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Aladin

Highly efficient and near zero-emission micro CHP gas engine appropriate for grid balancing*

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A Concept for Decentralized Energy Production

Future energy strategies are expected to be based on fluctuating renewable energy sources such as wind or photovoltaics, which ask for electricity grid balancing measures. Hence, decentralized and dynamic power generation is a very promising concept, even on the low-voltage electricity grid level. Combined heat and power (CHP) plants based on internal combustion gas engines combine advantages in exergetic efficiency, fast load uptake and high number of duty cycles. The choice of natural gas as a fuel reduces CO_2 emissions compared to other fossil fuels and the use of biogas even allows for CO_2 neutral operation.

Decentralized micro CHP plants could replace common heating systems in future households and together they could be combined to a virtual power plant, used for grid balancing.

Project Goals and Advantages

Aladin is a corporate research project of ETH Zurich and industrial partners with the aim to develop a micro CHP gas engine with the following requirements:

- 5-10 kW electric power and high electrical efficiency
- Near zero-pollutant-emissions
- Fast load-uptake and warm-up process with low transient emissions
- Compact design
- Reduced investment costs
- Low maintenance and long lifetime

The described requirement specification was converted to a combination of existing technologies and products from industrial collaborators as well as standard components.

Efficiency Measures

Considering the given power range, a single-cylinder engine results in the largest swept volume per cylinder with potentially highest thermodynamic efficiency due to low specific wall heat losses. Therefore, a 0.325 liter single-cylinder port-injected gasoline engine with low friction losses was chosen.

- Single-cylinder engine with large bore for high thermodynamic efficiency due to low specific wall losses.
- The engine runs at its optimal operating point only (full load operation at stoichiometric conditions).
- The engine cylinder block was machined in order to increase the compression ratio.
- The gas exchange process and the pumping losses are optimized by the adaption of the intake and exhaust system.

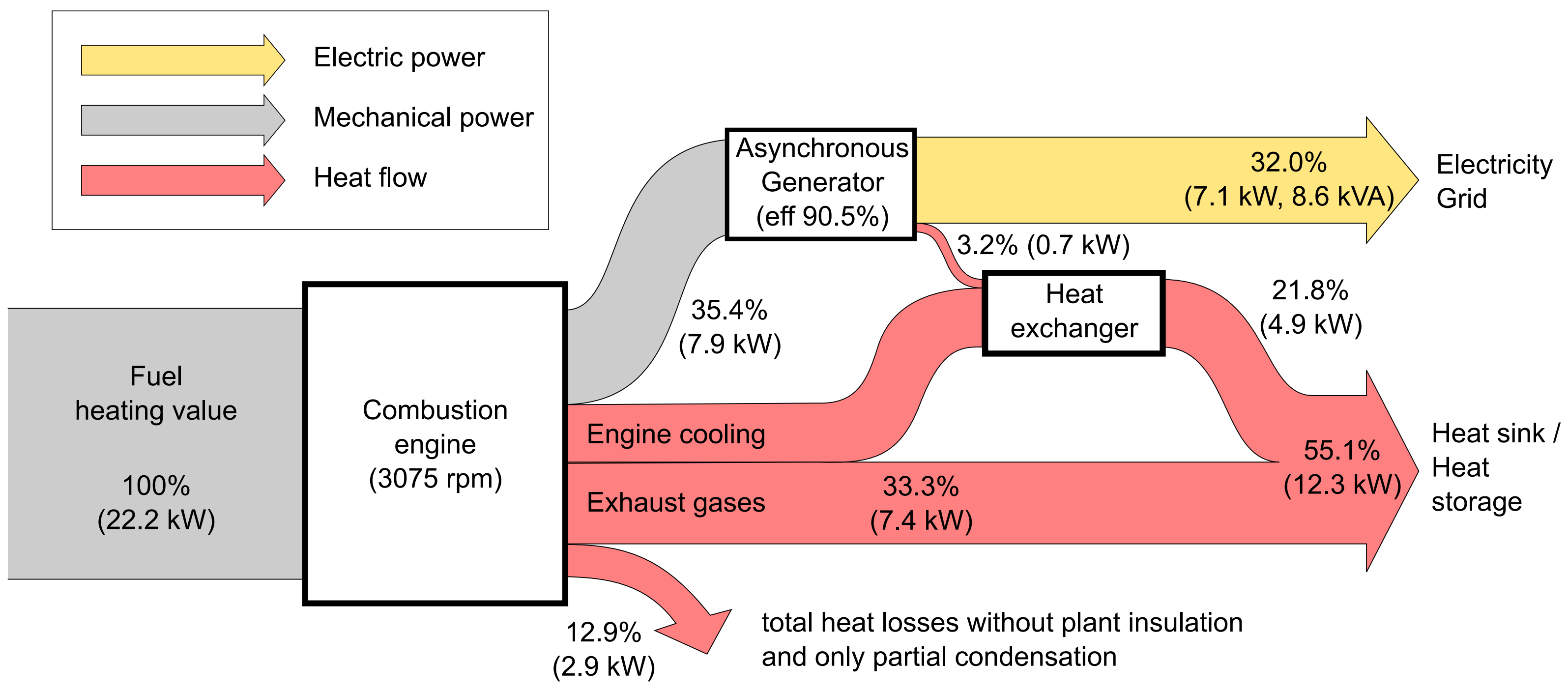

Figure: 1: Sankey diagram of the CHP plant stationary performance, including mechanical, thermal and electric power flows. The data was measured with an un-isolated system on a test bench at ETH Zurich.

Pollutant Emission Reduction

The use of a three-way catalytic converter significantly reduces pollutant emissions. By the feedback-control of the air-to-fuel ratio, the catalyst conversion rate exceeded 99% under steady-state conditions.

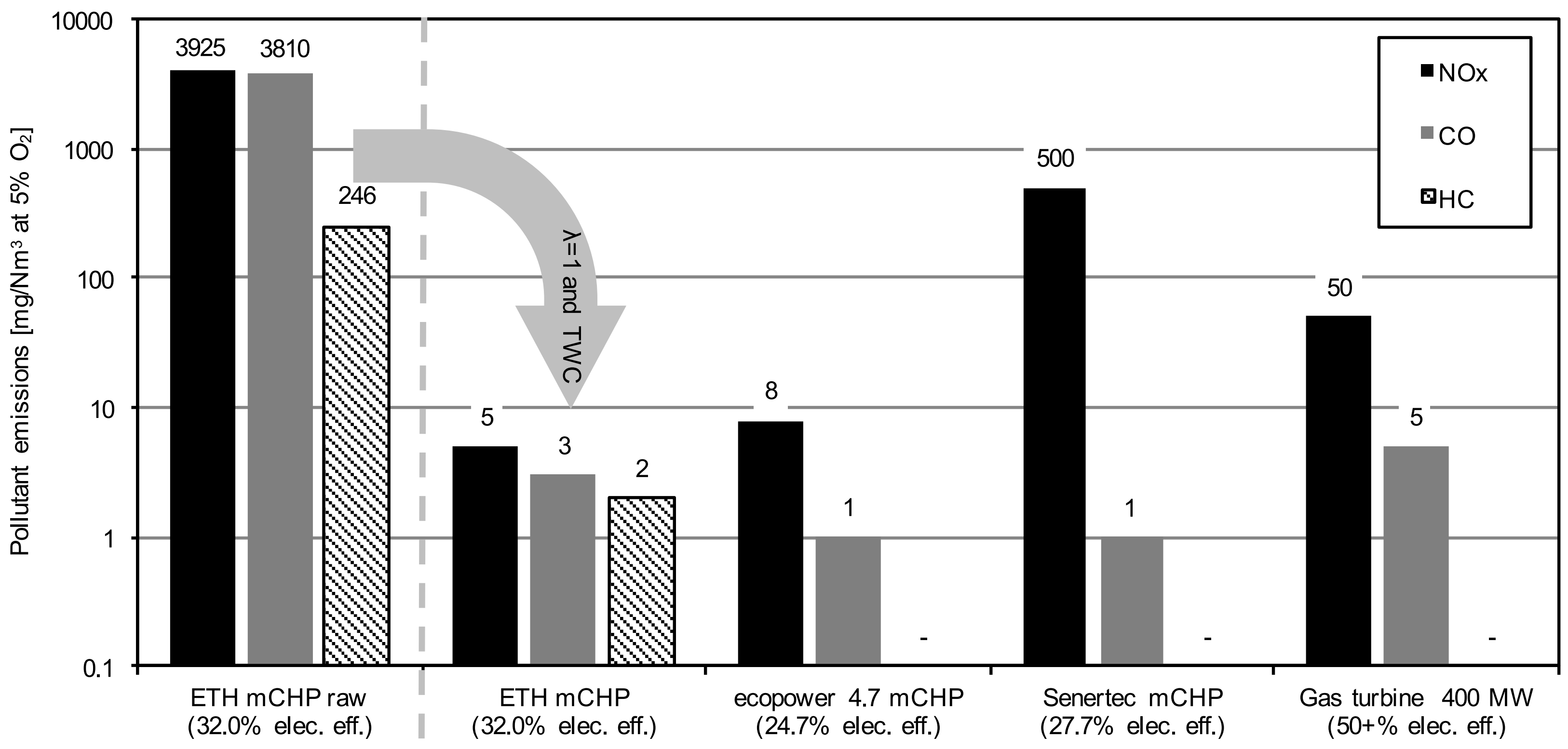

Figure: 2: Pollutant emission comparison of the CHP plant (ETH mCHP) with two similar existing products and a typical large-scale gas turbine power plant. Measurement data was gathered at steady-state operation.

* This poster is an adapted version of the following conference paper:

Vögelin, Ph.; Hutter, R., Schürch, Ch.; Ritter, A.; Obrecht, P., Onder, Ch.; Boulouchos, K.; "Highly efficient and near zero-emission micro combined heat and power gas engine appropriate for grid balancing"; Gas Engine Conference Dessau, 2015.

Design of the Micro CHP Unit

The micro CHP plant consists of a spark-ignited combustion engine that is powered by natural gas from the gas grid. Mixed with air at ambient conditions, the stoichiometric mixture is aspirated unthrottled by the single-cylinder engine. The exhaust gas flows directly through a three-way catalytic converter in order to remove the combustion residues. The engine operates at the fixed speed of 3075 rpm, defined by the asynchronous generator that is connected to the electric grid without an inverter.

- Naturally aspirated, spark-ignited, single-cylinder natural gas engine.
- Directly connected to the gas grid and the electric grid.
- Reduces expenses and complexity by avoiding an electric inverter.
- Sophisticated thermal management with two water circuits.

Hot water for domestic heating is produced by two water circuits, where the inner circuit cools the engine block and transfers the heat to the outer circuit. Finally, controlled by a three-way valve and another water pump, the outer water circuit uses in addition to the transferred heat the waste heat of the exhaust gas and supplies the hot water at 90°C to the building.

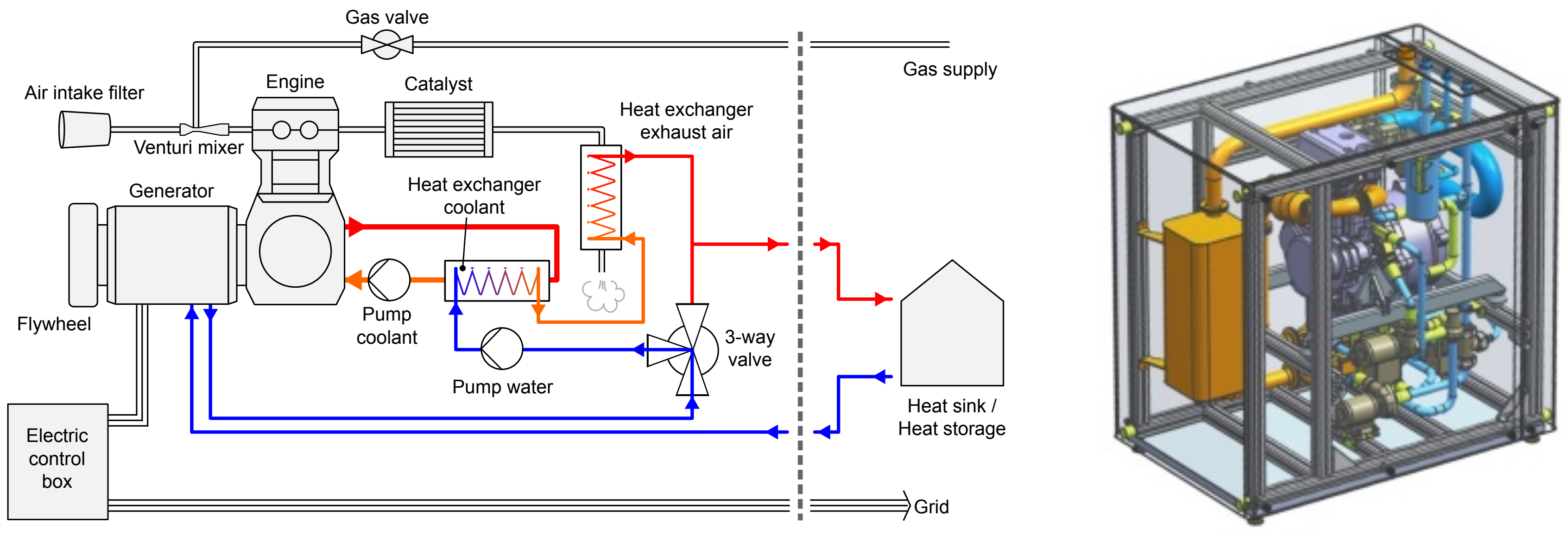

Figure 3: The construction of the micro CHP unit consists of a naturally aspirated gas engine, a generator that delivers electric power to the grid at 3075 rpm, i.e. the AC frequency of 50 Hz. On the left, a schematic illustration of the power plant indicates the two water circuits in stationary condition, where heat is removed from the engine block and the exhaust gas and delivered to the building's heat storage. On the right, a CAD drawing shows the final design.

Cold Start Optimization

When the micro CHP unit is operated after a longer standby time, the components are not at their usual operating temperatures. Two main problems arise from these so-called cold starts. Firstly, the water is too cold to be supplied to the building's heat storage. Secondly, the conversion rates of the catalytic reactions in the TWC are only in a useful range if the temperature of the monolith is above a certain light-off temperature, which is typically around 550°C. Therefore, the goal during the start-up phase is to heat up the water and the catalyst as fast as possible.

- Reach the catalyst light-off temperature as fast as possible to reduce emissions.
- Supply the building's heat storage solely with hot water.

The optimization of the cold start regarding the above criteria is achieved with simulations of the entire plant. The results are then tested and revised on the real test bench. The control inputs are two water pumps, one three-way valve, and the ignition angle. By keeping as much thermal energy as possible within the system at the start-up phase, it is possible to speed up the heating of the TWC. Furthermore, setting the ignition angle to a later ignition decreases the combustion efficiency and thus increases the exhaust gas temperature.

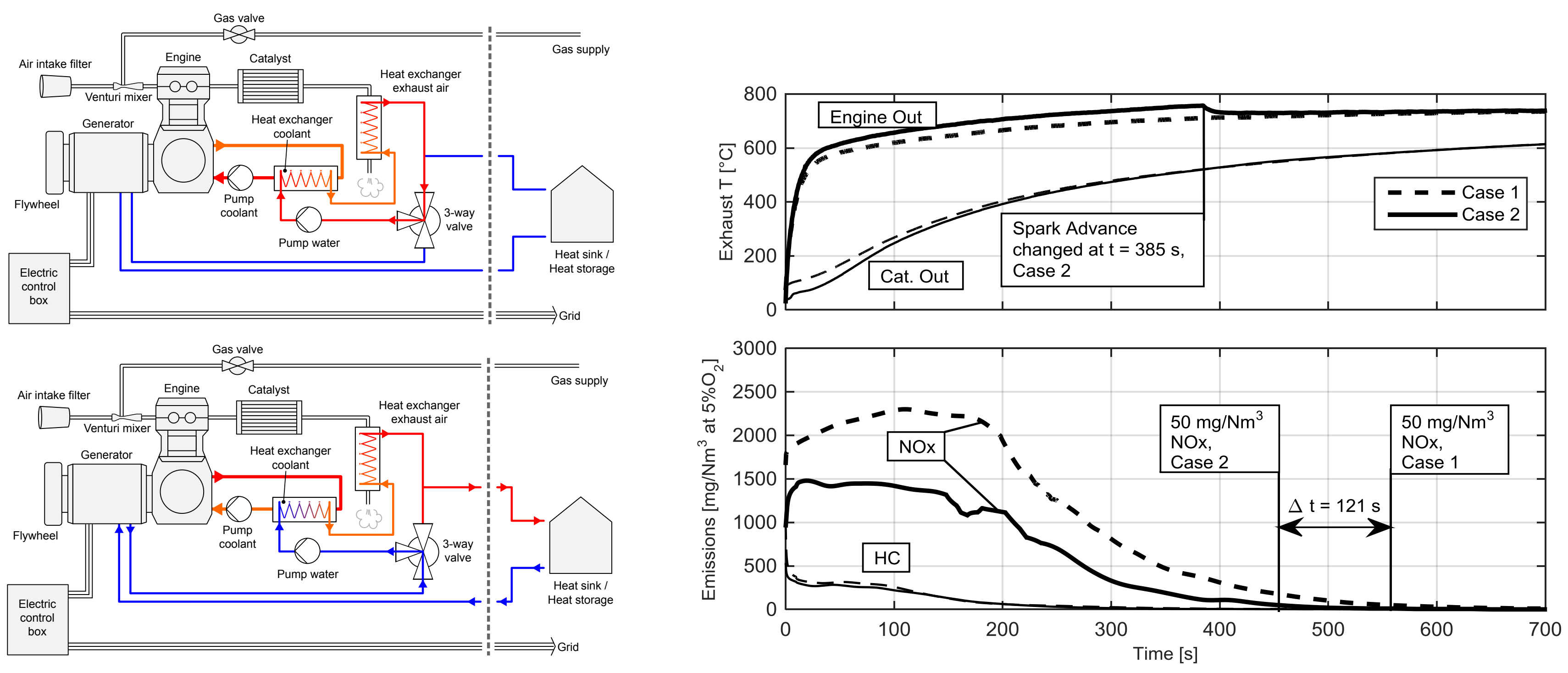

Figure 4: Heating up the TWC is crucial in order to reach its light-off temperature as fast as possible and thus reduce the emissions. Two approaches are pursued simultaneously. Firstly, the three-way valve is adjusted to cut off the water circuit through the heat storage. Thereby, the heat from the exhaust gas is transferred to the inner water circuit in order to heat up the engine block, as the upper graphic on the left indicates. Secondly, the spark advance is decreased from 30° to 22.5° before top dead center (TDC), as indicated on the right plots with case 1 and case 2, respectively. As a result, the NO_x emission threshold of 50 mg/Nm³ is reached two minutes earlier. The stationary operation then uses an ignition angle of 30° before TDC and a three-way valve position as shown in the lower left graphic.

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