HORIBA
Automotive Test Systems

Introduction of measurement technics regarding mass emissions and real time fuel consumption using direct exhaust gas flow meter

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2. Conventional measurement method
3. Direct mass emission measurement
4. Test equipment and test system
5. Test results
6. Other applications
7. Summary

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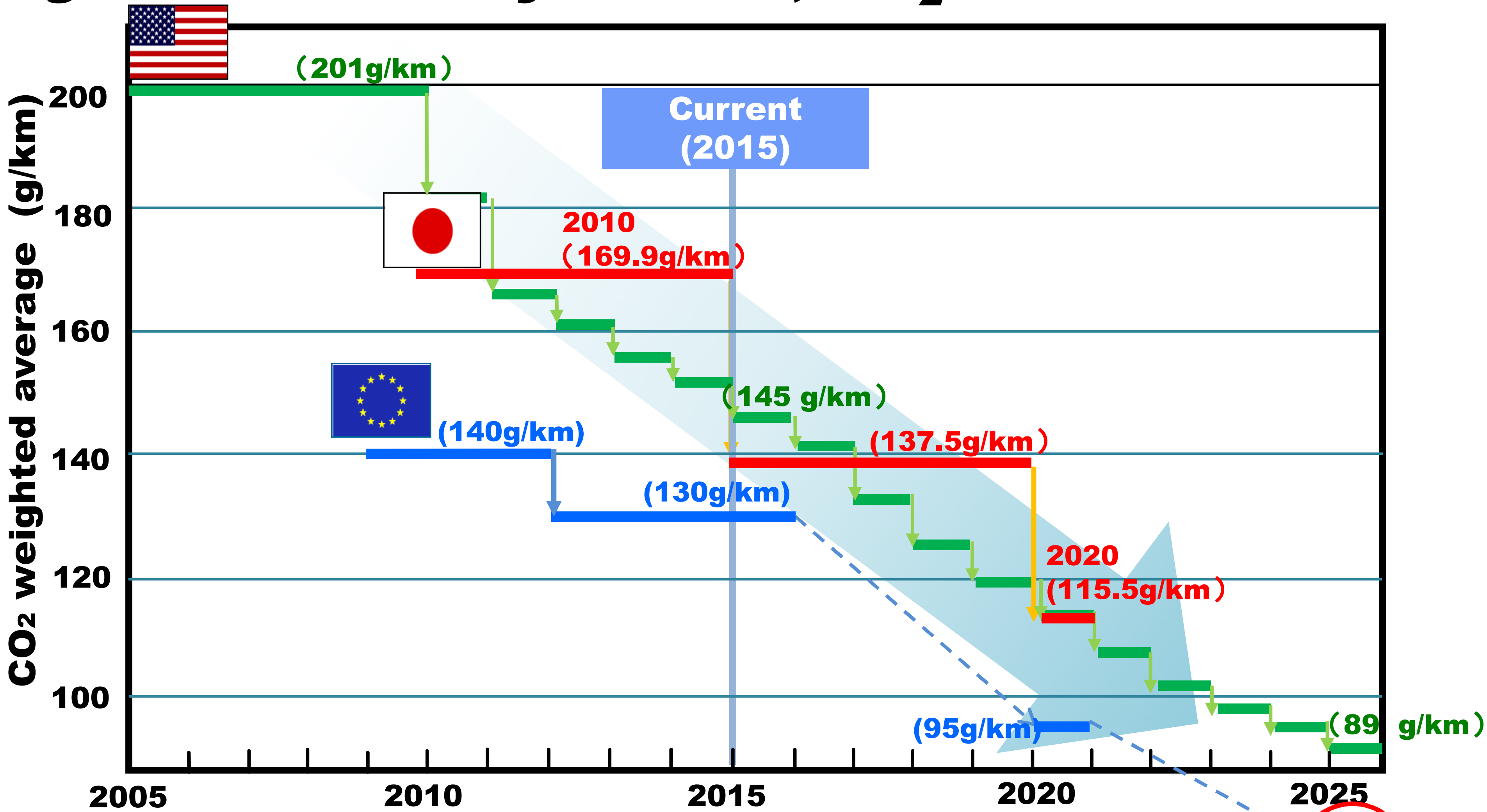
World Fuel Economy Targets

Light-Medium Duty Vehicle; CO_2 emission criteria



Current EU CO_2 emissions based on NEDC and EURO5/6 procedures
EU is more aggressive than USA/JAPAN ***EU requests 68-78g/km by 2025***

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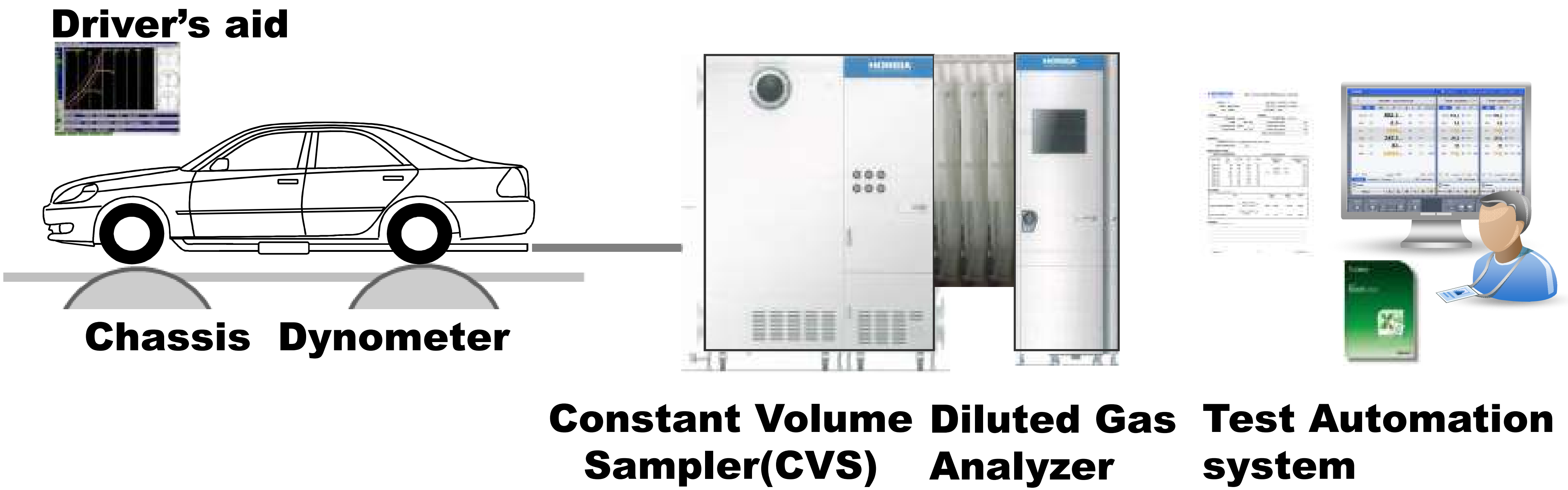
Conventional Fuel economy measurement method for light duty vehicle

CVS method

Combination of Dilute sampling using CVS and Gas concentration measurement using Gas analyzer

CVS Measurement System



Conventional Fuel economy measurement method for light duty vehicle

CVS method

Combination of Dilute sampling using CVS and Gas concentration measurement using Gas analyzer

CVS Measurement System

Driver's aid

Test vehicle is driven on a chassis dyno using driver's aid or auto driving system

→

Diluted exhaust gas is stored in a sample bag which has constant volume

Mass emissions are calculated from the concentration of the exhaust gas

→

Fuel economy is calculated by the mass emissions and the driving distance

Fuel consumption calculation from mass emissions

Carbon Balance Method for fuel consumption

$$F_{CB}(t) = \frac{1}{R_{CWF}} \times \left(\frac{M_C}{\alpha_{exh} \times M_H + M_C} \times Mass_{THC}(t) + \frac{M_C}{M_{CO}} \times Mass_{CO}(t) + \frac{M_C}{M_{CO_2}} \times Mass_{CO2}(t) \right)$$

Fuel **THC** **CO** **CO_2**

Mass Measurement of each emissions by CVS

$$Mass_x = \rho_x \times C_{x\_ex} \times V_{ex} \times 10^{-6}$$

Mass Emission

$$= \rho_x \times \left(C_{x\_sam} - C_{x\_amb} \times \left(1 - \frac{1}{DF} \right) \right) \times V_{mix} \times 10^{-6}$$

Gas Density **Gas Concentration** **Diluted Gas Volume**

Fuel economy is calculated by gas emissions and it is important to optimize not only fuel economy but also totally mass emissions

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Development challenges of the automobile

Increasing of test patterns

Test cycles of each countries
JC08, FTP-75,
NEDC, WLTC,,,,
Demands from Each county
Various Fuel,
Low cost vehicle

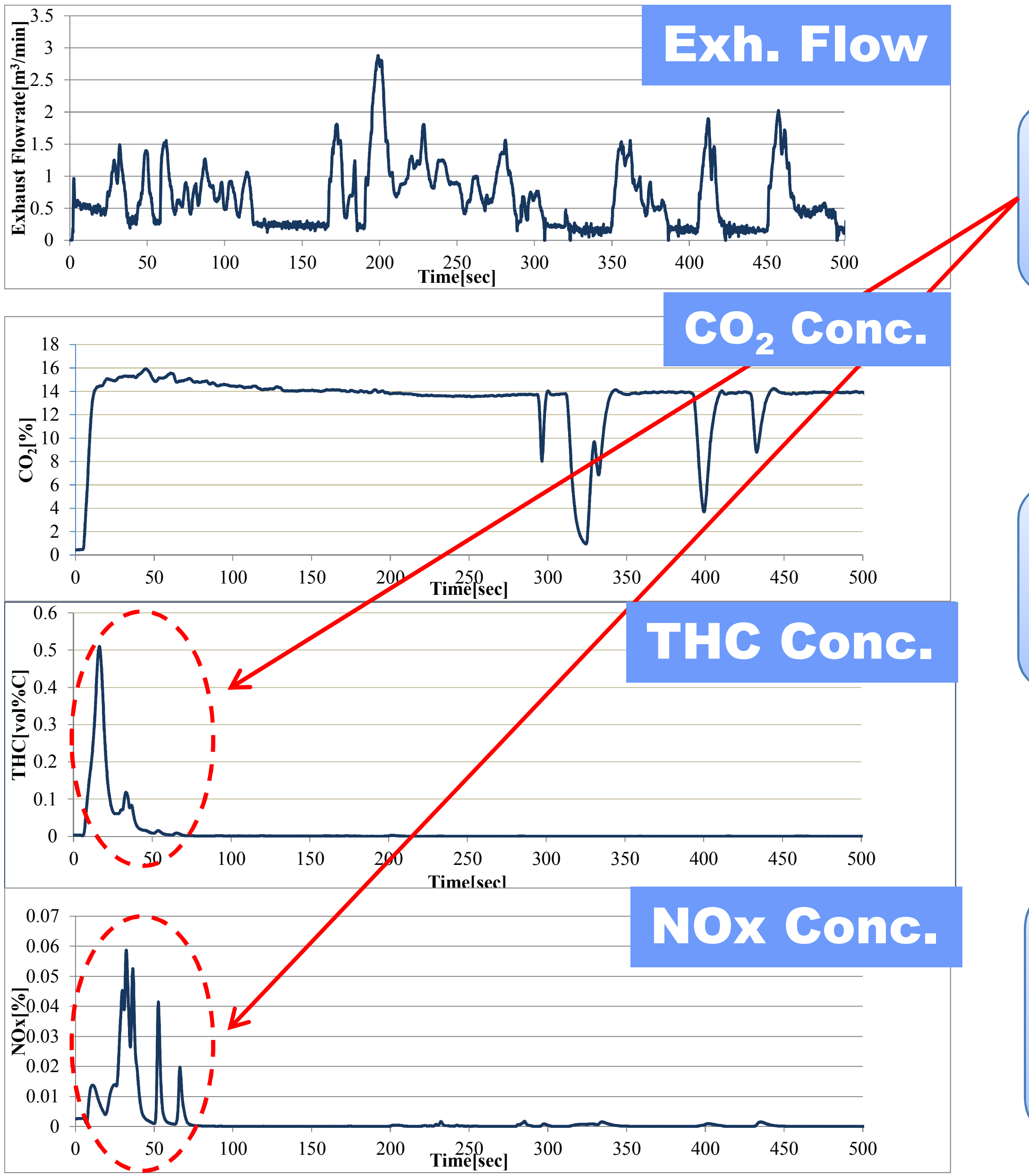
Increasing of measured gas compositions

Regulation of gas emissions
CO, NO_x, THC, PM, PN
Environmental law
CO_2, GHG
NH_3, Sulfur Compounds

Efficient emission test is required on R&D of vehicles

- Optimization in engine test cell
- Instantaneous emission measurement linked with engine speed/torque

Importance of transient mass measurement



Example:FTP-75 CT Phase

Most of regulated emissions are emitted in early stage of a test cycle

CVS method basically measures average mass through the test cycle

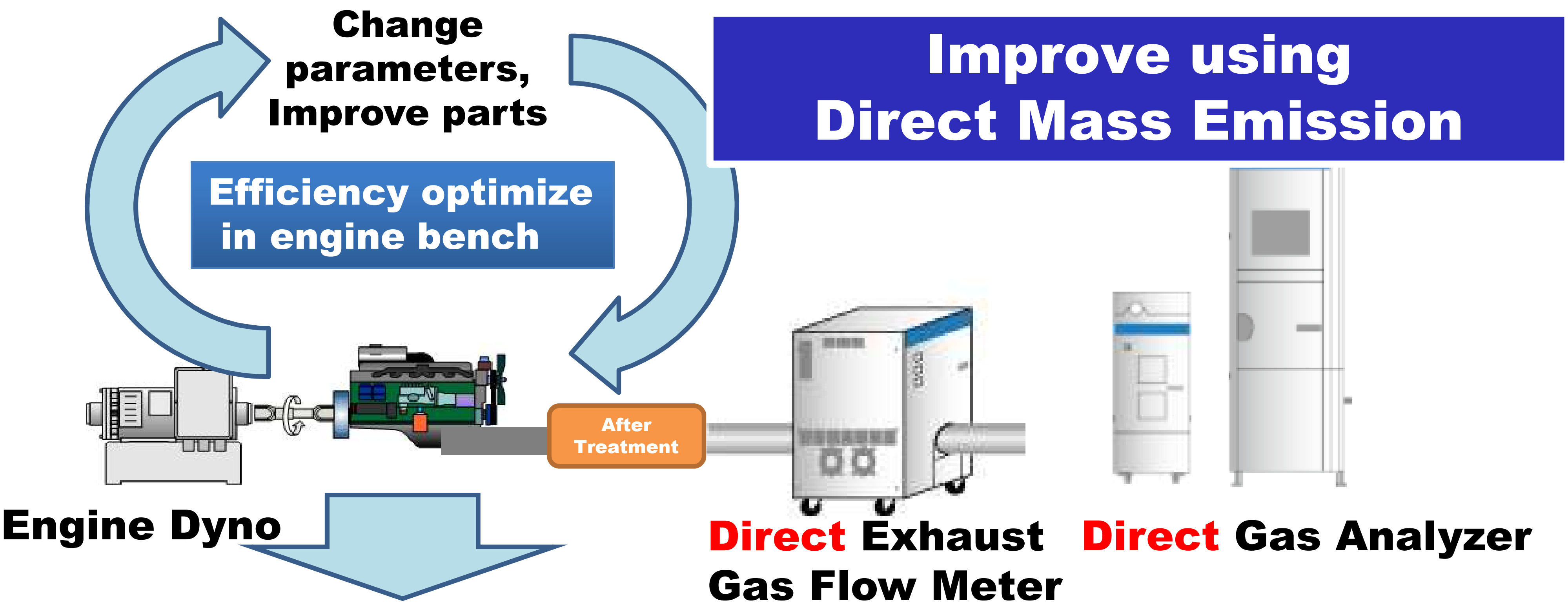
It is more effective to measure transient mass variation for optimizing fuel economy and emissions

Proposal of Direct mass emission measurement

Direct Mass Emission Measurement

Transient variation is measured
by combination Direct gas flow meter and analyzer

Improve using Direct Mass Emission



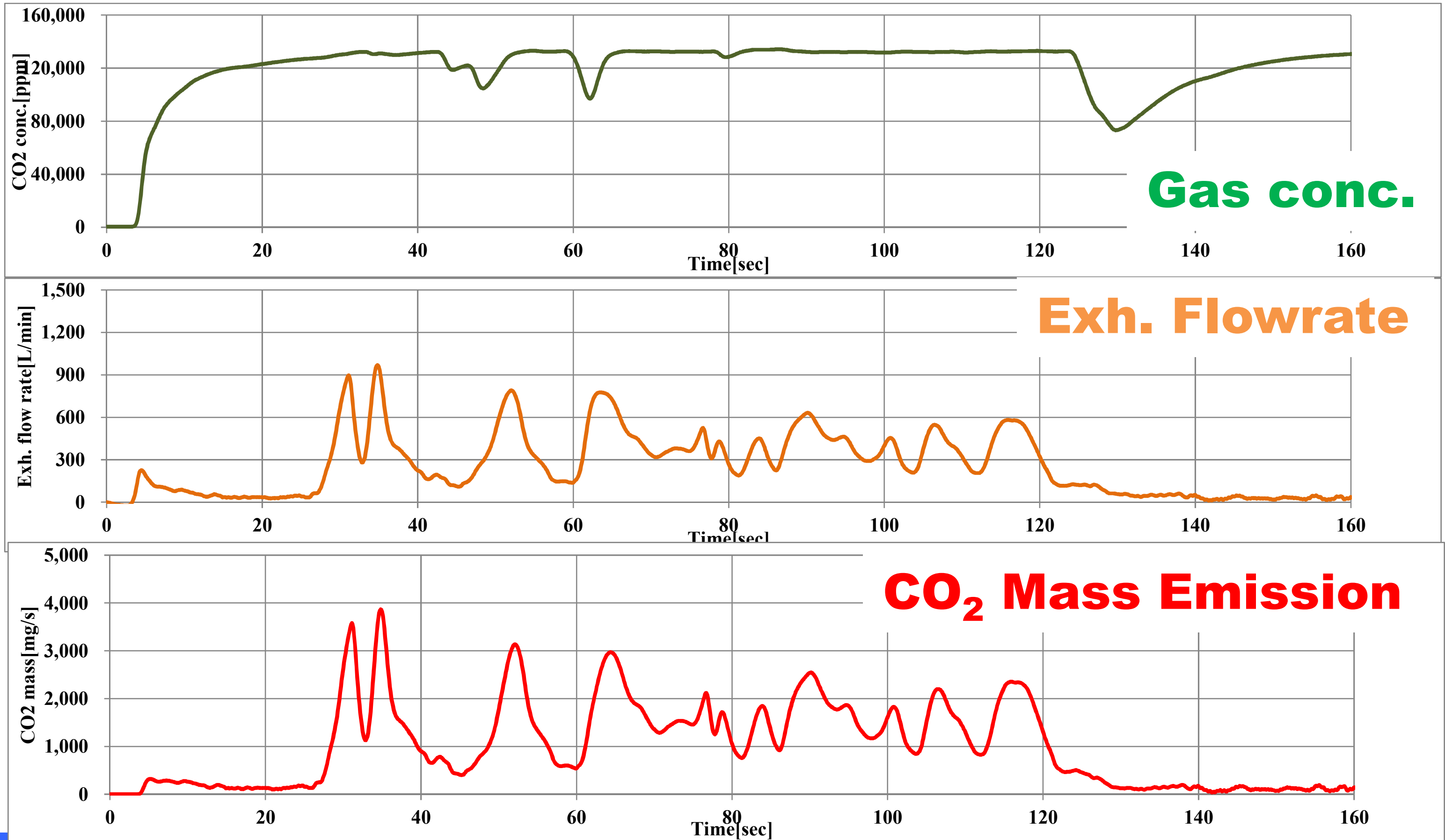
Final regulation test is executed by CVS method

Direct mass emission measurement [1/2]

Basic equation

$$m_x(t) = \rho_x \times C_x(t) \times Q_{exh}(t)$$

Mass Emission **Gas Density** **Gas Conc.** **Exhaust Flowrate**



Example of CO_2 Mass emission

Gasoline E/G
FTP75 CT
～160sec

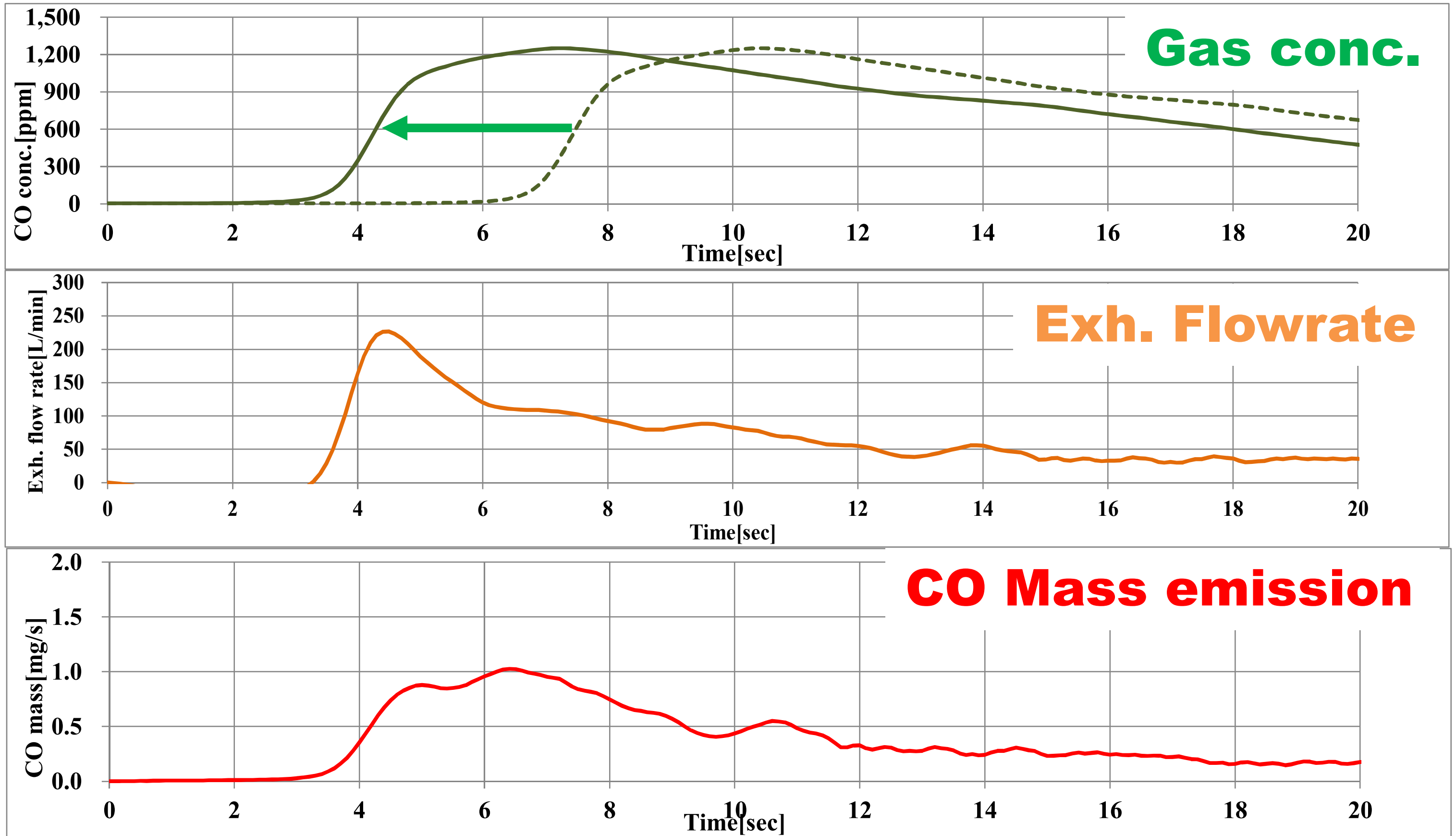
Direct mass emission measurement [2/2]

Actual equation

$$m_x(t) = M_x \times C_x(t + DT_x) \times (1 - C_{H_2O}(t)) \times Q_{exh}(t) \times \frac{1}{22.415} \times \frac{273.15}{293.15}$$

Molecular Mass **Delay Time** **Water Correction**

Response Time Correction



Example of CO Mass emission

Gasoline E/G
FTP75 CT
～20sec

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Test Equipment [1/2]
Exhaust Volume Flow Meter

➢ **Ultrasonic Raw Exhaust Gas Flow Meter**

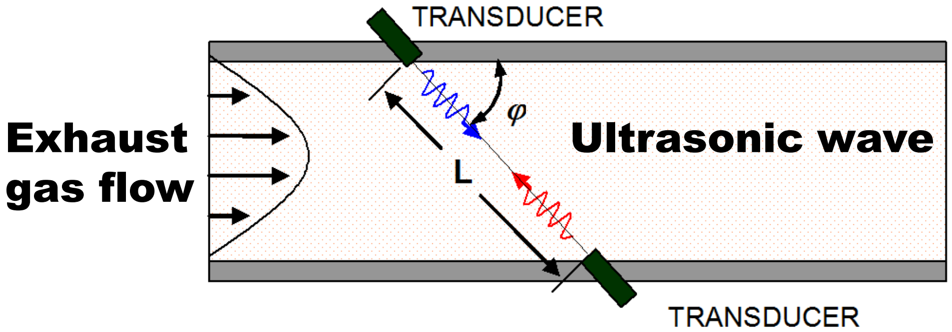
✓ **Principle**

Ultrasonic transit time method

✓ **Advantages for the method**

- No pressure loss
- No influence of compositions
- Wide measurement range
- Non Sampling

HORIBA EXFM-ONE



Measure the difference of the transit time

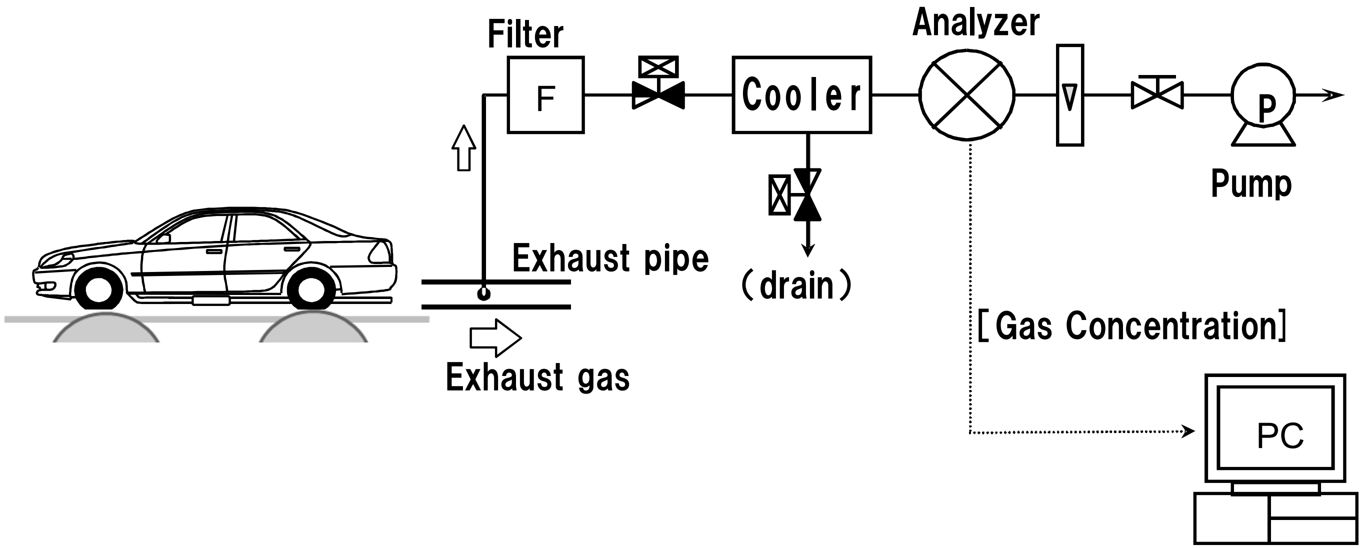
Test Equipment [2/2]
Exhaust Volume Flow Meter

✓ **Direct Exhaust Gas Analyzer**

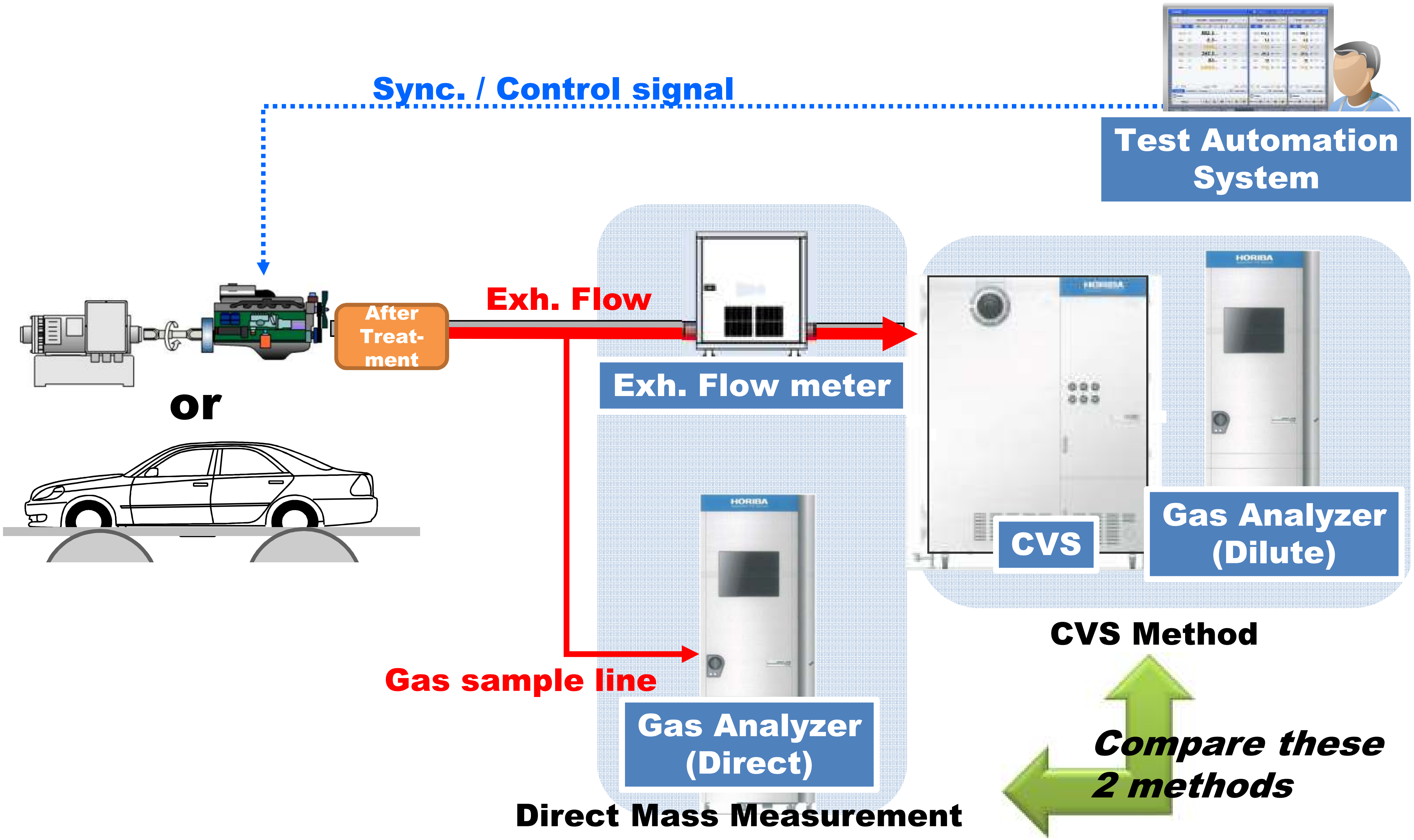
Compositions	CO_2	CO	THC	NOx	PN
Principle	Non Dispersive Infrared Detector(NDIR)		Flame Ionization Detector (FID)	Chemiluminescence Detector (CLD)	Condensation Particle Counter (CPC)

HORIBA MEXA-ONE

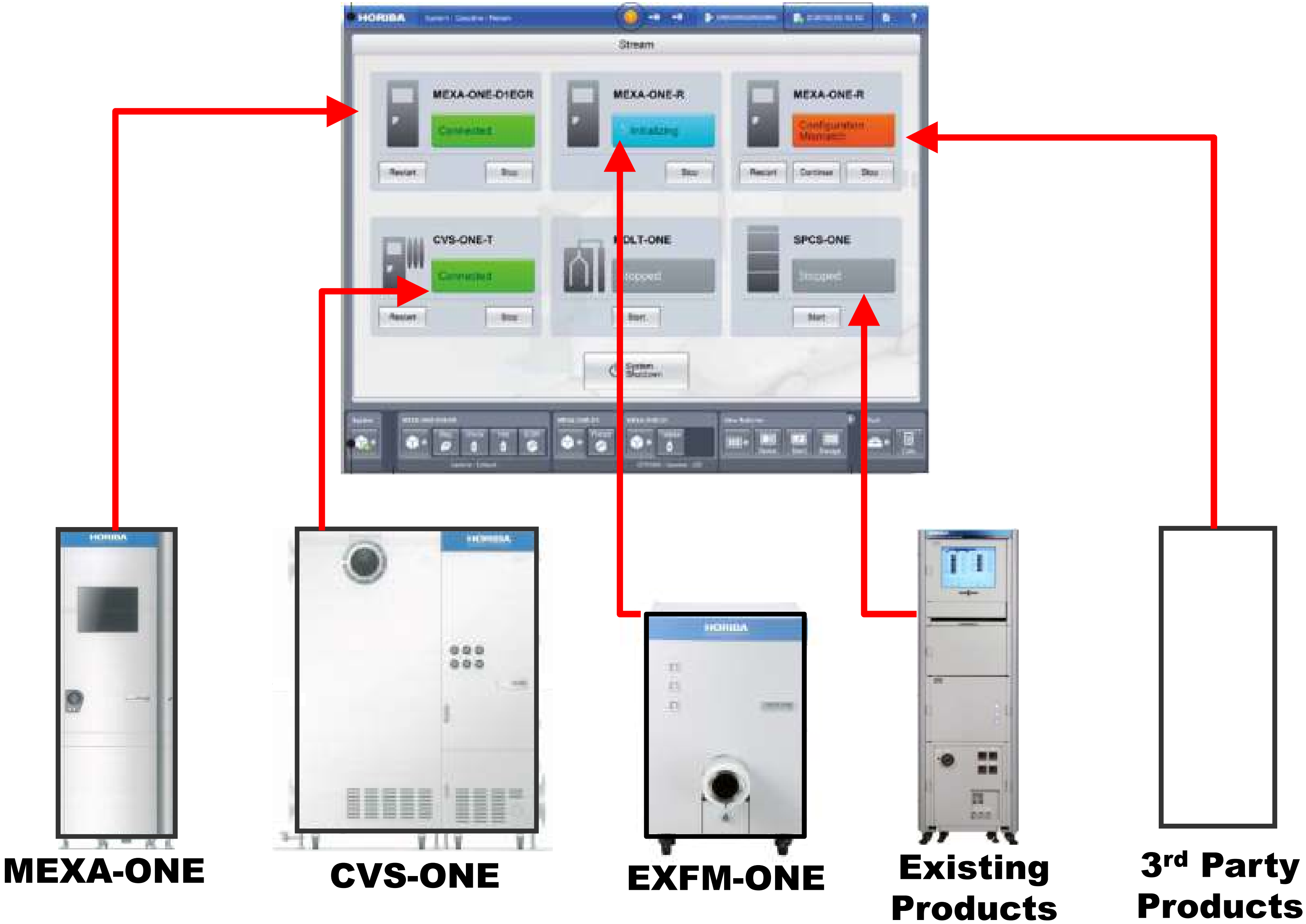
✓ **Gas Flow**



Evaluation Test System



Integrated operation system HORIBA ONE Platform[1/2]



Integrated operation system HORIBA ONE Platform[2/2]

■ Operation screen

Evaluated Engine/Vehicles (14/28)

Items	Specifications		
	Engine A	Vehicle A	Vehicle B
Engine	DI Diesel	DI Diesel	Gasoline
Engine displacement	1.6 L	1.4 L	1.5 L
Injection system	Common Rail	Common Rail	Port Injection
Intake system	TC IC	TC IC	N/A

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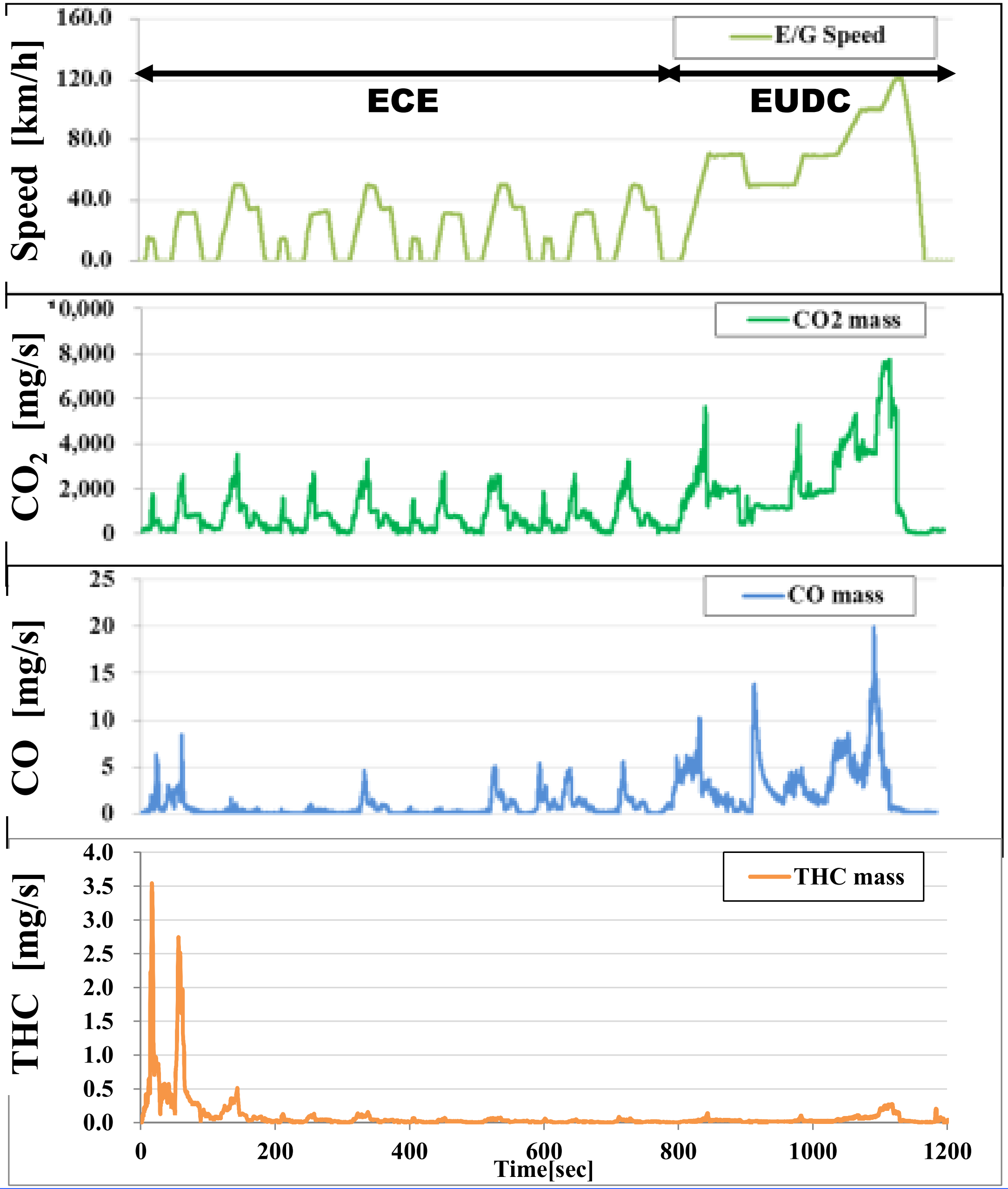
Example of Real time Mass Emission[1/2]



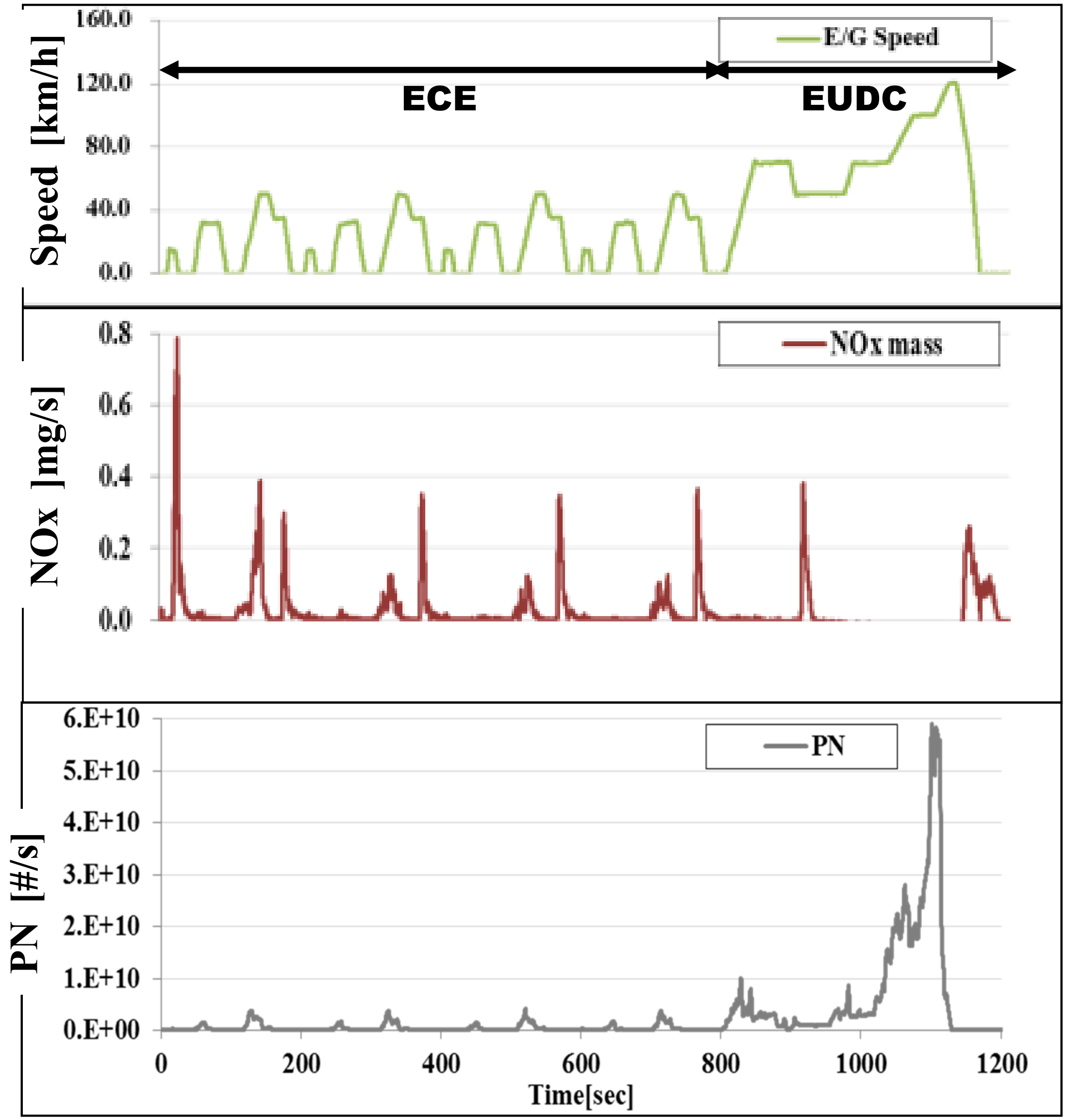
Vehicle A(DI Diesel)
[NEDC Test cycle]

CO_2
Mass emission is related with acceleration

CO
Emission is remarkable at High speed phase(EUDC)

THC
Almost all THC is emitted at the beginning of the cycle

Example of Real time Mass Emission[2/2]



Vehicle A(DI Diesel) [NEDC Test cycle]

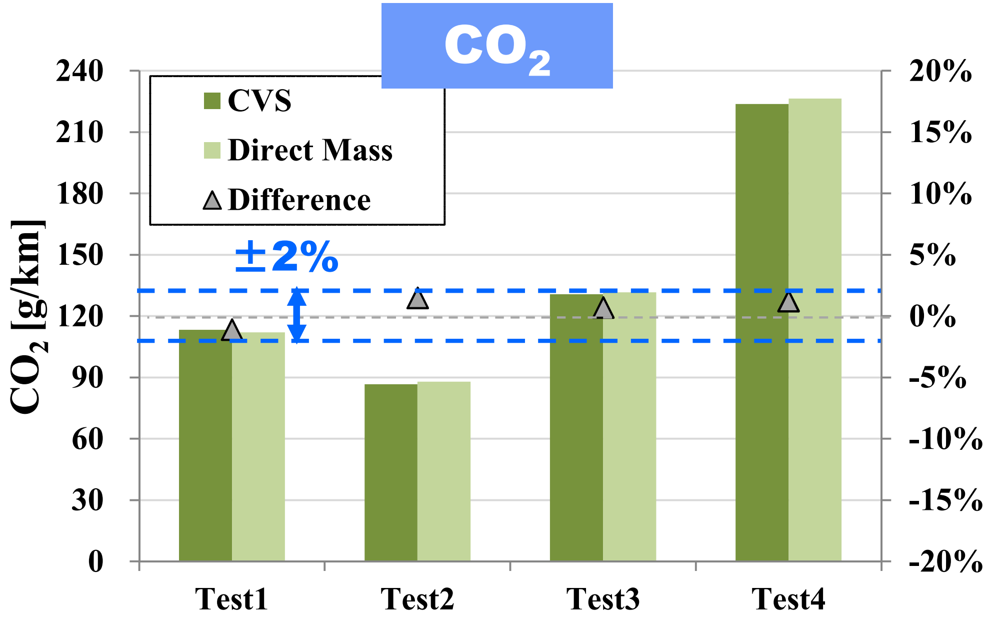
NO_x

Mass emission is increased stabilized phase after deceleration

PN

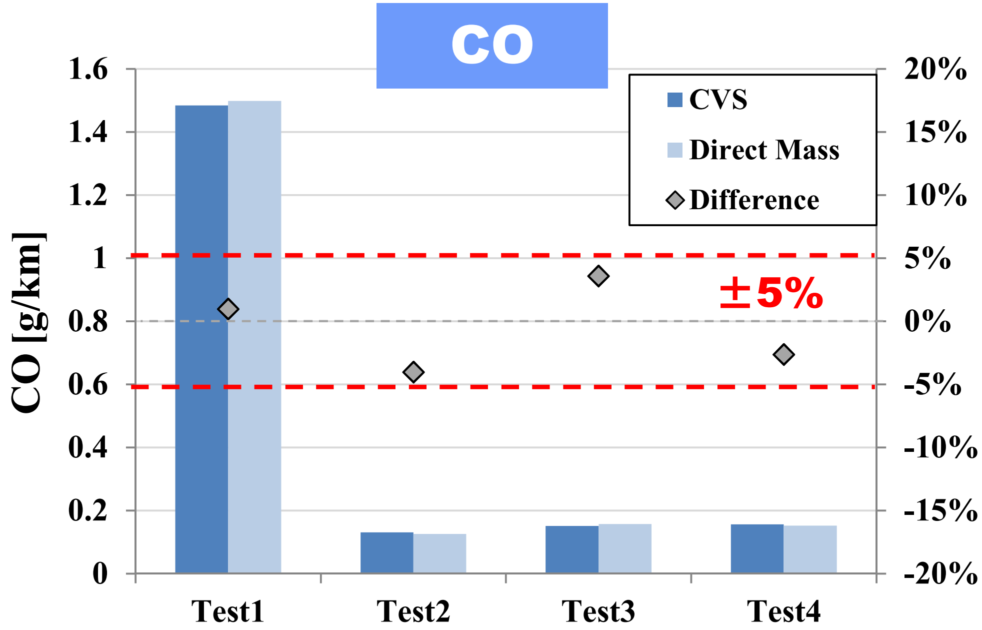
Particle Number (#/s) contrastive with NOx is observed

Difference from CVS [1/2] (Integrated mass emissions)



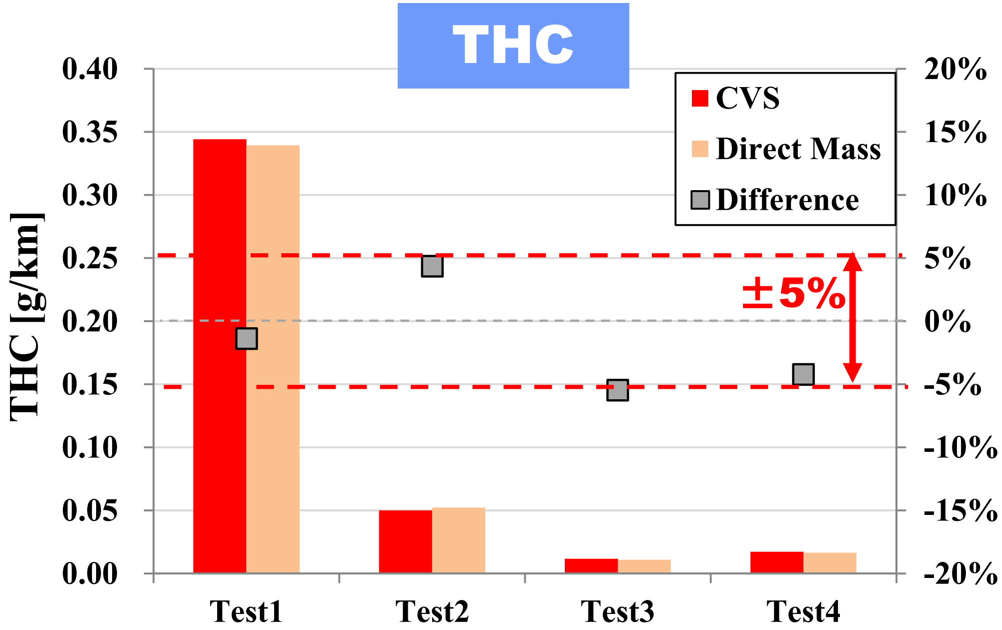
Test conditions

Test1：Engine A(CI) ECE
Test2：Engine A(CI) EUDC
Test3：Vehicle A(CI) NEDC
Test4：Vehicle B(SI) FTP75 HT



CO_2, CO
CO_2±2% difference
CO±5% difference
in this tests

Difference from CVS [2/2] (Integrated mass emissions)



Test conditions

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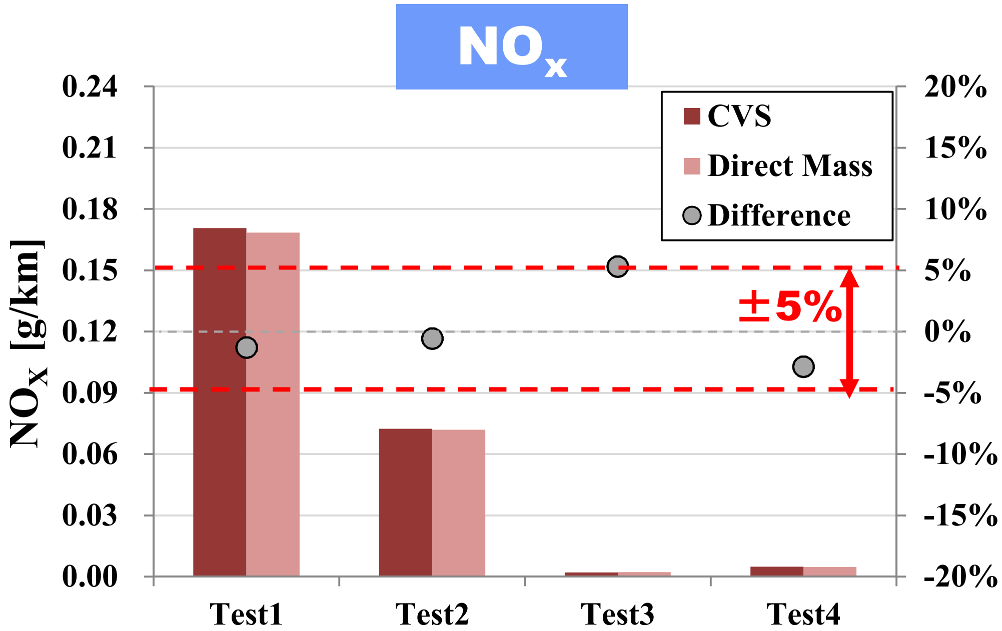
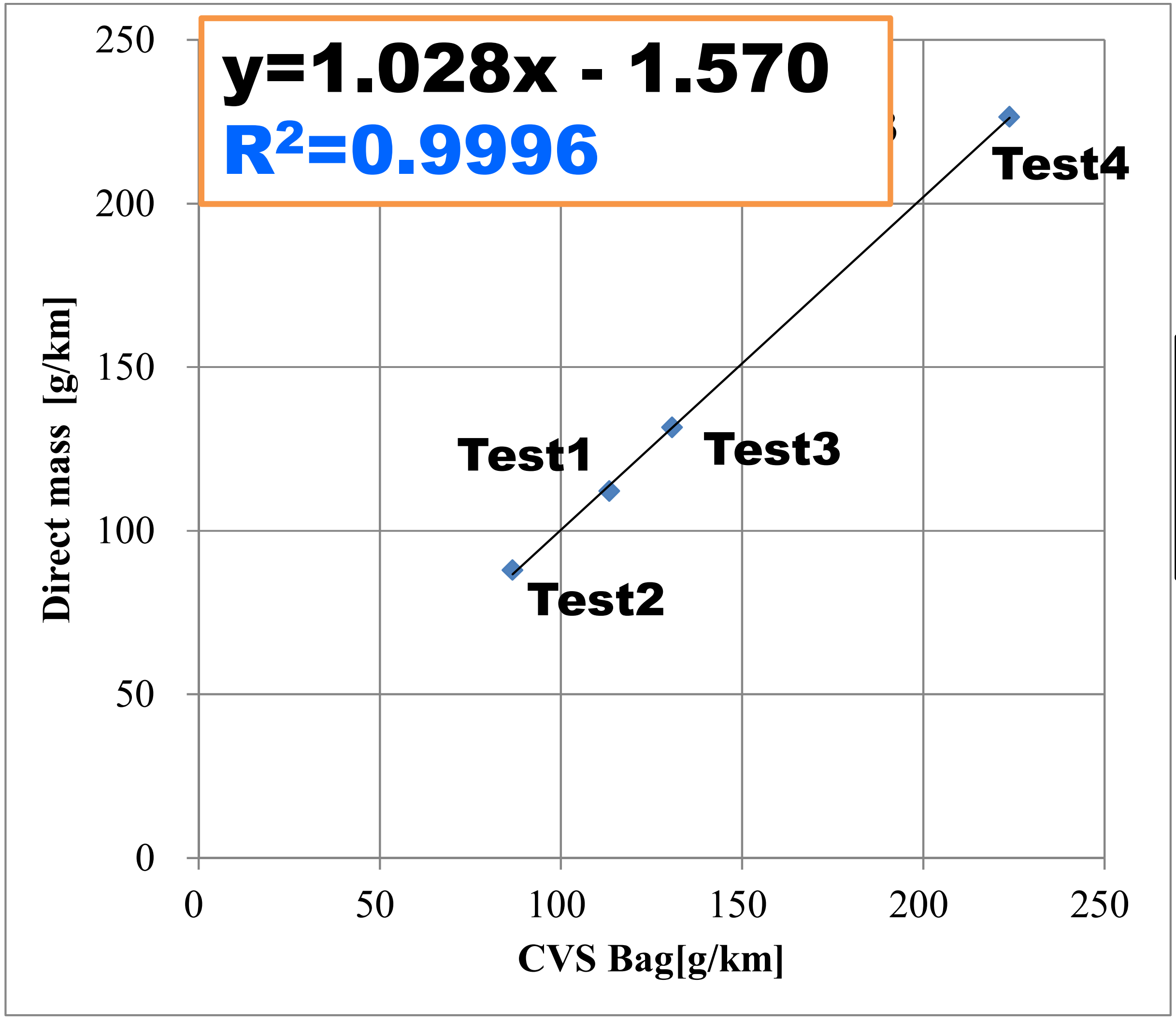


THC, NO_x
THC±5% difference
NO_x±5% difference
in this tests

Correlation with CVS[CO_2 mass]



Test conditions

Test1	Engine A(CI) ECE
Test2	Engine A(CI) EUDC
Test3	Vehicle A(CI) NEDC
Test4	Vehicle B(SI) FTP75 HT

R^2 indicates a strong correlation between direct mass and CVS

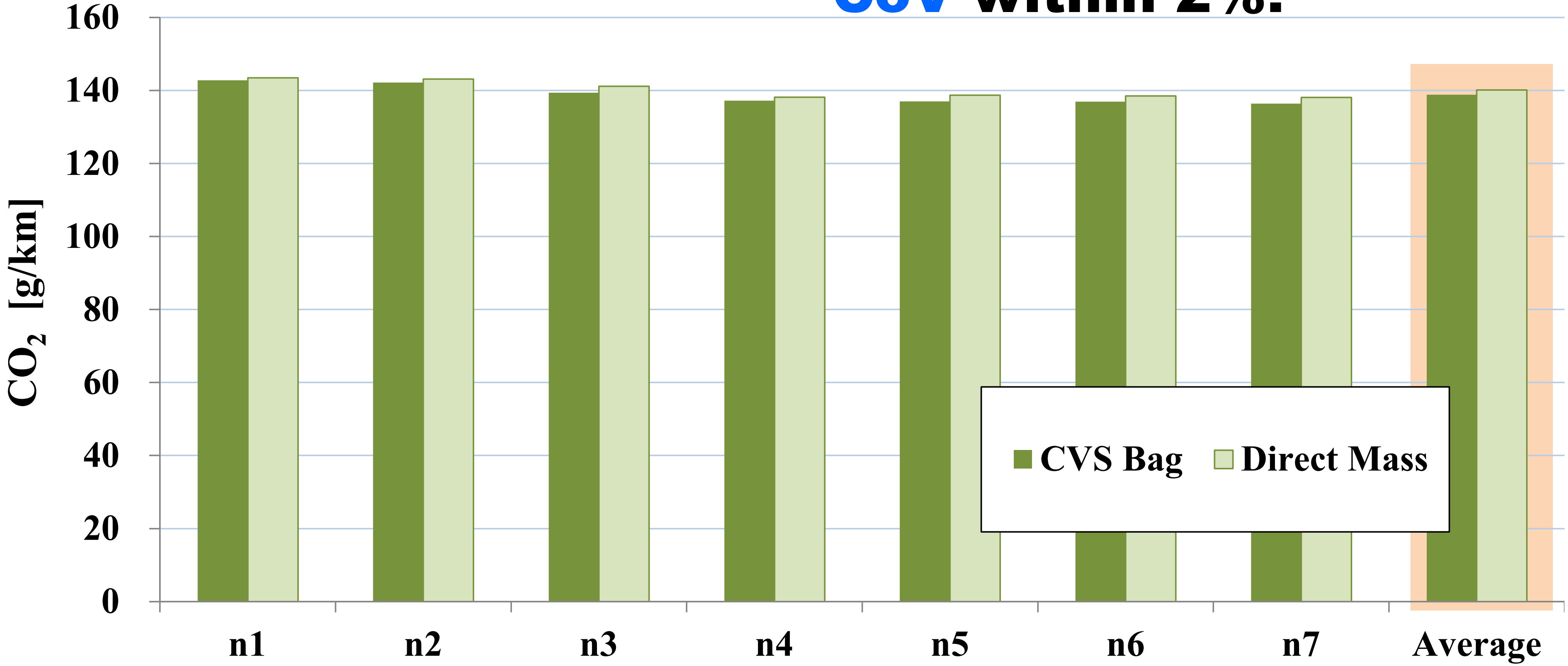
Repeatability [CO_2 mass]

Vehicle B
Repeat test
FTP-75 HT505sec

Standard deviations

CVS Bag	2.67
Direct mass	2.37

CoV within 2%!



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Other Application ～PEMS alternative in a cell～

RDE(Real Driving Emissions) regulation requires to measure emissions(NOx, PN(2017～)) using PEMS

PEMS: Portable Emission Measurement System)

HORIBA
On Board System
(PEMS)
OBS-ONE

However,,,

Vehicles under development can not be driven on a normal road!

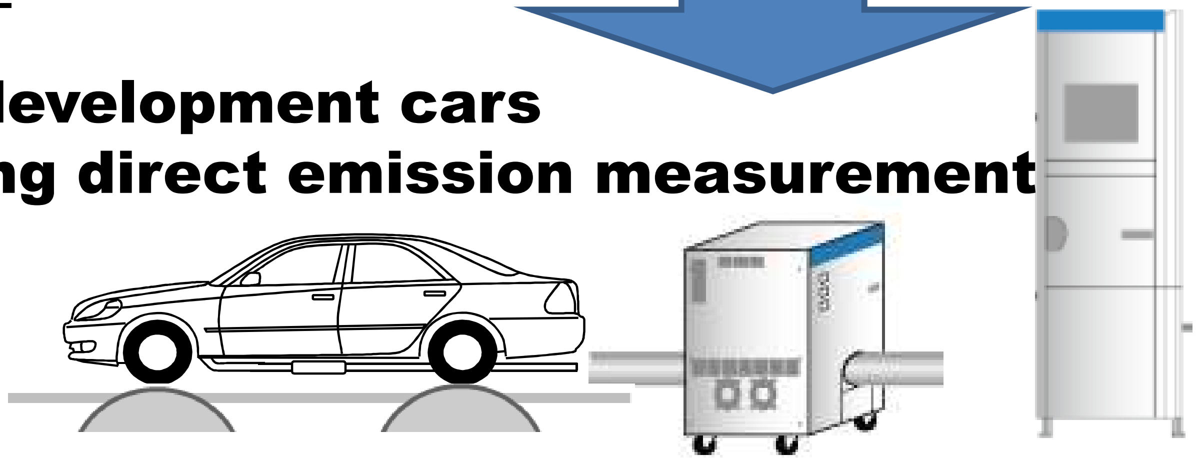
Other Application ～PEMS alternative in a cell～

Real World

Regulation test for commercial cars
Real Drive using PEMS

Chassis Cell

R&D evaluation for development cars
Simulation drive using direct emission measurement

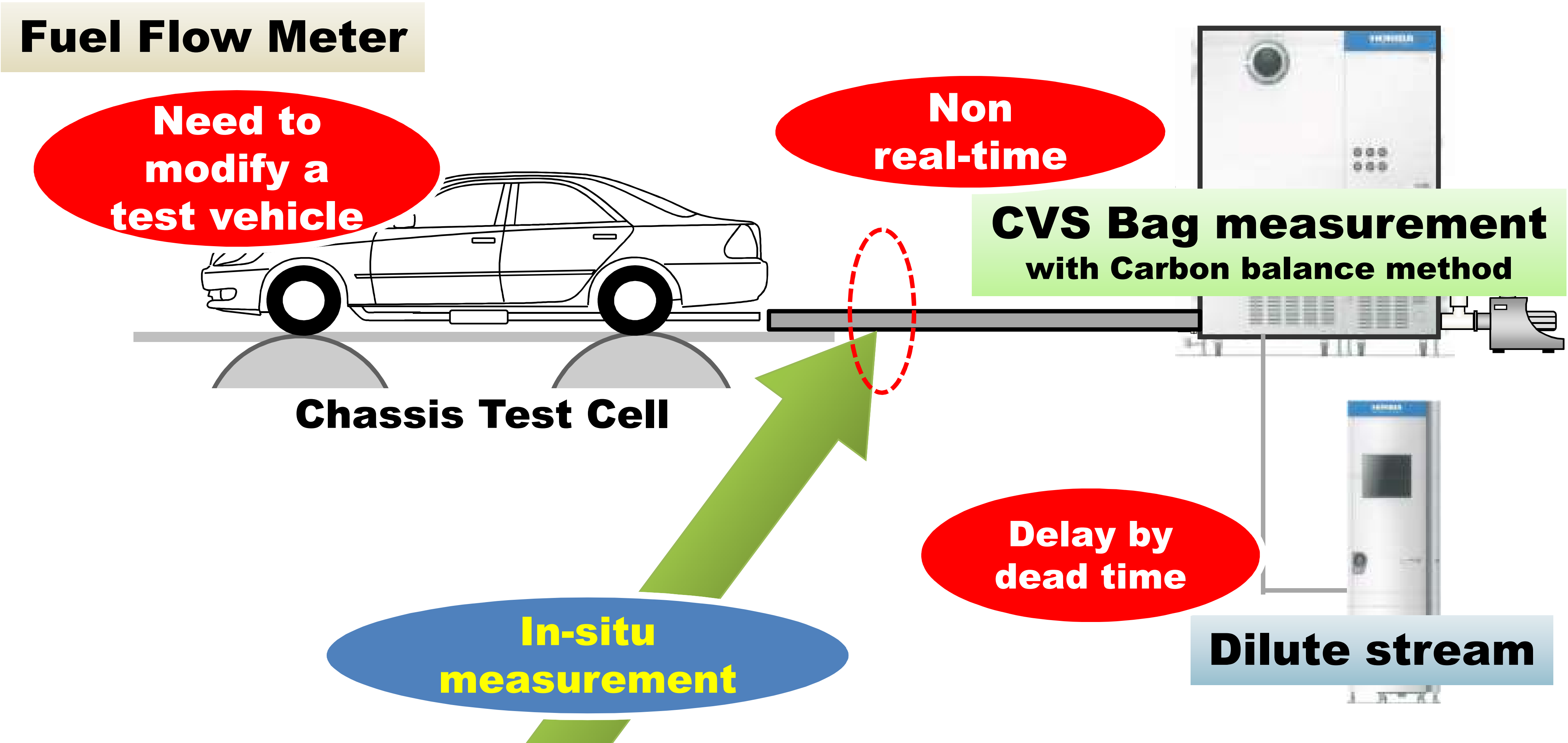


Vehicle for R&D

Direct Exhaust Gas Flow Meter

(Existing) Gas Analyzer

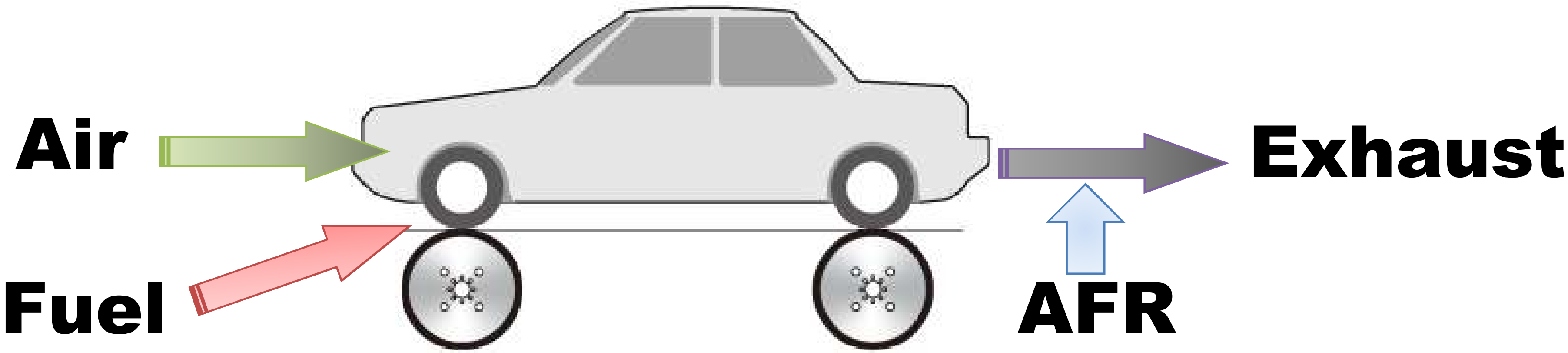
Challenge to easy measurement of fuel consumption



Challenge: Real-time, No modify, High response method

Principle of Proposed Method

Measure Real-time Fuel Consumption from Exhaust Flow rate and Air-to-Fuel Ratio(AFR)



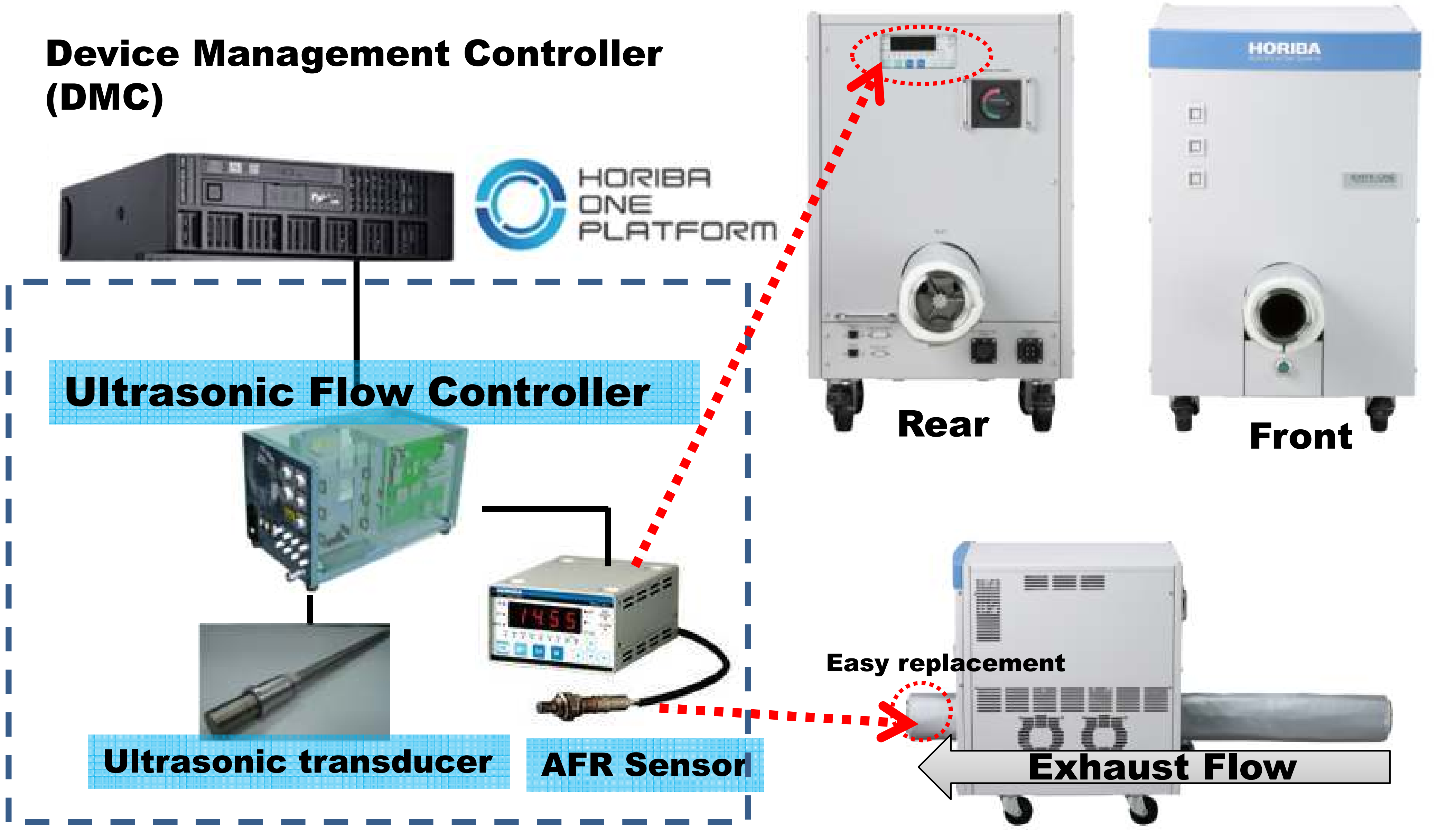
①Exhaust = Air + Fuel

②AFR = Air / Fuel

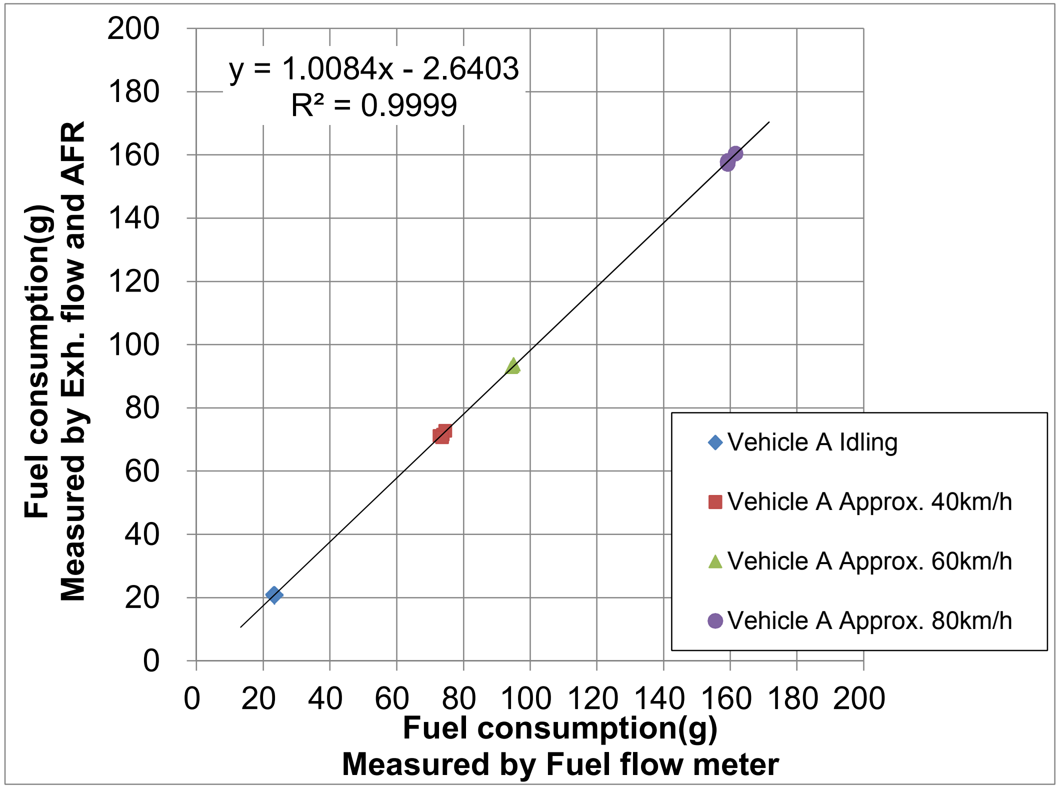
From these 2 relations,,,

$$Fuel = \frac{Exhaust}{1+AFR}$$

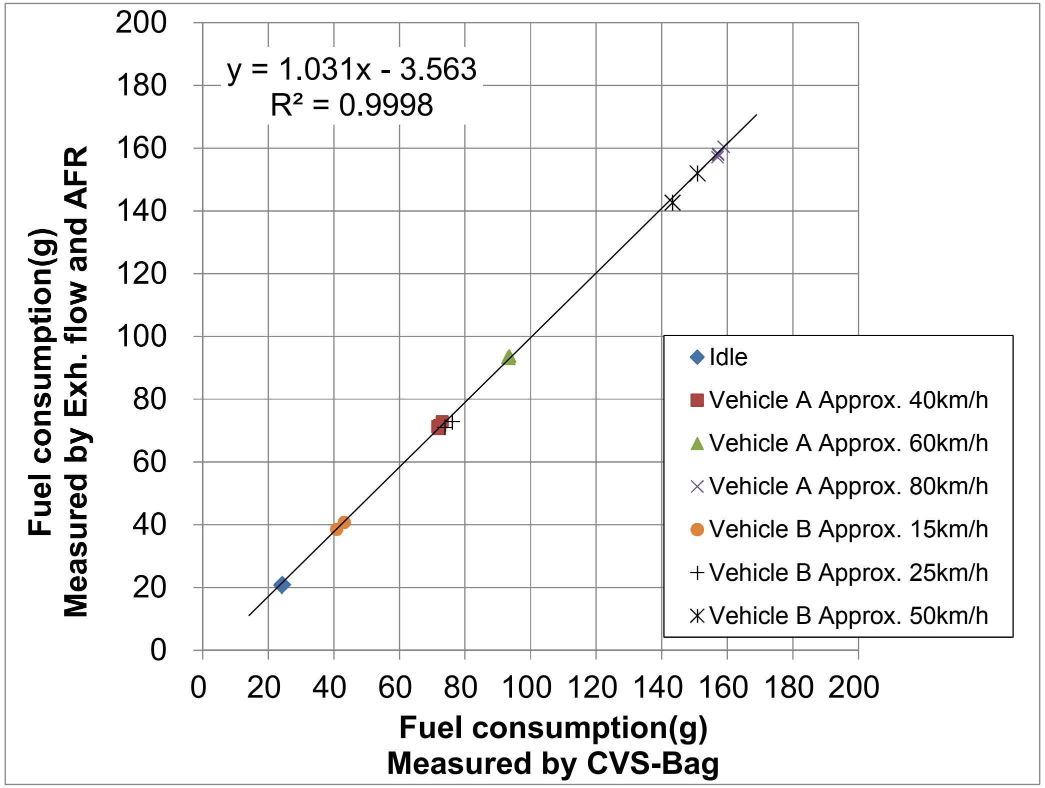
EXFM-ONE integrates AFR Sensor inside



Correlation of Integrated fuel consumption



Correlation with Fuel Flow Meter



Correlation with CVS bag method

- **Good correlation is observed for both conventional method**

Possibility to measure reliable fuel consumption

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Summary

- **Direct mass emission measurement technique is effective method for R&D of vehicles**
- **The usability of this measurement method was verified by comparing CVS method, and some good correlations and equivalencies suggested the potential of the method**
- **Direct mass emission is based on a raw exhaust gas measurement, and easy and in-situ real-time fuel consumption measurement is achieved by combination of exhaust flow meter and AFR sensor**

Thank you very much for your attention.