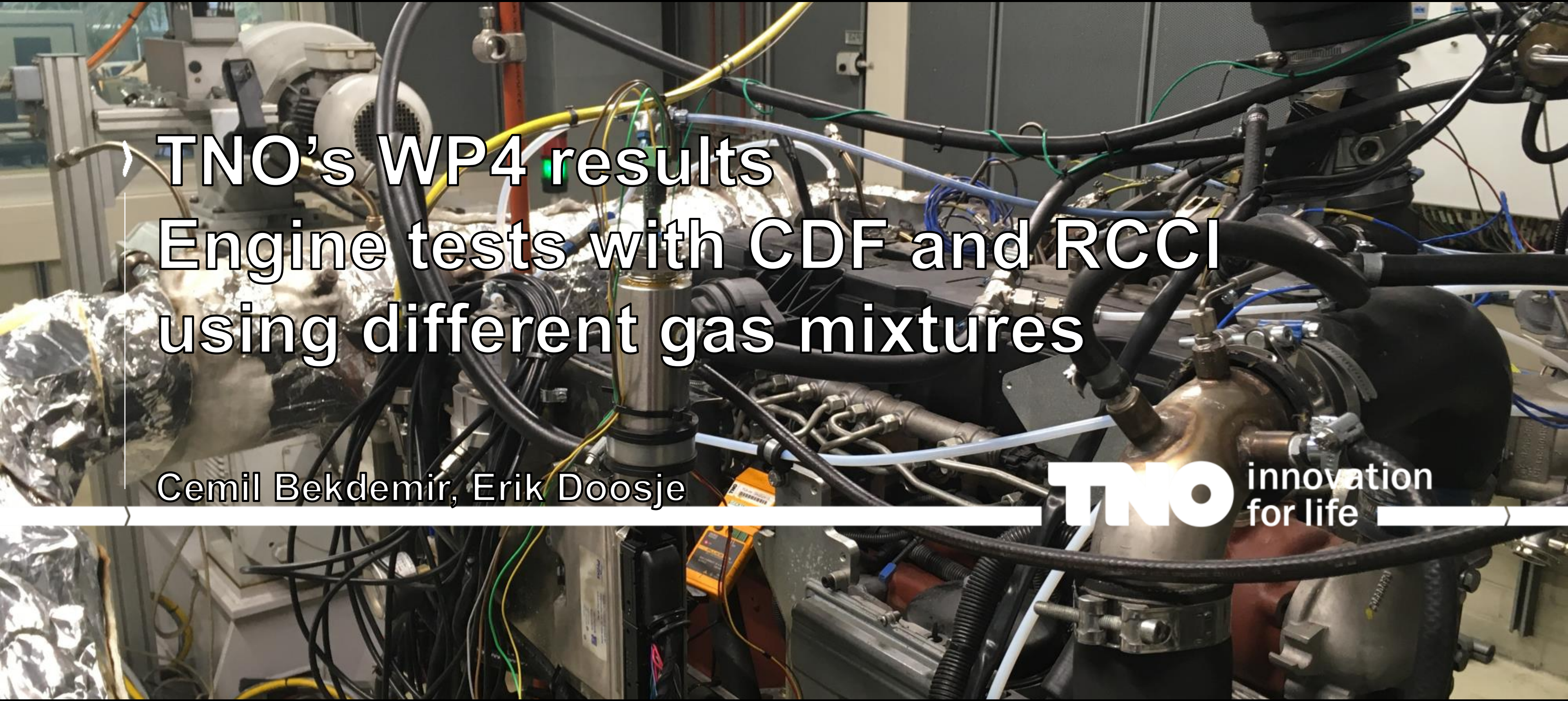

# TNO’s WP4 results
# Engine tests with CDF and RCCI using different gas mixtures

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TNO innovation for life

# CONTENTS

# TNO ENGINE TESTS

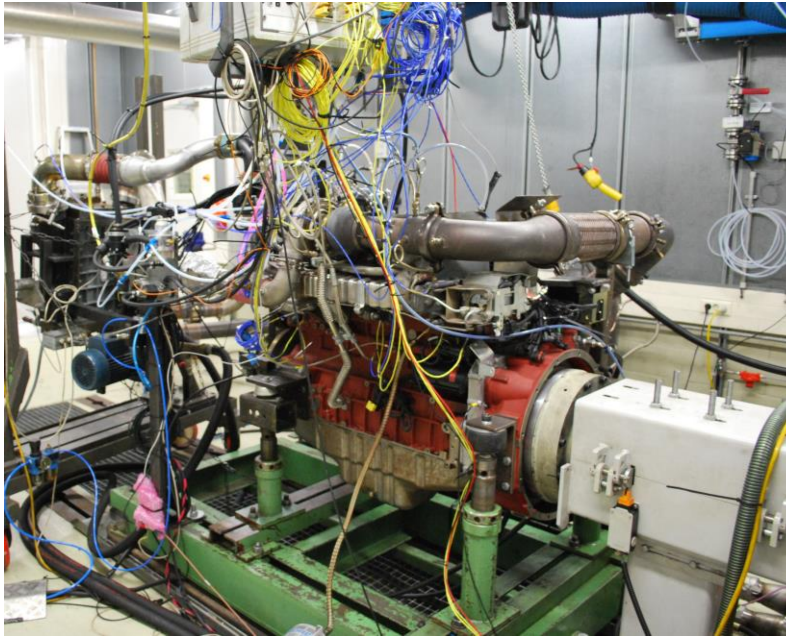
## DUAL-FUEL COMBUSTION ON 6 CYLINDER TRUCK ENGINE

**Motivation**

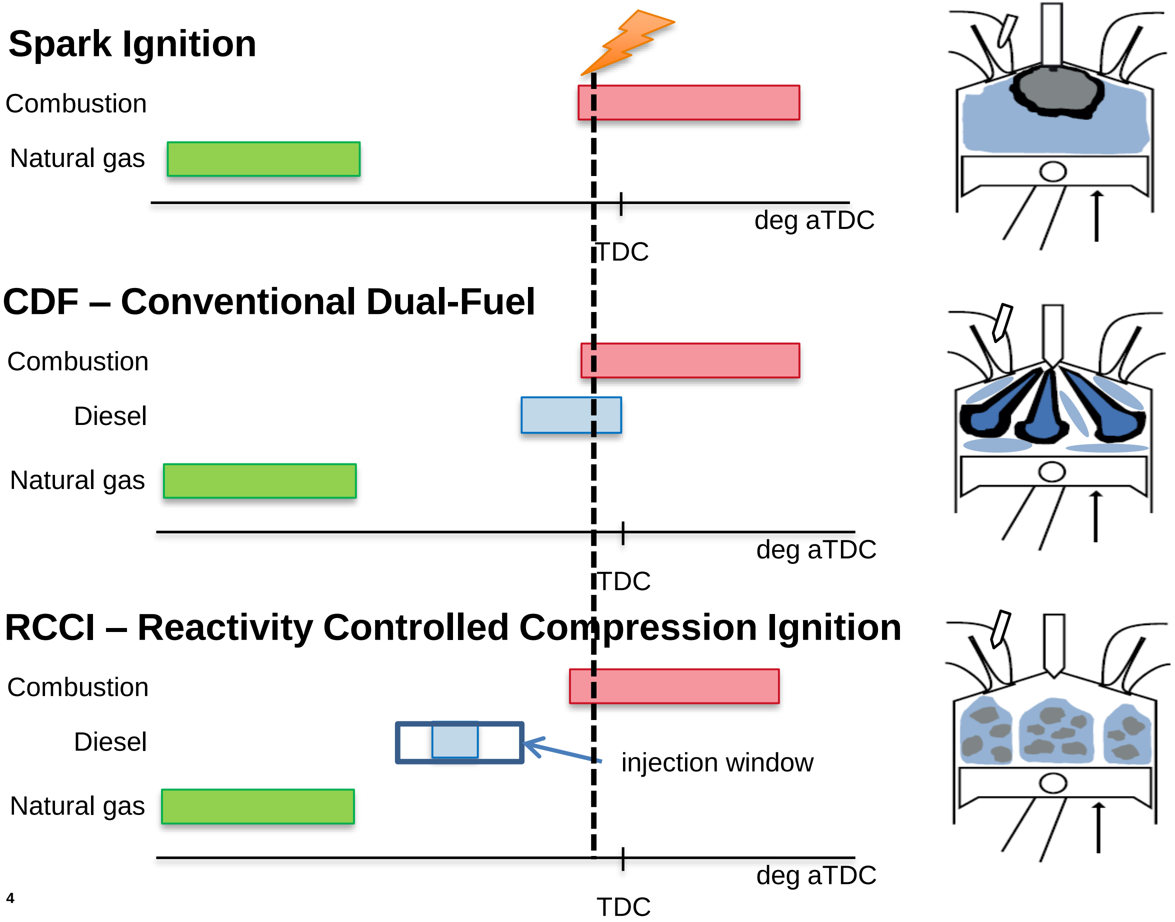
For light-duty engines the spark ignition (SI) concept is common, whereas for heavy-duty engines also dual-fuel engines are increasingly considered as a viable alternative. This is because the dual-fuel technology promises higher efficiency, higher load performance, and the fall back option to 100% diesel operation.

**Objectives**

- Validation of the gas composition sensor developed in WP3 on an environment that is typical for present and future heavy-duty gas engines:
- Validation of MN – knock relation for conventional dual-fuel (**CDF**) using natural gas and diesel;
- Outlook towards the meaning and value of MN for advanced dual-fuel combustion concept **RCCI**.
- Potential assessment of sensor signals for control purposes in dual-fuel applications.



# DUAL-FUEL (CDF AND RCCI) COMPARED TO SPARK-IGNITED MONO-FUEL COMBUSTION



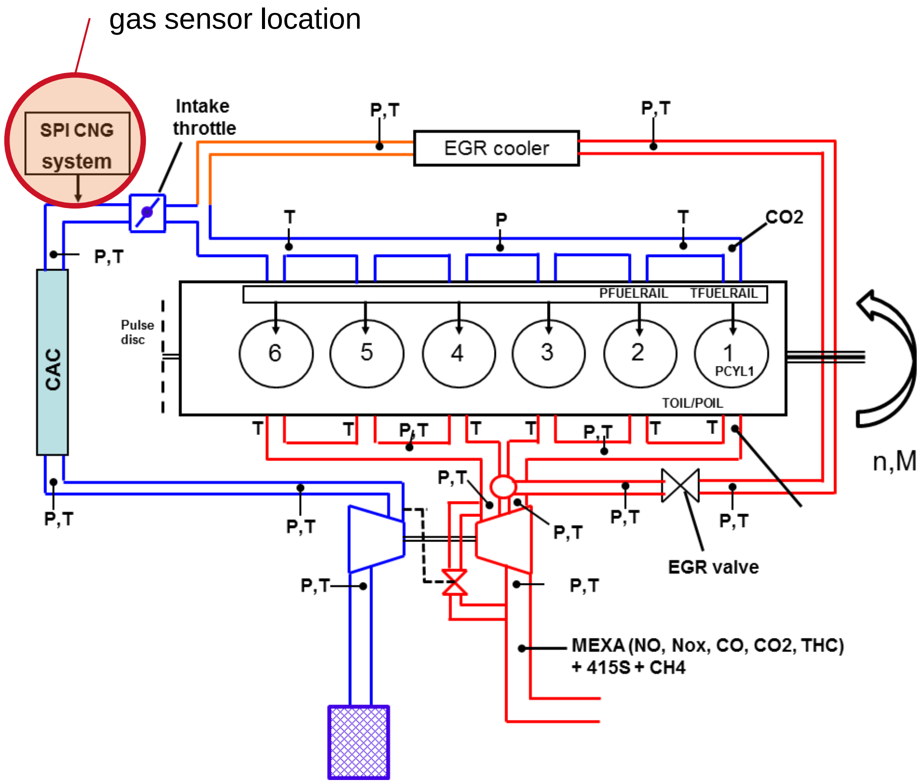

What are the End-gas properties for Dual-Fuel?

How are these affected by the gas Methane Number?

How are these affected by engine control parameters?

# ENGINE SETUP

| | |
|---|---|
| **Engine** | 6 cylinder in-line, 8 liter, 250 kW |
| **Compression ratio** | 18:1 |
| **Bore/stroke ratio** | 0.8 |
| **Fuel injection equipment** | Common rail system, maximum injection pressure 2000 bar, multiple injection capability |
| **Air path** | Waste-gated turbocharger, intake throttle |
| **EGR path** | High-pressure, cooled EGR system with EGR valve |
| **Engine test fuels** | • 4 different natural gas compositions:<br>• G20<br>• MZ70<br>• TUBS "Mix9"<br>• Dutch Natural Gas (DNG)<br>• Diesel fuel type: EN590; |

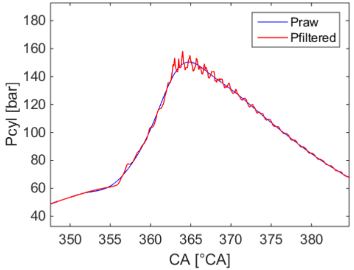


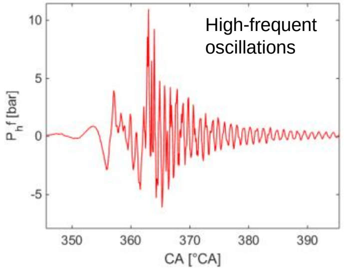
# KNOCK DETECTION AND INDICATORS

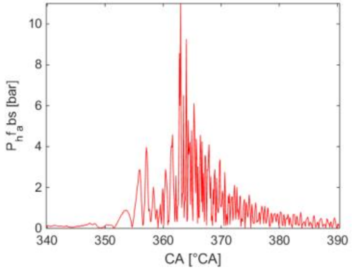
- Knock: uncontrolled end-gas auto-ignition, resulting in excessive pressure gradients

- Detection through
  - Engine block vibrations (acceleration or ‘knock’ sensor)
  - Cylinder pressure measurement and analysis

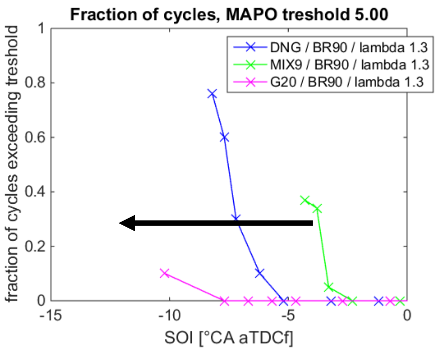
- Different methods are in use:
  - PPR - maximum pressure rise rate
  - MAPO - maximum amplitude of pressure oscillations
    - used for **CDF**
  - IMPO - integral of pressure oscillations
  - Knock ratio - ratio of pressure oscillation integral before/after reference point (location of peak pressure)
    - used for **RCCI**. Sharp pressure oscillations seem to be less for RCCI (more ‘volume’ reaction compared to CDF), therefore, the Knock ratio seems to be a better indicator.



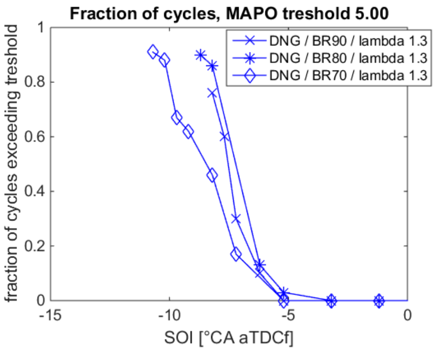



# SELECTED RESULTS CDF



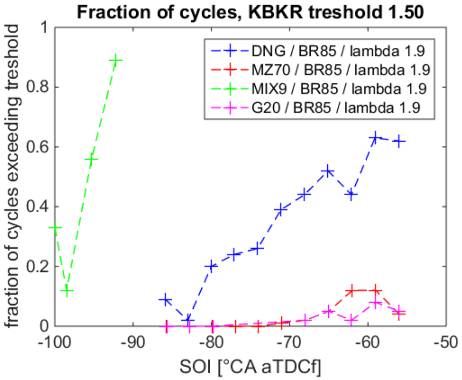

Gas with higher MN enables earlier ignition (diesel injection) before knock occurs.

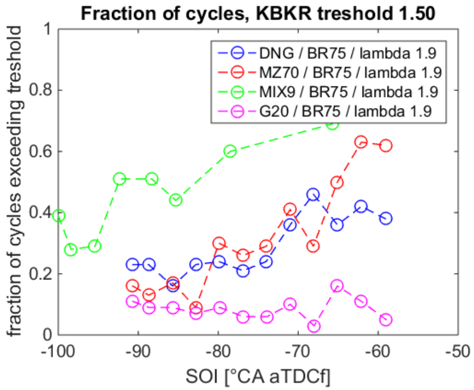



Lower blend ratio means higher air-to-fuel ratio (lambda) of gas in end-gas. Ignition through diesel injection can be performed earlier.

SOI = start of injection of diesel fuel, lambda = air-to-fuel ratio, BR = fuel blend ratio

# SELECTED RESULTS RCCI




- For RCCI combustion, knocking behaviour increases for lower fuel blend ratio (higher end-gas air-to-fuel ratio). This response is opposite to CDF combustion
- It seems that for RCCI combustion, end-gas conditions are more determined by the amount of diesel and not so much by the end-gas air-to-fuel ratio
- For later diesel injection, more concentration differences/gradients are expected as diesel has less time to mix. As knock indicators show a higher response for later injection timing, it seems that diesel rich areas promote knocking
- Much higher sensitivity of MIX9 compared to other gases not explained yet



SOI = start of injection of diesel fuel, lambda = air-to-fuel ratio, BR = fuel blend ratio

# CONCLUSIONS

- Alike SI engine optimization, aim to combust close as possible to TDC for highest thermal efficiency
- Control the combustion process towards this point using information of the gas quality (reactivity, MN)
- Dual-fuel concept provides more than one control parameter to avoid knock: fuel injection timing, fuel blend ratio, air-to-fuel ratio
- Setpoint may be chosen based on gas quality to run the engine at optimum efficiency