Japan Simulation Model Overview

Simulation methods for Fuel Consumption measurement of HD and HD hybrid vehicles

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FC test method - Simulation

Fuel consumption for HDV is calculated using Simulation method.

Assumptions for the calculation:

- **FC value is vehicle based one.**
  Not enough to improve only engine performance.
  Combination of engine and transmission is important.

- **Regulation Target is for vehicle manufactures.**
  Vehicles without loading platform; Cab and chassis

- **To calculate simply, small things are neglected.**
  e.g. Rolling resistant coefficient is set to the constant value based on the vehicle weight.

Simulation Method Overview

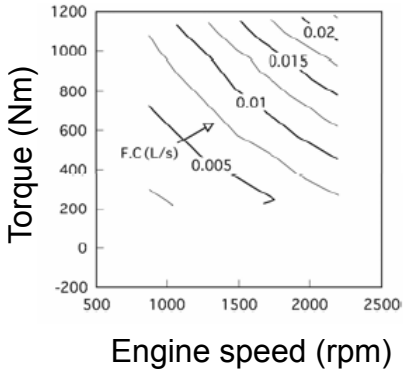
Driving cycle = Urban driving mode / Interurban driving mode

Conversion program
- **Determine gear-shift positions.**
- **Calculate engine speed and torque.**

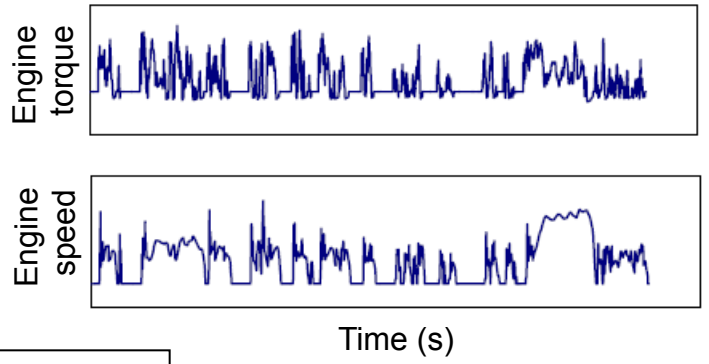
Vehicle specifications and maximum engine torque

Fuel efficiency map

Engine Operating Mode



Computing



Fuel consumption = $\sum_{i=start}^{end} F.C.(i)$

Fuel efficiency

*Before simulation, perform engine operation tests to create a fuel efficiency map

Phase of conversion

Cycle based on Vehicle speed

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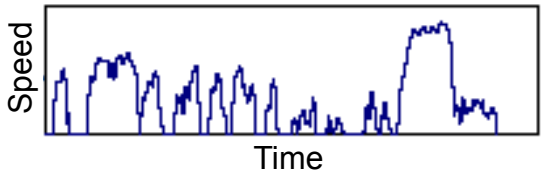
Cycle based on engine speed and engine torque

Phase of calculation of fuel efficiency

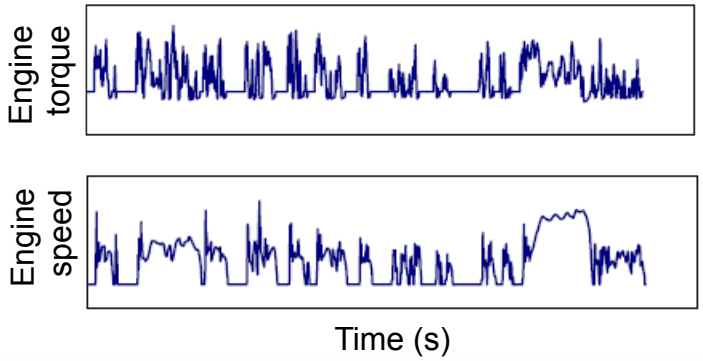
Conversion Program Overview



Driving mode

Conversion program
Determine the shift lever position

Engine operating mode
- Engine speed
- Engine torque



The vehicle specifications (technical data)

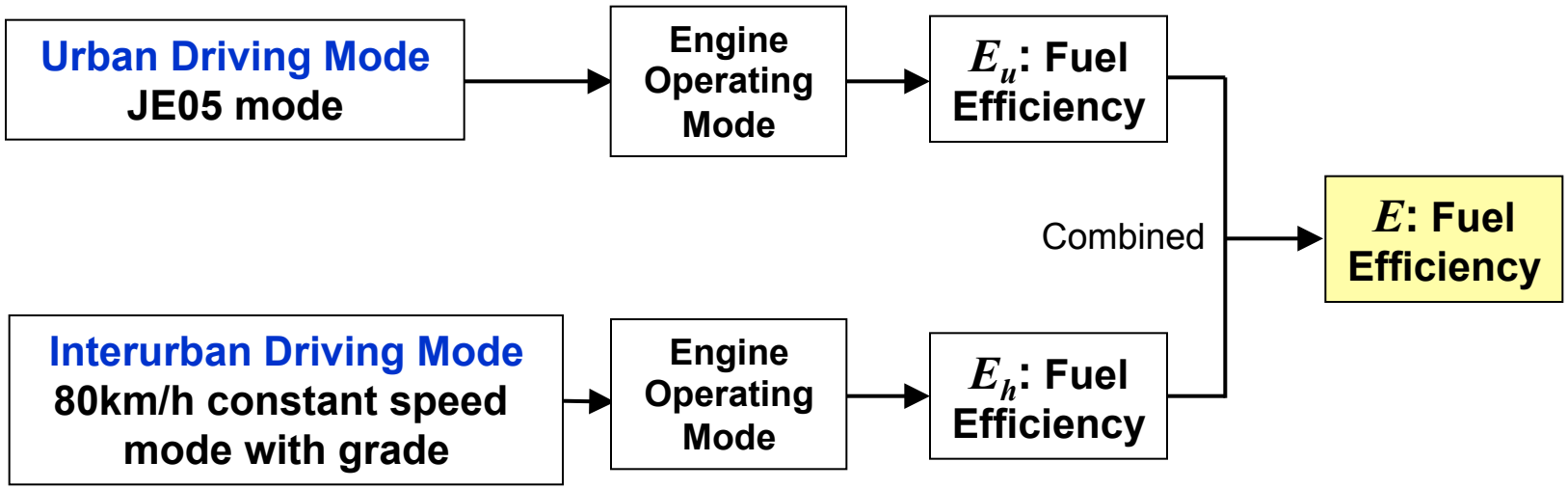
- Full load engine torque for each engine speed
- Idling engine speed
- Rated engine speed
- Maximum engine speed with load

Drivetrain related parameters
- Number of transmission gears
- Transmission gear ratios
- Final reduction gear ratio
- Tire dynamic load radius

Driving resistance parameters
- Rolling resistance coefficient
- Air resistance coefficient

Vehicle weight related parameters
- Vehicle curb weight
- Maximum load
- Riding capacity

Flow of Calculation Phase



$$E = 1 / (\alpha_u / E_u + \alpha_h / E_h)$$

E: Fuel efficiency of HD vehicle mode (km/L)
E_u: Urban driving mode fuel efficiency (km/L)
E_h: Interurban driving mode fuel efficiency (km/L)
α_u: Proportion of urban driving mode
α_h: Proportion of interurban driving mode

Correlation between Simulation and Actual Vehicle Tests

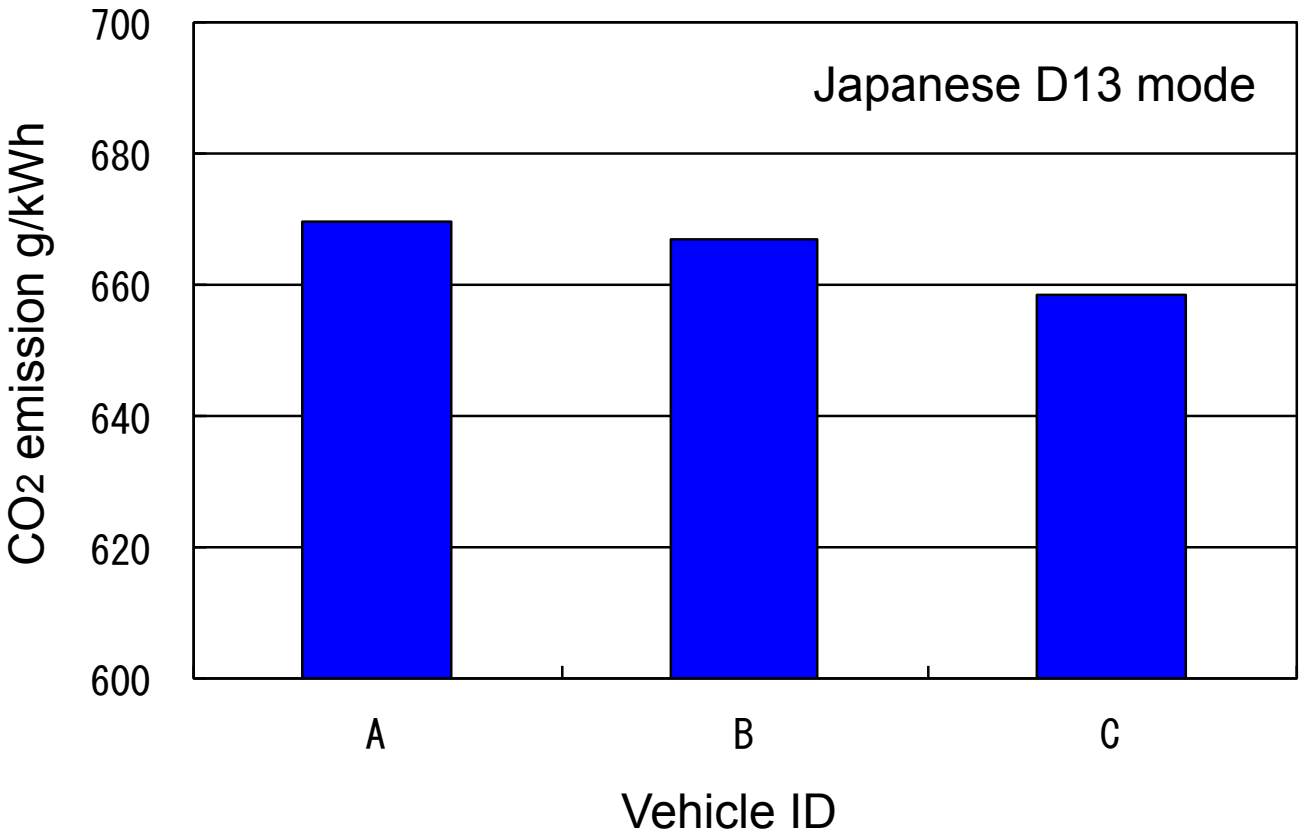
- Most important point in the simulation is whether the results correspond to the real world or not.
- When fuel efficiency standard was set up, validations for simulation and actual engine were conducted. But, more than half of engines used for validation were Natural Aspiration engines. (NA engine is not in existent today.)
- Comparison tests were conducted with actual vehicles on chassis dynamometer, driving of JE05 and inter-city mode.
- Matching assessment of engine with vehicle was also conducted.

Test Vehicle Specification

Vehicle ID	A	B	C
Displacement L	9.84	12.88	13.07
Max.power kW/rpm	279/2000	257/2000	279/1800
Max.torque Nm/rpm	1800/1400	1810/1100	1648/1400
Injection system	Common rail	Common rail	Unit injector
Aftertreatment device	DPF	Urea SCR	Urea SCR
Curb mass kg	11330	9630	10270
GVW kg	24940	23300	24980
Vehicle weight at test	18135	17625	16465
Transmission	7MT	7MT	7MT
Driving distance km	221000	25650	68290
Emission regulation	'05	'05	'05

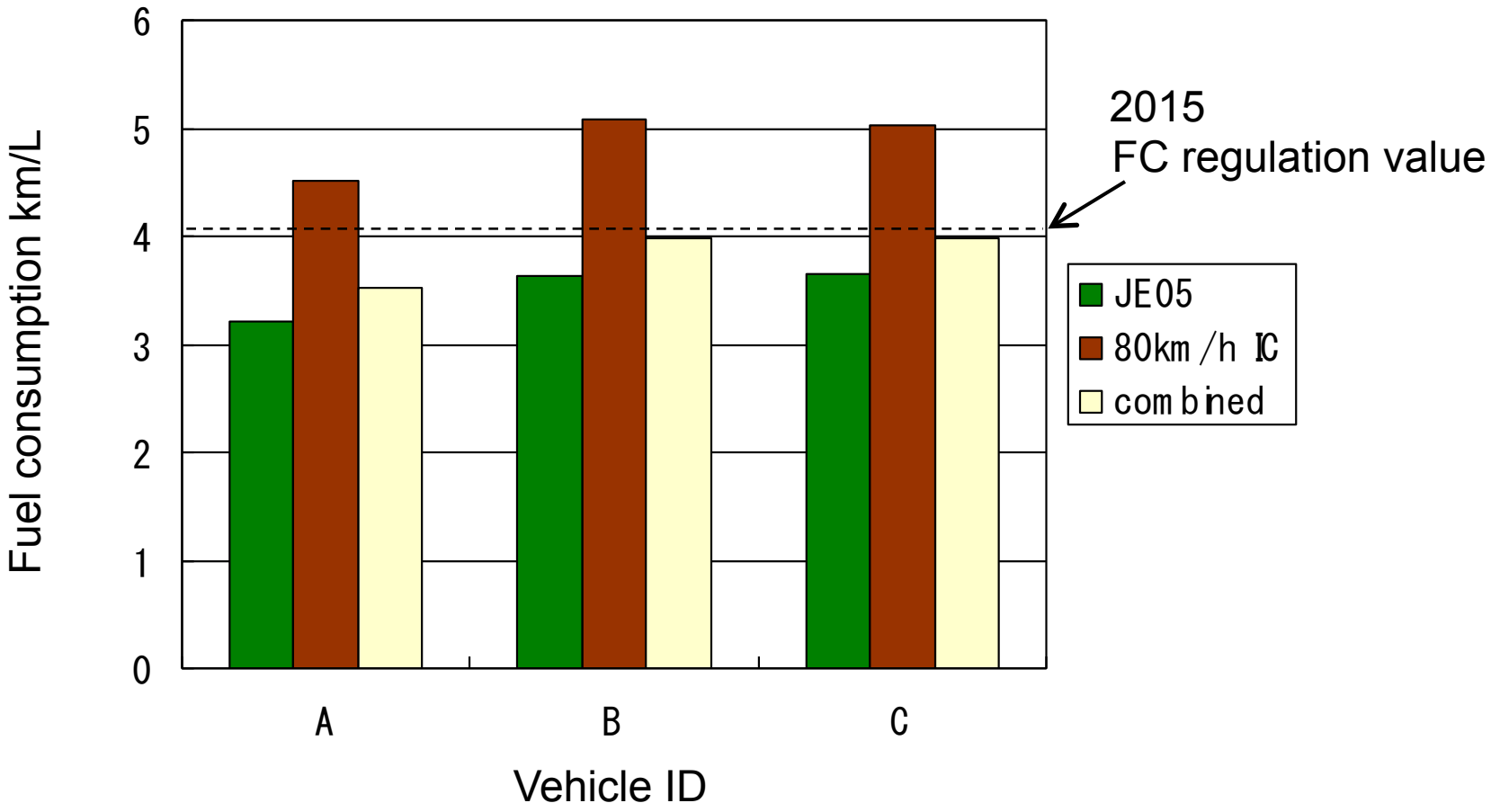
3 test vehicles are in the same weight category but different manufactures.
All of tests were conducted on chassis dynamometer.

CO_2 Emissions in Steady State Cycle



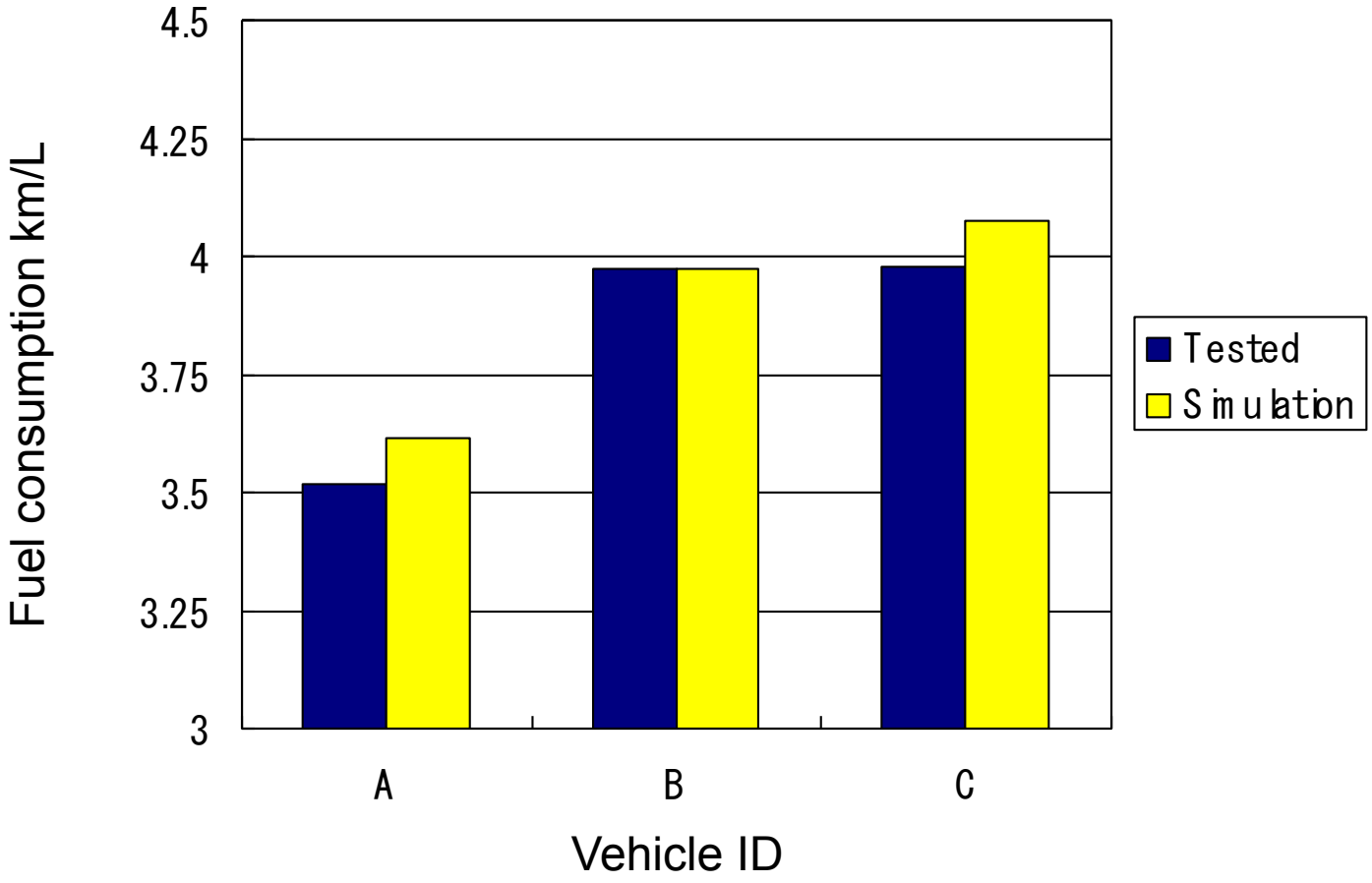
Engine operating of D13 mode is determined by engine speed and torque. CO2 emissions in steady state cycle from 3 vehicles are almost same level ・・・ equivalent engine thermal efficiency.

FC Measurement Test Results



Equivalent engine thermal efficiency, but Vehicle A is inferior in fuel consumption. Engine reduces NOx only with EGR, but due to small displacement Vehicle A had to often use high loaded area, where the fuel consumption in EGR get worse.

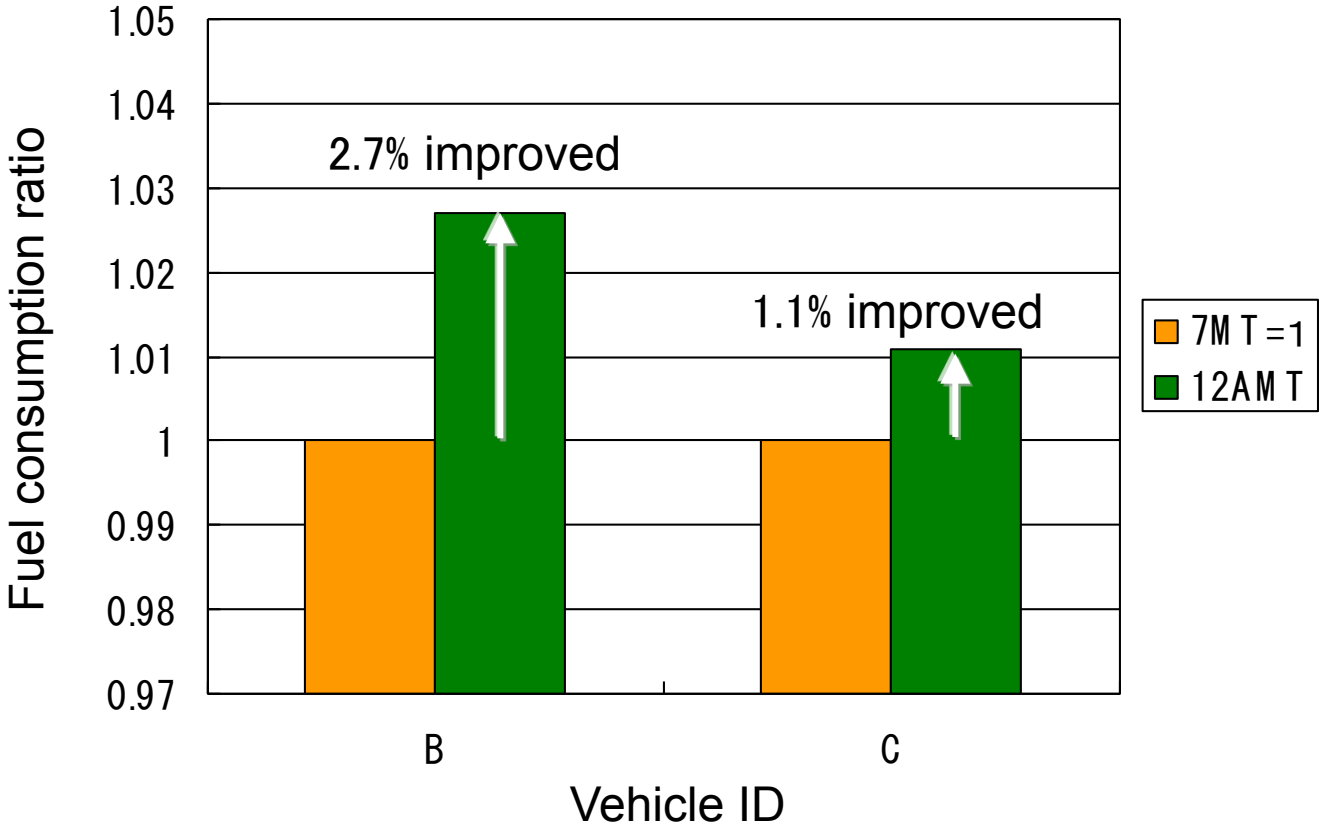
Relationship between Vehicle Tests and Simulation



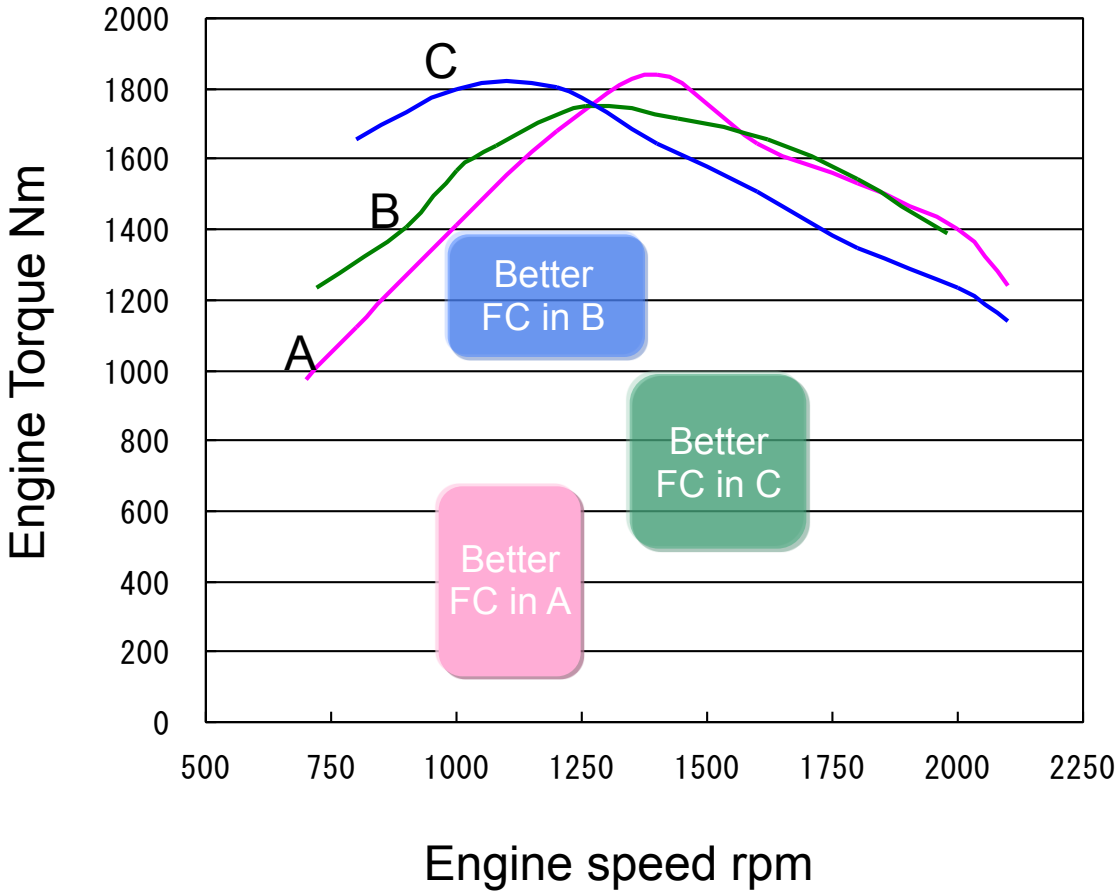
The difference is within 0.1km/L.
Good correlation between actual vehicle test and simulation.
Fuel consumption inferior in Vehicle A was also observed.

Assumption in Using 12-speed AMT

Many vehicles meeting fuel efficiency standard have 12-speed AMT.
With Vehicle B and Vehicle C, the effect of 12-speed AMT on FC was estimated by the simulation.



Maximum Torque Curve in Each Engine



The effect of FC improvement devices vary with engine or vehicle characteristics

FC or emission test method for HD HEV

In vehicles of conventional engine, the engine speed or torque condition can be calculated by the vehicle specification and vehicle speed pattern.

But in hybrid vehicles, engines are sometimes assisted by electric motor(s), power demand for the vehicle is not always corresponded to the actual engine output.

In order to resolve this issue, HILS (Hardware in the Loop Simulator) method was adopted to emission and FC measurement for HD HEV.

Other than HILS method, system bench (power pack) method is also certificated.

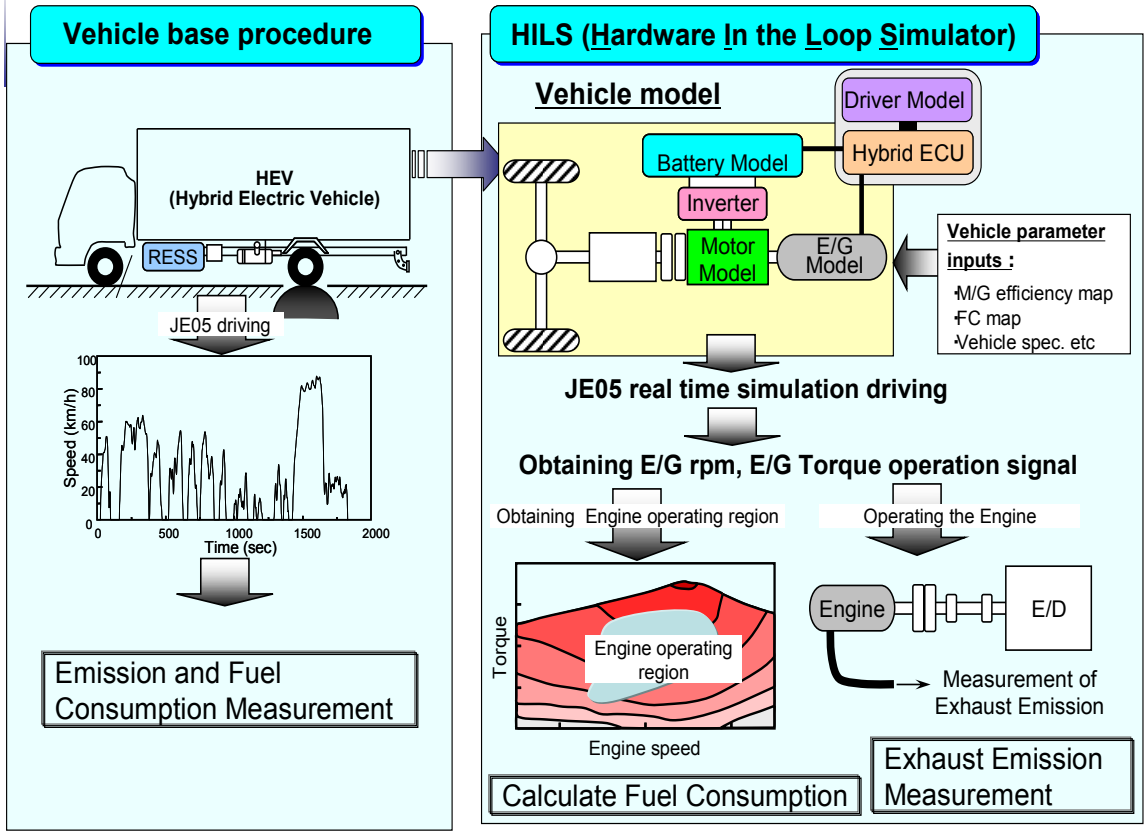
Hardware in the Loop Simulator (HILS) for HEV

＊ Exhaust emission and fuel consumption measurement procedure for Heavy Duty Hybrid Vehicle

Establish the measurement procedure for Heavy Duty Hybrid Vehicle using HILS method for the first time in the world in Japan

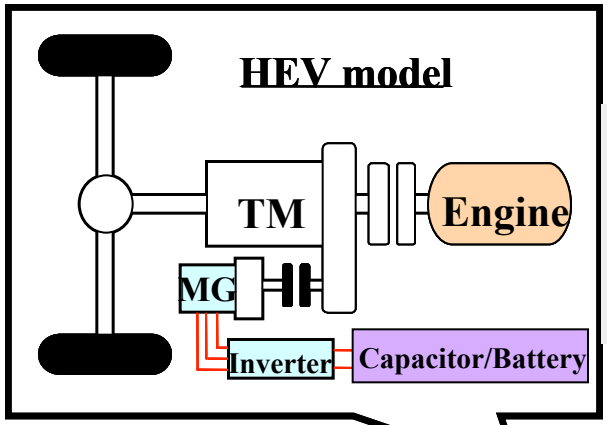
Start discussion of international regulation based on Japanese regulation

＊Real time simulation using on-board hybrid ECU detached from heavy duty HEV



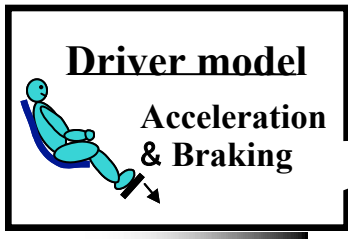
Execute emission test using engine speed and torque signal with the engine dismantled from vehicle only

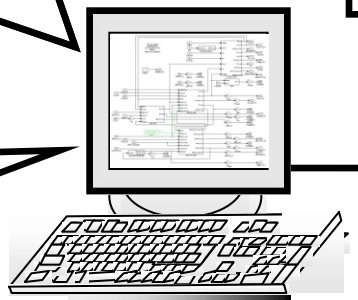
HILS System for FC Simulation



Main parameters

- Engine (Torque map)
- MG (Torque map, Electric power consumption map)
- RESS (Internal resistance, Open circuit voltage)
- Vehicle mass
- Inertia
- Transmission efficiency
- Gear ratio



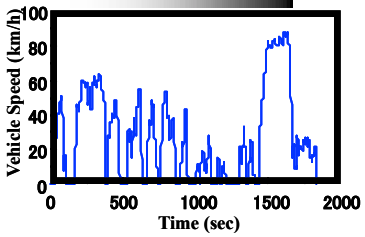


Digital signal processor

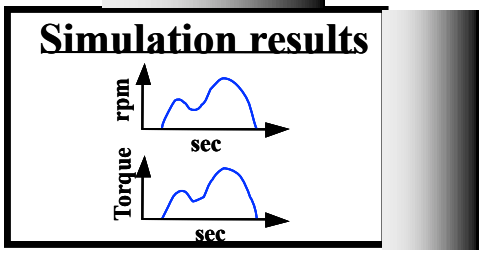
Interface

Actual ECUs

24V Power Supply

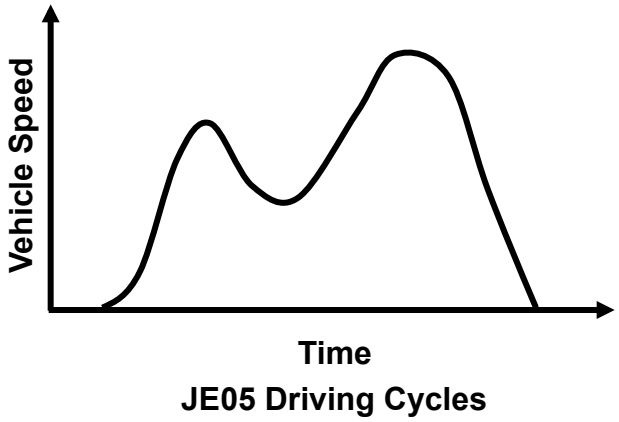


Reference vehicle speed (JE05 driving cycle)

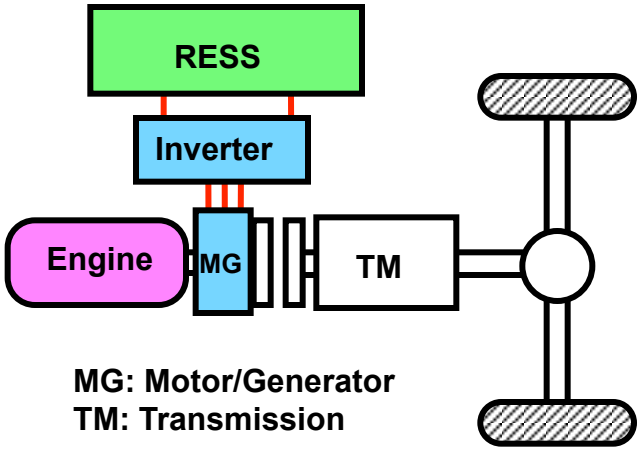


Calculated fuel economy with F.C. map or Measure exhaust emissions with an engine unit

System Bench Method for Heavy-Duty HEVs



JE05 Driving Cycles



MG: Motor/Generator
TM: Transmission

<Vehicle Basis>

HEV Conversion Algorithm

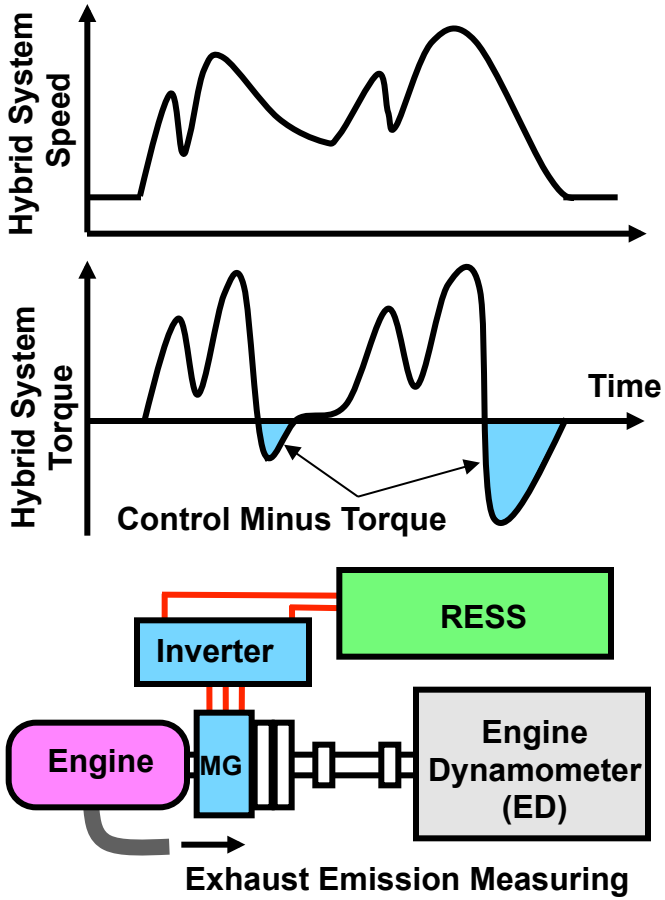
Input Items

(1) Same Items with Conventional Vehicles

- Vehicle Mass
- Road Load
- Engine Speed
- Engine Torque
- Gear Ratio
- Gear Efficiency

(2) Special Items

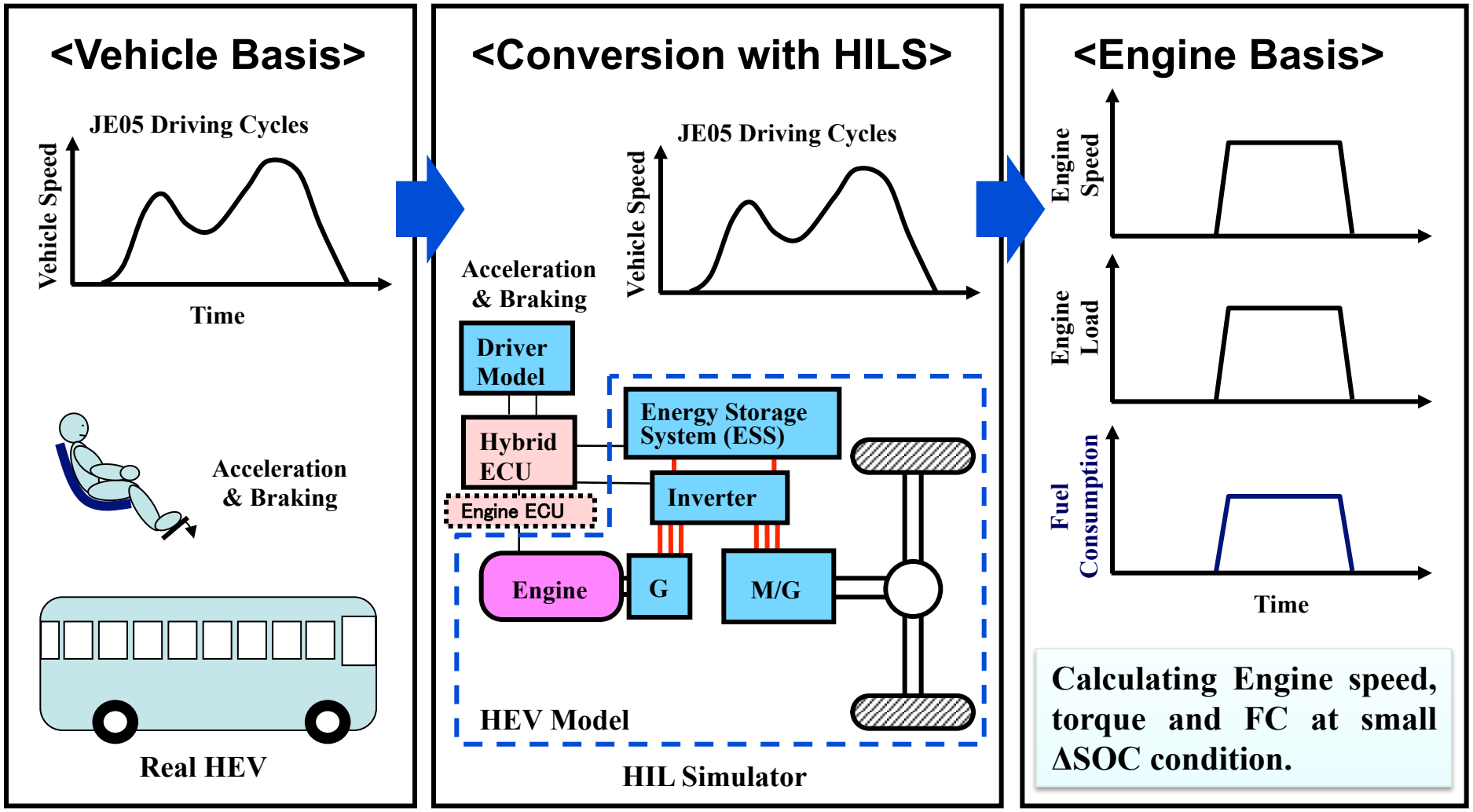
Max. Regeneration Torque or Ratio of Regenerative Brake/ Mechanical Brake



<Hybrid System Basis>

Adding regen. brake calculation for conversion program for conv. HD vehicle.

HILS Method for Fuel Consumption



Fuel Consumption of Commercial HD HEV

HEV is not suitable for a long haul trucks,
but for small sized trucks or route buses.

Example of route bus:

Bus with conventional diesel engine

Approved FC value

4.25km/L

1st generation HEV had low regeneration efficiency and same FC level as existing vehicles. The latest HEV was improved.

HEV bus

1st generation in '06

4.25km/L

2nd generation in '11

4.60km/L

FC of HD HEV in Real World

FC comparison between diesel bus and hybrid bus by a route bus company in Tokyo (yearly average)

Type	Fuel consumption km/L		# of the vehicles
	Certification value	Real world	
Conventional	4.25	2.18	102
HEV 1st gen.	4.25	2.25	100
HEV 2nd gen.	4.60	2.55	20

FC in real world is significantly worse than approved value.
2 reasons: Average vehicle speed is lower than JE05, and air conditioner is used in summer.
In real world, 1st generation HEV had the same level of FC as existing vehicles, but in 2nd generation FC was improved up to near approved value's difference.

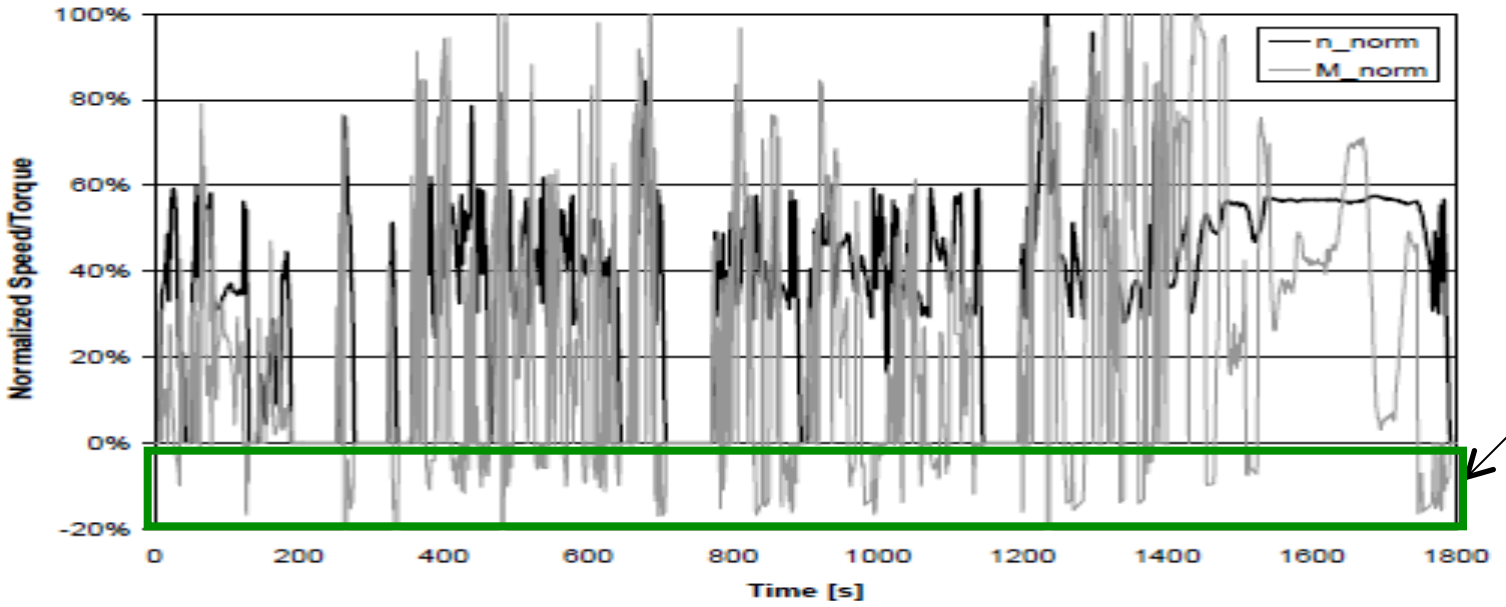
FC measurement with HILS method has good correlation with FC in real world. HILS is appropriate for FC evaluation.

Issue of HILS for WHTC #1

WHTC defines motoring torque of ICE as braking side.

=> Motoring torque shall be replaced by appropriate recuperating power calculated on WHVC on flat condition with some vehicle data, i.e. tire, diff, TM and air/rolling resistance, etc.

Detailed replacing method is now under discussing.



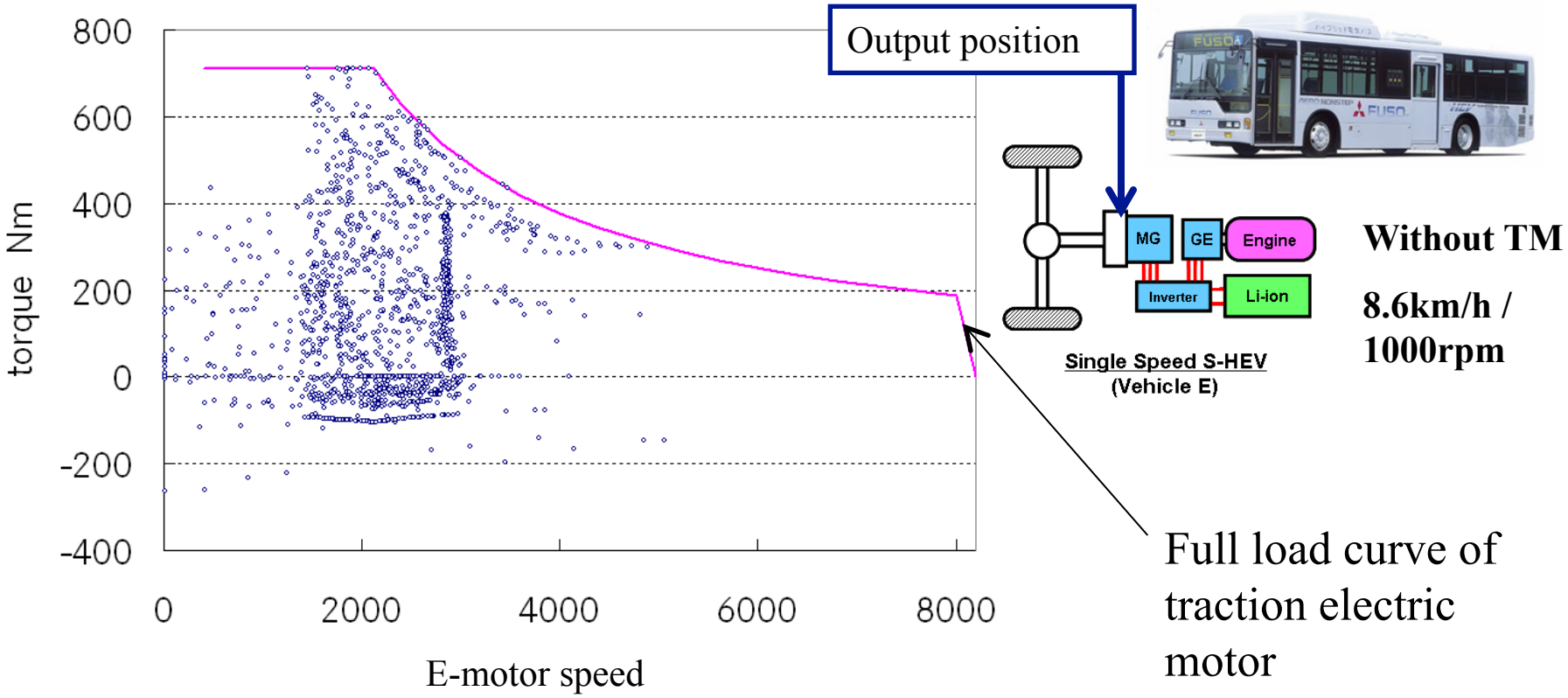
Motoring torque of ICE

WHTC normalized speed / torque source: GRPE/WHDC/FE31('09.6)

Issue of HILS for WHTC #2

Series hybrid shall be applied with WHTC normalized "motor" speed/torque method as well.

=> Japan is afraid of the deviation from the actual vehicle behavior



The last message

Thank you for your kind attention

Contact to :

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