

FEV Signature Solutions CMD Process for H₂ ICE



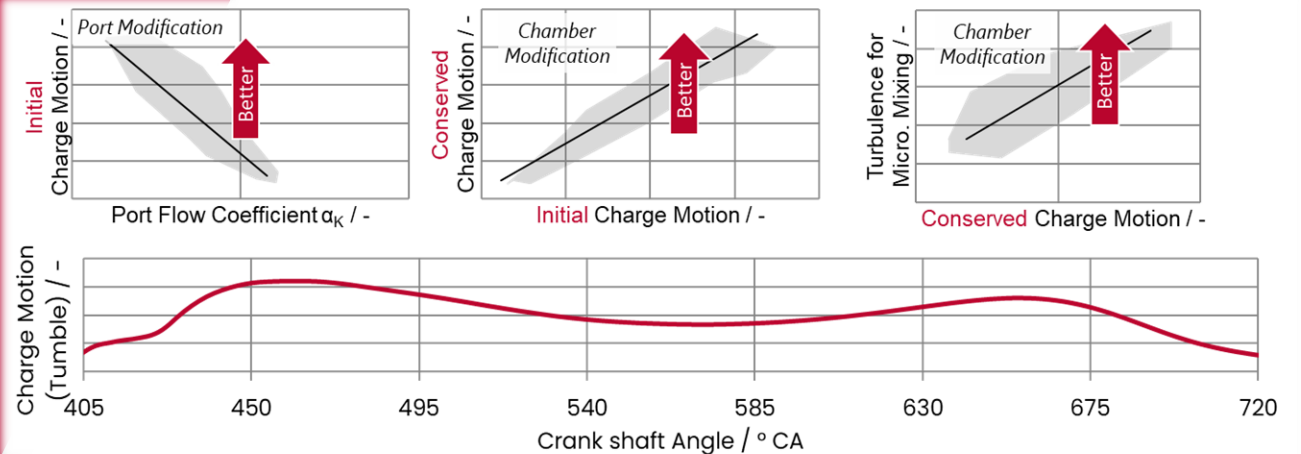
Charge Motion Design (CMD) process enables effective mixture formation for H₂ ICE based on charge motion & turbulence

FEV offers

- ▶ Determination of port quality and comparison to benchmark
- ▶ Evaluation of charge motion & turbulence level in pre-development stage
- ▶ Estimation of burn duration for HRR estimation
- ▶ Optimization of mixture formation layout via 3D CFD simulations
- ▶ Comparison of customer layout with FEV benchmark

Why FEV

- ▶ >30 scatter bands from previous engine developments to identify weak points
- ▶ More than 80 different premixed engine concepts ranging from pass-car to heavy duty applications (see reference slides)
- ▶ Optimization of relevant design parameters based on scatter band data



Comprehensive experience with different technologies and applications

SELECTED H2-ICE REFERENCE PROJECTS


Commercial Vehicle DI H2 engine development

Reference project hydrogen combustion engine

140 HD HYDROGEN DI COMBUSTION ENGINE
ENGINE DESIGN AND COMBUSTION SIMULATION

FEV DELIVERABLES

- Direct injector design integration
 - Supplier nomination
 - Integration in the diesel engine head
- Thermodynamic simulation 1D and 3D
 - Piston design
 - Injector targeting
 - Mixture formation
 - Subcharge layout



» FINISHED

» VEHICLE READY 2022

Off-Road Application PFI H2 MACHINE demonstrator

Reference Project Hydrogen Combustion Engine
Courtesy of JCB Ltd.

HYDROGEN COMBUSTION ENGINE
DEMONSTRATOR INTEGRATION

HYDROGEN ICE INTEGRATION

- 4.3 engine, 71 kW

FEV DELIVERABLES

- Concept development
- Engine commissioning and testing
- Development of control software
- Commissioning support



» DEMO MACHINE RUNNING

» VEHICLE READY 2022

Commercial Vehicle DI H2 engine development

Reference project hydrogen combustion engine
Courtesy of Cummins Inc.

HYDROGEN COMBUSTION
DI ENGINE DEVELOPMENT

- Conversion of a Cummins MD engine to H2 DI demonstrator

FEV INVOLVEMENT

- Concept definition and design
- Thermodynamic simulation
- Manufacturing and procurement of new/modified components for H2 DI
- Engine commissioning, first firing and thermodynamic investigations on a test bench



» ON TEST BENCH

» FIRST FIRING 2022

Commercial Vehicle DI H2 engine design

Reference project hydrogen combustion engine

15L HD HYDROGEN DI ENGINE
CONVERSION FROM NG ENGINE

- Development of HD DI hydrogen combustion engine

FEV involvement

- Concept layout and design
- 1D and 3D simulation
- EATS layout
- FEA analysis
- Calibration support



» SIMULATION STAGE


» SOP 2023

Reference project hydrogen combustion engine

2-LITER HYDROGEN DI COMBUSTION ENGINE
ENGINE DESIGN/CALIBRATION + DEMONSTRATOR INTEGRATION

FEV DELIVERABLES

- Simulation and design of the CV concept engine incl. Hardware adaptations
- Identification and definition of prototype supplier. Parts procurement for adapted engine components and H2 tanks
- SAE development for all hydrogen related control functionality including H₂ injection, H₂ storage and H₂ supply system
- Setup, commissioning and complete calibration of first prototype engine
- Vehicle assembly/construction of a near-series prototype
- Feasibility study and assessment for series production



Automotive

DI H2 **VEHICLE** demonstrator

Reference Project Hydrogen combustion engine

8 LITER HYDROGEN PFI COMBUSTION ENGINE
VEHICLE CALIBRATION ENGINE + EATS

FEV DELIVERABLES

- Full scope vehicle support for Daimler Special truck
- Calibration of different environmental conditions especially for "working while driving" - Power take off
- Software specification
- Optimization of transient behavior
 - Potentially investigate electrical supported turbocharger
- EATS calibration
 - Full scope emission calibration targeting Euro VI levels including PEMS measurement



Commercial Vehicle


PFI H2 engine development

Reference project hydrogen combustion engine
Courtesy of Iveco Group

13L HD HYDROGEN DI COMBUSTION ENGINE
ENGINE DESIGN AND COMBUSTION SYSTEM DEVELOPMENT

FEV DELIVERABLES

- H2 Direct injector design integration
 - Integration of H2 DI system in the NG engine cylinder head
- Thermodynamic simulation 1D and 3D
- Engine testing
- Development of control software



Commercial Vehicle


DI H2 engine development

Reference project hydrogen combustion engine

6L MD HYDROGEN PFI COMBUSTION ENGINE
ENGINE DESIGN AND COMBUSTION SYSTEM DEVELOPMENT

FEV DELIVERABLES

- Concept development
- Thermodynamic simulation 1D and 3D
 - Piston design
 - Injector targeting
 - Mixture formation
 - Subcharge layout
- Engine commissioning
- Engine testing
 - Emission and performance
- Vehicle calibration



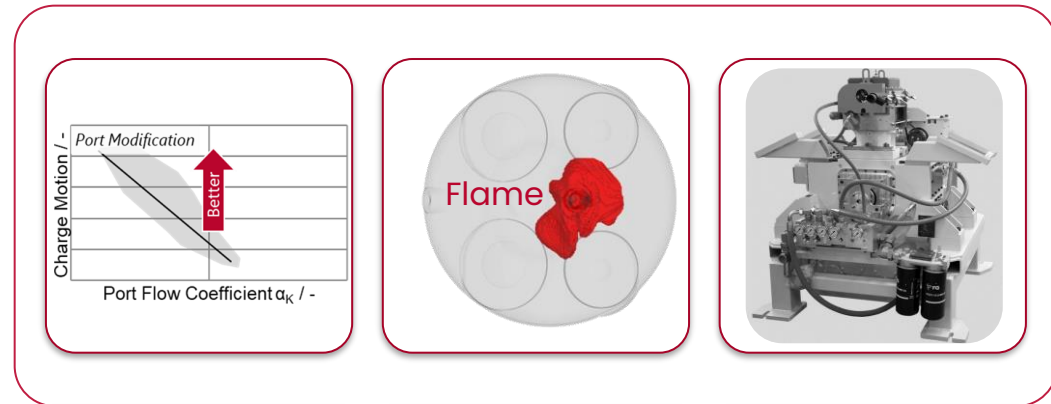
Commercial Vehicle

PFI H2 engine development

FEV charge motion design for pre-mixed engines

Optimization of combustion system in engine design layout phase

CMD ANALYSIS IS TRIGGERED AND VERIFIED BY BENCHMARK AND TEST BENCH CORRELATIONS



Concept Phase

- ▶ Based on FEV's unique scatter band collection
- ▶ Benchmarking data
- ▶ Layout of port, valve seat rings, etc.

Development Phase

- ▶ Based on FEV's combustion prediction tool
- ▶ Fast post-processing tool
- ▶ Evaluation based on relevant quantities

Test Bench Validation

- ▶ Optical test bench
- ▶ SCE & MCE engine test bench
- ▶ Validation tools

Definition of Flow Leading Surfaces

Design of port, valve seat rings & bottom chamfers, etc. and comparison/benchmarking with FEV scatter bands.

Steady State Flow & Charge Motion Generation

3D CFD steady state CFD to calculate flow coefficients & charge motion. Comparison to FEV scatter bands.

Transient Charge Motion & Combustion Quality

Calculation of transient charge motion, turbulence and correlation of CFD results to burn duration (within minutes during post-processing) .

Quality of H₂ Mixture Formation

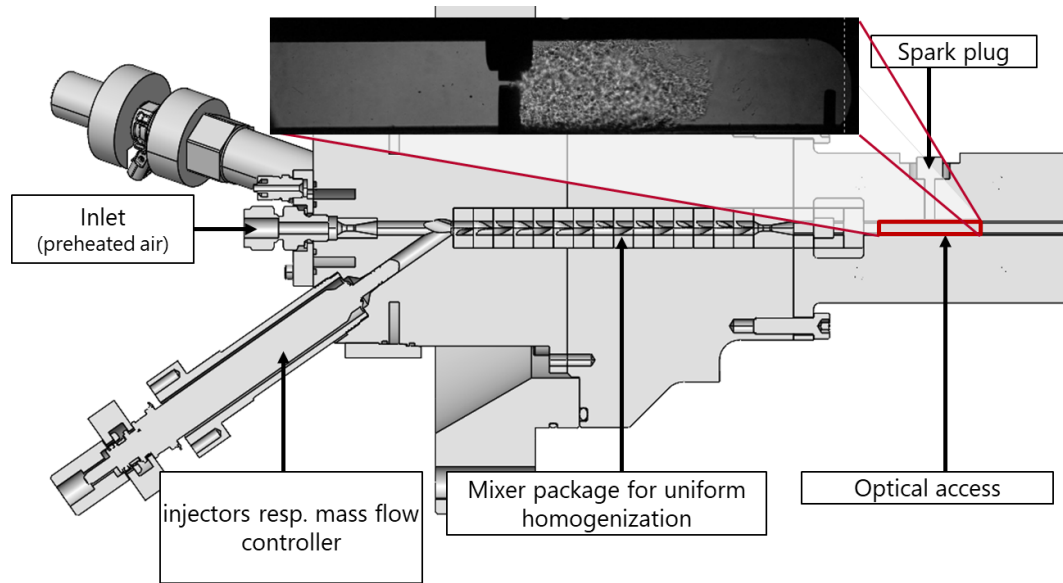
Calculation of lambda and temperature inhomogeneity with assessment of the effect on combustion.

Test Bench Verification

Verification of performance on test bench. Explanation of test results.

From charge motion to combustion: Extended hydrogen combustion and numerical approach to consider wrinkling effects

MODEL IMPROVEMENT BY PREDICTION OF EARLY FLAME KERNEL GROWTH
(CONSIDERING LEWIS NUMBER & MARKSTEIN LENGTH EFFECTS)

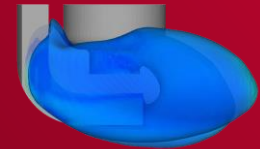


From fundamentals to industry proven tools

- ▶ Measurements in hydrogen pipe and optical high pressure combustion chamber
- ▶ Allows reproduction of engine-like conditions
- ▶ Yields detailed insights into early flame kernel growth



Standard models:



Flame speed



FEV model:



Prediction error reduced to < 3%

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