Summary of TNF17 and Planning for TNF18

The TNF17 workshop (International Workshop on Measurement and Computation of Turbulent Flames) was held at Doshisha University in Kyoto, Japan on 25-26 July 2026 as one of five co-located satellite workshops of the Combustion Institute's International Symposium. Sessions on the first day were held jointly with the Premixed Turbulent Flames (PTF) workshop, such that the agenda included a blend of TNF-style curated sessions and PTF-style individual talks on related topics. The combined attendance was roughly 180.

This summary briefly outlines the scope and history of the TNF workshop series, the contents of the TNF17 technical sessions, including some key discussion points, and suggested strategies to prepare effectively for TNF18 in 2028.

The TNF17 Proceedings and the proceedings from all previous TNF workshops may be downloaded from tnfworkshop.org. Summaries and presentation slides for the TNF17 sessions are included, along with TNF poster abstracts. Slides from PTF talks presented during the joint Saturday session are included in these proceedings, while the slides and abstracts for all of the PTF contributed talks are available from the PTF website.

IMPORTANT NOTE: Results presented at the TNF Workshop may represent work in progress. It would be inappropriate to quote or reference unpublished information from the proceedings without first checking with the authors for permission and for the latest information on results and references.

TNF Scope and History

The TNF workshop series focuses on fundamental issues of turbulence chemistry interactions in gaseous flames of relatively simple fuels. The objectives are to:

- Establish a library of well-documented flames that advance fundamental scientific understanding of turbulent combustion and are appropriate for testing and extending models for combustion systems.
- Provide a framework for collaborative comparisons of refence data from experiments and DNS with modeled results from LES, with the aim of improving predictive capabilities over time.
- Identify priorities for further experimental and computational research, particularly where collaborative work can be beneficial.

Up to TNF14 in Dublin (2018), a wide range of flames with different modes (premixed, stratified, partially premixed, non-premixed) and regimes (Re, Da, Ka number) were investigated mainly for CH_4. TNF sessions evolved around detailed scalar (Raman/Rayleigh) and velocity data sets for selected target cases, and numerical results from different groups were compared to experimental data. In many cases there was advanced coordination among modeling groups to specify common aspects of the simulations (e.g., the treatment of boundary conditions and inflows, the use of preferred chemical kinetic mechanisms, grid resolution tests, and what results should be compared). The open workshop atmosphere allowed discussions on the physics of the flames and how the models could be improved, and new experimental configurations were discussed to challenge the models.

Several factors limited TNF activities from 2018 through 2022, including defunding of turbulent combustion experiments at Sandia, cancellation of the 2020 workshop due to COVID, and the redirection of combustion research funding toward carbon-free fuels, which reduced interest in the existing hydrocarbon flame datasets before new datasets on hydrogen and ammonia flames became available. All sessions in Vancouver (2022) were held jointly with the PTF workshop as a

practical response to the relatively low on-site attendance at the Combustion Symposium and the satellite workshops. Since then, several experimental and DNS data sets for flames of carbon-free fuels have become available, and the programs for both TNF16 in Milan (2024) and TNF17 emphasized this new focus.

Turbulent flames of carbon-free fuels present significant challenges for combustion models, including strong effects of differential diffusion and thermodiffusive instability in lean premixed hydrogen flames and potentially high levels of NOx formation in ammonia flames. The collaborative experimental/numerical framework of the TNF workshop can help to focus and accelerate community efforts to address these challenges.

TNF17 Technical Sessions

The technical sessions of the TNF workshop are briefly summarized below, with key point being taken from individual session summaries in the full proceedings. For those sessions that followed the PTF-style format of separate individual talks, the titles, presenters, and key points (optional) are simply listed.

Fundamentals of Premixed Hydrogen and High-Hydrogen Blends

Coordinators: Andy Aspden and Antonio Atilli *Chair: Sina Kheirkhah*

This session followed a PTF-style format with five individual short talks: *Thermo-diffusive instability in H_2/CH_4 blends* (Antonio Attili); *Fuel consumption in H_2/CH_4 flames* (Bruno Savard); *The TKE budget and counter-gradient behavior of the combustion progress variable in H_2/CH_4/air premixed flames* (Sina Kheirkhah); *Turbulent burning rate of hydrogen-air flames at gas turbine conditions – DNS and experimental data* (Jackie Chen); *Should we care in hydrogen-LES if filtered/thickened flames have a more stable dispersion relation?* (Pasquale Lapenna). A few key points were:

- DNS studies showed that thermos-diffusive instability remains significant for H_2/CH_4 blends.
- Preferential diffusion causes macro-scale demixing in H_2/CH_4 flames.
- Analysis of experimental data from low-*Ka* H_2/CH_4 flames showed that decreasing *Le* leads to increases in flame generated turbulence and in counter-gradient transport of the combustion progress variable via enhanced gradient of mean pressure.
- Scaling laws for turbulent burning velocity and Io factor cast in terms of *Ze*/*Pe*, *Ka* and *Da* were tested for a wide range of conditions from DNS and experiments.
- Artificial flame broadening significantly alters the ability of LES to solve the thermos-diffusive instability; SGS modeling is required.

Comparisons on the TU Darmstadt premixed hydrogen jet flames

Coordinators: Christian Hasse and Tao Li

The piloted jet flame series with the McKenna-burner configuration offers a laboratory test case for thermo-diffusive effects in turbulent lean premixed hydrogen–air combustion. The session combined experiments, DNS and LES. Two experimental series and four DNS cases were presented. LES contributions from four groups were then compared for two of the flames, both at 0.4 equivalence ratio. All LES results used OpenFOAM as base solver but differed substantially in resolution, combustion models, and generation of inflow conditions. The main objective of the comparison was to assess how the simulation approaches do perform and how well is the thermo-diffusive response captured.

The workshop discussion identified the following findings and next steps:

1. Flame shape and velocity predictions depend strongly on the prescribed turbulent inflow and the resulting jet break-up. Differences among the simulations are apparent for both velocities and especially pronounced in the lower-velocity case. A common non-reacting flow comparison to corresponding experimental and DNS data may be needed before attributing these differences to combustion models.
2. All models reproduce super-adiabatic thermochemical states in broad terms but differ in the scatter and internal structure of the flame. For the H100P040U100 case, the DNS shows the widest scatter as expected; all simulations show a slight underprediction of H_2 and an overprediction of H_2O around T=1250 K. The PKU/CSU chemistry model shows a mismatch in flame structure. Experimental data are unavailable for some plotted thermochemical comparisons, so DNS remains an important reference.
3. A rigorous model comparison requires aligned boundary conditions and mesh resolution. Further analysis of the DNS and experiments is needed to assess the radical pool and flame internal structure, including the *a priori* results at the flame base and tip.

Model validation framework for premixed turbulent H2-air flames

Speaker: Heinz Pitsch *Chair: Assaad Masri*

An LES validation framework was introduced that allows a user to automatically test a developed model for hydrogen combustion against a large number of different experimental and DNS cases. The framework, which is accessible on a git repository [1] and described in an open access article [2], is based on the open-source OpenFOAM toolbox that allows for straightforward integration of newly developed combustion models. It presently includes eight validation cases based on both experimental data and direct numerical simulations, and is designed to be readily expandable by the community to accommodate an arbitrarily large number of additional cases. For all cases, the reference data, together with the required configurations and mesh files, are provided. The framework facilitates the systematic assessment of combustion models by automatically performing simulations for all intended cases and providing comparisons between model predictions and reference data in a generated PDF file.

The framework is meant to be a community effort, and we encourage modelers who have performed LES of hydrogen combustion cases with OpenFOAM to submit these cases to the framework so that others can use these as part of an automatic validation process. Instruction for how to submit cases are included in the git repository.

[1] https://gitlab.git.nrw/rwth-itv-public/combustion-model-validation-framework-openfoam

[2] Nerzak, S., Nista, L., Vivenzo, M. et al. A Combustion Model Validation Framework for Turbulent Premixed Hydrogen-Air Flames Utilizing OpenFOAM. Flow Turbulence Combust 117, 22 (2026), https://doi.org/10.1007/s10494-026-00745-z

Comparisons on the HYLON Phase 2 Burner

Coordinators: Thierry Poinsot, Thierry Schuller and Gaetano Magnotti

The HYLON setup is a dual swirl hydrogen-air confined flame developed at IMF Toulouse and KAUST. It is a challenging case for validation codes used in gas turbines as it gathers many of their complexities, including confined geometry, stabilization by recirculation zones on the axis and on the sides of the jets, large heat losses to injector lips and walls, and multi regime flames.

HYLON was introduced to the TNF community in 2023, and two databases are now available: HYLON PHASE 1—measurements of velocities without and with flame, mixing without flame for a lifted and an attached flame at 1 bar; and HYLON PHASE 2—measurements of velocities, temperatures, species and NO without and with flame, mixing without flame for a lifted and an

attached flame at 1 bar. A third measurement phase (HYLON Phase 3) has been completed, using the same geometry as HYLON2 but at 3 and 6 bar, and results should be available before the end of 2026.

In this session, the main experimental characteristics of the HYLON burners and the applied diagnostic were summarized. Then simulation results on HYLON PHASE 2 from 14 groups were compared with IMFT/KAUST experimental data, leading to the following key points:

1. Capturing velocity fields (mean and RMS) is reasonably simple and was achieved by multiple groups. However, capturing the temperature profiles within 200 K proved much more difficult as well as the main species (H_2, O_2, N_2, H_2O). NOx profiles were computed by 4 groups with acceptable accuracy but errors which can reach 50% locally.
2. Spatial resolution was extensively discussed. For HYLON PHASE 2, the typical premixed and diffusion flame thicknesses for the lifted flame (the most difficult one) are of the order of 300 microns, while most LES codes used meshes of the order of 100 microns, so that the flames were 'almost' resolved. This was identified as a lucky coincidence which will not happen again for HYLON PHASE 3 at 3 and 6 bar and will never occur for high pressure gas turbine flames.
3. As a consequence, while many groups were able to compute HYLON PHASE 2 without any subgrid-scale model, the future computations at higher pressures will definitely need to account for under resolution. This question is usually solved for premixed flames using thickening or filtering approaches, but such methods do not exist yet for diffusion flames or for triple flames.

Comparisons on the TU Darmstadt multi-regime burner (MRB)

Coordinators: Etienne Espada and Benoît Fiorina

The Multi-Regime Burner (MRB) configuration consists of three concentric inlet streams, which can be operated independently at different equivalence ratios. A rich premixed hydrogen/air flow is injected through the central tube, referred to as the “jet”. This main injection stream is surrounded by two concentric annular tubes, referred to as “slot 1” and “slot 2”. Pure air is injected through slot 1, while a lean premixed hydrogen/air flow, with an equivalence ratio of 0.26, is injected through slot 2. A temperature-regulated conical bluff body separates slots 1 and 2, and a second bluff body separates slot 2 from a low-speed air co-flow.

The joint numerical study focused on three configurations—H100-350-026-a, H100-350-026-b, and H100-900-026-a—which differ in terms of jet equivalence ratio (3.5 and 9.0) and slot 1 bulk velocity (a-7.5 and b-12.5 m/s). The objective of the joint study was to provide a state-of-the-art assessment of current turbulent combustion modeling capabilities. More specifically, the study aimed to assess the overall performance of current simulation approaches and identify physical phenomena that are not adequately captured by most modeling strategies. Three numerical groups were involved in the simulations: Technische Universität Darmstadt (TUDa), the EM2C-CNRS laboratory at Université Paris-Saclay (EM2C), and the Institut de Mécanique des Fluides de Toulouse (IMFT). Quantitative comparisons were presented for the H100-350-026-a configuration, while the results for H100-350-026-b and H100-900-026-a were discussed qualitatively.

Simulations were performed using four different solvers. Reference DNS solutions were computed with the NekCRF reactive flow solver, using 910 million grid points and a detailed chemical mechanism, for the three target configurations. LES simulations were then performed using PRECISE-UNS, YALES2, and AVBP. Hydrogen combustion chemistry was modeled using either reduced or tabulated chemistry. Flame under-resolution was addressed using TFLES for the transported-chemistry approach and F-TACLES for the tabulated-chemistry approach. Different grid resolutions were employed, with mesh sizes ranging from 10 million to 126 million cells.

The analysis of the results showed that all participants were able to capture the overall lifted-flame structure. However, the analysis of the temperature profiles revealed that all simulations underestimated the experimental temperatures. Significant discrepancies were also observed in the predicted lift-off heights compared with the experimental measurements.

The final discussions highlighted the need to further validate the numerical models against NOx emissions. TUDa plans to perform experimental measurements of NOx production within the turbulent flame structure. Future work will also investigate the MRB configuration using H_2/CH_4 blends.

Challenges of resolving high-pressure flames in LES

Coordinators: Benoît Fiorina and Thierry Poinsot

This session focused on the issue of spatial under resolution in LES of diffusion and multi-regime flames, especially at high pressure. The presentation had four parts:

1. Why spatial resolution is a difficult issue for LES especially at high pressure
2. Interaction between SGS models and numerical limiters at high pressure
3. Thickening models for diffusion flames: diffusion front thickness control (DFTC) model
4. Flame filtering for multi-regime flames

These issues are expected to be of centrally important for simulation of HYLON Phase 3.

AI/ML for turbulence-chemistry interaction

Coordinator: Matthias Ihme

This PTF-style session included six talks: *TNF Machine Learning BLASTNet Update* (Matthias Ihme); *Uncovering flame physics with machine learning* (Antonio Attili); *Towards Generative Adversarial Network-based LES closures for turbulent lean H2 flames* (Heinz Pitsch); *Neural ISAM: AI embedding for computational acceleration and manifold model generalization* (Michael Mueller); *Scientific machine learning and frontier AI for advancing modeling and design of combustion systems* (Pinaki Pal); *Can multi-fidelity active learning reduce the cost of DNS studies?* (Hongchao Chu).

Update on flame-wall interaction

Coordinators: Andreas Dreizler and Christian Hasse

Flame-wall interaction (FWI) has been one of the focus topics of several past TNF workshops, with sessions providing a broad overview of community activities in this research area. For 2026, this was scaled back to simply provide an update on recent progress because there was not a commonly agreed target case for comparison of experiments and simulations. Four short talks were given: *DNS* (Max Schneider); *Comparative experimental study of FWI for CH_4 and H_2* (Andrew Macfarlane); *Investigation of turbulent momentum and heat transport in flame-wall interactions* (Brian Peterson); Flame-Cooling Air Interaction in Gas Turbines (Pradip Xavier).

Chemical kinetics for TNF ammonia target flames

Speaker: Alessandro Stagni *Chair: Peter Lindstadt*

It was agreed at TNF16 (2024) that it would be important for this community, with help from experts in chemical kinetic modeling, to identify the best available mechanisms for ammonia/hydrogen combustion, so that preferred mechanisms could be used in common in future collaborative simulation efforts on ammonia target flames. With encouragement from several members of the TNF Organizing Committee, Alessandro Stagni and Timoteo Dinelli conducted a comparative evaluation of recently-published chemical kinetic mechanisms for ammonia combustion, with emphasis on aspects of particular importance to the TNF community. The highly informative presentation was well-directed toward the TNF audience. In

addition to the material in the proceedings, a pdf report on the mechanism comparisons is available under tnfworkshop.org/chemistry/.

Three representative mechanisms (C3MechLite V4.0.1, CRECK 2025 and KAUST 2024), representing independent kinetic lineages, were compared against a broad and curated experimental database using the same numerical framework, boundary conditions and physical assumptions.

The comparison showed that modern mechanisms consistently reproduce the global response of NH_3 and NH_3/H_2 flames over a wide range of atmospheric conditions. Agreement remains robust across hydrogen blending ratios, and the correct trends are also reproduced for extinction in strained counterflow flames. At elevated pressure, however, differences among mechanisms progressively increase, particularly in rich conditions. The analysis indicates that pressure-dependent reactions, third-body efficiencies and collisional energy transfer become increasingly important under these conditions, making high-pressure flames a more stringent validation target than atmospheric flame speeds alone.

Species measurements provided a complementary and more demanding assessment of the underlying chemistry. Major species, overall flame structure and the dominant reaction pathways are generally predicted consistently across the mechanisms, whereas quantitative pollutant predictions, specifically NO, remain substantially more sensitive to both the selected mechanism and the experimental configuration. Moreover, it was shown that no single mechanism reproduces all independent species datasets equally well. Cross-facility reconciliation and validation across complementary configurations are identified as the most important challenges in the near future.

The Kyoto discussion identified the following implications and next steps:

- Validation should increasingly focus on generalization across independent datasets, laboratories and experimental configurations rather than agreement with individual datasets.
- For TNF target flames, current mechanisms provide a sufficiently mature basis for predictions of global flame behavior and major chemistry, while quantitative NO predictions should be interpreted with greater caution.
- Mechanism reduction should target the minimum chemical complexity that preserves validated predictive capability for LES and DNS, rather than mechanism size alone.
- Future validation should progressively extend toward higher-pressure and more application-relevant conditions, with predictive simulations of TNF target flames providing the ultimate test of the chemistry.

Simulations of the partially premixed, piloted cracked ammonia jet flames

Coordinators: Gaetano Magnotti and Hong Im

The piloted partially-premixed $NH_3/H_2/N_2$/air jet flames, measured at KAUST, were a target of the TNF16 workshop (2024). This series of ammonia flames features varying levels of localized extinction, analogous to the Sandia/Sydney piloted CH_4/air jet flames that were early TNF targets. The 2024 comparisons, which involved nine contributing groups, were viewed as preliminary, and none of the simulations correctly predicted the extinction behavior in flame F. Only three groups had updates on their simulations for 2026, and these were presented as separate PTF-style talks, following a brief review of the flame configuration and previous comparisons. Titles: *Sandia/Sydney piloted $NH_3/H_2/N_2$/air flames: Joint experimental-numerical comparisons* (Gaetano Magnotti); *Transported PDF and MMC modeling of turbulent piloted $NH_3/H_2/N_2$ jet flames* (Lu Tian); *A DNS study on combustion mode and heat release characteristics of turbulent piloted $NH_3/H_2/N_2$ jet flames* (Jiangkuan Xing); *Large eddy simulations of turbulent piloted $NH_3/H_2/N_2$ jet flames using principal component transport* (Suliman Abdelwahid).

Both the PDF/MMC and the LES/PCT simulations achieved reasonable success in predicting local extinction behavior. For reasons that are unclear, the DNS of flame F significantly under predicted extinction. From past experimental and numerical experience with the piloted methane flames, it is known that the extinction behavior for this burner configuration can be highly sensitive to small changes flow conditions, especially when approaching flame blowoff. For the present flames, it was demonstrated for the PDF/MMC simulations that agreement on flame F extinction could be noticeably improved by increasing the jet velocity by only 1.1 percent, which is within experimental uncertainty. Such sensitivity should be kept in mind in future comparisons.

Other potential future TNF target cases

Coordinator: Rob Barlow

This session included short presentations to introduce new and recently published experimental or DNS configurations that might serve as future TNF target flames and were not already covered in earlier session: *TNF target flames – DNS cases* (Antonio Attili); *HYLON Phase 4* (Thierry Schuller); *New cases from TU Darmstadt* (Tao Li); *Sydney mixed-mode bluff-body (M2B2) burner* (Matt Dunn). Information on new datasets will be added to the TNF website as they become available.

Key Points and Perspectives

Collaborative comparisons of multiple simulations of selected detailed datasets are the most important contribution of the TNF workshop series. Four configurations were considered for collaborative comparisons at TFN17: HYLON2, the lean premixed H_2 jet flames and the H_2 multi-regime (MRB) flames from TU Darmstadt, and the piloted partially premixed cracked ammonia jet flames measured at KAUST. Each of these configurations offers interesting physics and modeling challenges that are relevant to practical combustion of carbon free fuels. The lean premixed jet flames traverse a range in *Ka* that reveals significant changes in the measured signatures of preferential diffusion. HYLON and the H_2-MRB both feature multi-regime combustion, and the piloted ammonia flames feature varying levels of localized extinction and, again, multi-regime combustion.

While the HYLON program has attracted contributions from a large number of modeling groups (14), the comparisons on other TNF17 target cases involved relatively few participants. Furthermore, the comparisons did not really allow for clear interpretation of the performance of combustion submodels, either because relatively high grid resolution meant that combustion models were not stressed or because other aspects of the simulations were not handled in a common or consistent way, making it difficult to identify reasons for disagreement.

TNF17 set a record for attendance, and there was a lot of positive feedback, especially from younger participants, regarding the format and technical quality of the workshop. However, from the perspective of the organizers and long-time veterans of the TNF series, the TNF17 workshop fell short of the high expectations outlined at the conclusion of TNF16, and there is still work to be done to get back to having a workshop program build mainly around curated sessions on collaborative examination and advancement of models for turbulence-chemistry interaction.

Such collaborative comparisons are most informative when they combine most, if not all, of the following components. The target problems should include at least two flame conditions that show clear differences in physical behavior associated with an aspect of turbulent combustion that is challenging to capture with current models. Experimental datasets should include both scalar and velocity data, using as many complementary diagnostics as possible and with uncertainties provided. Boundary conditions must be well-documented, unambiguous, and applied consistently across the different simulations. Modeling efforts should be coordinated so

that simulations are carried out in ways that facilitate informative comparisons (e.g., targeting the same set of flames, using the same chemical kinetic mechanism, using the same precalculated inflow, and sharing information on grid resolution/convergence and parameter sensitivity). Information on results and issues should be shared well ahead of the workshop (with appropriate agreements on nondisclosure) to allow for additional investigations and thoughtful interpretation. This sort of inter-group coordination and information exchange can be especially beneficial to the young researchers involved in the work.

Preparations for TNF18

TNF18 is expected to be held as a satellite workshop of the 42nd International Symposium on Combustion (Rio de Janeiro, Brazil, 23-28 July 2028). There has also been a suggestion from Thierry Poinsot and Laurant Selle to hold a related but more focused workshop on modeling of premixed and multi-regime hydrogen flames, particularly under-resolved flames at elevated pressure. This would be connected with MCS14 in Marseille (20-24 June 2027).

Many of the available experimental and DNS datasets already have brief descriptions on the TNF website, and data archives for some cases can be downloaded. Additional descriptions and data will be added as it becomes available. A full list of potential targets will be maintained on the TNF18 WORKSHOP—PLANNING page.

It is essential that the targets for collaborative comparisons be selected well ahead of the workshop to allow for coordination among the participating groups. We anticipate that there will be an email broadcast early in 2027 to update the community regarding available datasets and to gauge interest in some of the more likely targets for TNF18. We also anticipate that there will be an email broadcast in summer 2027 to identify specific target cases for comparative simulation and to begin coordination among the interested group. Those interested in participating in collaborative model comparisons are encouraged to contact the data owners or corresponding members of the TNF Organizing Committee.