# ECN 9 outcomes

## Experiment

1. Liquid Volume Fraction (LVF) obtained from Diffused Back Illumination Extinction Imaging (DBIEI) and Computed Tomography (CT) can be used as quantitative experimental data for numerical validation of evaporation and spray collapse models.
2. New assessments of LVF uncertainties allow for better corrections of their sources, such as multi-scattering, ballistic photons, incomplete sinograms or extinction coefficients estimations.
3. Different spray patterns at the same thermodynamic conditions were identified between two sprays M donated by BorgWarner with serial numbers 756 (measured in Sandia Livermore) and 772 (measured in FAU Erlangen).
4. Due to its higher evaporation enthalpy, methanol (MeOH) exhibits a longer penetration depth. It also takes a longer time after the end of injection to evaporate completely, which could be indication of local cooling of the ambient.
5. High speed thermocouples can provide information of fuel film depositions for wall impingement cases.

## Simulation

### Late-injection condition (M1) (Free spray):

1. In the experiment session, the “Spray M Injector with serial number 756 that was used as benchmark for the simulation” has unique spray morphologies compared to the original “Spray G” injector, facilitating spray collapse and further inducing spray sweeping.
2. The process of spray collapse and sweep can be clearly observed from 3-D CT LVF plane section data 20 mm downstream. The spray morphologies are captured by TU Darmstadt and POLIMI.
3. An important take-away message is that one could not believe and rely solely on one type of experimental data for validation. By applying the merit function using multiple datasets and operating conditions, the simulation data can be well assessed.
4. Multi-component fuels (PACE 20 and E00) possess preferential evaporation characteristics. High volatile fuels tend to evaporates along the spray core and due to light molecular weight distributes mainly downstream. In contrast, the evaporation of low volatile fuels takes place mainly on the spray shear layer which is the location in between ambient gas and spray core.
5. RANS simulation cannot capture the preferential evaporation while LES simulation can.

### Early-injection condition (M2) (Free spray):

1. According to the vapor pressure and fuel temperature diagram, methanol and PACE20 possess stronger volatility and higher vapour pressure than iso-octane. This is important/apparent particularly under the original G2 condition where the temperature of fuel and ambient are 363 K and 333 K and the ambient pressure is 0.5 bar. (Note: due to different injectors, the condition G2 is renamed as M2, reflecting the currently targeted injector)
2. Under the M2 condition, methanol and PACE20 lie within a flash-boiling regime with the P\_vap/P\_amp ≈ 5, in which the spray collapse plays a significant role.
3. By applying different models to deal with the spray collapse due to flash boiling phenomenon, the breakup model from the University of Aquila shows the capability of reproducing the collapsing effects.

### Spray-wall interaction (G2 Cold):

1. In this section three different targets merit investigations of different physics: Spray-wall interaction, spray cooling and fuel film deposition.
2. Simulation can capture facets of Spray-wall Interaction, including the near-wall jet and vortices.
3. Spray cooling due to evaporation effects induced by air entrainment is predicted in the simulations, in accordance to trends predicted by 0-D analysis using liquid-vapor equilibrium calculations at different mixture fraction. Cooling of the fuel from 293 K to 271 K at a mixture fraction at the wall is predicted from equilibrium.
4. However, due to the boundary condition of constant temperature, the simulation tends to provide a higher heat flux, indicating the importance of Conjugate Heat Transfer.
5. Using single layer strategy solving the wall film deposition, the simulation can reproduce the evolution of the fuel film motion and further reveals that the fuel film deposition mainly take place during a second injection into a pre-existing flow and fuel mixture.

# ECN9 future directions

## General comments:

1. Since methanol can be widely utilized in both direct-injection compression (use of additives or dual fuel systems) and spark-ignition engines, the target injector can be expanded to not only the gasoline direct-injection (GDI) injector but the diesel injector with high injection pressure.
2. Furthermore, to further extend the usage of methanol on heavy-duty and ship engines, port-fuel (PF) injection type injectors and conditions are of interest.

## Simulation:

1. In the ECN9, the exposure of the model weakness in terms of accounting for the strong flash boiling indicates that prior efforts dedicated on the flash-boiling modelling, including evaporation and breakup modelling, are not sufficient.
2. To develop the adequate flash-boiling models and approach, it may require support from more detailed experimental dataset such as microscopy.
3. To better predict the heat transfer in the spray-wall impingement case, conjugate heat transfer is imperative.

# Experiment:

1. In order to prepare an ECN benchmark for PF injection it would be of interest to agree on a common PF injector to use.
2. Near nozzle X-ray measurements for spray M as available for spray G are of interest for simulation.
3. To assert the origin of discrepancies between Sprays M 772 and 756 (differences in injector geometry, different electronic drivers, purity of the MeOH…) is of interest.