



Contributing to the Environment through Negative Emissions using ICEs with a Simple Exhaust System

Beitrag zum Umweltschutz durch negative Emissionen mit Verbrennungsmotoren und einem einfachen Abgassystem

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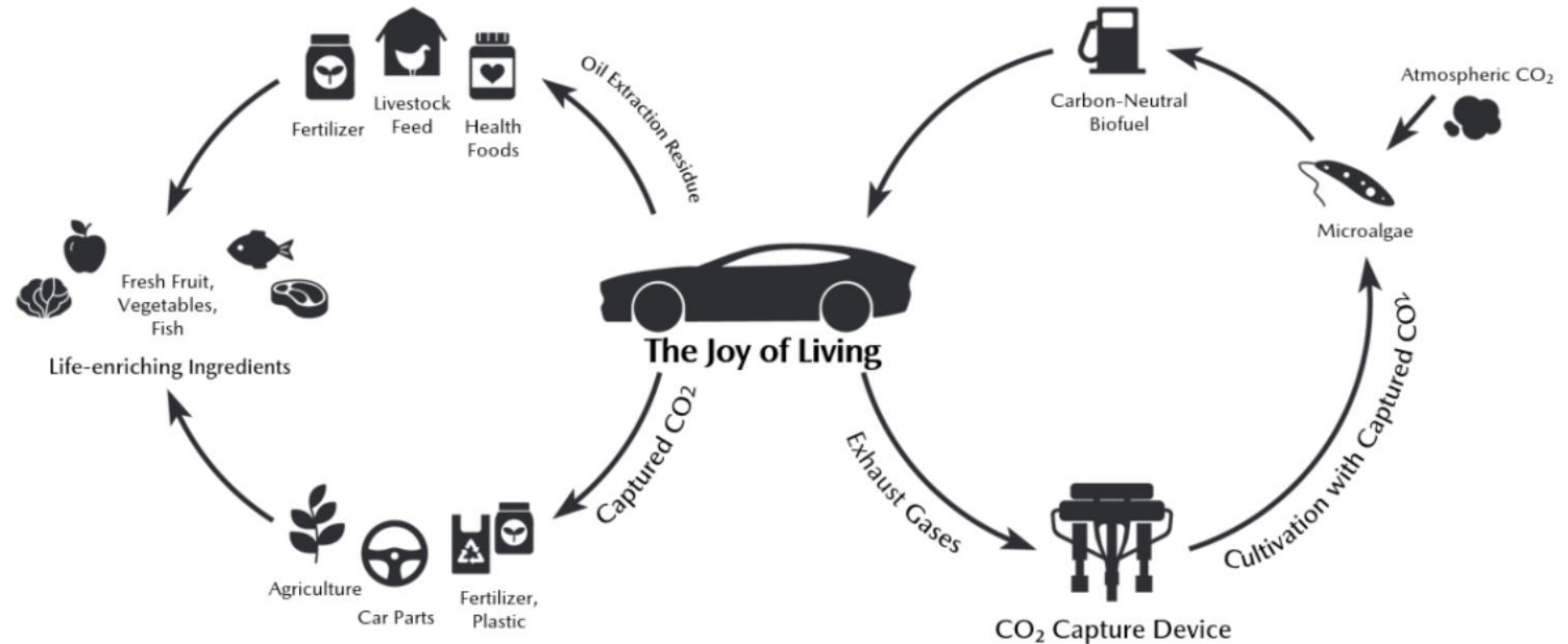
October 5th-7th, 2026

1. Background

1-1. Vision for 2035

- Valuing the joy of driving in the journey towards sustainability.
- Incorporating mobility into the cycle of carbon neutrality.
- Pursuing the enrichment of people's lives.

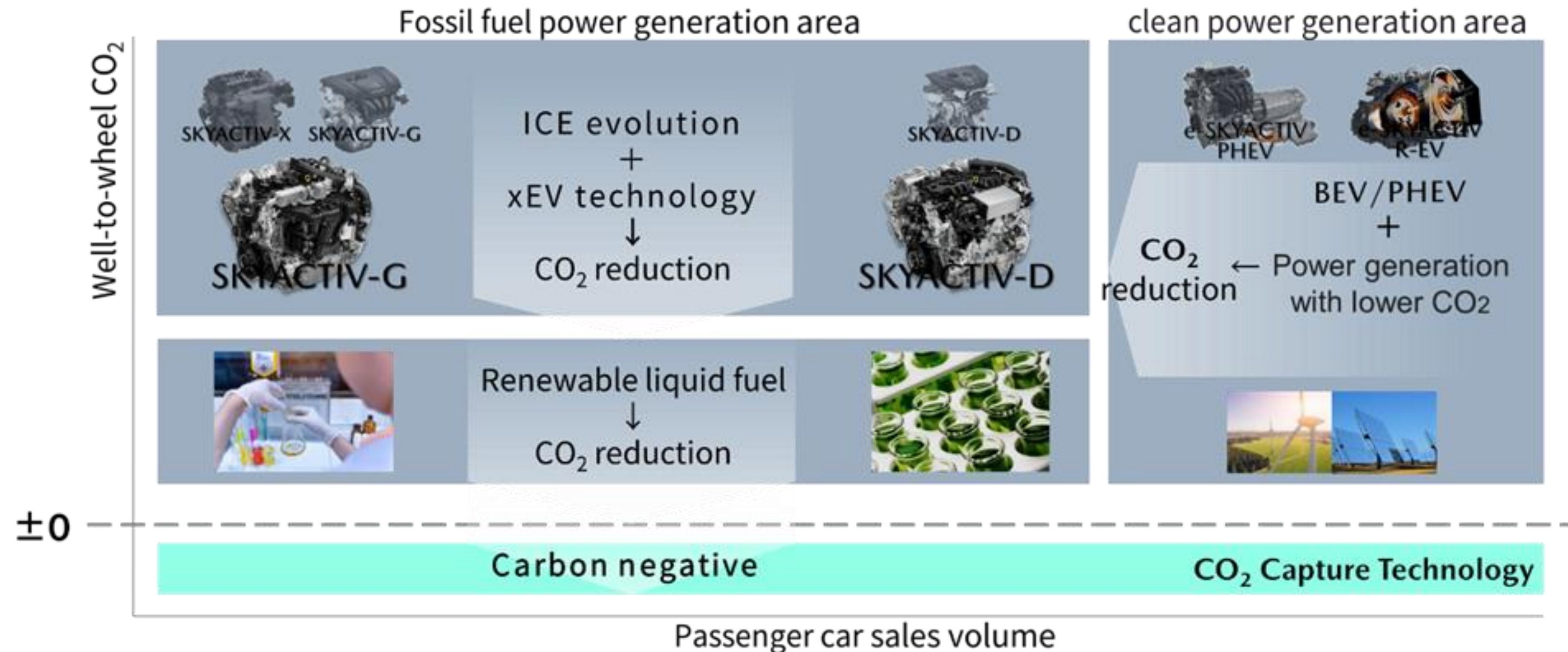
THE JOY OF DRIVING FUELS A SUSTAINABLE TOMORROW



1. Background

1-2. Multiple-solution approach

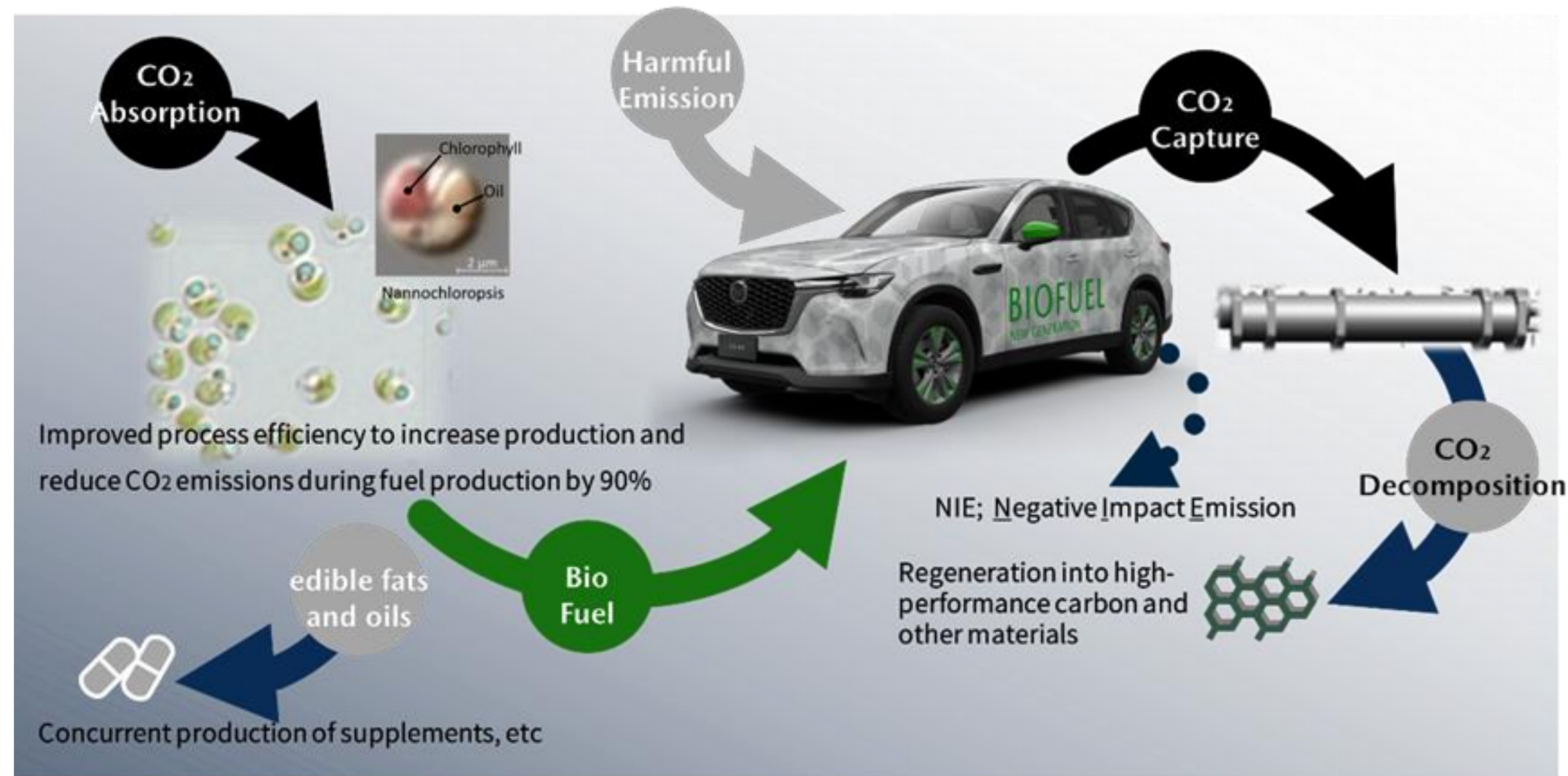
- Achieve carbon neutrality by 2050 robustly by applying BEV with renewable electricity and ICE with renewable fuels according to the power generation intensity of CO₂ emissions in each region.



1. Background

1-3. Pursuit of the potential of negative CO₂

- Based on a multi-solution approach, we pursue environmental improvement by driving cars to experience more 'joy of driving.'
- Our goal is to make both CO₂ and harmful emissions negative.

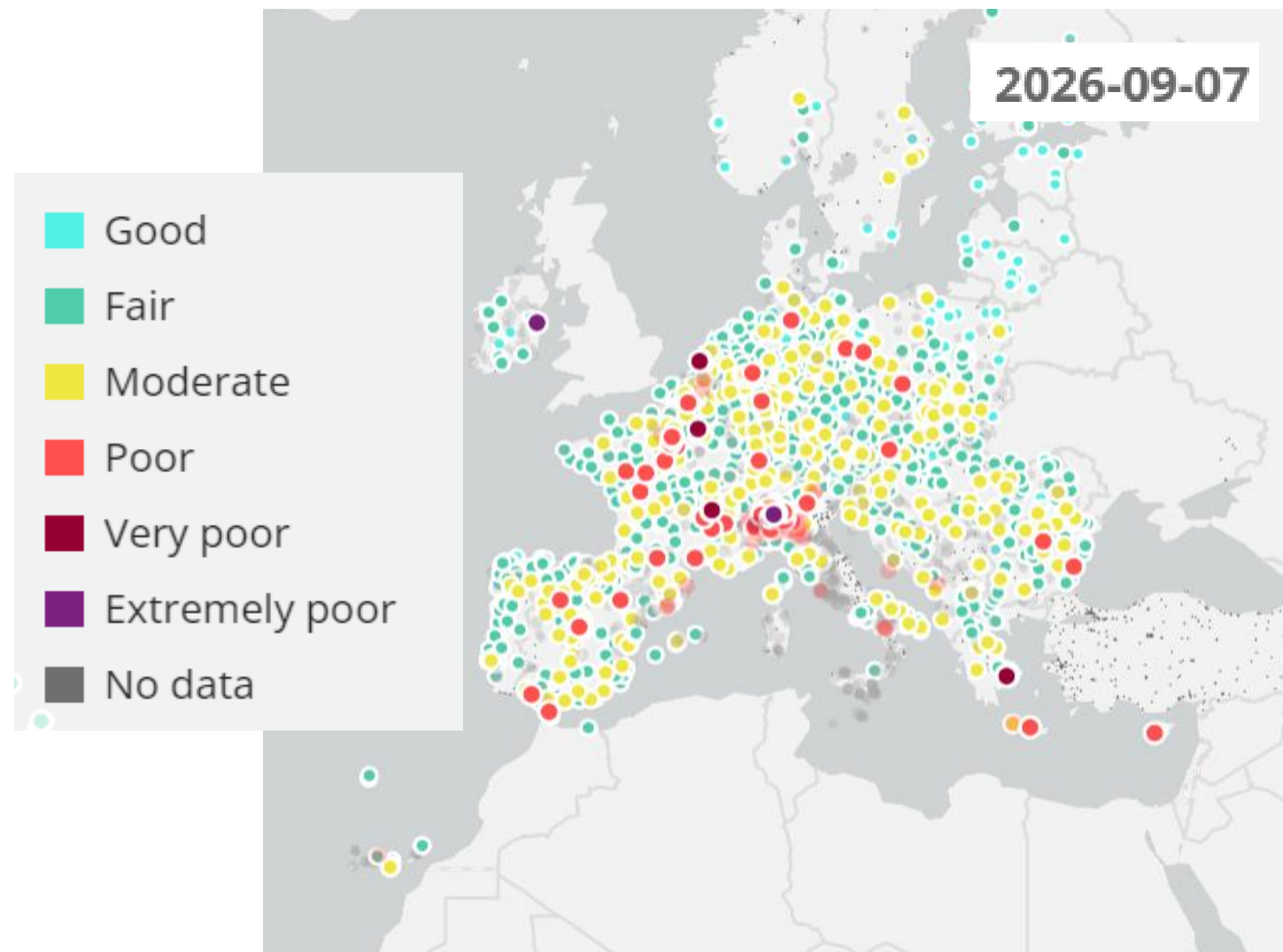


Conceptual diagram for Negative CO₂

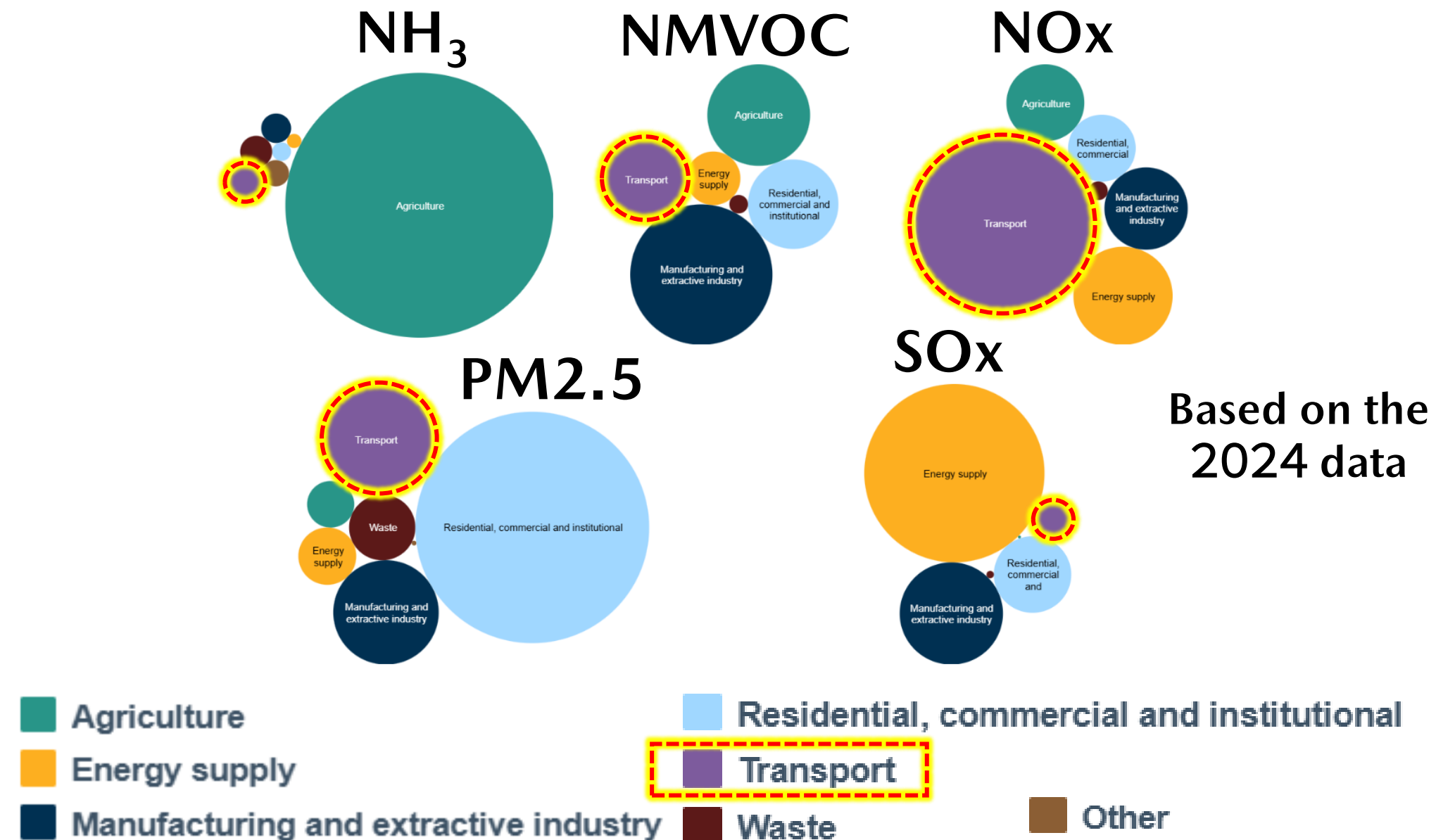
2. Negative emissions

2-1. Emission of harmful substances into the atmosphere

- Air quality is defined and monitored as the Air Quality Index (AQI).
- It aims to clean the air that has been deteriorated not only by transportation but also by emissions from other sectors activities.



European Air Quality Index(AQI)

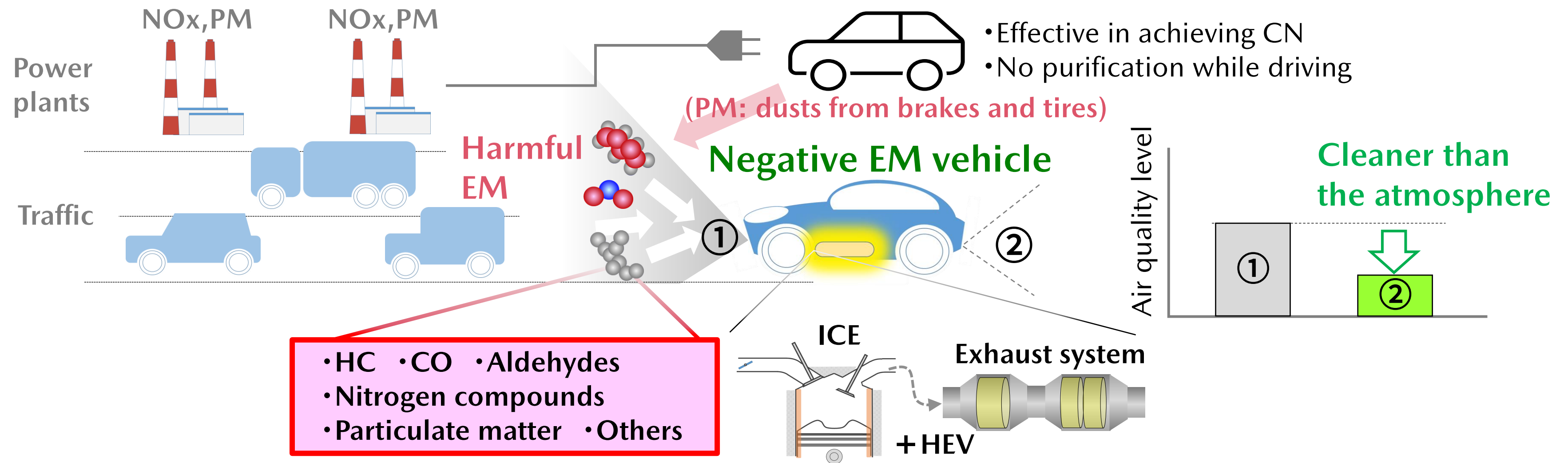


Main Sectors contributing to the emission of the five main pollutants

2. Negative emissions

2-2. Pursuit of the potential of negative emission

- Consider not only CO₂ but also exhaust gas emissions to improve the environment.
- Evolving exhaust purification technology harmonized with the engine and electric drive system, aiming significantly reduce pollutants from the air while driving as an inherent value of internal combustion engines.

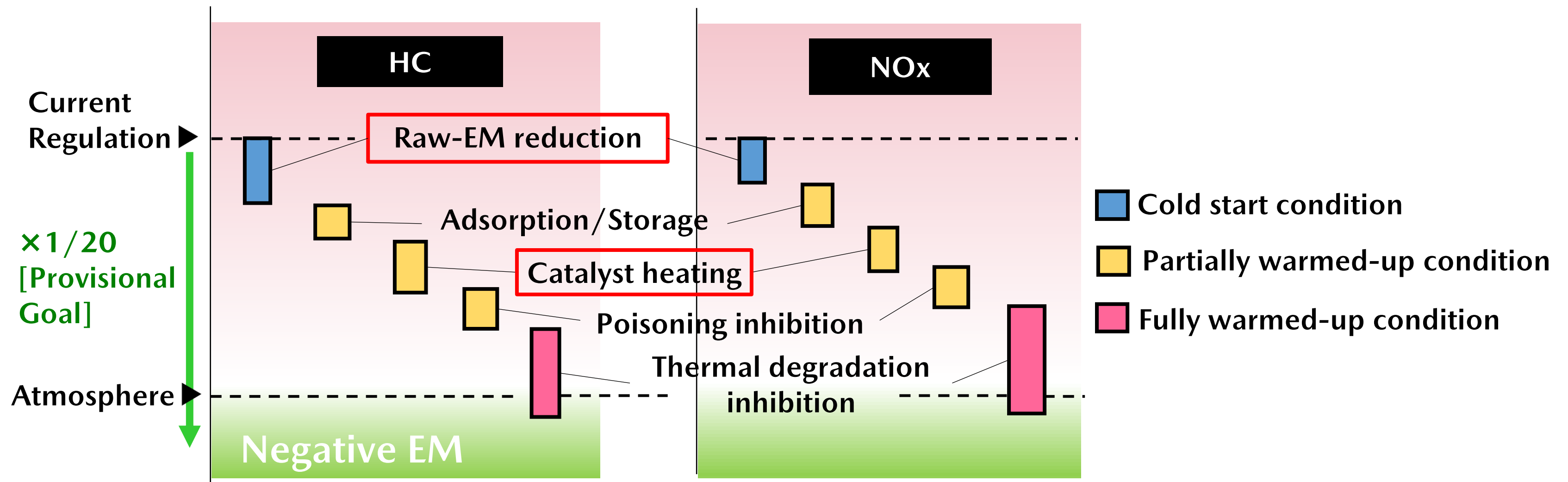


Schematic for cleaning the air while you drive ICE vehicles including PHEVs and HEVs

2. Negative emissions

2-3. Achievement strategy through incremental functional improvements

- Capabilities to each temperature range to maximize emission reduction effects are assigned.
- New control factors and methods are applied to engine and exhaust systems.

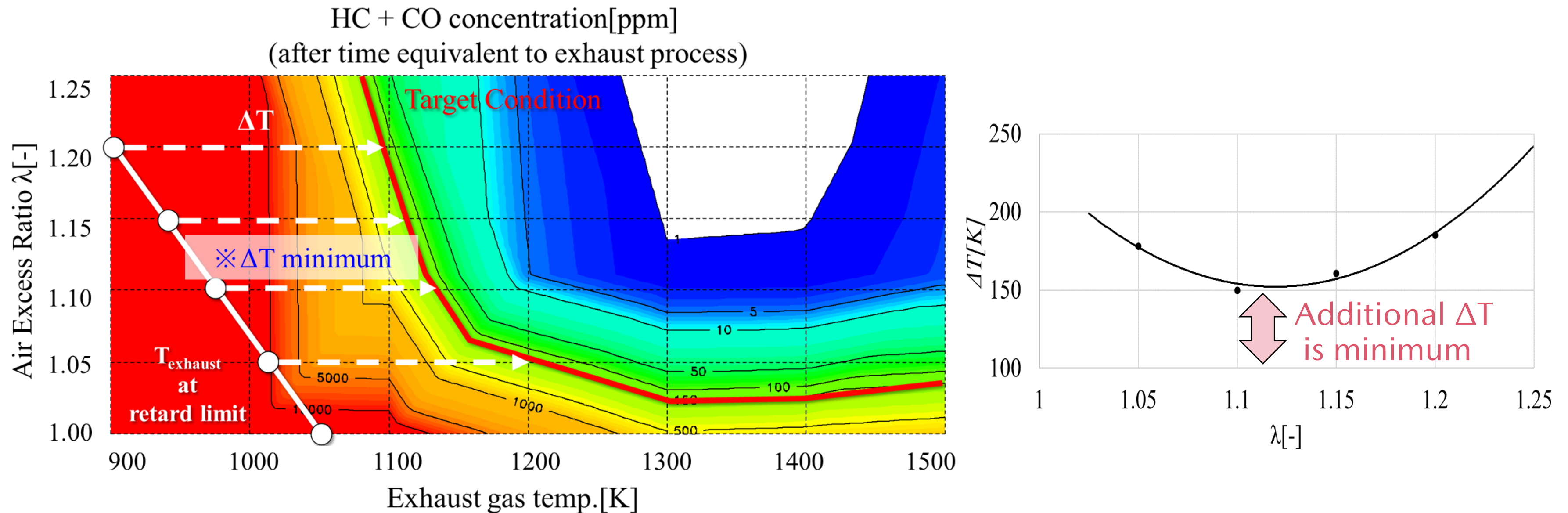


A Scenario to achieve negative emissions with ICE vehicle

3. Cold emissions reduction

3-1. A/F ratio for promoting post-oxidation

- To promote cold Raw-EM reduction, we utilize afterburning.
- To enhance the HC and CO reduction effect through temperature increase, an excess air ratio of $\lambda=1.1$ is desirable.

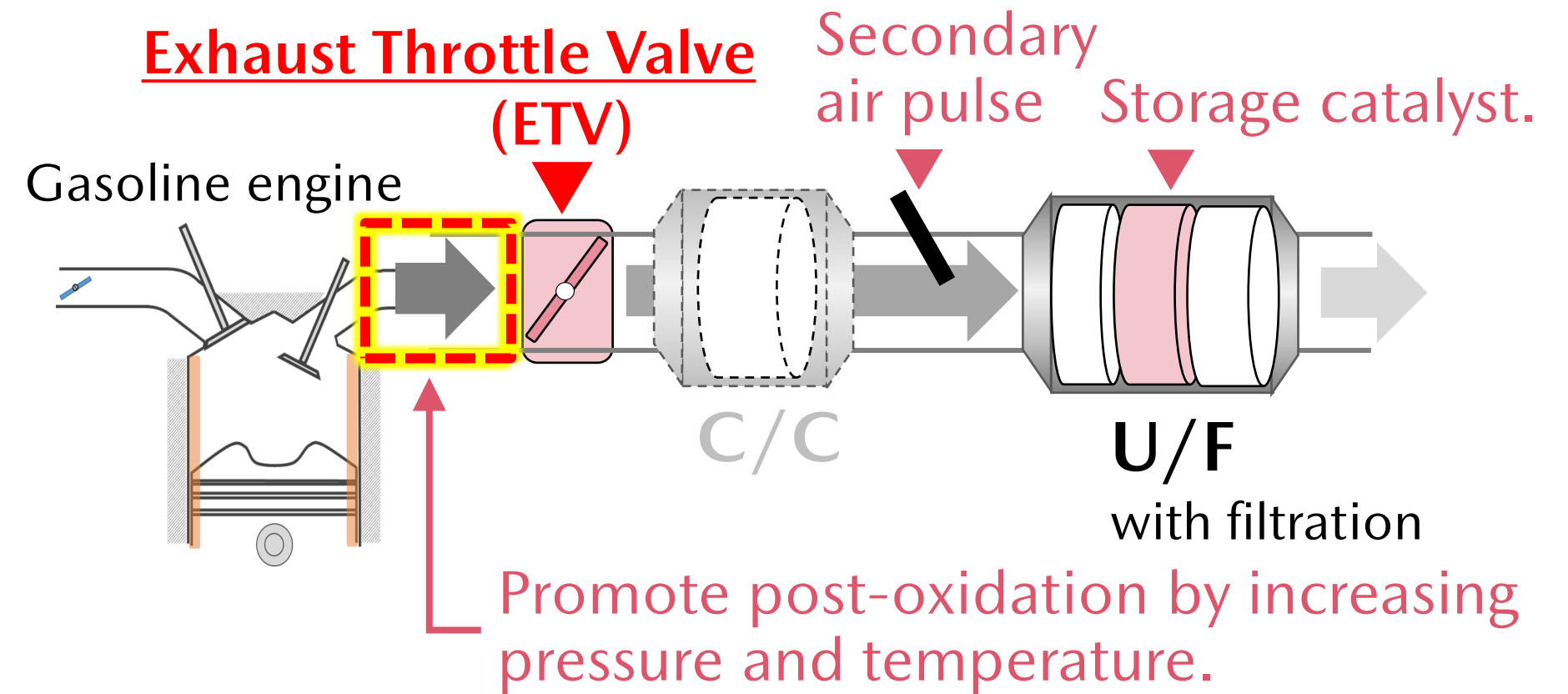
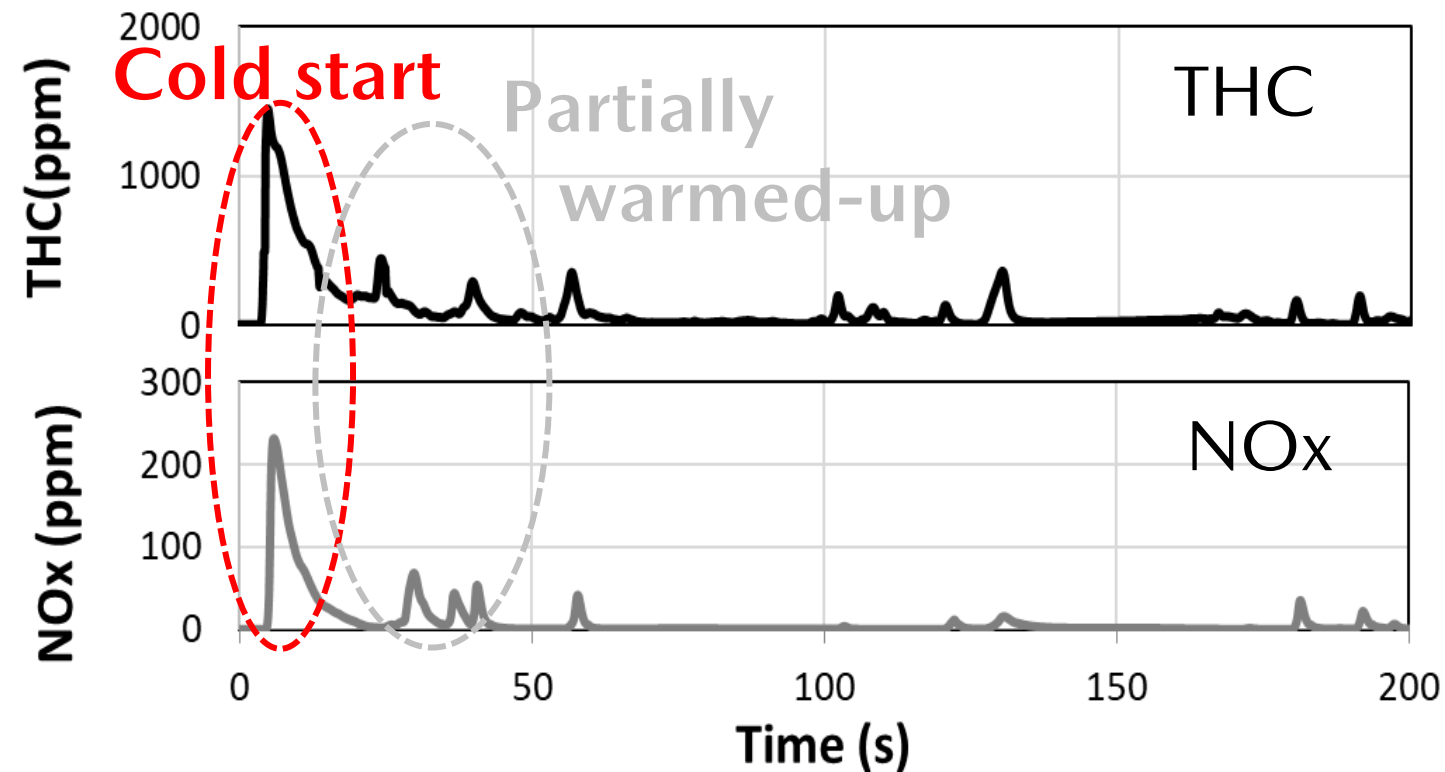


Total HC and CO concentrations after exhaust process [simulation results]

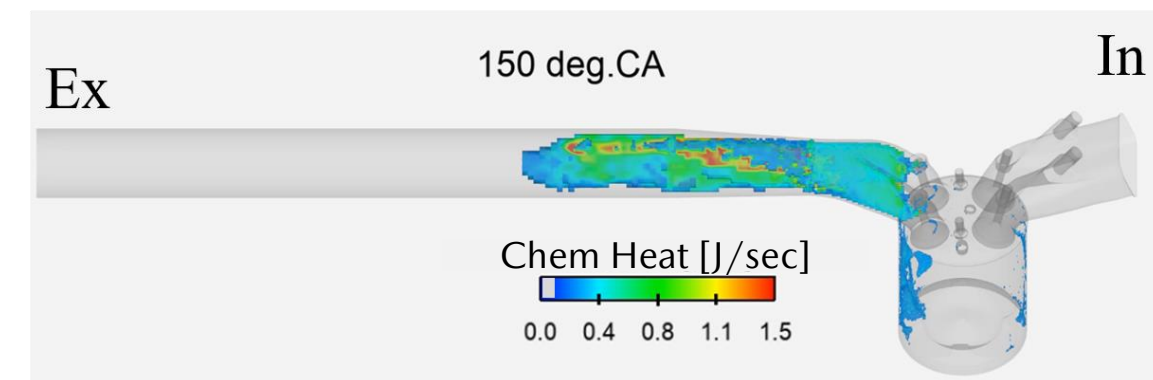
3. Cold emissions reduction

3-2. Emissions reduction strategy

Mode tailpipe THC,NOx



- Cold Raw-EM is significantly reduced by 'ETV', and 'adsorption catalysts' are used as a supplementary measure.

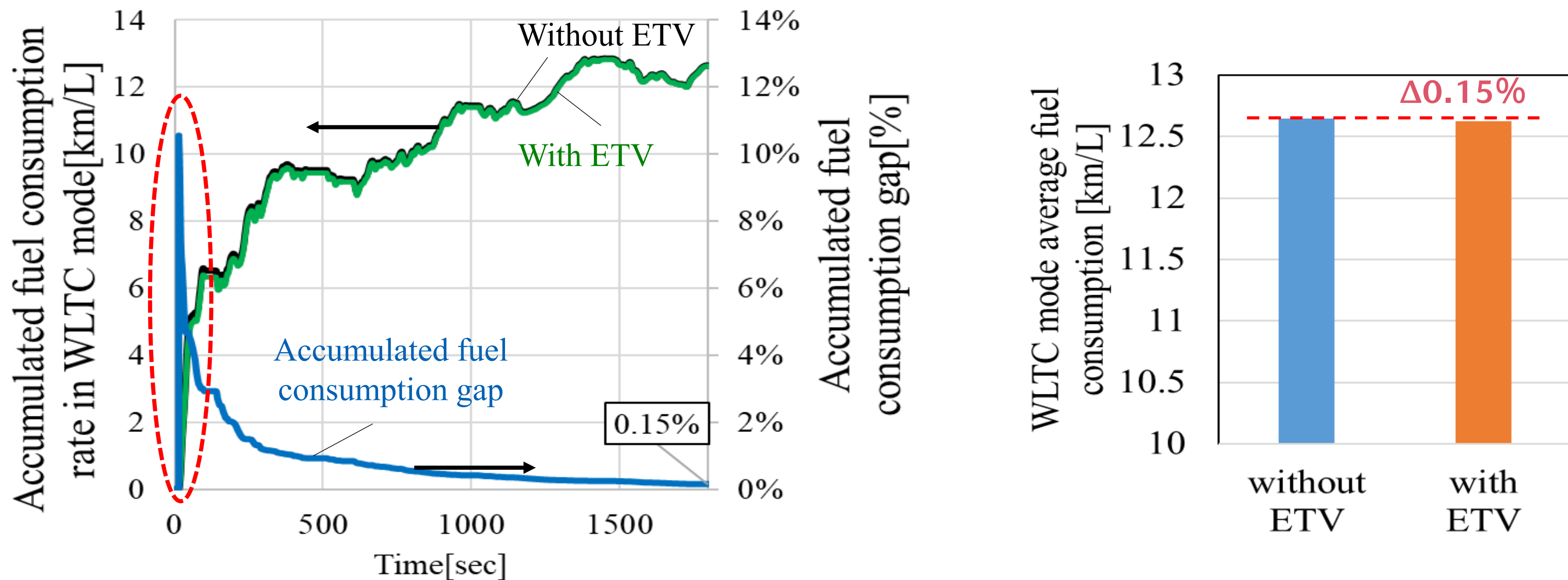


Location of post-oxidation at EVC

3. Cold emissions reduction

3-3. fuel consumption

- Although the exhaust gas pressure increase by ETV immediately after start-up affects fuel efficiency, the increase in fuel consumption in the WLTC mode is limited to a deterioration of 0.15% for the entire WLTC mode.

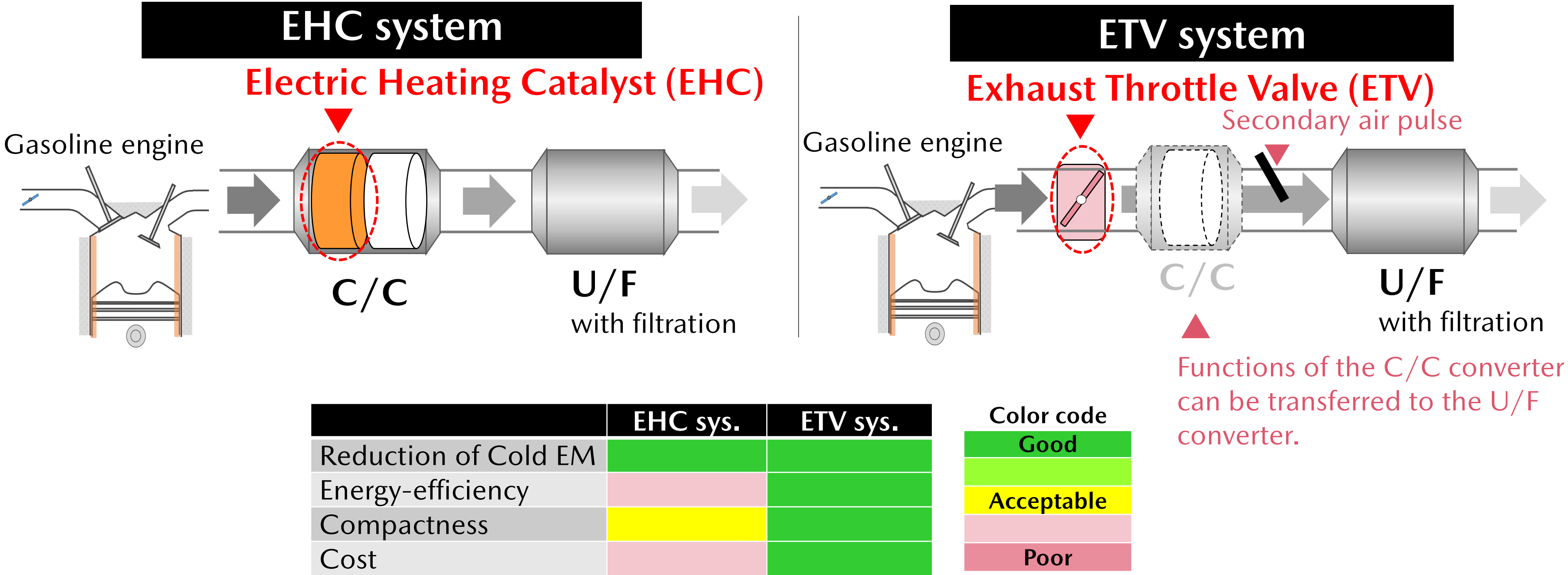


Predicted impact on fuel efficiency in WLTC mode

3. Cold emissions reduction

3-4. Features of the exhaust throttle valve system

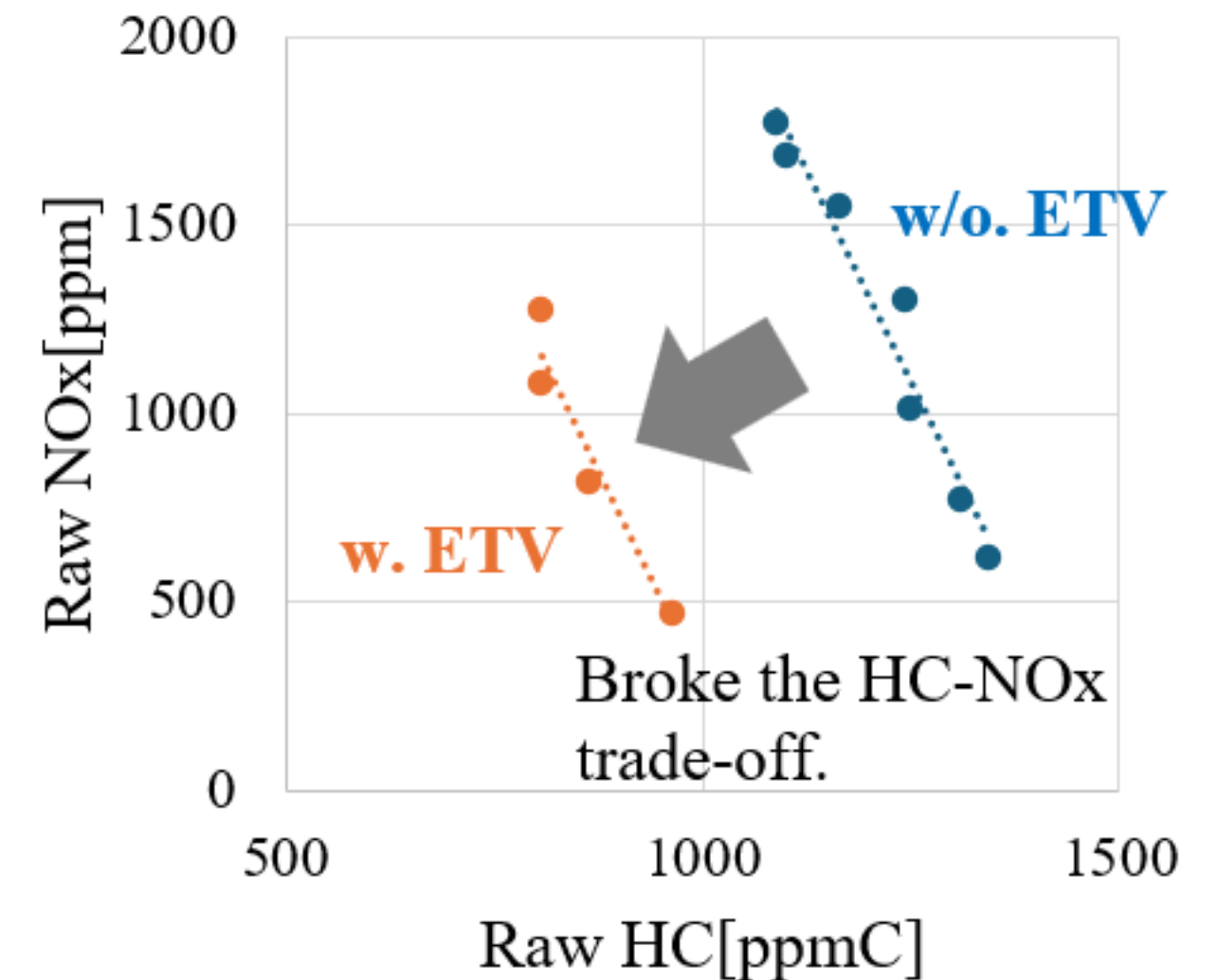
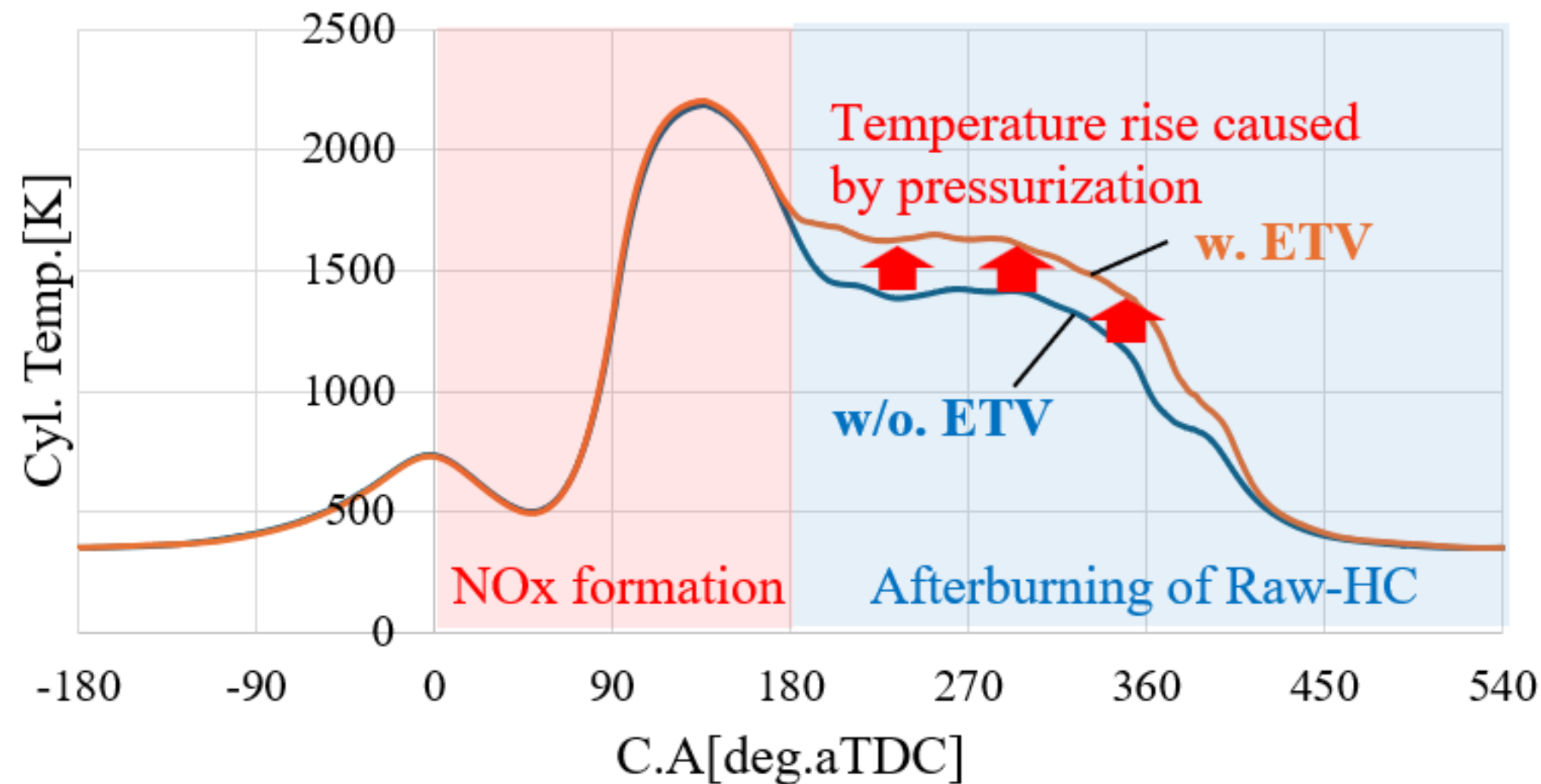
- A simplified system applying ETV minimizes energy consumption while being compact and low-cost, and it holds the potential to purify the air.



3. Cold emissions reduction

3-5. Mechanism for reducing HC and NOx

- The pressure increase by ETV raises the in-cylinder gas temperature, particularly during the exhaust stroke, which reduces HC without increasing NOx. (NOx is reduced due to the internal EGR effect.)

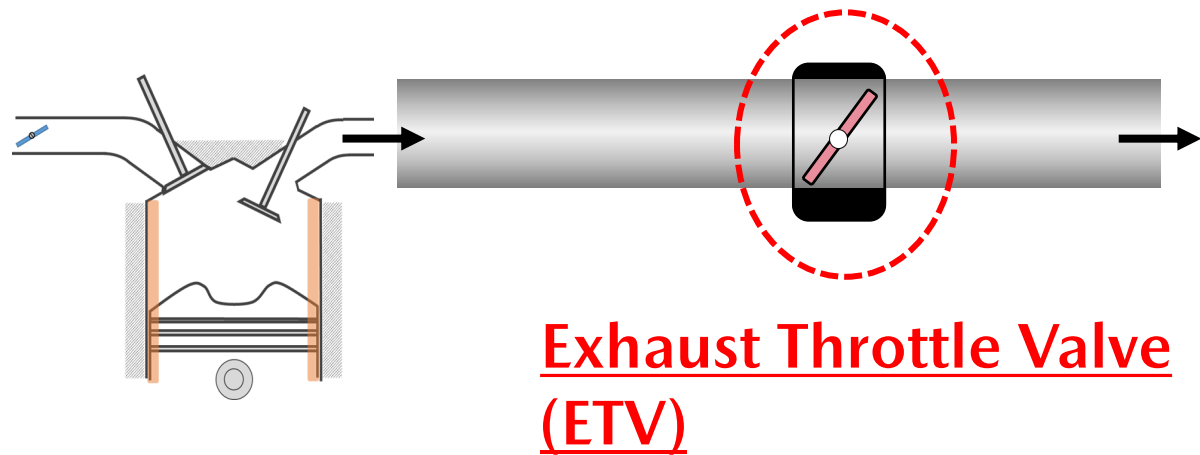


In-cylinder temperature increase by ETV and the reduction effects on Raw HC/NOx [simulation results]

3. Cold emissions reduction

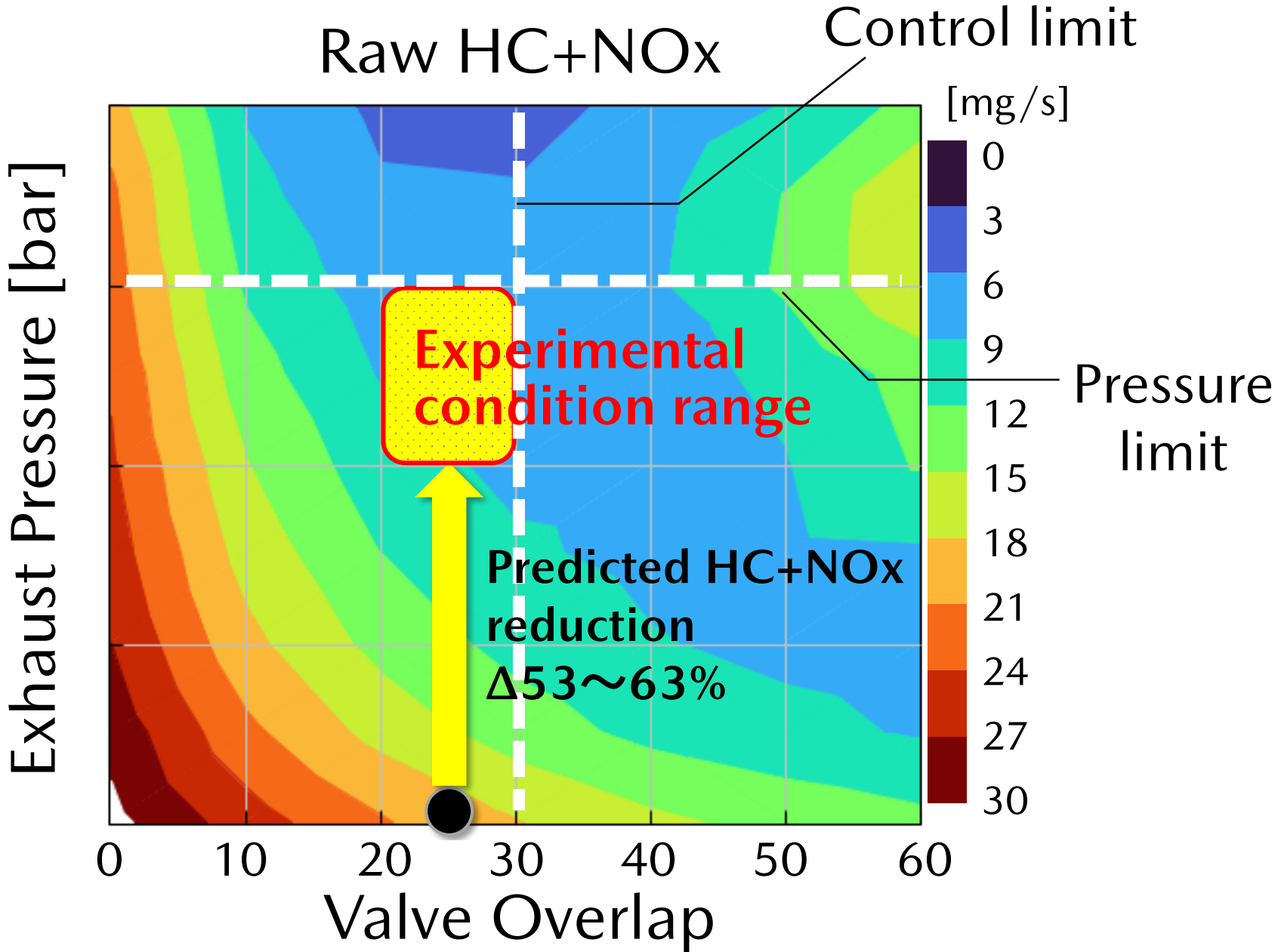
3-6. Verification of ETV technology

Four-cylinder engine



Specifications and test conditions	
Bore[mm]	89
Stroke[mm]	100
Compression ratio[-]	13.0
Engine speed[rpm]	1400
Lambda[-]	1.0 or 1.1 (w.ETV)
Oil and water temp.[°C]	30

- Conducted engine dyno evaluation (steady-state conditions) reflecting oil and water temperatures simulating cold start, as well as engine valve timing control conditions derived from model calculations.

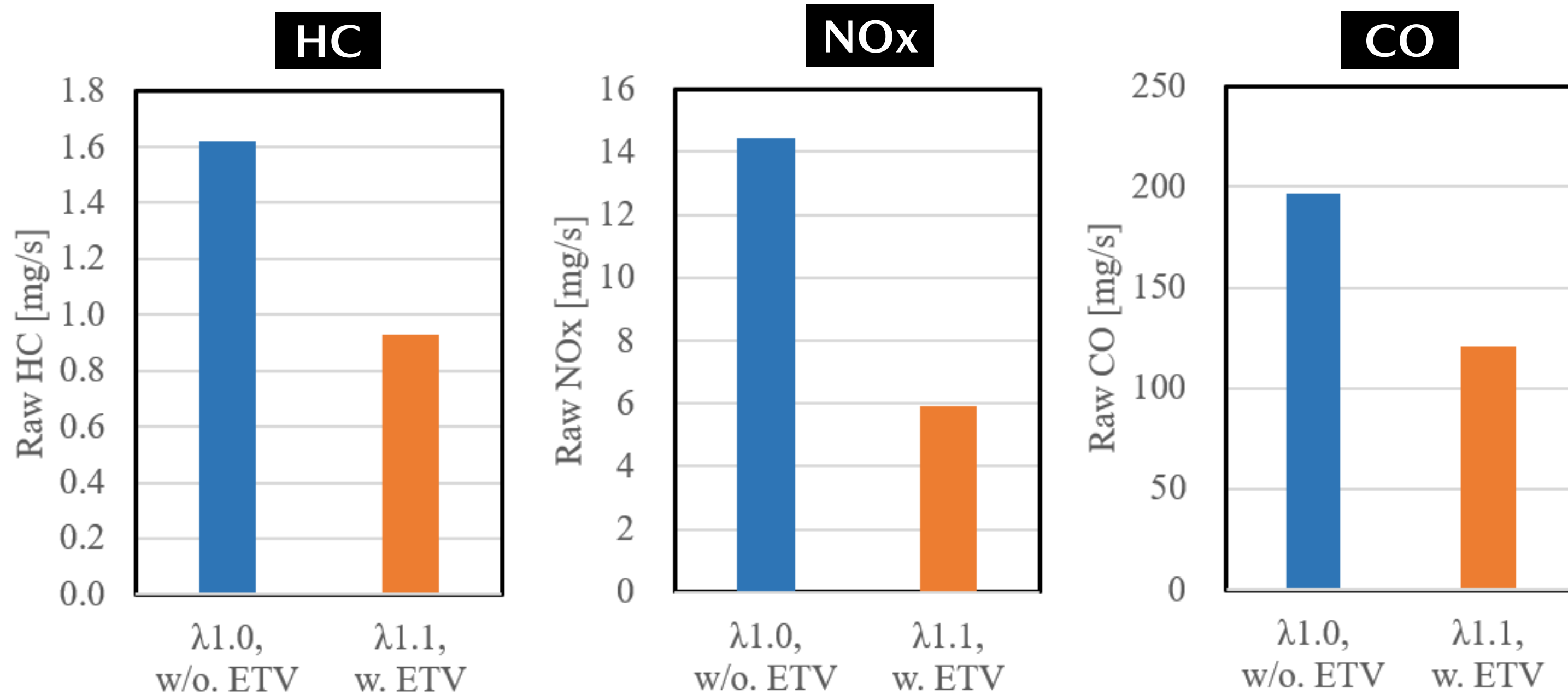


Experimental conditions [simulation results]

3. Cold emissions reduction

3-6. Verification of ETV technology

- The combination of exhaust gas pressure increase by ETV and a change in λ conditions (1.0 to 1.1) resulted in the reduction of HC, NO_x, and CO.

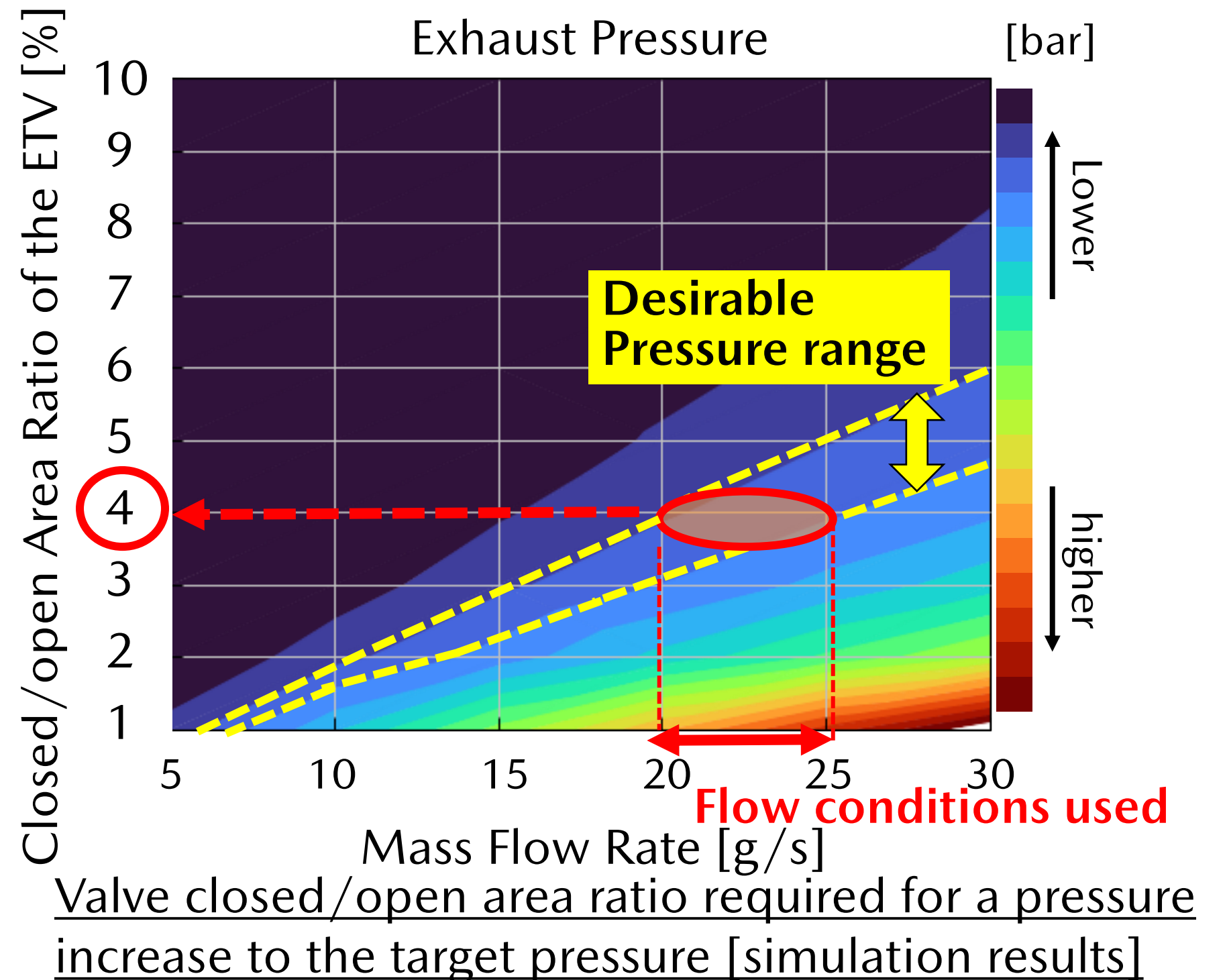
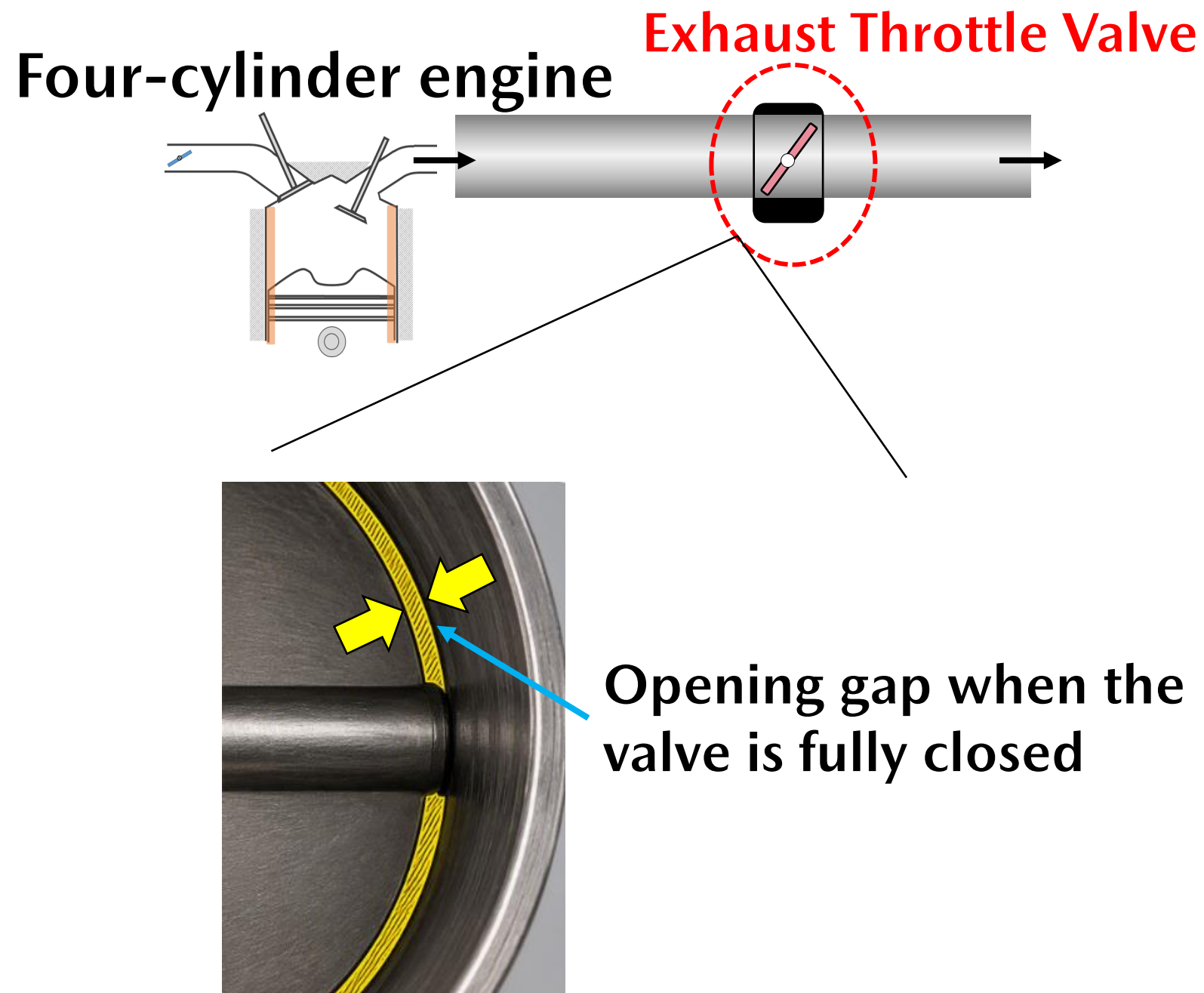


Effects of the combination of pressure increase by ETV and lean combustion [experimental results]

3. Cold emissions reduction

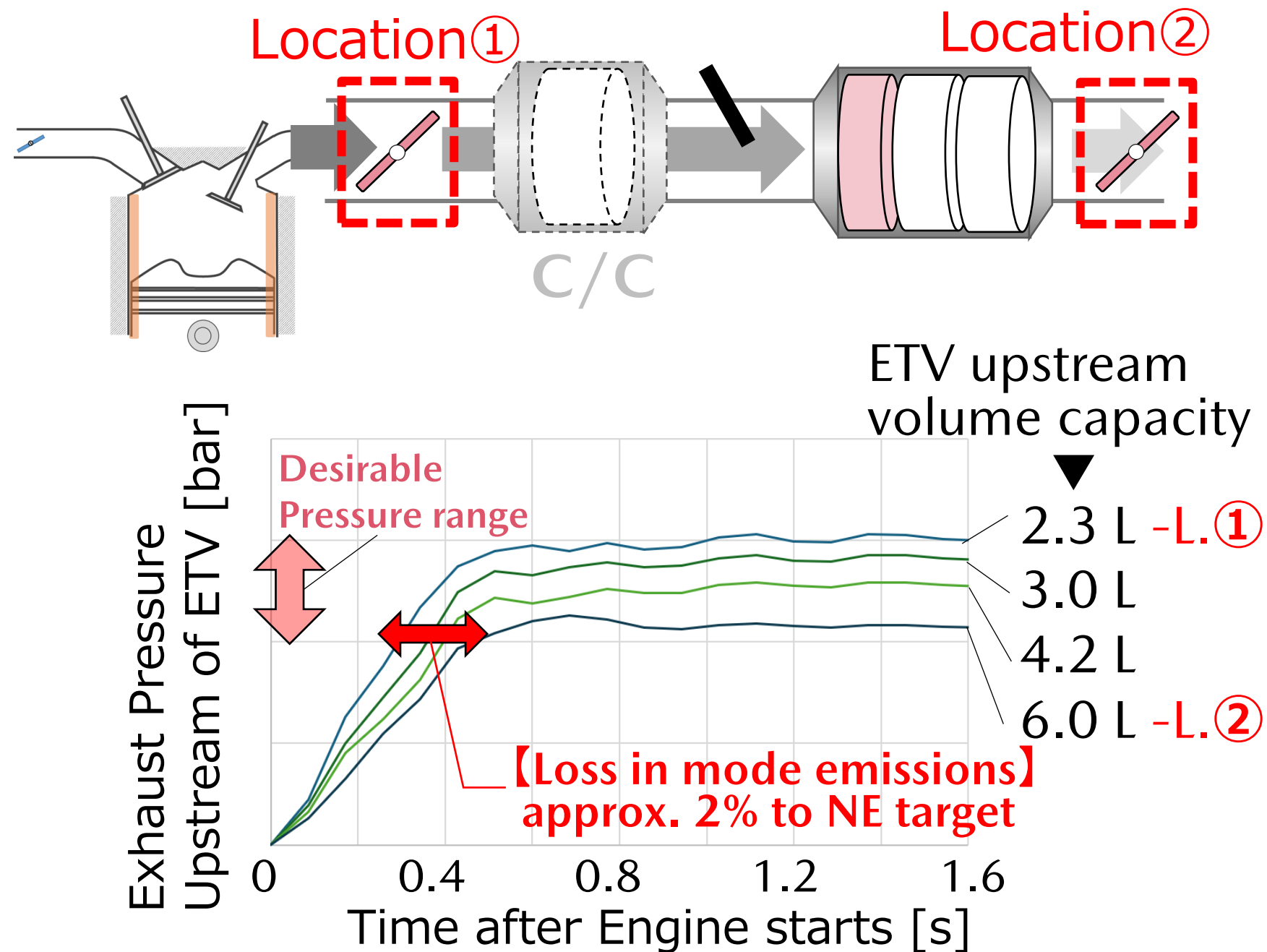
3-7. ETV specifications

- The desired pressure for promoting afterburning can be achieved with an opening area ratio of about 4% when the valve is fully closed, allowing the use of a general-purpose valve.



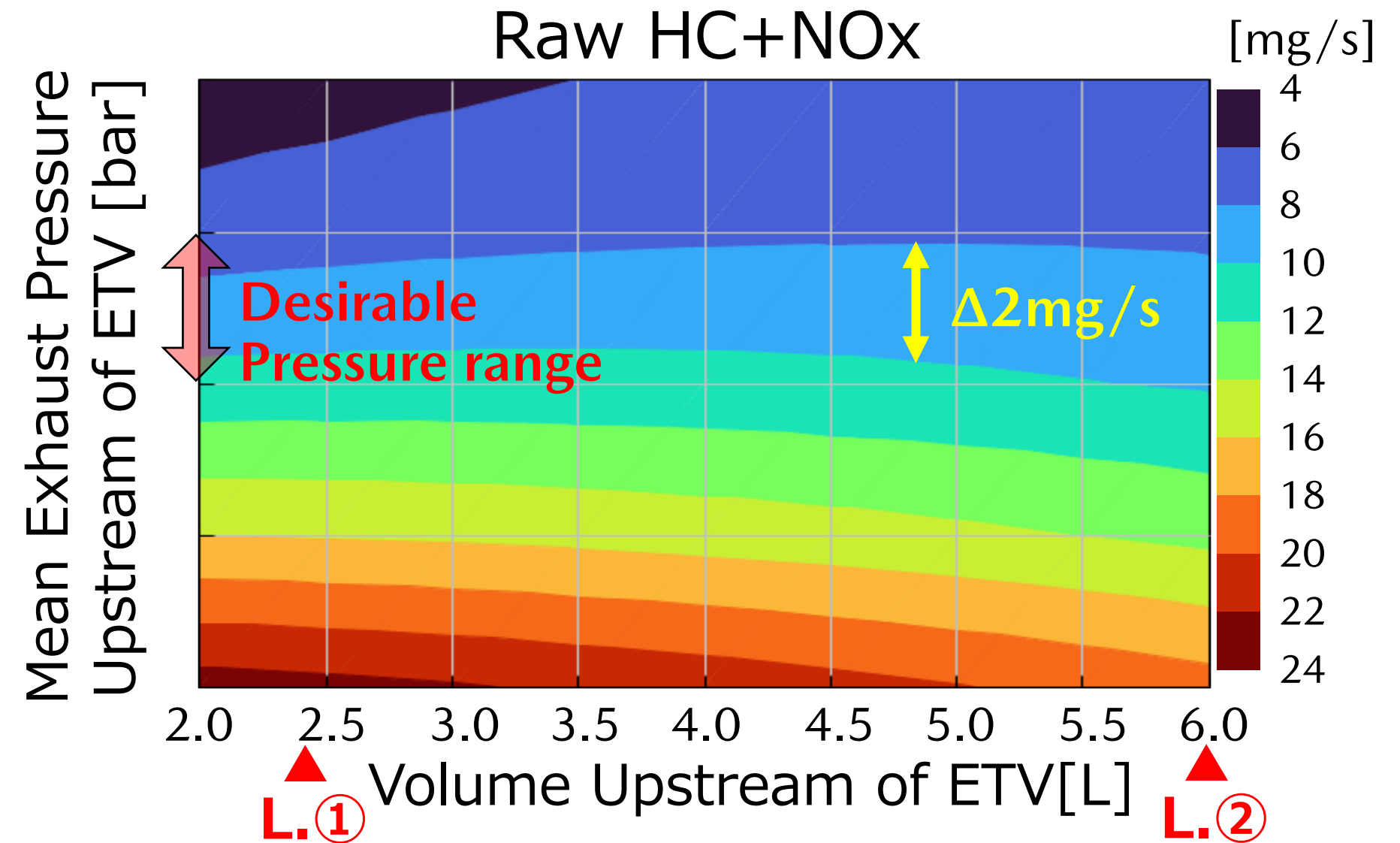
3. Cold emissions reduction

3-8. ETV installation position



Pressure change immediately after starting the engine at different ETV installation positions [simulation results]

- The pressure increase by ETV occurs instantaneously, so the sensitivity to the ETV position is low for Raw-EM reduction.
- ETV can be installed downstream of the U/F catalyst for Raw EM reduction, offering potential cost savings.

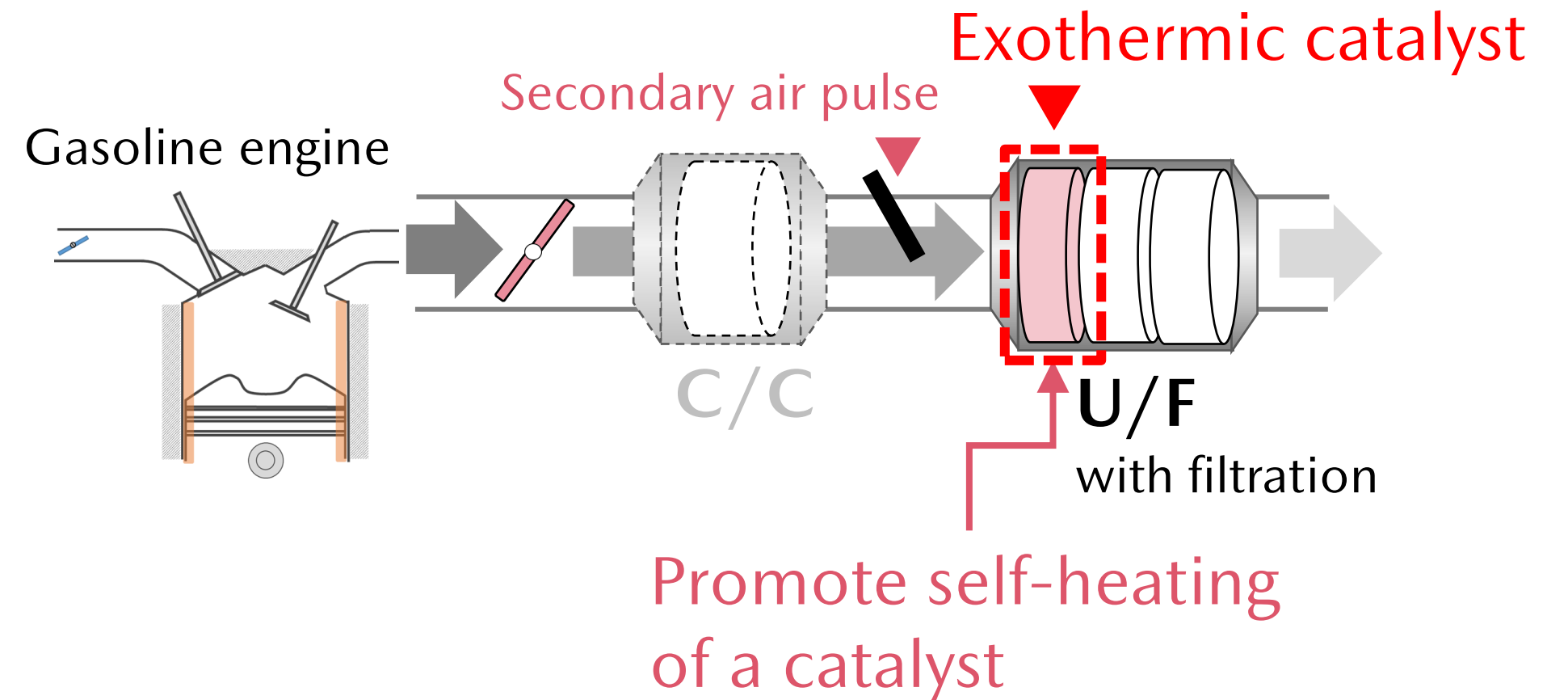
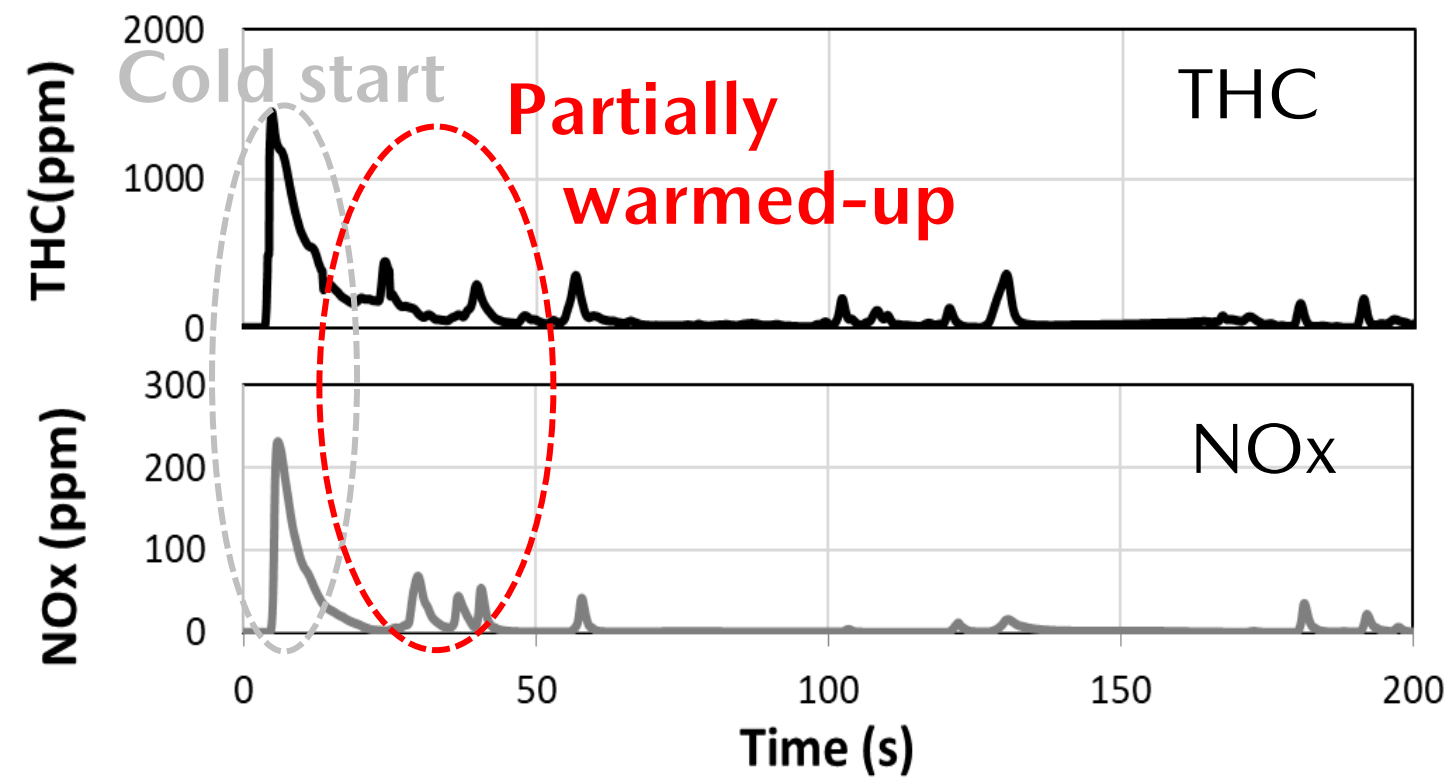


Total emission rates of Raw HC and NOx (steady-state condition) [simulation results]

4. Partially warmed-up emissions reduction

4-1. Emissions reduction strategy

Mode tailpipe THC,NO_x

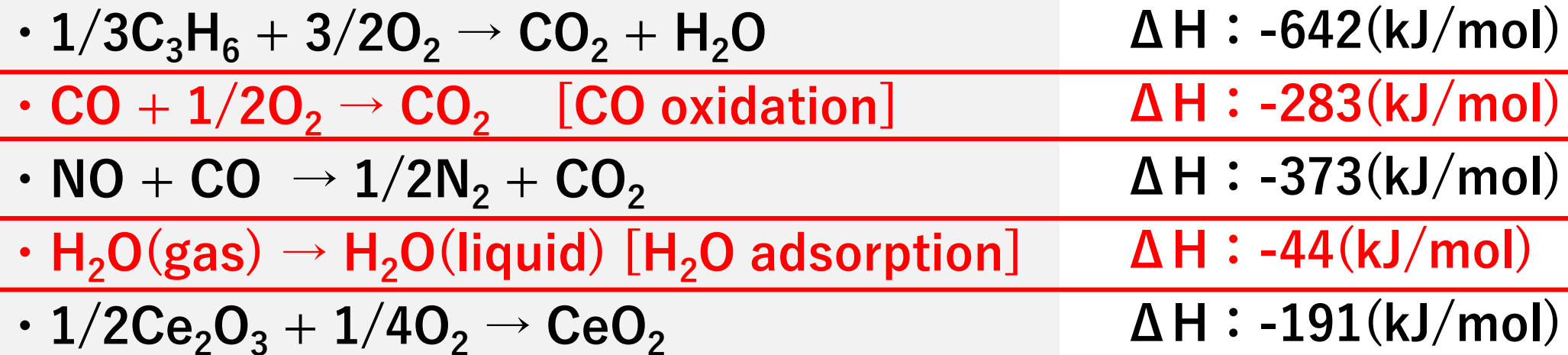


- To reduce partially warmed-up emissions, utilize catalyst self-heating.

4. Partially warmed-up emissions reduction

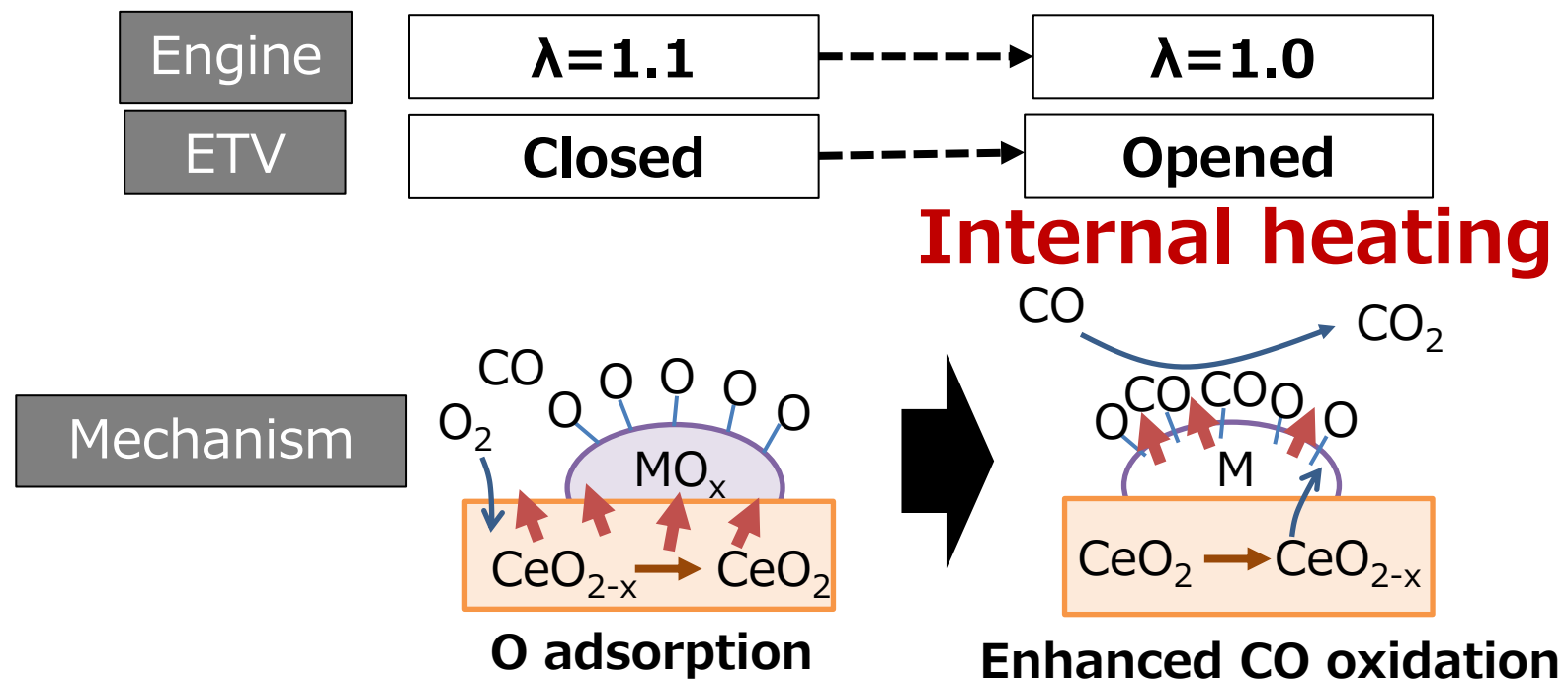
4-2. Enhancement of exothermic function

□ Exothermic Reactions

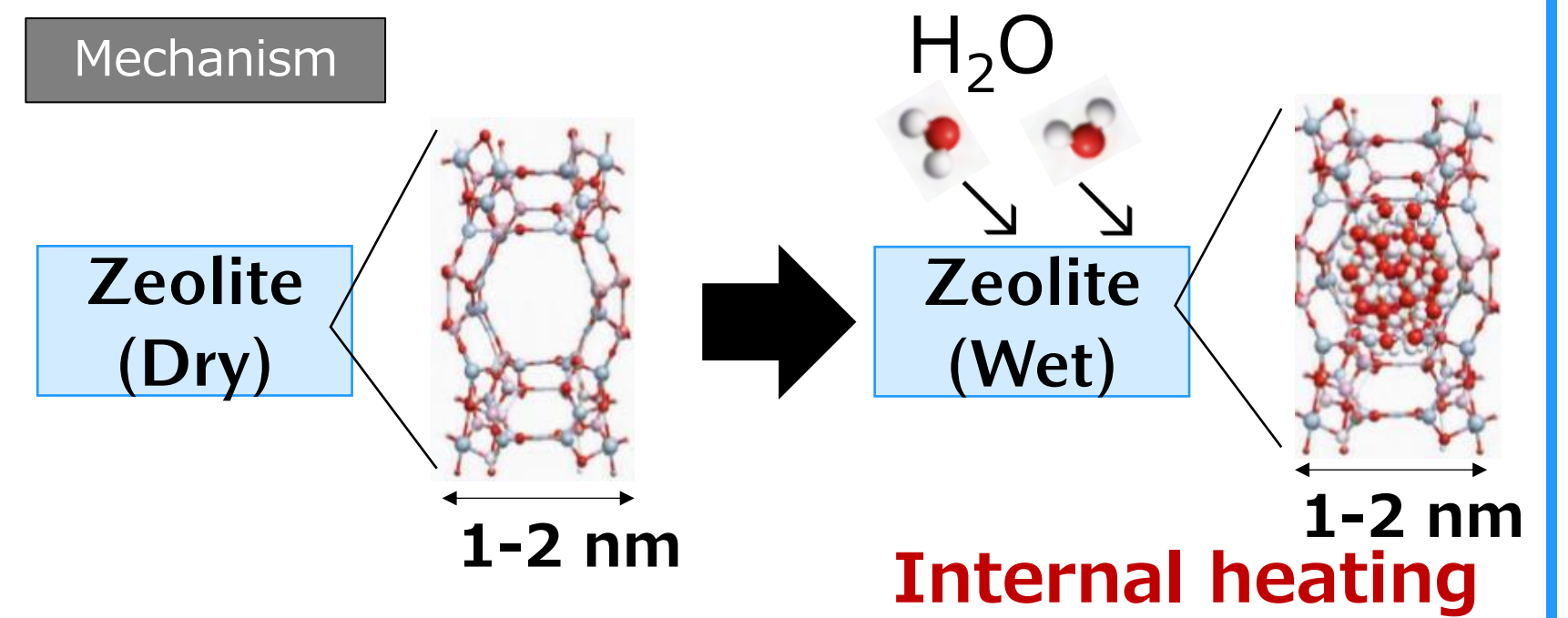


- Utilize ETV to provide CO to the oxidized catalyst, causing heat generation.
- Enhance the heat generation effect further by utilizing the heat effect of H₂O adsorption.

□ Utilization of CO oxidation heat



□ Utilization of zeolite self-heating



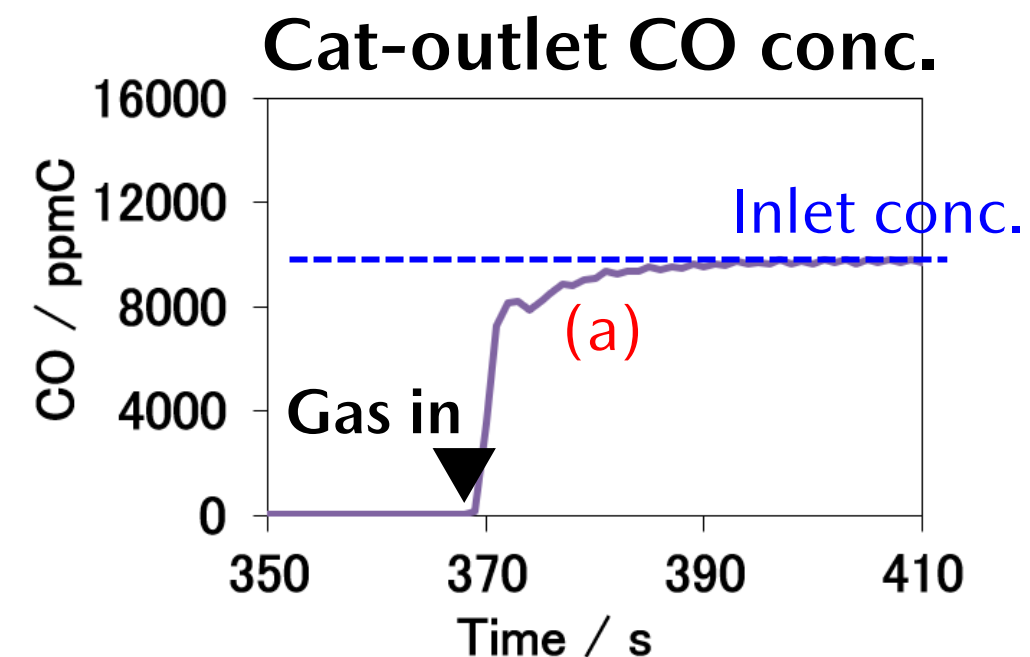
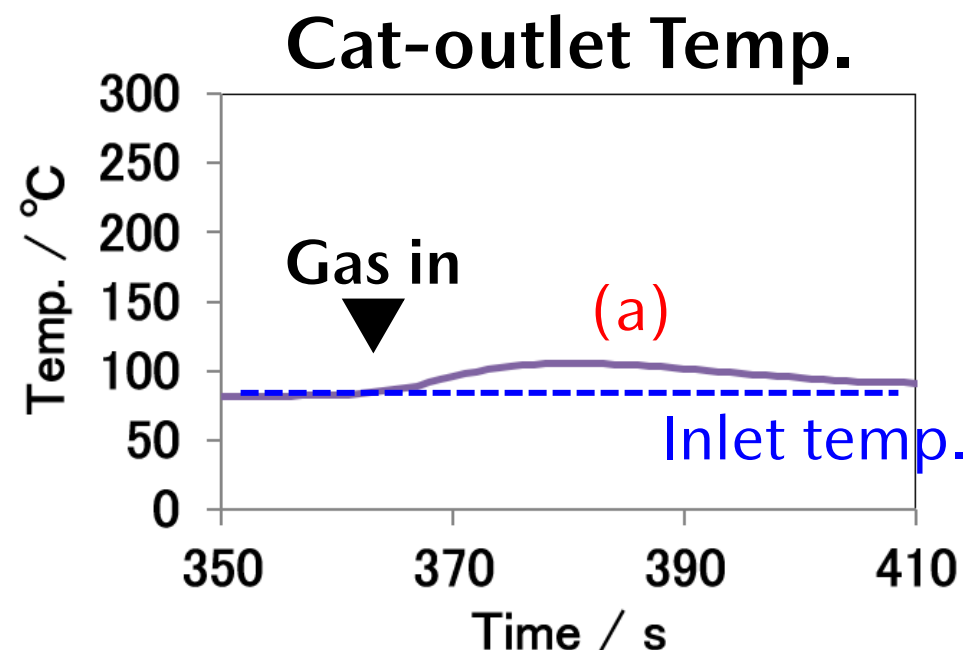
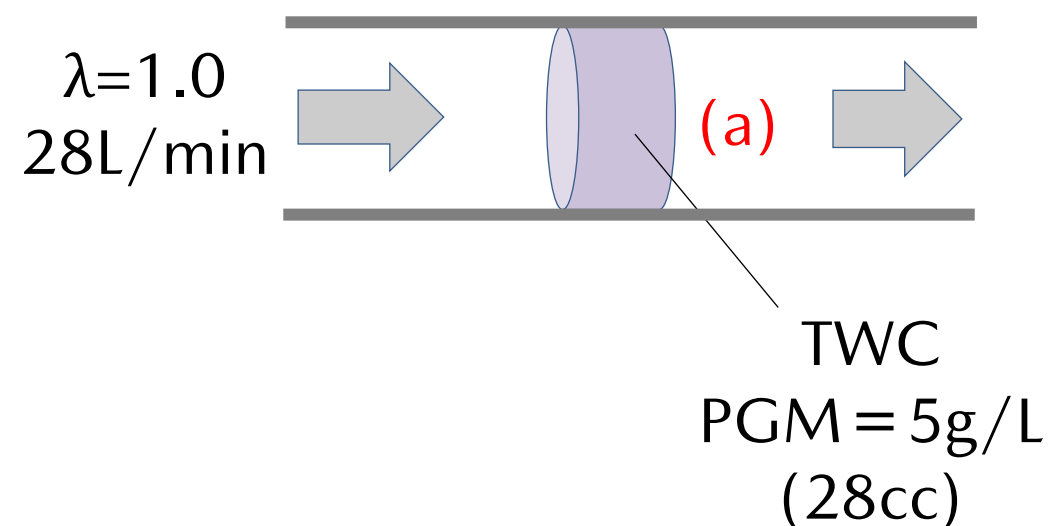
4. Partially warmed-up emissions reduction

4-3. Adaptation of a self-heating zeolite

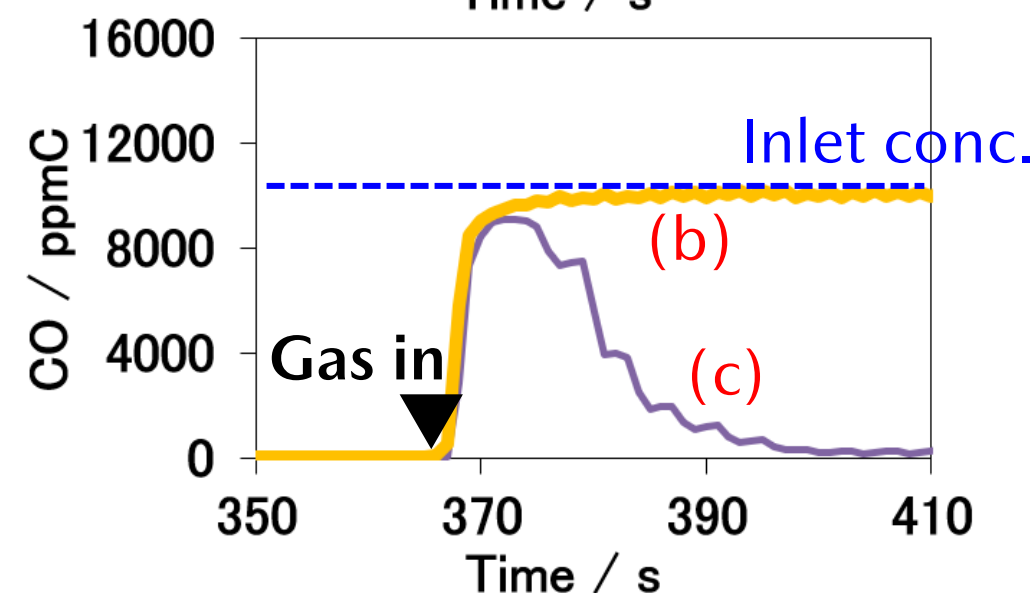
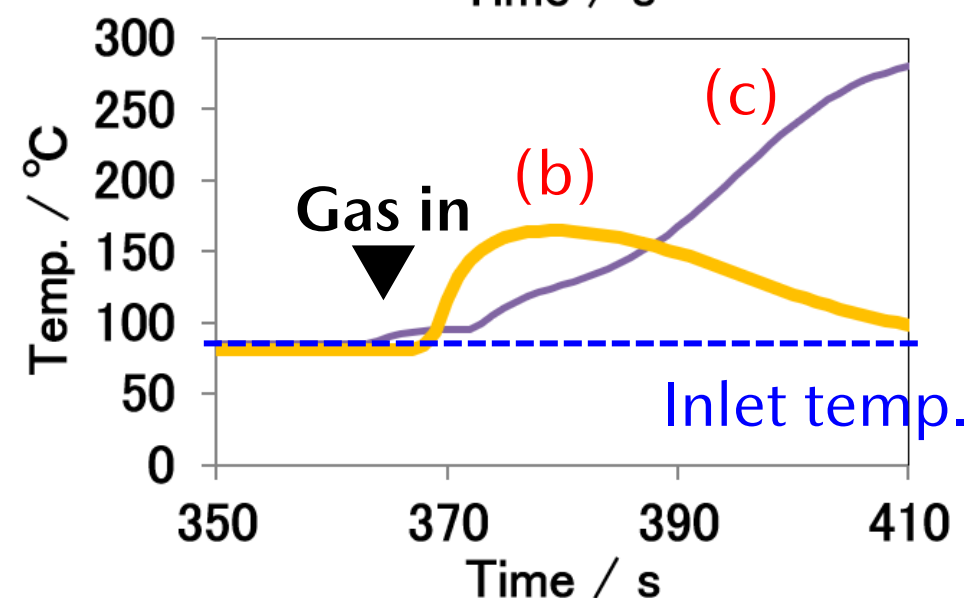
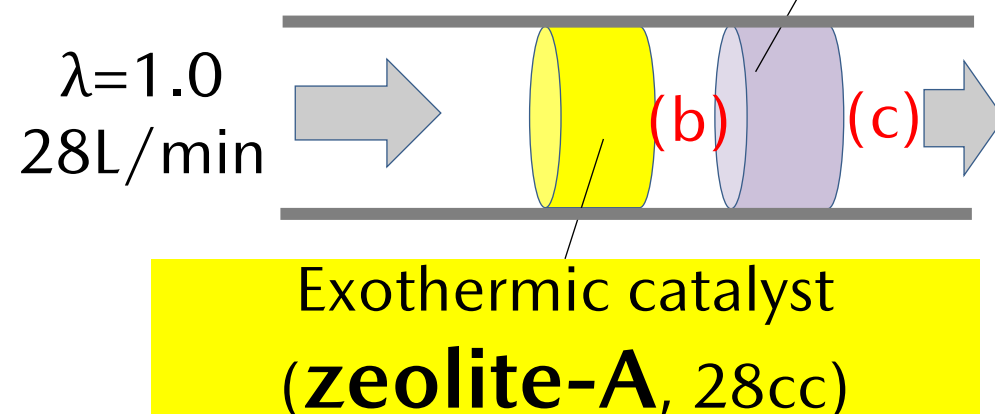
- When self-heating of the zeolite occurs due to water adsorption, the increased inlet temperature of the downstream TWC leads to significant progress in purification reactions.

Reactor test conditions

□ TWC only



□ Exothermic catalyst+TWC



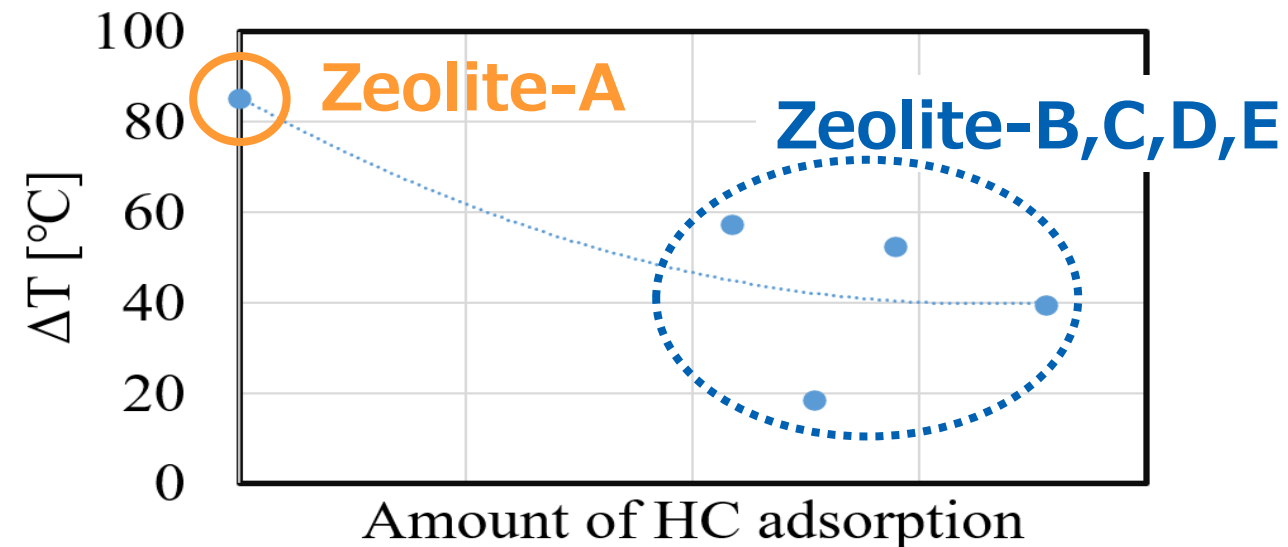
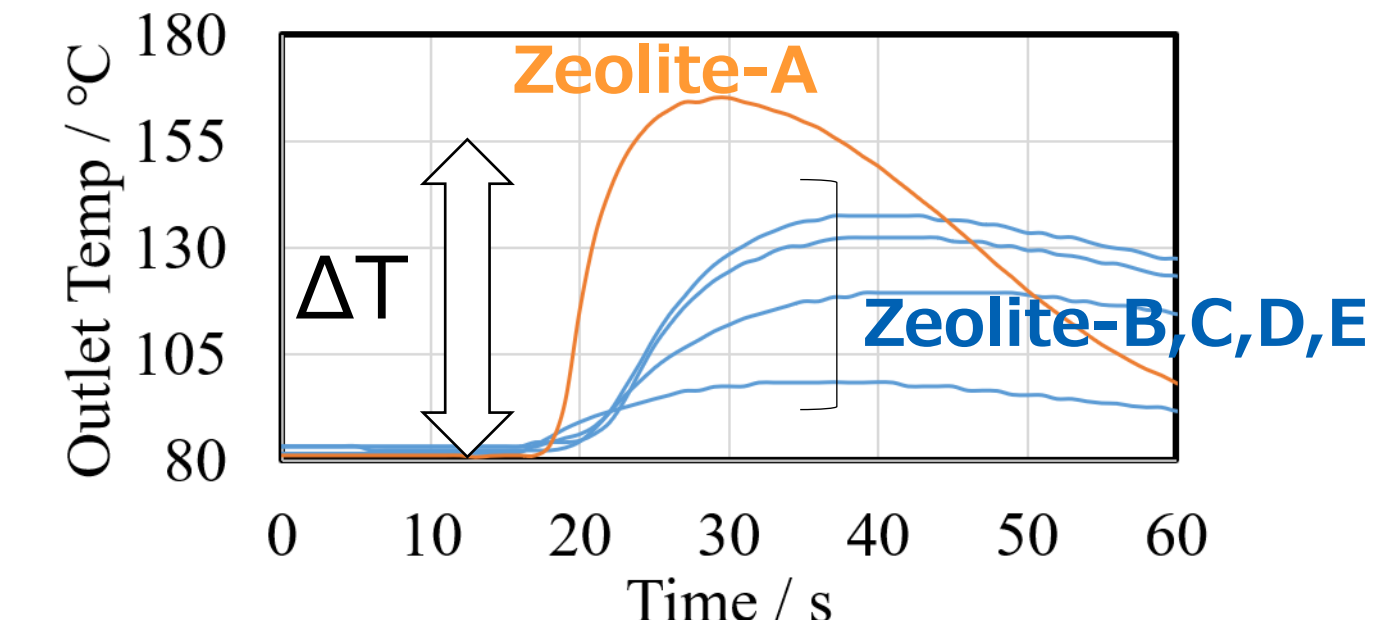
Preconditioning: $\lambda 1$ with 10% H_2O to 600°C
→ cooling in N_2 to 80°C
Test: $\lambda 1$ with 10% H_2O at 80°C

Gas heating by exothermic catalyst and promotion of low-temperature CO purification [reactor test results]

4. Partially warmed-up emissions reduction

4-4. Application method of self-heating zeolite

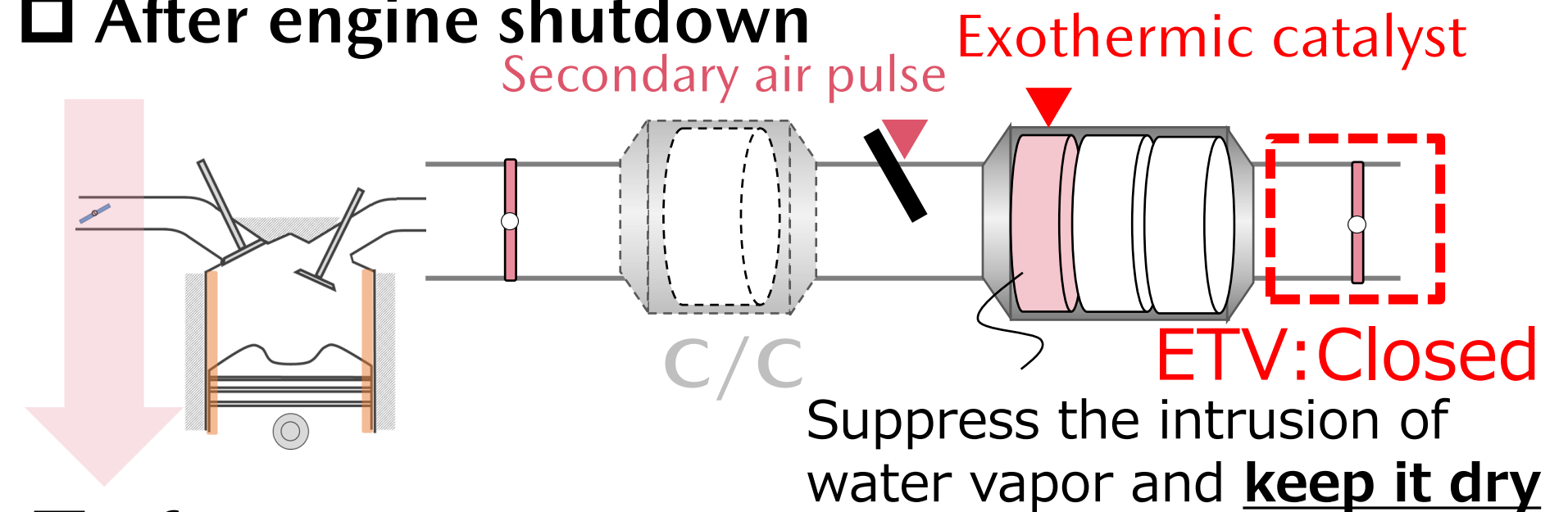
- Zeolite-A, which doesn't adsorb HC, maximizes heat generation responsiveness.



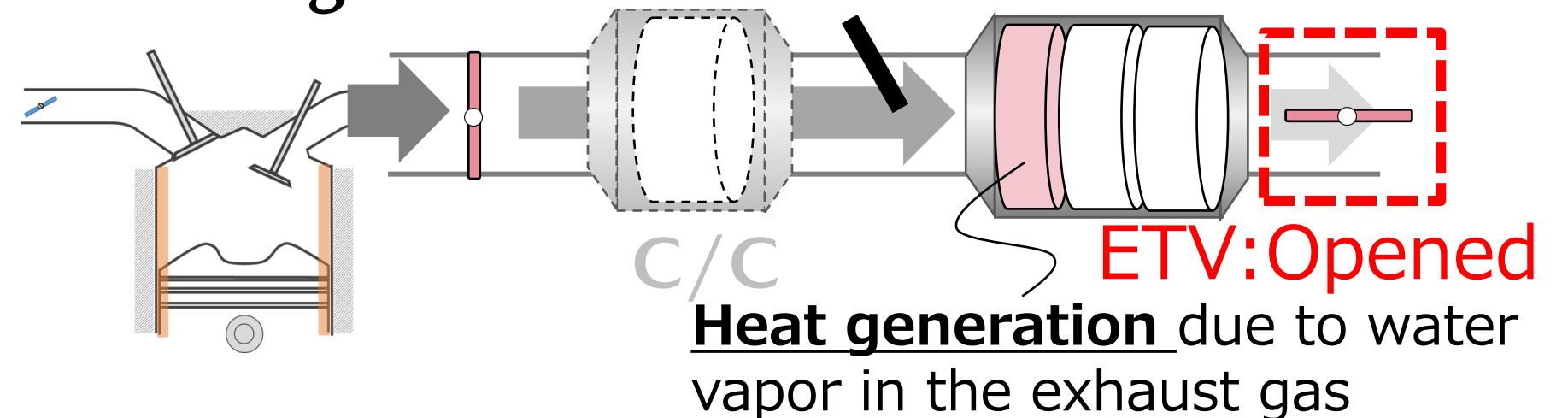
Heat generation and its relationship with HC adsorption capacity [reactor test results]

- Install ETV downstream of the U/F catalyst to control the dry state of the zeolite.

□ After engine shutdown



□ After engine start

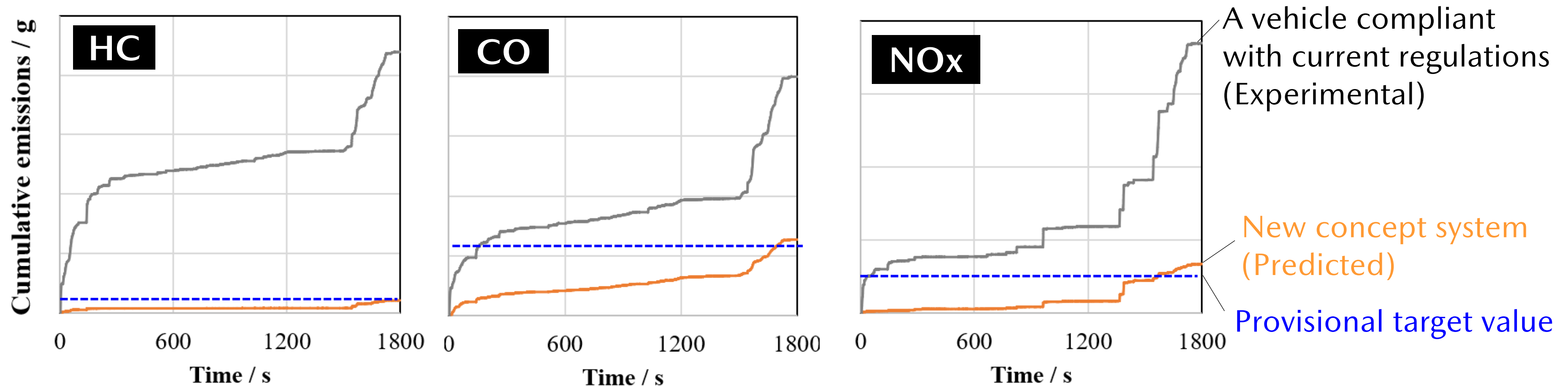


Valve control for promoting heat generation through water adsorption

5. Mode emissions prediction

5-1. The feasibility of achieving the provisional target (simulation results)

- It was estimated that a system combining ETV, exothermic catalysts (CO oxidation/water adsorption), NOx storage catalysts, and other components could generally achieve emissions close to the provisional target.
- For any shortfalls, we will explore the possibility of recovery through motor assist integration in HEVs.

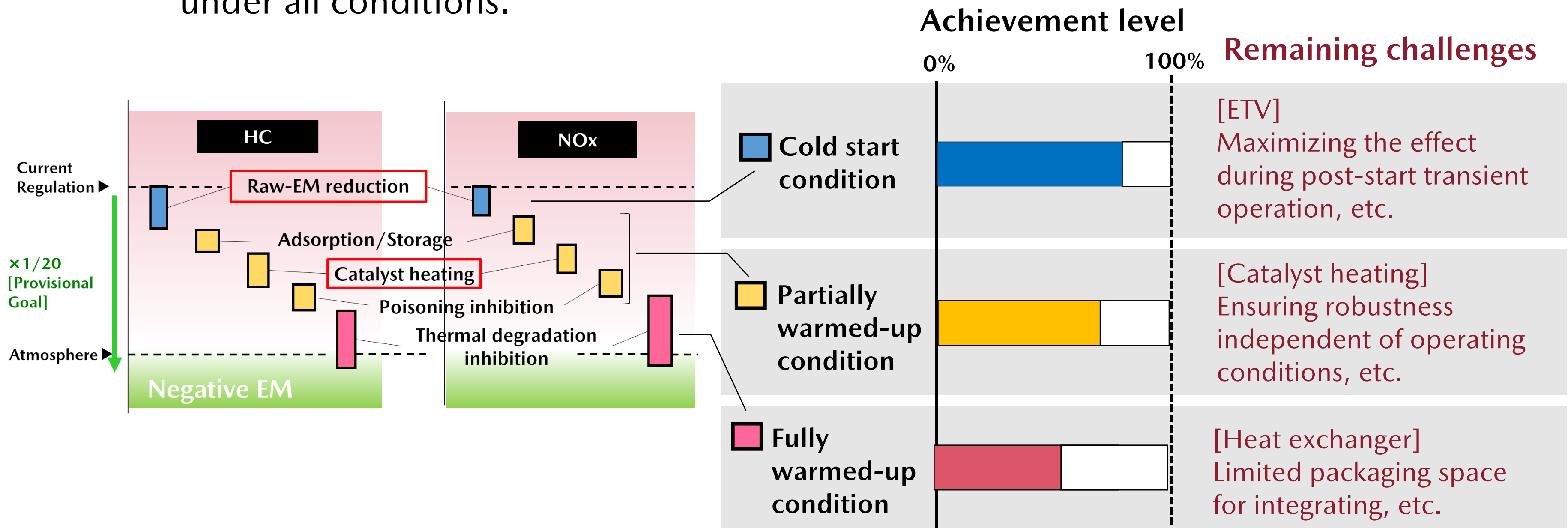


Emissions over the WLTC cycle

6. Current status of negative emissions technology

6-1. Challenges for achieving the targets of each function

- By utilizing new control factors aimed at achieving negative emissions, we are steadily progressing in reducing emissions beyond conventional levels.
- Moving forward, we will enhance robustness to ensure maximum effectiveness under all conditions.



7. Summary

- We explore the potential for negative CO₂ by applying biofuels to internal combustion engine vehicles, including hybrid vehicles, and capturing CO₂ from exhaust gases. In addition, we aim to enhance the reduction of harmful emissions to a level that purifies the air while driving, without compromising CO₂ reduction.
- To significantly reduce CO₂ emissions and atmospheric pollutants, we aim to develop energy-efficient and simple systems based on the evolution of exhaust purification technology in harmony with engines and electric drive systems. To achieve this, we will use exhaust throttle valve technology as an enabler to reduce emissions from cold starts.
- The transition from cold to semi-warm conditions will be advanced by applying new heat sources that do not rely on external heating to accelerate catalyst activation.
- These efforts contribute to the reduction of CO₂ emissions (carbon negativity) that humanity continues to emit, from a global perspective, and are effective in mitigating climate change risks early.



Thank you for your attention!

