Co-Simulation Platform Connecting Chemistry and Powertrain Dynamics to Traffic Simulation

Project overview

LOGE GmbH & VKA RWTH Aachen

March 2020

Agenda

- Background
- Project goal
- Consortium
- Solution concept
- Development stages
- Implementation
- Project impact
- Progress

Background | Emission gap: reality vs laboratory

Since September 1, 2017, passenger car emissions have been measured under real conditions

"normal driving" required, but coverage of 95%+ of EU driving expected.
Considered as parameter of highest influence

Source: Bosch

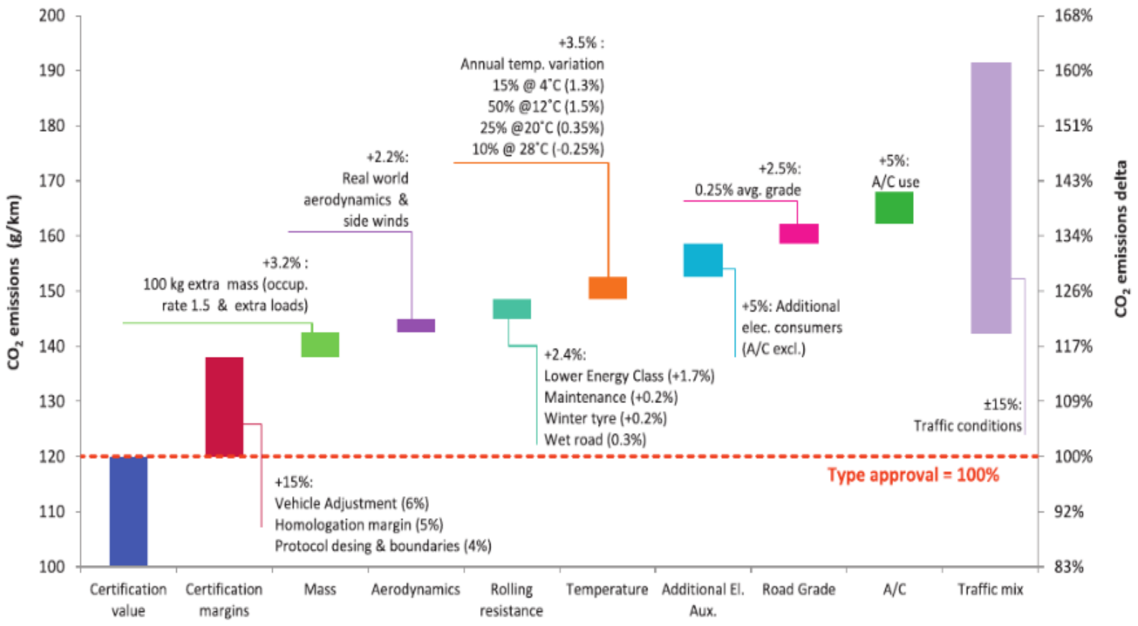


Fig. 7.1. Reality vs Certification gap estimation for an average 2015 passenger car; breakdown of factors contributing to the gap.

Source: Fuel consumption and CO2 emissions from passenger cars in Europe – Laboratory versus real-world emissions lGeorgios Fontaras, Nikiforos-Georgios Zacharof, Biagio Ciuffo https://doi.org/10.1016/j.pecs.2016.12.004

Solution: measurement- or simulation(virtual)-based vehicle calibration and optimisation for real driving conditions

Background | Motivation for virtual calibration

Lower interest in developing new combustion systems, but high pressure on cost-effective product and process

Expensive development and calibration procedures that rely on measurements on engine/vehicle test benches

Simulation based front-loading enables cost reduction, efficiency increase and quality improvement

- **Computer Aided Engineering (CAE)** tools are used to reduce cost and time of powertrain development ECU calibration.
- **Hardware-in-the-Loop (HiL) / X-in-the-Loop (XiL)** platforms allow the integration of CAE tools in the powertrain development and ECU online calibration.
- Incorporation in the XiL platform **physical-based models** is essential to increase the accuracy of simulations and the acceptance of the novel HiL co-simulation model toolbox.
- The virtualization of test drives for **Real Driving Emissions (RDE)** requires a **holistic simulation approach**; to meet the requirements; incorporation of combustion → aftertreatment → powertrain → vehicle → driver → traffic; **multi-level co-simulation**

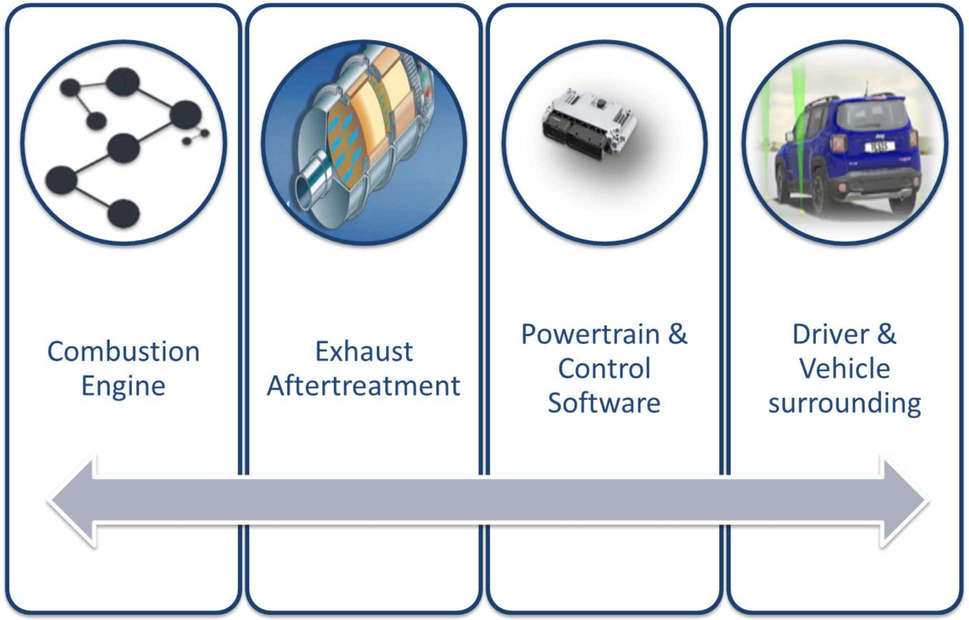
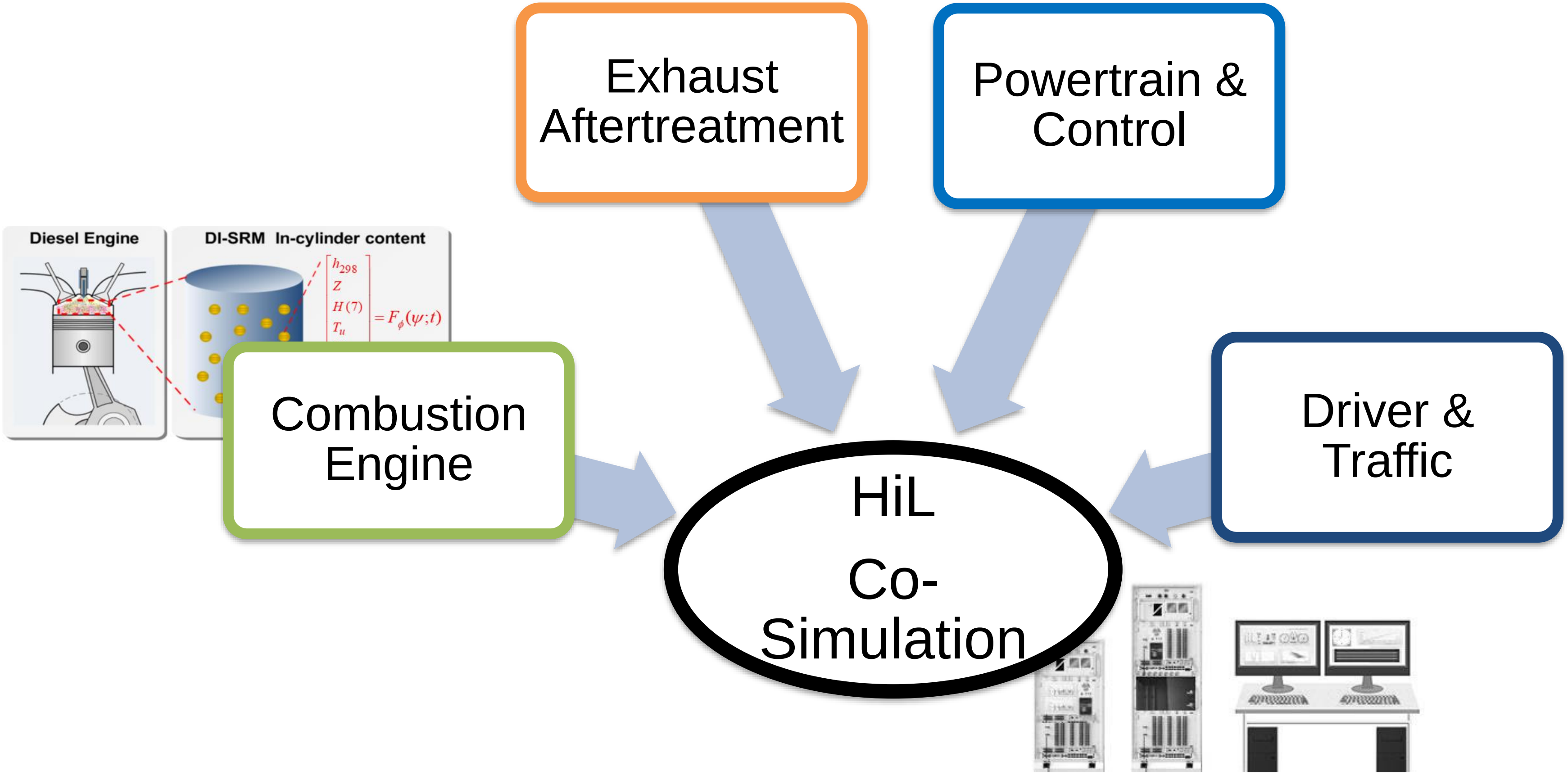


Image source: RWTH-Aachen, TESIS, BOSCH, Gamma

Hardware-in-the-Loop (HiL) as a key for efficient development of environmentally friendly vehicle powertrains

Project goal

- **LOGE-RT engine software employing detailed chemistry for real-time emissions prediction for RDE applications of a compression ignition diesel engine**
- **Co-simulation of LOGE-RT – 0D physics-based model for Hardware-in-the-Loop based applications**



Source: LOGE AB, VKA RWTH Aachen

Consortium

XiL Platform

Simulation framework for virtual prototyping/ECU calibration

LOGE-RT

Modelling of engine in-cylinder processes

Consortium | Team members

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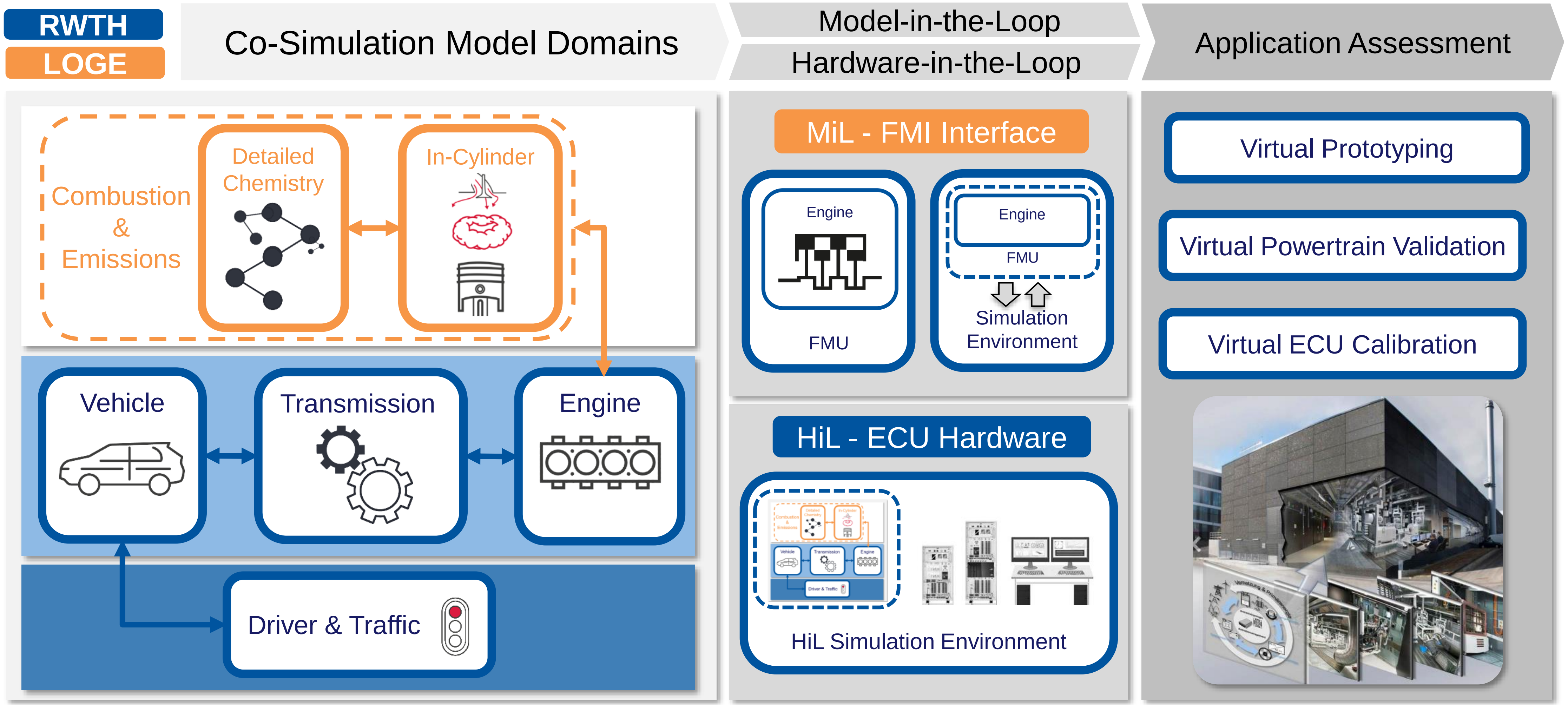
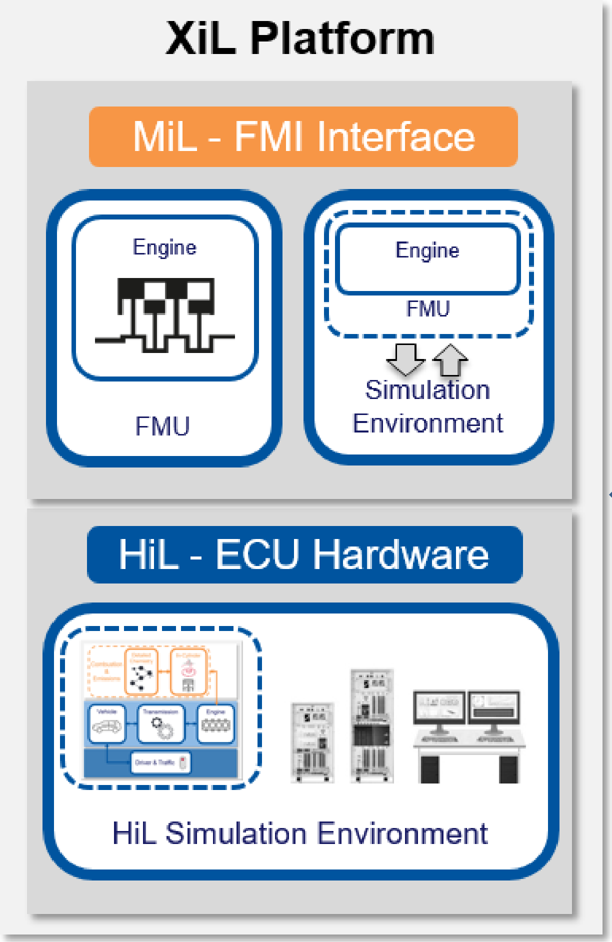
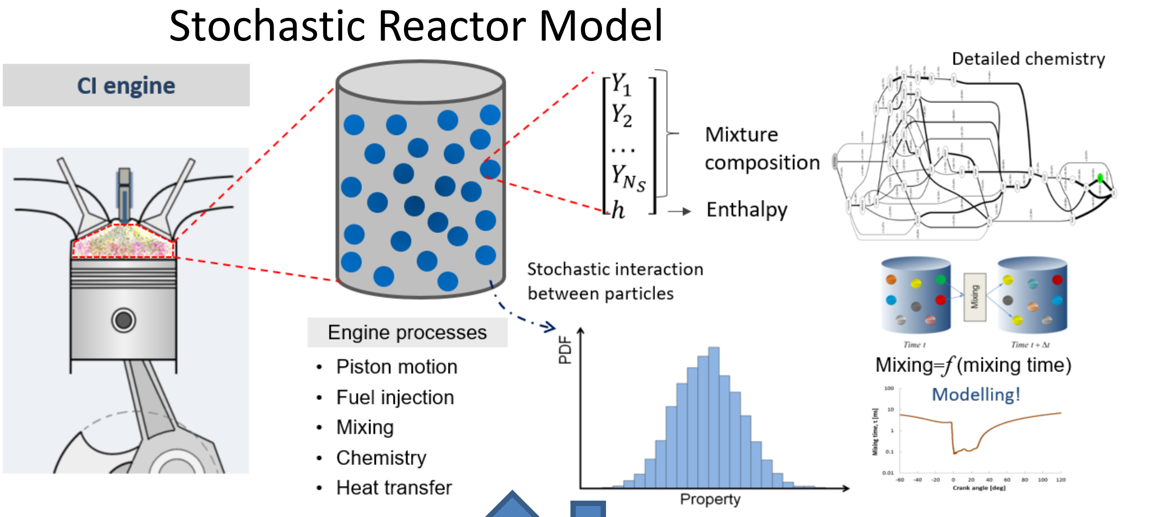
Solution concept



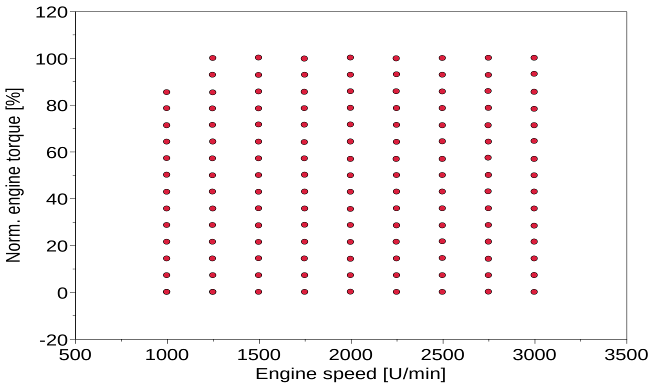
Solution concept | Engine cylinder modelling



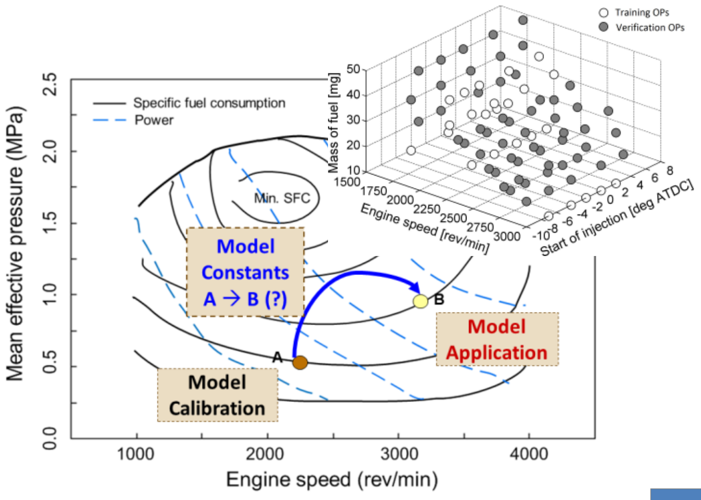
LOGE-RT based on SRM and 1D full engine model in GTP

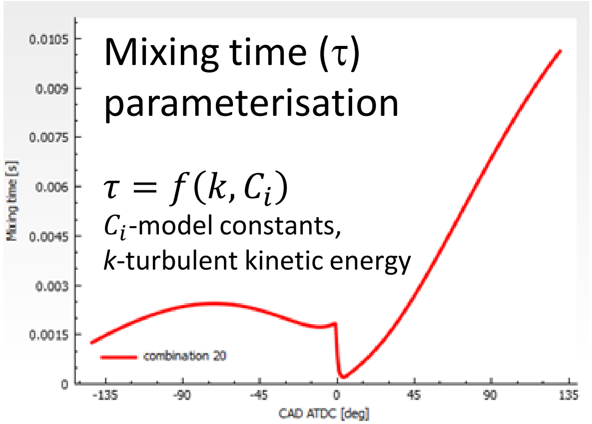


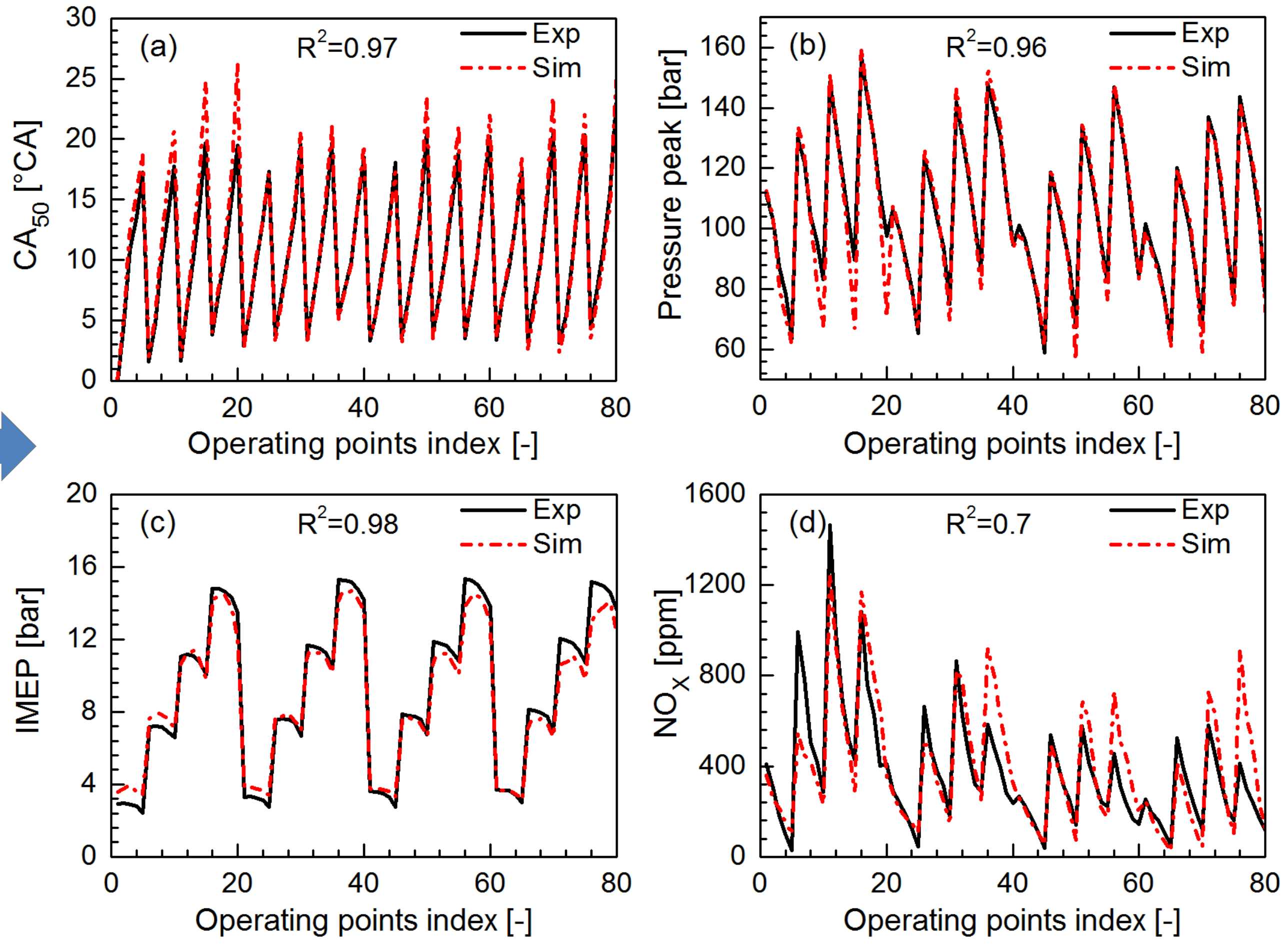
- Measured data for model development, training and validation
- Model application to real driving cycle conditions such as WLTP



Engine performance mapping using LOGE SRM

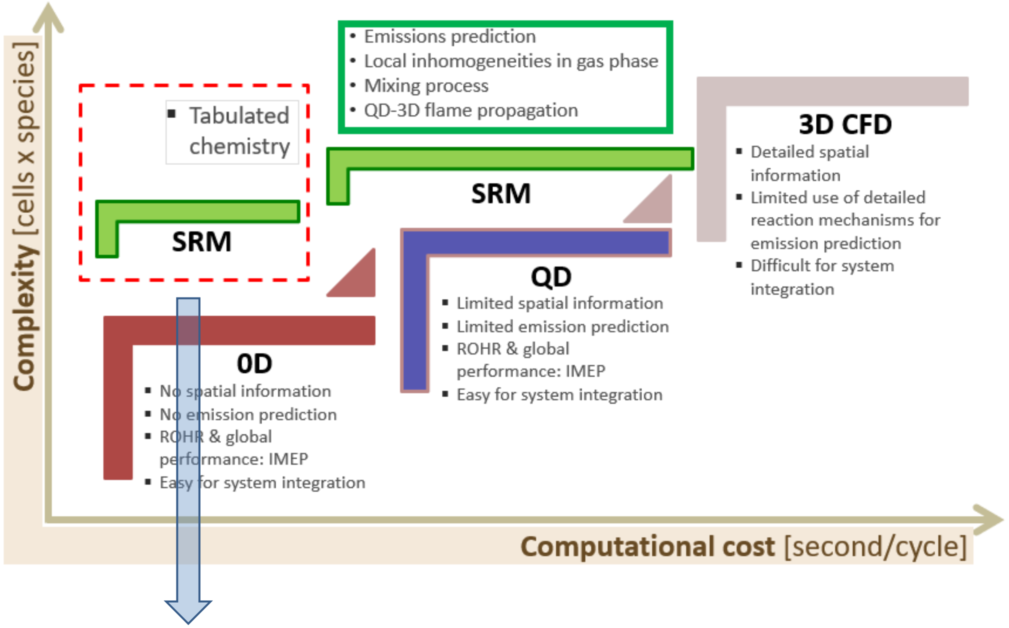






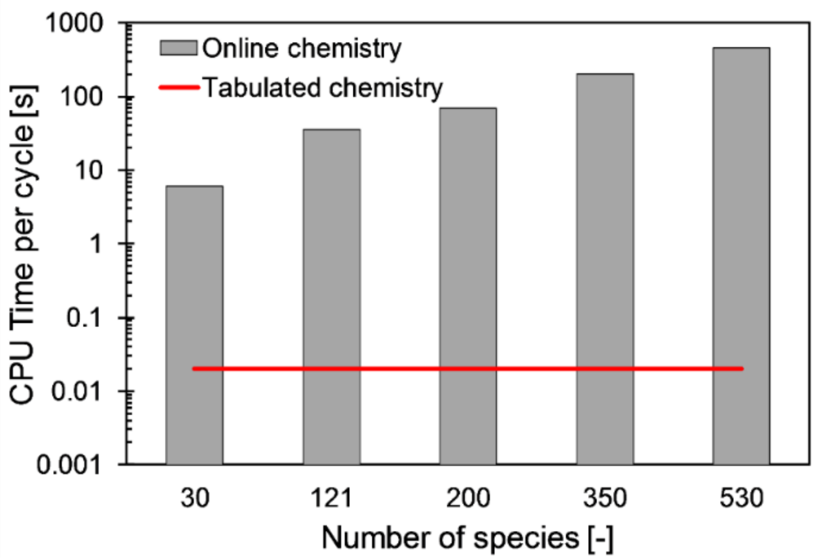
Towards real time driving cycle simulations

- **LOGE SRM |** Relation to other methods

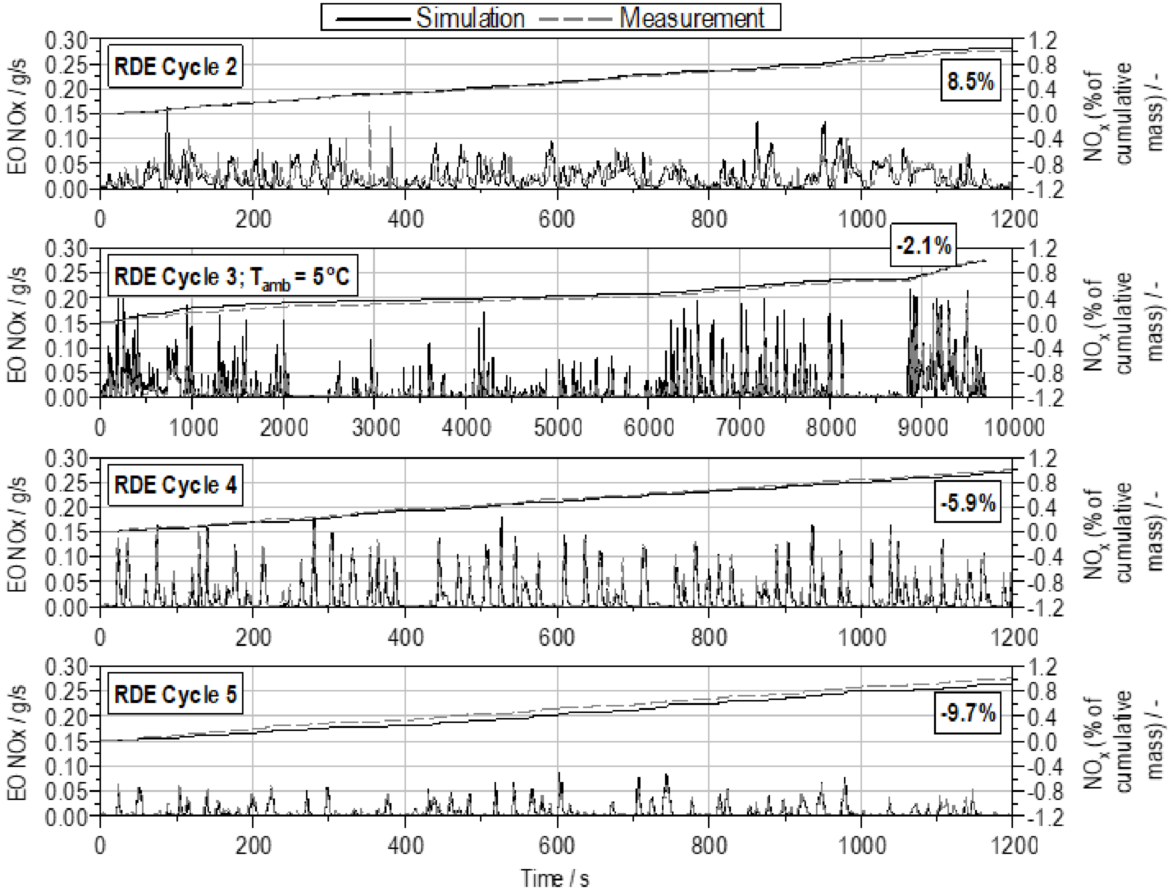


- Possibility to use complex fuel surrogates with no drawback on computational cost
- Advantages for full cycle simulations and control algorithms development and optimisation

- **Tabulated chemistry**
  - Instead of using product species as indicators of the reaction progress, the evolution of the chemistry is parametrized with a progress variable (C) using chemical enthalpy (h298) $C = (h_{298} - h_{298,0})/(h_{298,maxHR} - h_{298,0})$
  - Detailed chemistry scheme is pre-compiled in a look-up table containing dc/dt source, molar mass of the mixture, polynomial coefficients, species to be monitored and emissions source terms; the look-up tableparameters are pressure, unburned temperature, equivalence ratio and EGR



HiL modeling approach using physics-based engine model



Validation of the HiL simulation results for the engine-out NOx emission

Source: Virtual Real driving environment and emissions: a road towards XiL-based digitalization of the powertrain calibration, International Conference on Calibration Methods and Automotive Data Analytics May 21–22, 2019, Berlin

- The engine model is calibrated using steady-state engine mapping from the test bench
- Achieved cycle NOx emission target ±10% set during the project begin
- Effort for HiL system set-up
  - Depending upon the verified inputs (hardware information, measurement data, ECU, rest bus simulation, etc.) required for the HiL set-up

Relevant publications

[1] Lee, S. ; Andert, J. ; Hardware-in-the-Loop-Based Virtual Calibration Approach to Meet Real Driving Emissions Requirements. In: *SAE Int. Journal Engines*.

[2] Lee, S. ; Andert, J. ; Pischinger, S. ; Scalable Mean Value Modeling for Real-Time Engine Simulations with Improved Consistency and Adaptability. In: *WCX SAE World Congress Experience* :(SAE Technical Paper Series).

[3] Joerg, C. ; Lee, S. : Accurate Mean Value Process Models for Model-Based Engine Control Concepts by Means of Hybrid Modeling. In: *WCX SAE World Congress Experience* :(SAE Technical Paper Series).

Development stages | Overview

VKA & LOGE — **Specification** — **[M1]**

VKA
- GTP-LOGE model first release
- Platform development for MiL

LOGE
- GTP-SRM v1; initial calibration; focus on the external cylinder module
- Models development, refinement and validation

Update to GTP model

M1: Cross check GTP-SRM

VKA & LOGE

GTP-SRM v2; LOGE-RT integration in the MiL platform; S-function

[M12]

VKA
- Testing co-sim on MiL
- Testing co-sim on HiL

LOGE
- LOGE-RT refinement in co-sim
- Work on FMI

[M16]

M2: Cross check GTP-SRM

VKA & LOGE

Applications;
driving cycle on the HiL

Development stages | Work packages

<table>
<tr><th colspan="2">Specification</th><th colspan="2">WP1</th><th colspan="2">Specification</th></tr>
<tr><td colspan="6">Test engine, Fuel specification, Operating points selection, RDE application case, Input- and output for co-sim; . . .</td></tr>
<tr><th colspan="2">MiL platform</th><th colspan="2">WP2</th><th colspan="2">Real-time engine model</th></tr>
<tr><td colspan="3">Powertrain models extension and for RT applications</td><td colspan="3">Modelling updates: 0D turbulence, vaporization, heat transfer</td></tr>
<tr><td colspan="3">MiL integration, simulation and validation</td><td colspan="3">Optimizations of sub-models (time and accuracy)</td></tr>
<tr><td colspan="6">LOGE-RT on the MiL platform</td></tr>
<tr><th colspan="2">HiL platform</th><th colspan="2">WP3</th><th colspan="2">Real-time tabulated chemistry</th></tr>
<tr><td colspan="3">Driver and environment model adaptations for RT compilation</td><td colspan="3">Interpolation method for tabulated chemistry</td></tr>
<tr><td colspan="3">RT capability of all models considering HiL specification</td><td colspan="3">Automated calibration of emission parameters</td></tr>
<tr><td colspan="6">Integration of LOGE-RT on the HiL platform</td></tr>
<tr><th colspan="2">Functional-Mockup Interface</th><th colspan="2">WP4</th><th colspan="2">Functional-Mockup Interface</th></tr>
<tr><td colspan="3">HiL simulation and validation</td><td colspan="3">FMI programming and validation</td></tr>
<tr><td colspan="6">Driving cycle on the HiL platform</td></tr>
<tr><th colspan="2">Management</th><th colspan="2">WP5</th><th colspan="2">Management</th></tr>
<tr><td colspan="6">Meetings, Workshops, Conferences, Reports, Advertising, Market introduction, . . .</td></tr>
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Implementation strategy

“We already start advertising and showing results during the project increasing the impact of the project results”

“We inform our customers about the project and keep them involved to increase their interest”

Project kick-off
Oct 2019

LOGE-RT development
2020

LOGE-RT & HiL RDE application
2021

Project end
Sep 2021

LOGE-RT software market introduction **2021 - 2025**

OEMs, Tier 1 in application field of Virtual vehicle calibration
- Function development
- Hybrid & electrification
- Automotive software development

“There is a high interest in this technology in different application fields”

Impact of the Project

Strategies for knowledge transfer to improve the impact of the CONNECDT project:

Action	Description	Time frame
Personal meetings	During the personal meetings with customers, OEMs and Tier 1 the project partners will present non-confidential results.	During and after the project
Workshops	The project partners will organize workshops with customers, OEMs and Tier 1 to discuss the project results and progress.	During the project
Conferences	The project partners will attend international conferences for scientific and industrial organization to present and discuss the latest project results.	During and after the project
Publications	The project partners will publish the project results in international journals.	During and after the project
Graduates	Graduates who are working on the project and get a new position in the industry could promote the project results.	After the project
Website	The website contains a description of the project, its goals, the project partners, recent news and publications.	During and after the project