**ECN9 Hydrogen topic session summary**

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The hydrogen topic was first identified during ECN8 as a future direction for the community and subsequently first organized for the ECN9 workshop in 2023. The motivation for this topic was that a clear future is projected for H2 engines in heavy-duty, off-road, and stationary applications. Within the topic, the aim was to gain better understanding of injection, mixture formation, and ignition of DI H2 injections. Confronted with hardware limitations, a simple free jet from a 0.65-mm single orifice was chosen as a baseline condition for numerical simulations. Experimentally, this one-off nozzle was characterized, and the internal geometry was made available, but results from different injectors (inward- and outward opening needles) were welcomed because of the lack of a standardized unit available to all contributors.

After introducing the topic and discussing potential (optical) diagnostic techniques for H2 jets, experimental results by TU/e, IFPEN, CMT, STEMS, KAUST, and UNSW were shown. The results highlighted how outward opening (poppet valve) injectors have a more linear jet penetration behavior when compared to inward opening single-orifice injectors. A lot of shock cells were observed, but the stability thereof needs studying. When considering ignition, a strong dependence on ambient temperature was found by many researchers. Flames tend to ignite at approximately 40% of the jet length and spread very fast. Multiple ignition spots were not frequently detected.

Numerical results were submitted by POLIMI, Perugia, TU/e, KAUST, and Sandia. Spray penetration predictions overall were quite accurate when compared to the experimental cases, but it was shown how needle transients and throttling to lower pressure before injection needed to be better described and investigated in the future. Again, the stability and magnitude of shock cells showed some different results depending on the used models, again warranting further studies. Finally, near- and in-nozzle results highlighted significant swirl because of the (pre-)swirler in the simulated modified gasoline injector leading to tangential velocities exceeding 75% of the axial velocity.

In a breakout session, a discussion was held for future directions. While many people were already in possession of prototype H2 injectors, NDAs were signed for them. For the ECN, off-shelf commercial injectors are required, such as the Bosch HDEV4 outward opening injector. This would offer injection pressures up to 200 bar and could be bought in a batch to avoid variability between different injectors. We want to prove consistency in experiments, and then in simulations. Near-field modeling should be sufficiently accurate to model the downstream, meaning that shock cells are very relevant. The good thing about any chosen direction would be that we are developing everything (models, diagnostics, etc.) anyway. Hopefully, what we develop will work with other future experiments or simulations.

Finally, it was decided to go with the Bosch HDEV4. Preliminary conditions target LPDI with 50 bar injection pressure and a low back pressure, simply to have a starting point that fits most relevant applications. It is noted but taken for granted that it would be difficult to inject sufficient hydrogen using the small-needle-lift HDEV4. Long injections, even during compression would be required. For optical techniques, higher back pressure could be beneficial, such as for instance a maximum of 20 bar. However, 5 bar ambient pressure would probably fit best as the nominal case, while 1 or 2.5 bar could be used at the lower end. There is also a need to identify the cheapest piezo injection drivers.