In cooperation with the CTI
Energy funding programme
Swiss Competence Centers for Energy Research
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Commission for Technology and Innovation CTI

# NextICE – The next generation of alternative fuel converters in the transportation sector

Alternative fuels, such as biofuels, fossil natural gas or synthetic methane have the potential to lower $CO_2$ emission of passenger cars, while pursuing the «energy-change». The conversion of such fuels into mechanical energy, however, requires the enhancements of today's internal combustion engines. The Institute for Dynamic Systems and Control (ETH/IDSC) investigates how the full potential of engines operated with alternative fuels can be utilized. In particular the thermal management of the exhaust aftertreatment system poses a challenging task. Recent pollutant emission limits are only met using advanced control engine strategies considering raw emissions and the efficiency of the exhaust aftertreatment system. Besides the IDSC the project partners are: Aerothermochemistry and Combustion Systems Laboratory (ETH/LAV) and Swiss Federal Laboratories for Materials Science and Technology (Empa).

Richard Hutter
ETH Zürich
Institute for Dynamic Systems and Control
rihutter@idsc.mavt.ethz.ch

Dr. Philipp Elbert
ETH Zürich
Institute for Dynamic Systems and Control
elbertp@ethz.ch

Prof. Dr. Chris Onder
ETH Zürich
Institute for Dynamic Systems and Control
onder@idsc.mavt.ethz.ch

## Introduction

The low $CO_2$ abatement cost of methane, favored on one hand by the high hydrogen-to-carbon ratio and on the other by the high knock resistance, makes methane gas one of the most promising alternative energy carriers for the use in passenger cars. Among all gas engines, the diesel-ignited gas engine is a unique concept. Diesel is used as the engine's ignition source and therefore provides ignition centers for the premixed methane gas. The diesel-ignited gas engines feature substantially enhanced ignition boundaries in contrast to spark-ignited engines and allow lean burn operation which enables high engine efficiency in general. However, unburnt hydrocarbon emissions poses a challenge for complying with the legal emission limits, especially as the problem is aggravated by the fact that methane needs high exhaust gas temperature for catalytic oxidation.

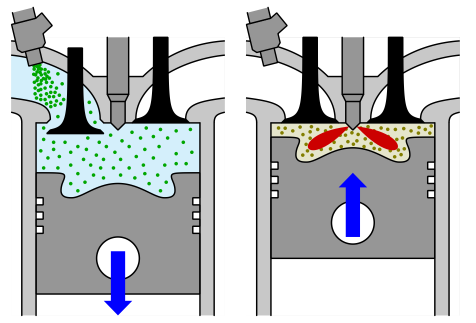

Fig 1: The two injection phases in a diesel-ignited gas engine: port fuel injection of methane gas and directly injected diesel [1]

There are three different modes the diesel-ignited gas engine can be operated with: diesel-only, stoichiometric combustion and lean combustion. Every mode features some distinct advantages/drawbacks regarding $CO_2$ and pollutant emissions. All modes are characterized experimentally on the testbench at the IDSC.

## Optimal engine control

The experimental data of the different engine modes are finally used for performing drive cycle simulations. Thereby, the tailpipe emissions of $CO_2$ and all major pollutant species are estimated based on a dynamic model of the exhaust aftertreatment system. The goal of minimizing the $CO_2$ emission while fulfilling the current pollution limits is formulated as an optimal control problem and is solved using the Dynamic Programming (DP) algorithm. The cost function that is minimized depends on two emission factors $\alpha$ and $\beta$.

$$\min_{u}\{\alpha m_{CO_2} + (1-\alpha)[\beta m_{NO_x} + (1-\beta) m_{HC}]\}$$

Solving the problem results in the optimal but non-causal solution for switching between the engine modes.

## Results

The optimal control problem is solved for a variety of weighting factors $\alpha$ and $\beta$. Based on the simulated cumulative emissions on the WLTC the following conclusions can be drawn:

- Switching from diesel-only to natural gas yields up to -16% $CO_2$ and -77% NOx
- $CO_2$ benefit of lean combustion is counteracted by the low conversion efficiency of the exhaust aftertreatment system

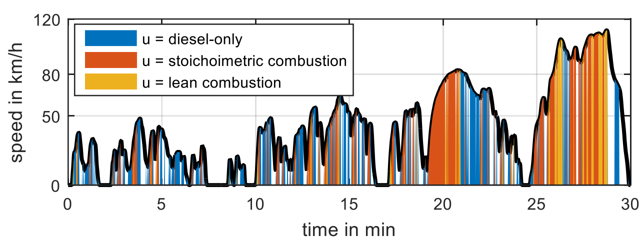


Fig 2: Optimal control solution on WLTC for $\alpha = 0.85$, $\beta$=0.35

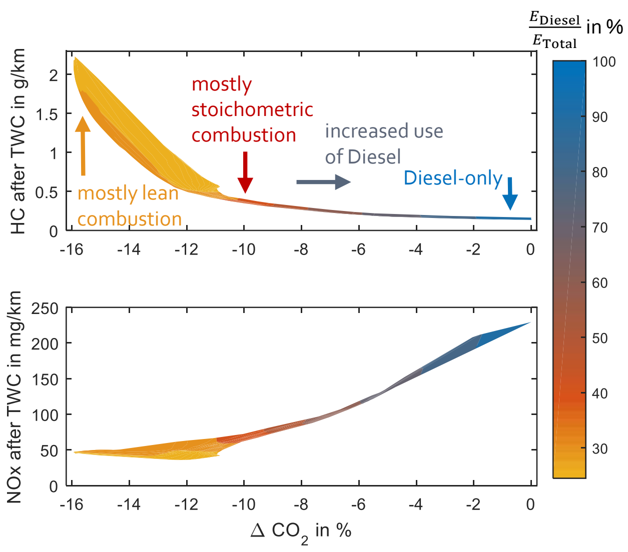


Fig 3: Simulation results for 441 differently weighted optimal solutions. The color indicates the mean energetic share of the diesel on the total fuel energy of the solution.

## Expected impact

This research project is meant to show how the $CO_2$ emissions of internal combustion engines can be substantially reduced. The capability of converting methane gas in an efficient and pollutant-free way is considered to be helpful in pursuing the «energy-change». As the development of renewable energy sources evolves, the problem of balancing demand and supply in the power network becomes increasingly challenging. Methane production using excess electric energy based on electrolysis may help to mitigate this problem. Methane could be used for two purposes at the same time: as a cost-effective energy storage as well as a fuel for energy converters in automotive application. Engines fueled with this synthetic methane operate $CO_2$ neutrally. Consequently, gas engines represent a promising alternative to the emerging pure electric solutions as used in electric vehicles.

## References

[1] Zurbriggen, F. J. Combustion control of a natural gas-diesel engine-feedback control and adaptation Dissertation, ETH-Zürich, 2016, Nr. 23022, 2016

## Partners

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Bundesamt für Energie BFE

Institute for Dynamic Systems and Control
IDSC
Institut für Dynamische Systeme und Regelungstechnik

ETH zürich