, smouldering sensitivities can threaten the prospects for large scale operations, as some sensitivities can weaken key reactions to the point of extinction and cause system failure. Sensitivities from perimeter heat losses can be particularly challenging to diagnose and overcome, as they can lead to unexpected negative effects that can worsen with increasing scale. For example, perimeter heat losses can drive non-uniform air flux that can severely compromise system performance through cooling peak temperatures, slowing propagation velocities, and leaving large regions in the reactor untreated. This study investigated heat loss effects through: (i) highly instrumented smouldering experiments with various fuels/wastes across numerous scales, (ii) a novel method of quantifying non-uniform air flux in the experiments, (iii) analytical modelling to predict non-uniform cooling, and (iv) energy balance calculations to quantify the non-uniform heat of smouldering. Altogether, the insight gained from these analyses provide new guidance to scale up smouldering science into robust waste-to-energy systems.



Investigation of ammonia:hydrogen mixtures and pilot-split strategies in a laboratory-scale radial swirl combustor.

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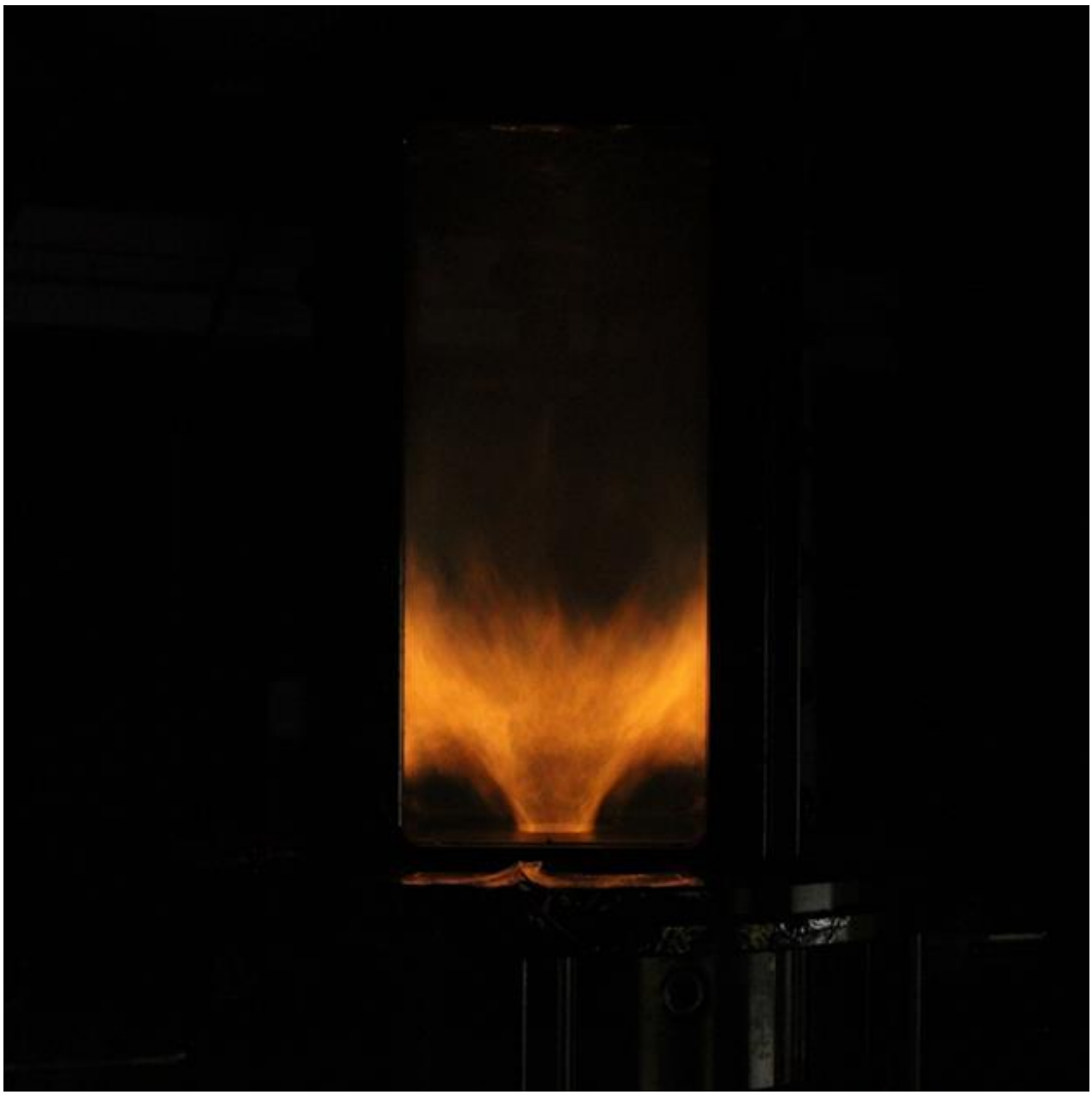
Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

The transition to a decarbonised energy future relies on identifying the most suitable alternative fuels that can meet the needs of various energy sectors. While both ammonia and hydrogen are zero-carbon energy vectors, their physical properties and burning characteristics sit on either side of that of natural gas. Hence, mixtures of ammonia and hydrogen are being increasingly looked at as having the potential to fuel current energy systems without requiring significant combustor redesign. However, the combustion characteristics, operation limits and NOx emissions for different ammonia:hydrogen blends still need to be evaluated. For gas turbine applications in particular, the effect of ammonia:hydrogen mixture composition and operating condition on flame behaviour and stability is not well understood and therefore was the focus of the current work.

The experiments conducted so far were carried out in a laboratory scale, radial swirl-stabilised turbulent combustor. A systematic study of two ammonia:hydrogen blend ratios (70:30 and 80:20 by volume) and a range of equivalence ratios were tested for different pilot-split ratios, to understand the effect on flame shape, stability and dynamics. Time-resolved pressure and integrated heat release fluctuations were measured to evaluate combustor dynamics, and NH2* chemiluminescence flame images were captured to understand spatial differences in flame structure. When comparing blend ratios, differences were observed in flame macro-structures and combustor dynamics, which could be largely attributed to the considerable difference in the laminar flame speeds of the blends. The addition of pilot generally improved the stability and lean operation for both blend ratios.



NO emissions in combustion of H_2/CH_4--air mixture with high H_2 content: parametric study of laminar premixed flames

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Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

Carbon dioxide formation in combustion of hydrogen/methane--blends is significantly reduced for a volume fuel fraction of hydrogen, α, of at least 70%, where the mixture reactivity is strongly non-linear with α. The formation of nitric oxide (NO) is one of the major concerns of replacing hydrocarbon-based fuels with hydrogen, and its formation occurs through the thermal, prompt, N_2O and NNH pathways. These are influenced by fuel composition and operating conditions. In this study, the effect of mixture temperature, T, pressure, p, equivalence ratio, Φ, and volume fuel fraction of hydrogen, α, on the absolute levels of NO and relative contribution of these pathways is studied in one-dimensional laminar premixed flames for T of [300, 500, 700 K], p of [1, 5, 10, 30 bar], Φ of [0.5, 0.75, 1.0, 1.25, 1.5] and α of [0.7, 0.85, 1.0]. The residence time of these flames is maintained at a typical value for gas turbine combustors. A detailed pathway flux methodology is employed for this purpose, and this methodology allows for clear distinction between the pathways. The interaction of the pathways as well as the accumulation of N in minor species are also accounted for. The thermal route is dominant for Φ=0.75 to 1.25, but its relative contribution is reduced for and fuel-rich (Φ=1.5) and especially fuel-lean (Φ=0.5) conditions as it is replaced by the NNH, prompt or N_2O pathways depending on operating conditions. For Φ=0.5 to 1.25, the addition of hydrogen increases total NO, but its effect is ambiguous for Φ=1.5. The sensitivity of NO to α is pronounced at ambient conditions but it is decreased for gas turbine operating conditions.

Effects of hydrogen addition on soot formation in ethylene-air premixed flat-flames including under nucleation flame conditions

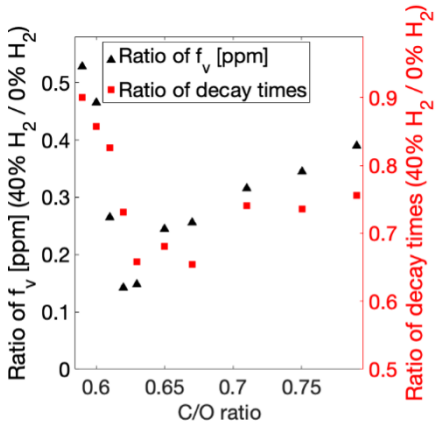
Anshul Seecharam, Iain Burns

Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

The influence of H_2 on soot formation has been investigated experimentally in atmospheric-pressure ethylene-air premixed flat flames across a broad range of flame conditions. The addition of H_2 was found to inhibit soot formation, with the extent of suppression dependent on the carbon-to-oxygen (C/O) ratio in the premixed gases. Time-resolved laser-induced incandescence (LII) was employed to measure soot concentration and signal decay rate across the range of flame conditions studied. Particular attention has been paid to the effect of H_2 addition on nucleation flames.

Doped flames were produced by replacing part of the premixed gas with H_2 while keeping constant C/O ratio and flowrate. At each C/O, two conditions were tested with H_2/C_2H_4 ratios of 0% and 40%. A horizontal beam-sheet provided the sensitivity needed for nucleation flame tests. Measurements were taken 16 mm above the burner.

Soot formation was found to be strongly suppressed by the presence of H_2: the figure (attached) presents the soot volume fraction (f_v) in H2-doped flames as a fraction of f_v in the equivalent, undoped flame. Beginning from the richest flame studied, the reduction in f_v with H_2 addition becomes progressively stronger with reducing C/O ratio until CO= 0.62 where f_v has fallen to only 14% of its value in the undoped flame. Thereafter, there is a sharp reduction in the influence of H_2 addition, as the “nucleation flame” condition is approached at a C/O ratio of 0.59. Decay times of LII signals decreased with H_2 addition, though less than soot concentration, reflecting impact on primary particle size. The trend shows the largest decay time reduction at a C/O ratio of 0.63, with effects diminishing as the nucleation condition is approached. Additional experiments have been performed using laser-induced fluorescence (LIF) to detect PAH precursors with and without H_2 addition.



Lean hydrogen-air premixed flames subjected to acoustic oscillations - Influence of Lewis number and sound pressure level

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Morning Break and Poster Session, September 25, 2025, 11:00 - 11:30

The interaction of acoustic oscillations with lean premixed hydrogen-air flames has been studied by performing simulations of two-dimensional laminar flames at equivalence ratios of 0.4 and 0.7. Flame-acoustic interaction, which can lead to thermoacoustic instabilities, has been simulated across a range of oscillation frequencies (ranging between 50-500 kHz) and sound pressure levels (ranging between 110-130 dB), with acoustic waves imposed through a monopole-type acoustic source at the inflow. To delineate the influence of differential diffusion of heat and mass under acoustic forcing, simulations with both mixture-averaged treatment for species diffusion and unity Lewis number for all species have been performed. The flame behaviour is investigated by studying the exponential growth of Fourier modes appearing on the flame surface, corresponding to the linear growth regime of flame evolution. Dispersion relations, quantifying the growth rate variation with wave number, are then compared across forcing conditions, as well as between mixture-averaged and unity Lewis number species diffusion treatments, to identify the relative contributions to the thermodiffusive instability at different conditions. Generally, an enhancement of the growth rates is seen for low wave number harmonics (high wavelength perturbations) under acoustic forcing, indicating an enhancement of thermodiffusive instability during flame-acoustic interaction, compared with non-forced cases. Differences are noted in the wave number where the dispersion relation trend terminates, with the dispersion relation for the lowest frequency cases (50 kHz) terminating at the lowest wave number for both equivalence ratios, implying an immediate transition to a non-linear growth phase for high wave number harmonics. Increases in SPL do not significantly alter the growth rates observed, only decreasing the time before transition to the non-linear regime. Variation in the magnitude of pressure gradients and the influence of these pressure gradients on mass diffusion are shown to be responsible for the distinct trends across acoustic conditions.

Poster Presentations

First Name	Last Name	Organisation	Paper Title
Mayokun	Afolabi	University College London	Experimental study of flame structure and NO formation in laminar flames of ammonia-hydrogen blends with nitrogen dilution
Rawan	Alkandari	University of Leeds	Experimental Investigation of Hydrogen Air Mixtures
Alexander	Castagna	Imperial College London	Historical Investigation into the First Burning Model of a Solid Fuel and the Origin of the Crank-Nicolson Numerical Method
Rojhat	Dere	University College London	Investigation of Novel Architectures For Hydrogen Lean Direct Injection (LDI) Combustors
Ankit	Dilip Kumar	University of Cambridge	An analytical solution to a one-dimensional thermoacoustic eigenvalue problem
Jan	Dobrzycki	Loughborough University	Predicting non-premixed hydrogen jet flames using Eulerian Stochastic Fields with prescribed inlet turbulence
Wenqi	Fu	Loughborough University	Fundamental investigation on the micro-explosion of iron-carbon alloy particle: Insights gained from molecular dynamics simulation
Nikhil	Gaur	University of Strathclyde	A laser-induced breakdown spectroscopy (LIBS) methodology for quantitative measurement of potassium in biomass thermal processing
Thomas	Gilmour	University of Edinburgh	Using external electric fields to control the trajectory of charged droplets in a crossflow
Yashvir	Jugduth	University College London	E-Methanol Combustion in a Lab-Scale Gas Turbine Jet Combustor
Sophie	Lindley	Newcastle University	Analysis of the Influence of Chemical Mechanism Choice on Direct Numerical Simulations of NH_3/H_2 Turbulent Premixed Flames
Tarek	Rashwan	University of Nottingham	Uncovering sensitivities in applied smouldering systems
Raad	Rizza	UCL	Investigation of ammonia:hydrogen mixtures and pilot-split strategies in a laboratory-scale radial swirl combustor.
Christoph	Schumann	University of Cambridge	NO emissions in combustion of H_2/CH_4–air mixture with high H_2 content: parametric study of laminar premixed flames
Anshul	Seecharam	University of Strathclyde	Effects of hydrogen addition on soot formation in ethylene-air premixed flat-flames including under nucleation flame conditions
Frederick	Young	Newcastle University	Lean hydrogen-air premixed flames subjected to acoustic oscillations - Influence of Lewis number and sound pressure level

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