Both the gasoline and diesel engines will be winners

26th International AVL Conference
« Engine & Environment »

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mazda

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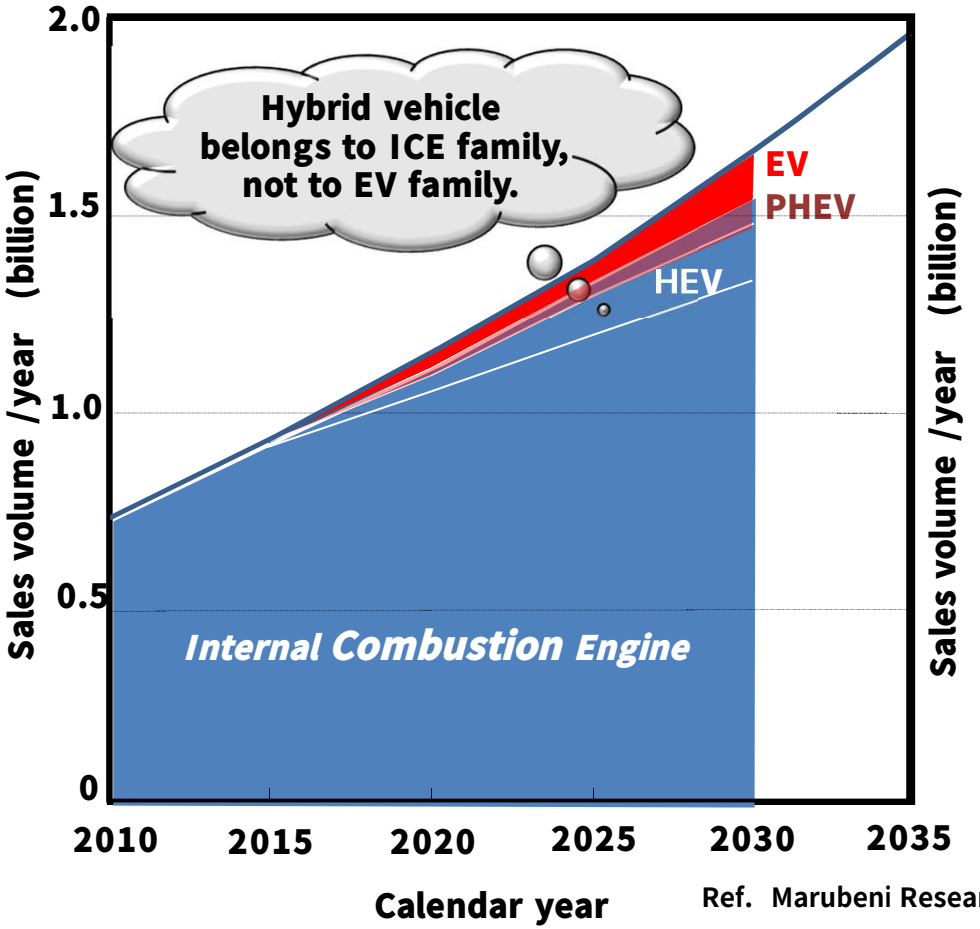
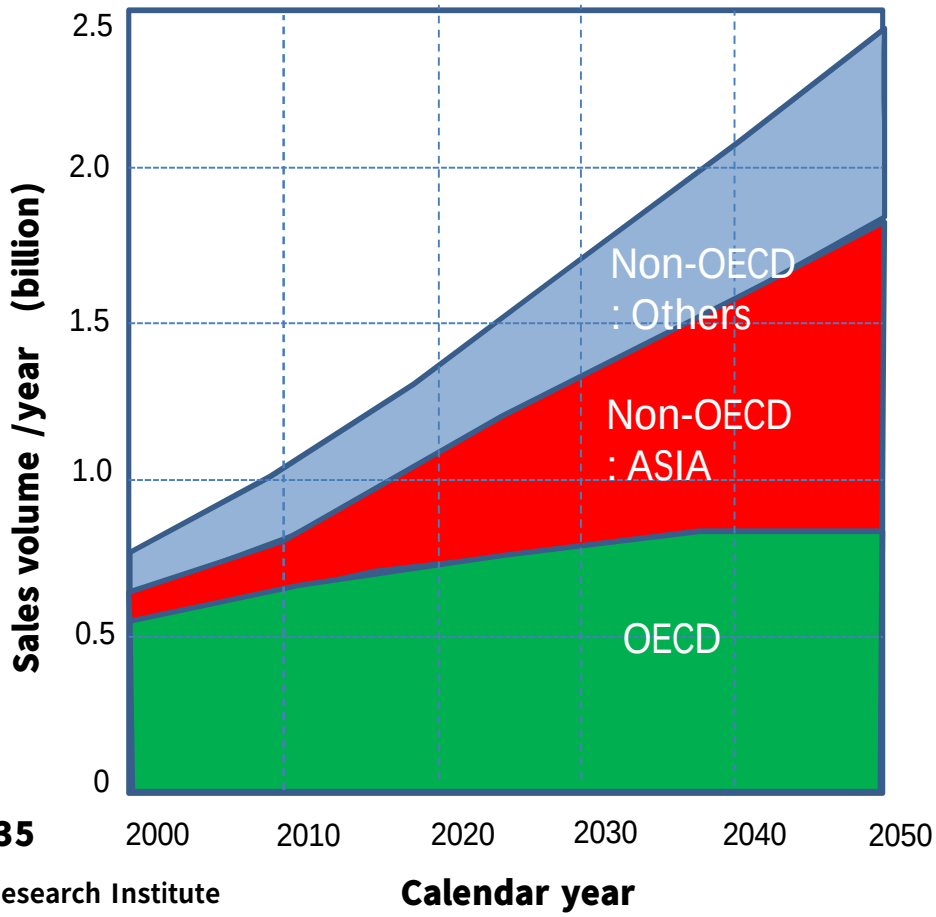
Target for ICE powered vehicles

Forecast of world annual vehicle sales volume



Automobile stocks by region

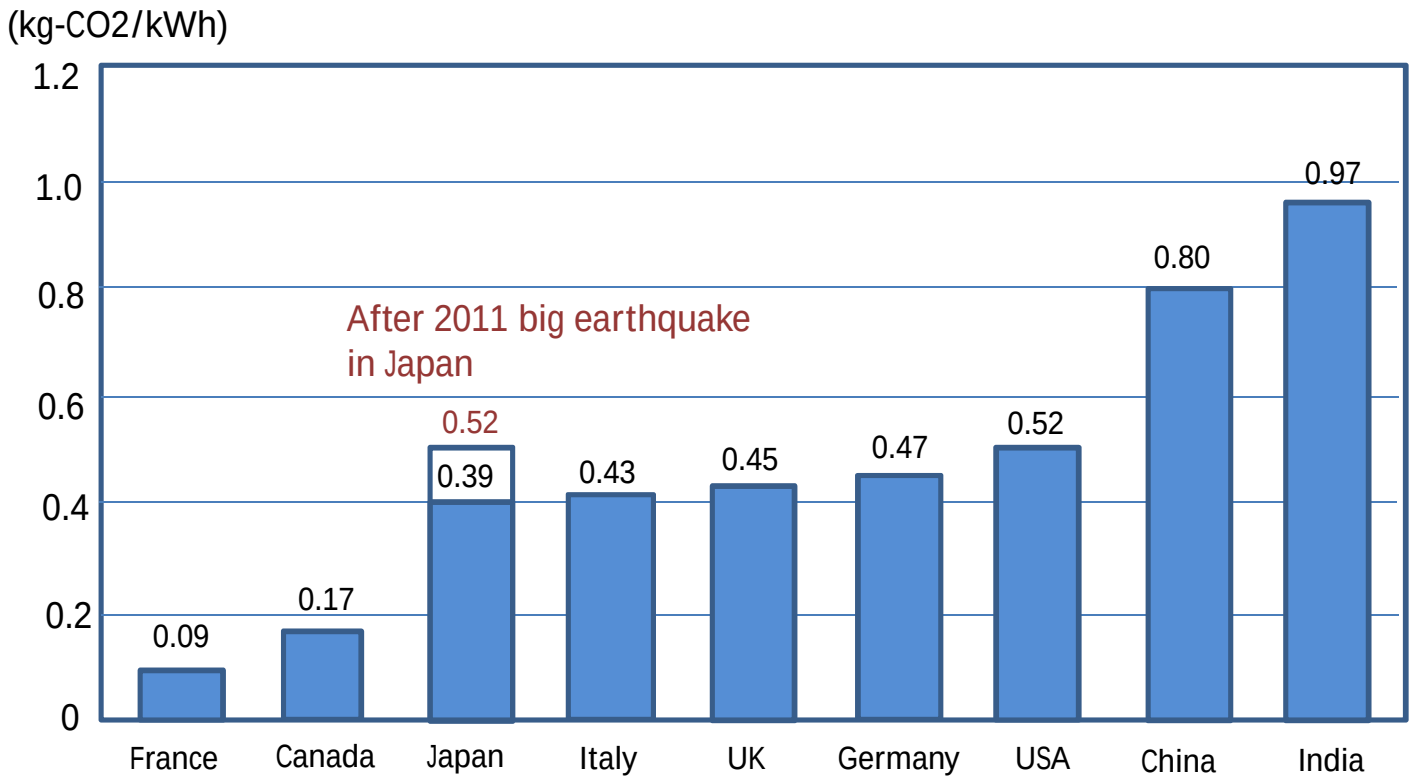


Ref. Marubeni Research Institute

It is impossible to improve environments without improving ICEs.

Target for ICE powered vehicles

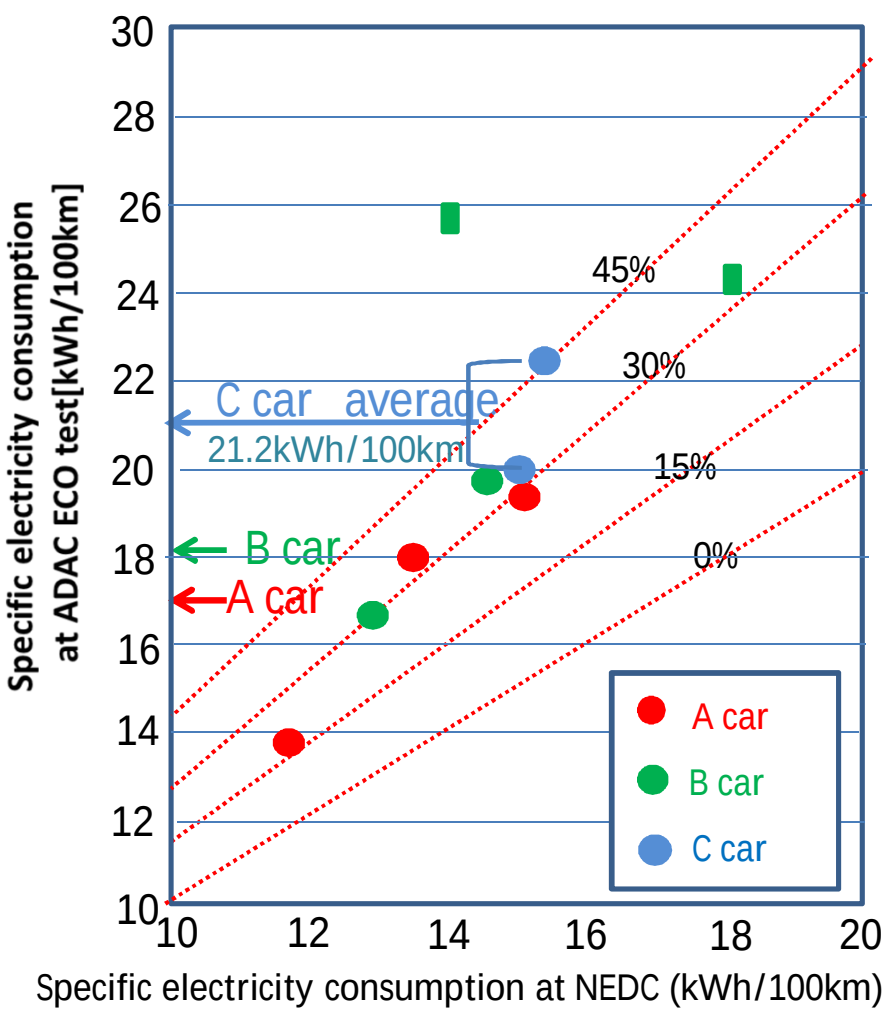
Specific CO2 emissions of electric power generation

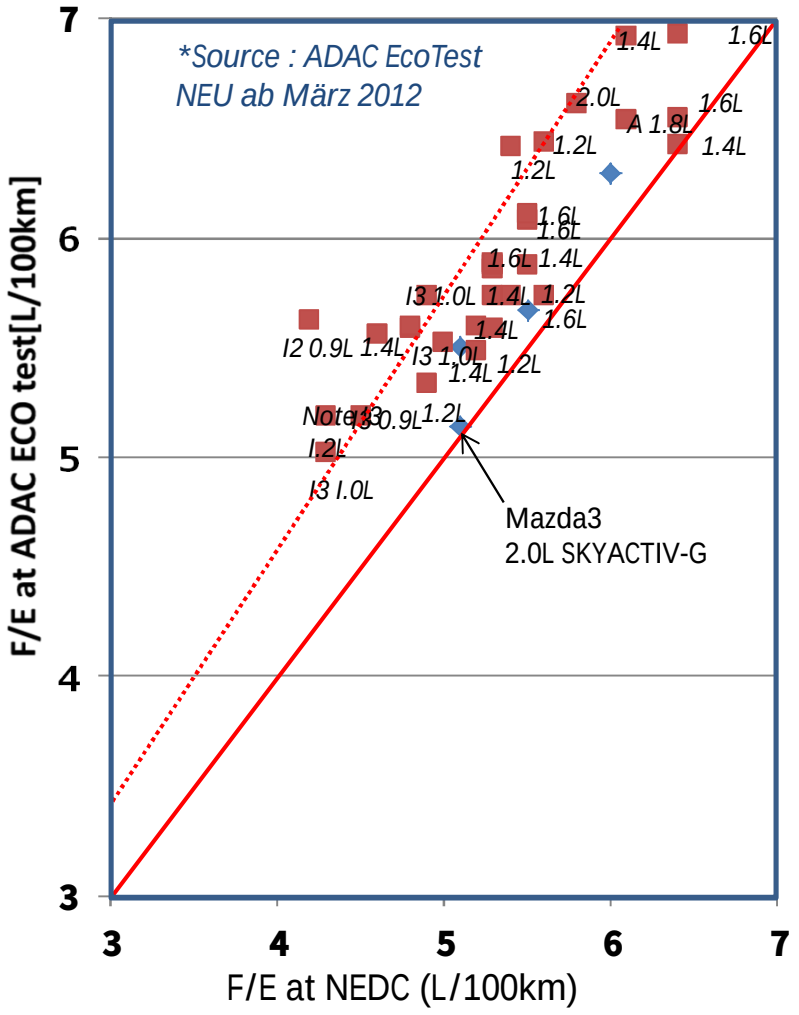


Specific CO2 emission from electric power generation is assumed to be 0.5kg-CO2/kWh.

Target for ICE powered vehicles

Fuel consumption reduction target for ICE powered vehicle in real world



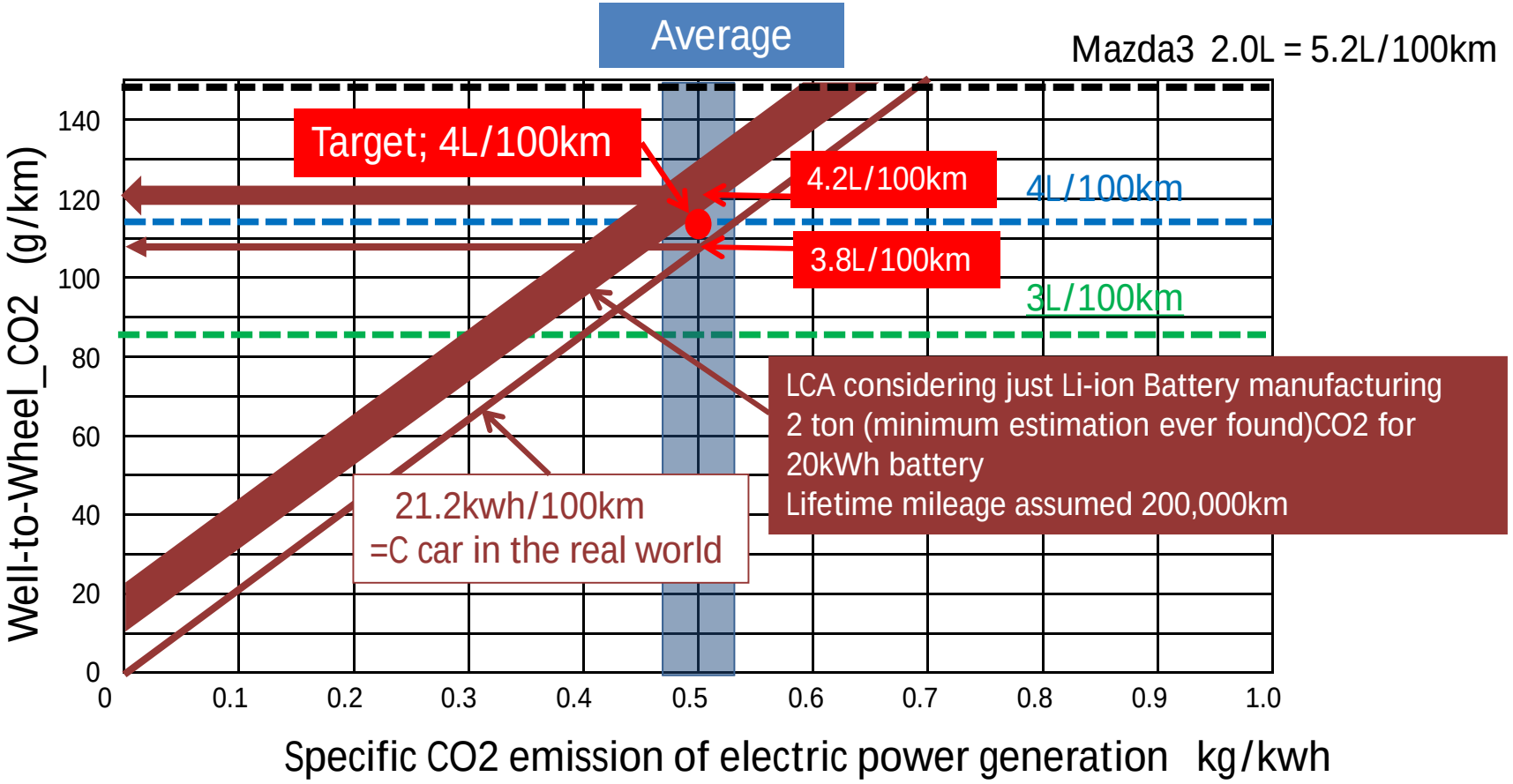


Electric power consumption of C car in the real world: 21.2kWh/100km.

Fuel consumption of Mazda 2L C car in the real world: 5.2L/100km

Target for ICE powered vehicles

Fuel consumption reduction target for ICE powered vehicle in real world



Target *for Mazda 3* 5.2L/100km ⟶ 4L (3.8L-4.2L)/100km

Around 25% fuel consumption reduction required

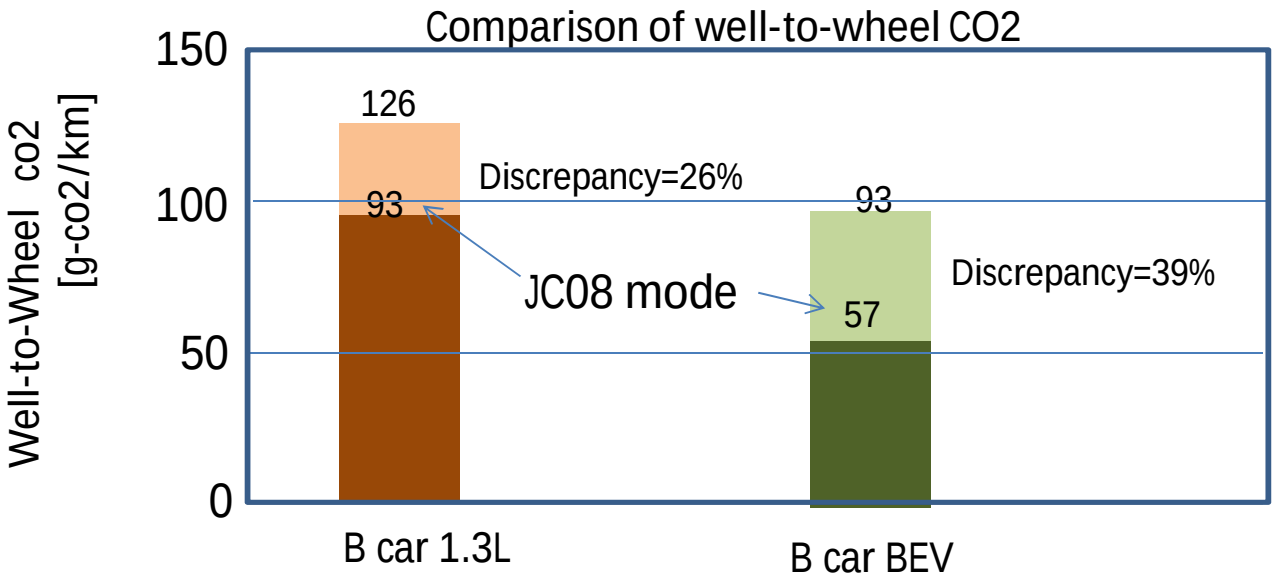
Target for ICE powered vehicles

Real-world CO2 emissions (In Japan)

Evaluation condition: Weighted average of results of below 3 tests, considering Japanese ambient temperature distribution in a year

1. JC08 Hot ambient temperature 25℃ air conditioner 25℃ AUTO
2. JC08 Hot ambient temperature 37℃ air conditioner 25℃ AUTO
3. JC08 Cold ambient temperature -7℃ air conditioner 25℃ AUTO

Average energy consumption = JC08H 25℃ − ((JC08H 25℃ − JC08H 37℃) *0.2+ (JC08H 25℃ − JC08C -7℃) *0.3) /4

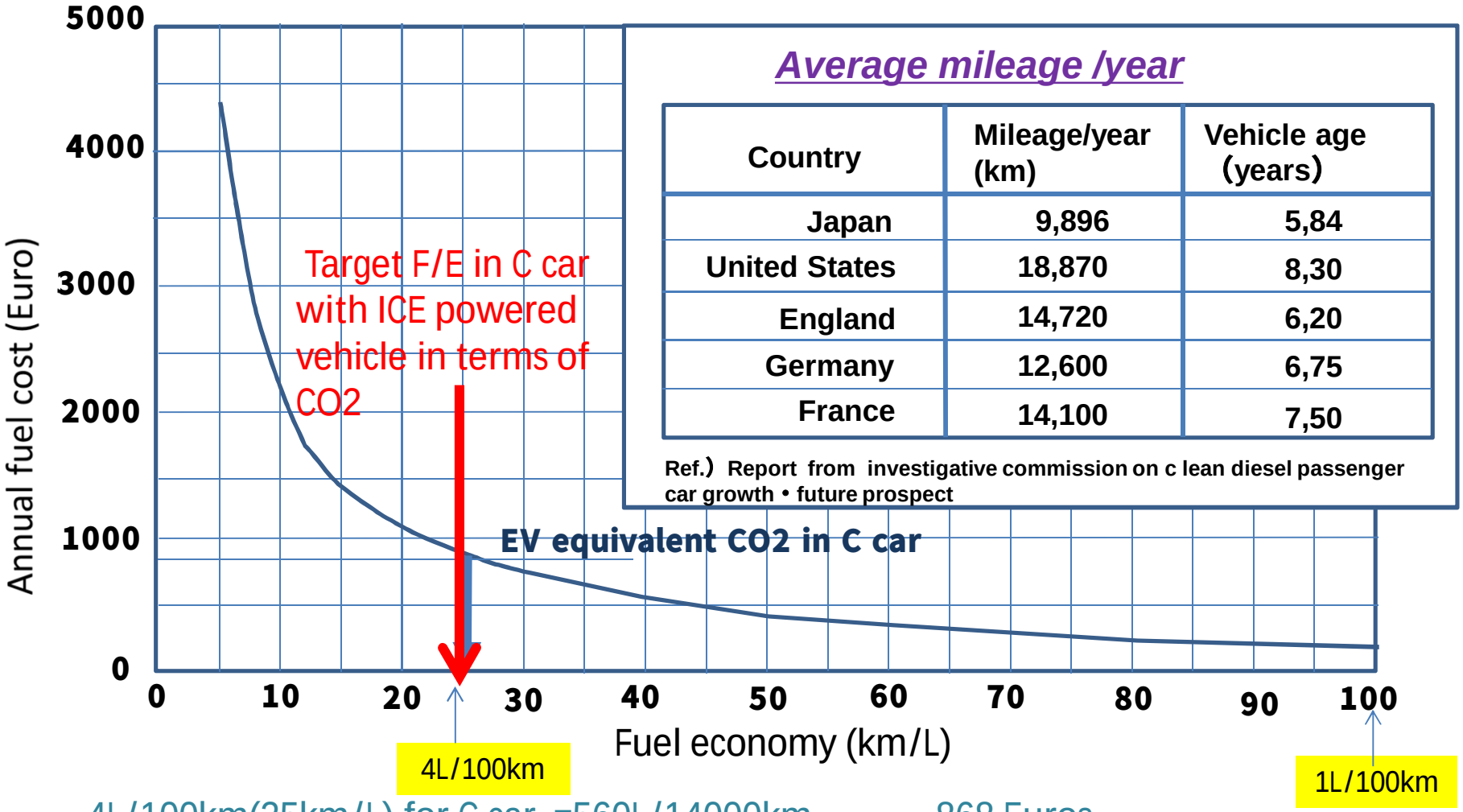


Fuel economy of internal combustion engines needs to be reduced by approx. 26%((126-93)/126=0.26) to attain the EV-level CO2 emissions.

Target for ICE powered vehicles

Fuel cost / year

Assumption: 14,000km mileage/year
1.55 Euro/L 0.285 Euros/kWh



Average mileage /year

Country	Mileage/year (km)	Vehicle age (years)
Japan	9,896	5,84
United States	18,870	8,30
England	14,720	6,20
Germany	12,600	6,75
France	14,100	7,50

Ref.) Report from investigative commission on c lean diesel passenger car growth • future prospect

4L/100km(25km/L) for C car =560L/14000km 868 Euros
21kwh/100km for C car =2940kwh/14000km 838 Euros
4L/100km of real-world fuel economy can be a target for customers.

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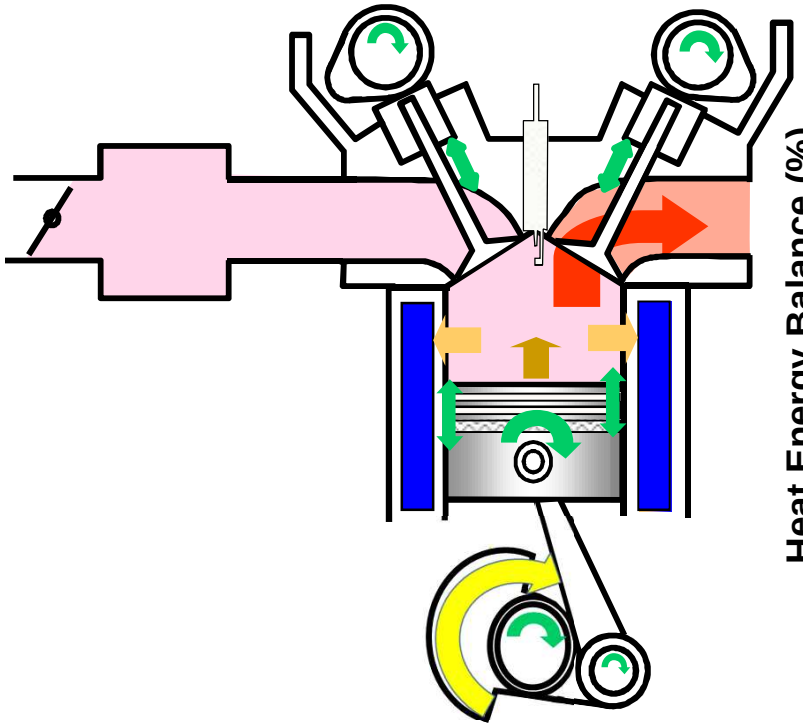
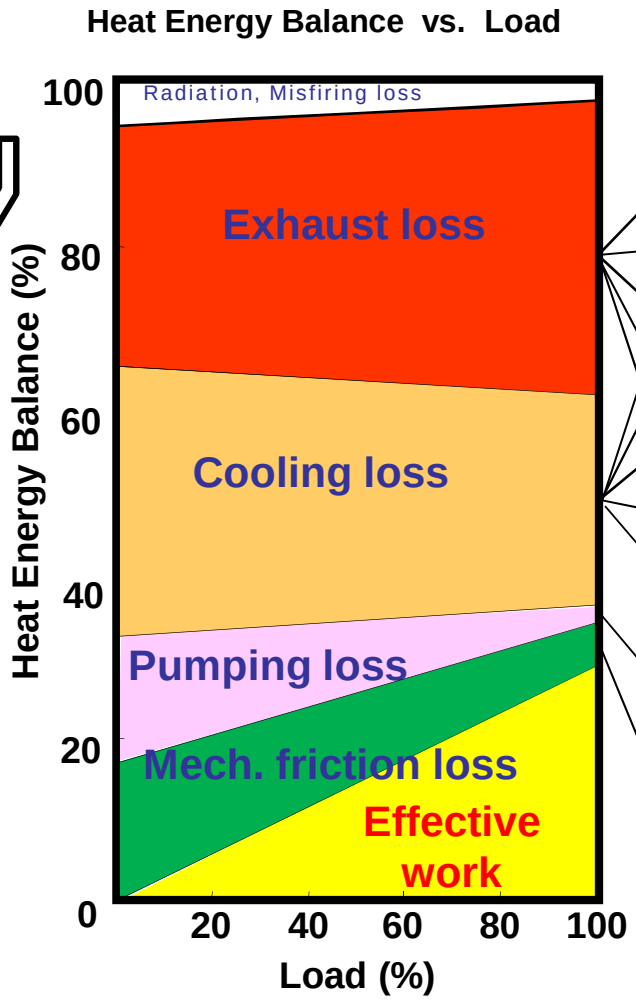
Improving thermal efficiency of ICEs

Energy losses of ICE





Control factors

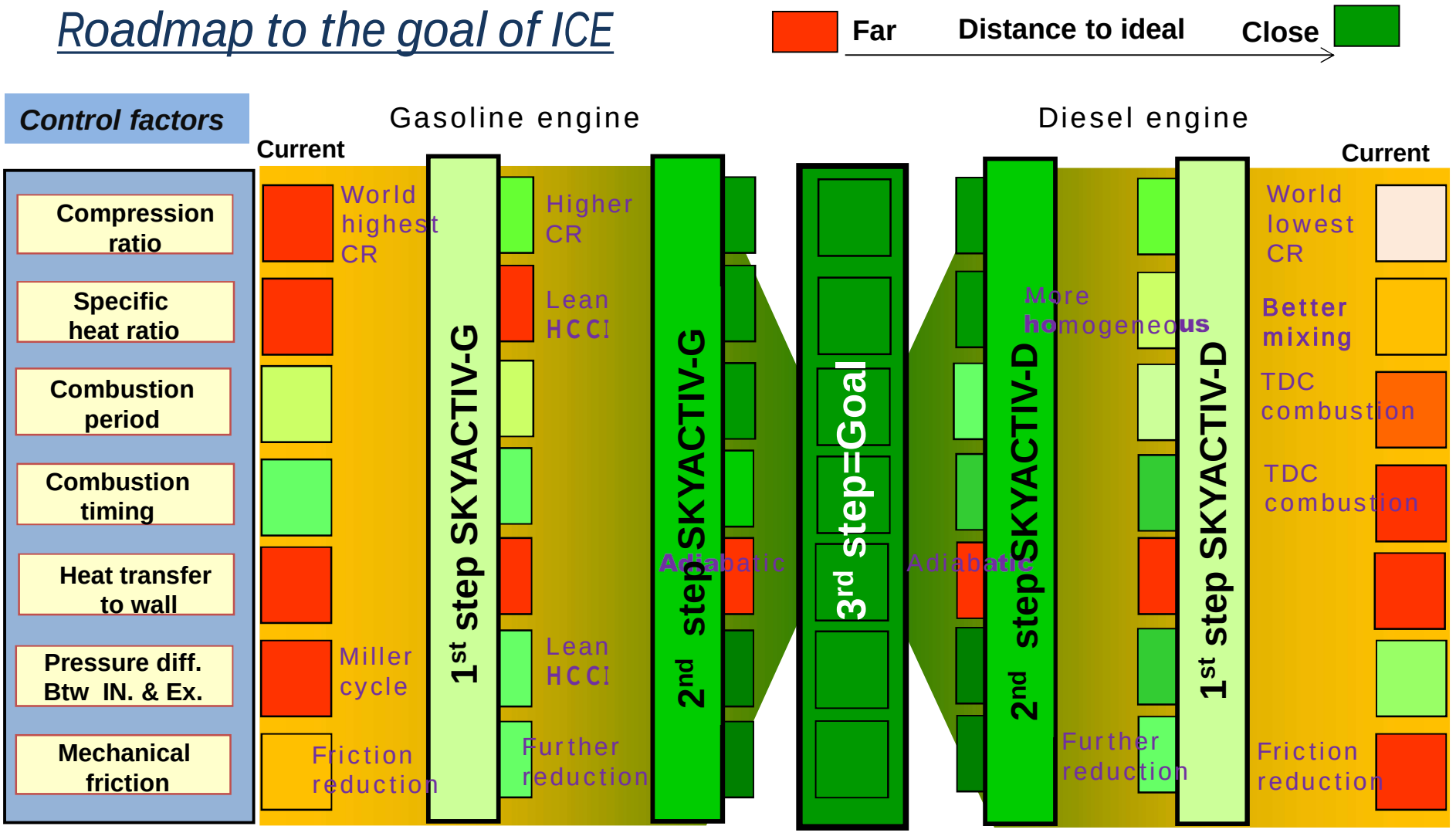
- Compression ratio
- Specific heat ratio
- Combustion period
- Combustion timing
- Heat transfer to wall
- Pressure difference between In. & Ex.
- Mechanical friction

Fuel economy improvement = Loss reduction

All fuel economy improving technologies involve these 7 factors.

Improving thermal efficiency of ICEs

Roadmap to the goal of ICE



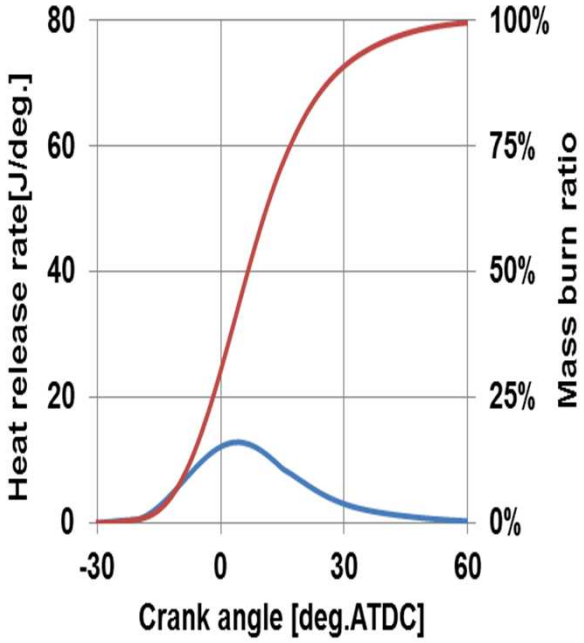
Gasoline engine and diesel engine will look similar in the future.

Contents

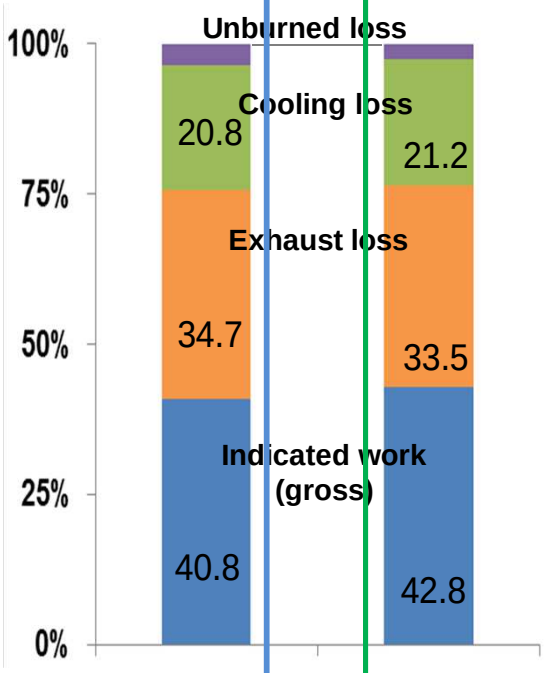
Status of gasoline and diesel engines

Light load：2000rpm – IMEP290kPa

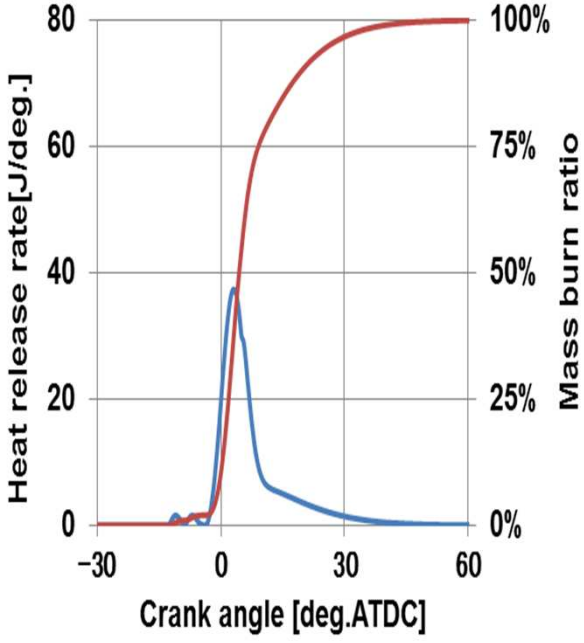
Gasoline



Heat balance analysis



Diesel

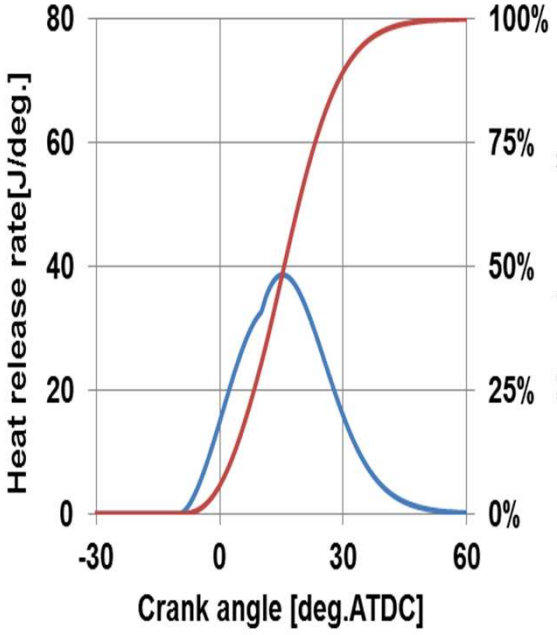


Thermal efficiency	40.8%	<	42.8%
Compression (Expansion) ratio	14	=	14
Specific heat ratio (λ, G/F)	λ：1, G/F:17	<	λ：2.8, EGR ratio：57%, G/F:63
Combustion period	75	<	40
Combustion timing		=	
Heat transfer to wall	LIC	>	

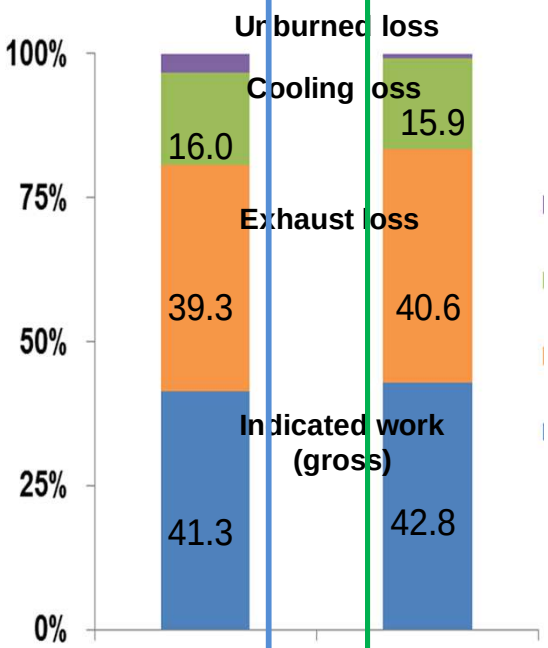
Status of gasoline and diesel engines

Middle load：2000rpm – IMEP940kPa

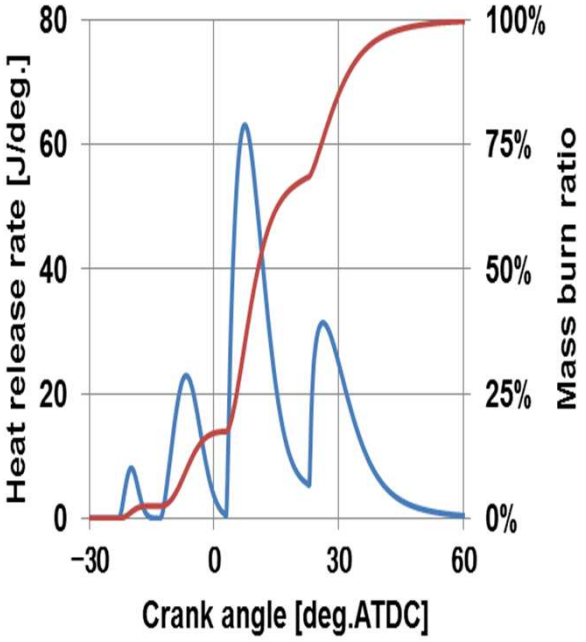
Gasoline



Heat balance analysis



Diesel



	Gasoline		Diesel
Thermal efficiency	41.3%	<	42.8%
Compression (Expansion) ratio	14	=	14
Specific heat ratio (λ, G/F)	λ：1, G/F:15	<	λ：1.6, EGR ratio：35%, G/F:33
Combustion period	50	>	75
Combustion timing		=	
Heat transfer to wall		=	

Status of gasoline and diesel engines

Improvement approaches

Gasoline	*Diesel*
Shorter combustion period in light-and-mid load ranges	Shorter combustion period in light-and-mid load ranges
Lean burn	Homogeneous learn burn
Heat insulation + higher compression ratio	Heat insulation + higher compression ratio

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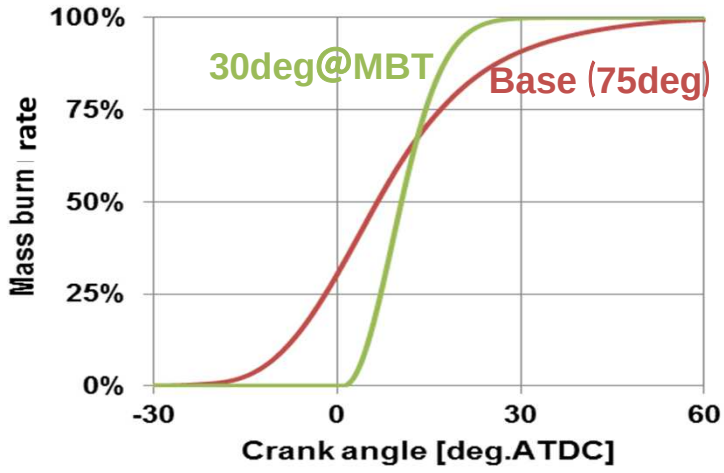
Thermal efficiency improvement

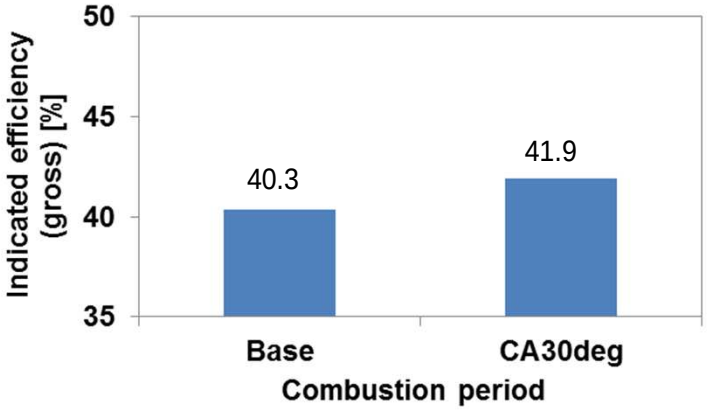
Effect of fast burn at low load

2000rpm – IMEP: 290kPa

Gasoline

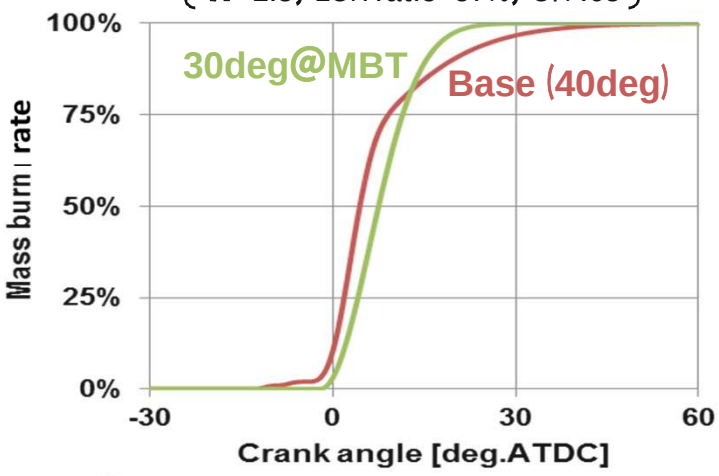
(λ : 1, G/F:17)

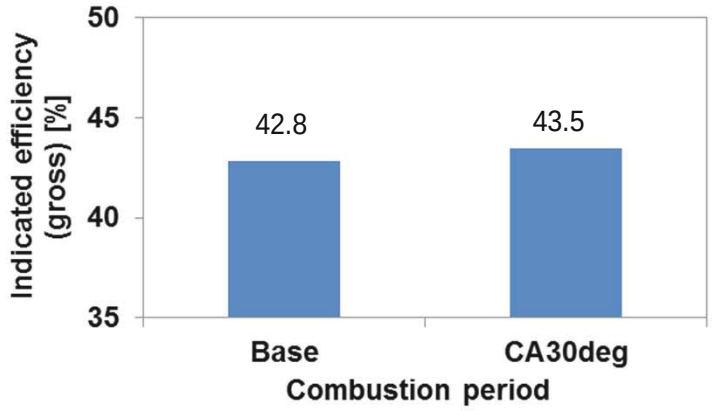




Diesel

(λ : 2.8, EGR ratio : 57%, G/F:63)





In the light load range, the effect of shortening the combustion period is two times greater in gasoline engines than in diesel engines.

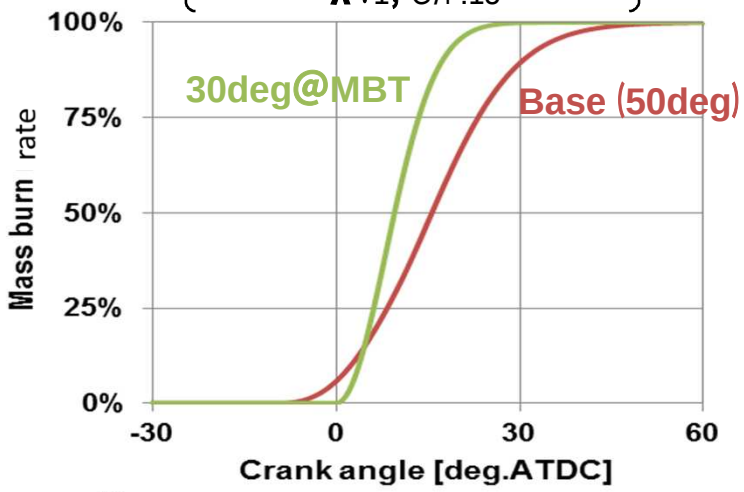
Thermal efficiency improvement

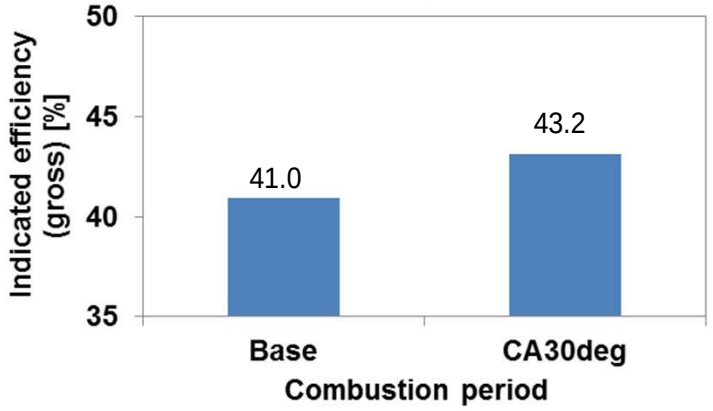
Effect of fast burn at high load

2000rpm – IMEP: 940kPa

Gasoline

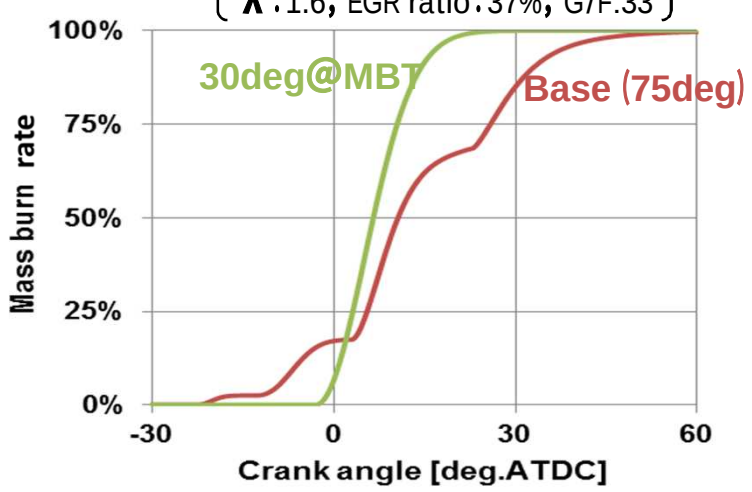
(λ : 1, G/F:15)

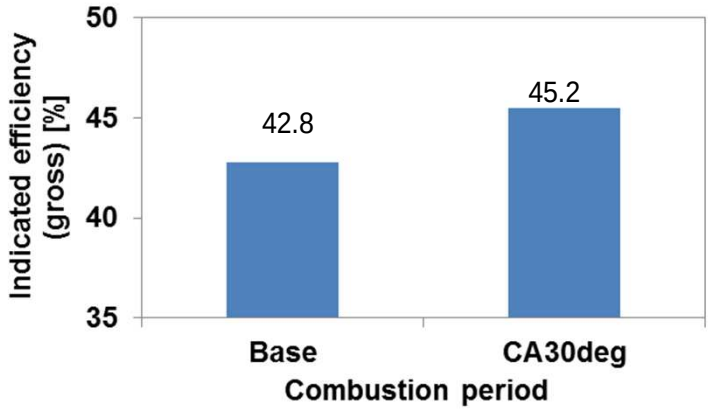




Diesel

(λ : 1.6, EGR ratio : 37%, G/F:33)



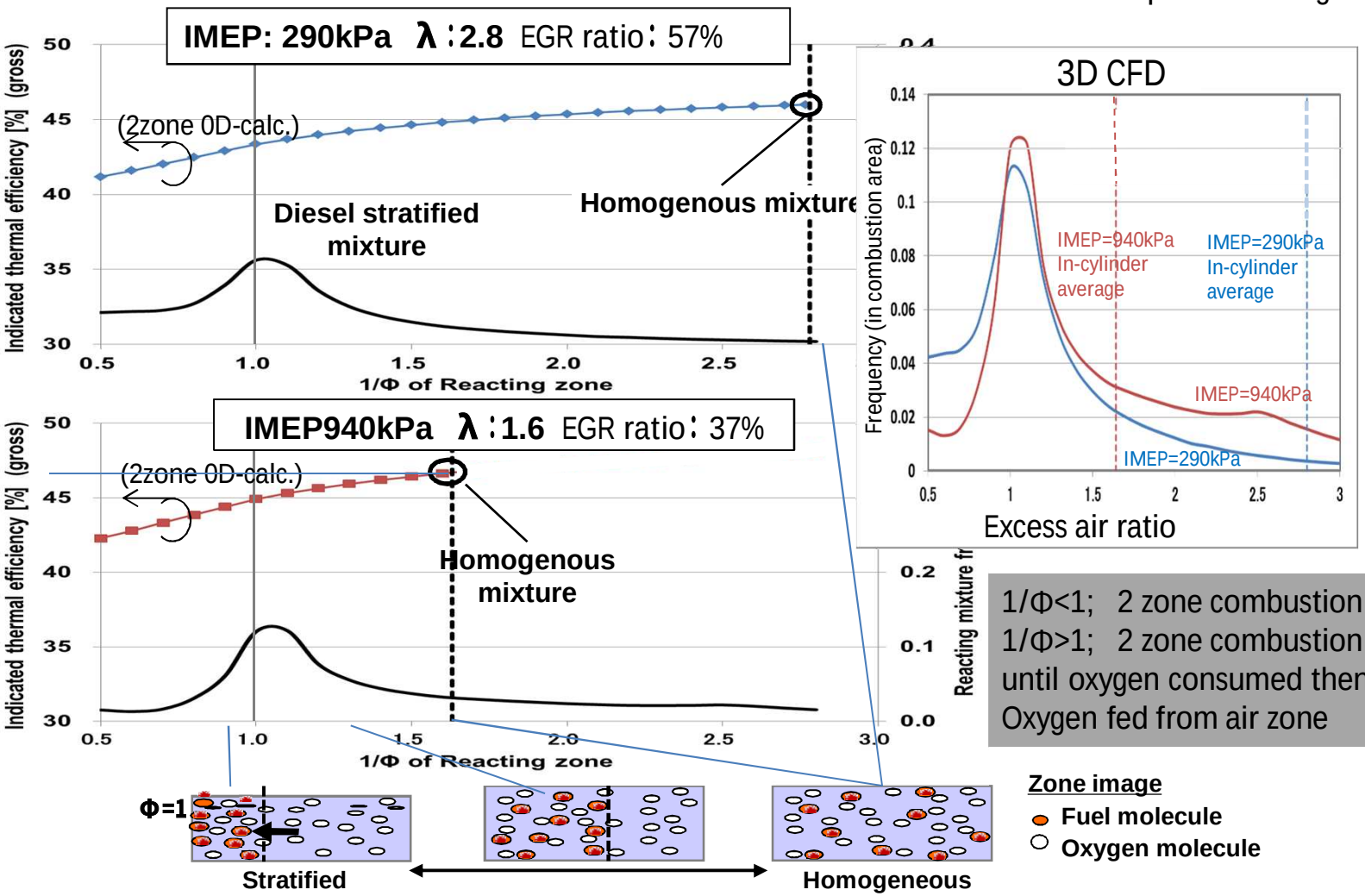


In the high load range, the effect of shortening the combustion period is almost the same between gasoline and diesel engines.

Thermal efficiency improvement

Effect of homogeneity in diesel

2000rpm CR：14 Combustion timing：MBT
Combustion period：30deg



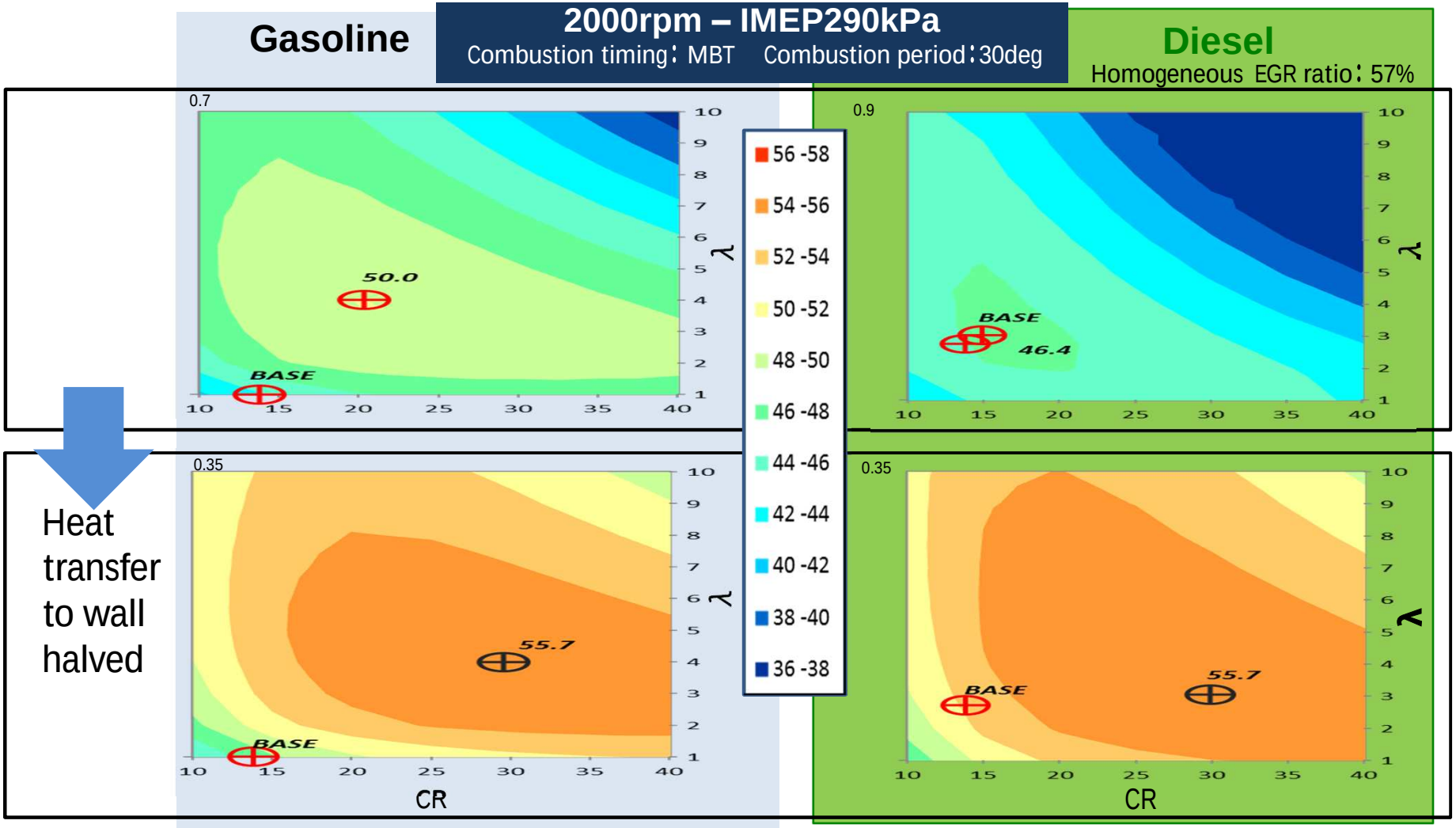
1/Φ<1; 2 zone combustion
1/Φ>1; 2 zone combustion until oxygen consumed then Oxygen fed from air zone

Zone image
- Fuel molecule
- Oxygen molecule

Thermal efficiency improvement is possible to some degree with an enhancement of homogeneous air and fuel mixture during fuel combustion.

Thermal efficiency improvement

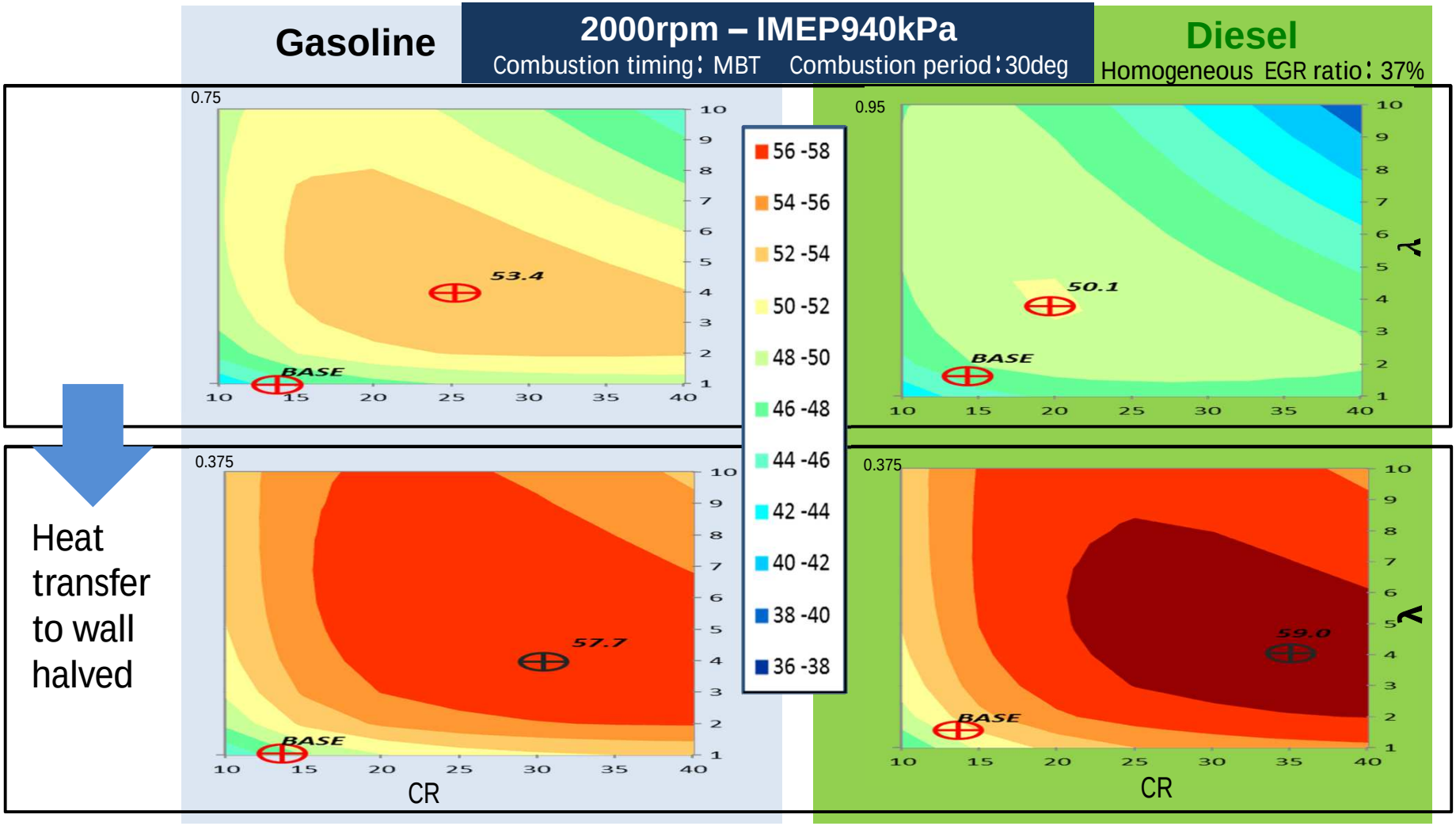
Effect of heat insulation



50% heat insulation improves thermal efficiency by approx. 10 % for both the gasoline and diesel engines.

Thermal efficiency improvement

Effect of heat insulation

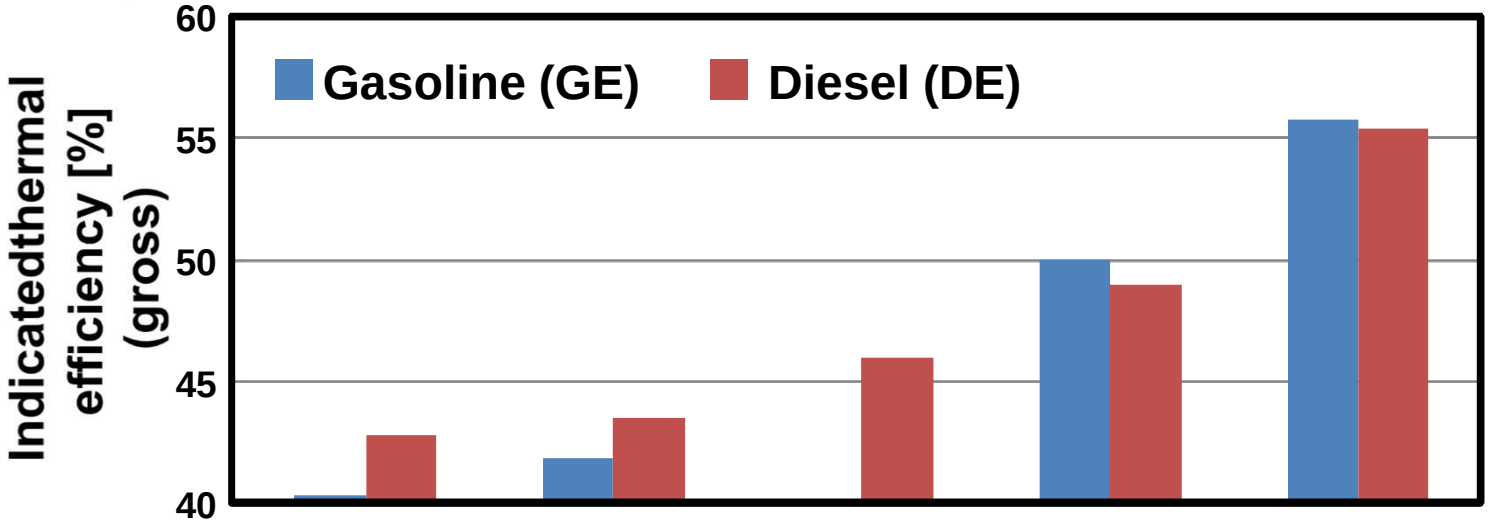


Effects of heat insulation on thermal efficiency in the high load range are almost equal to those in the light-and-mid load ranges.

Thermal efficiency improvement

Walk of efficiency improvement

Light load：2000rpm – IMEP290kPa



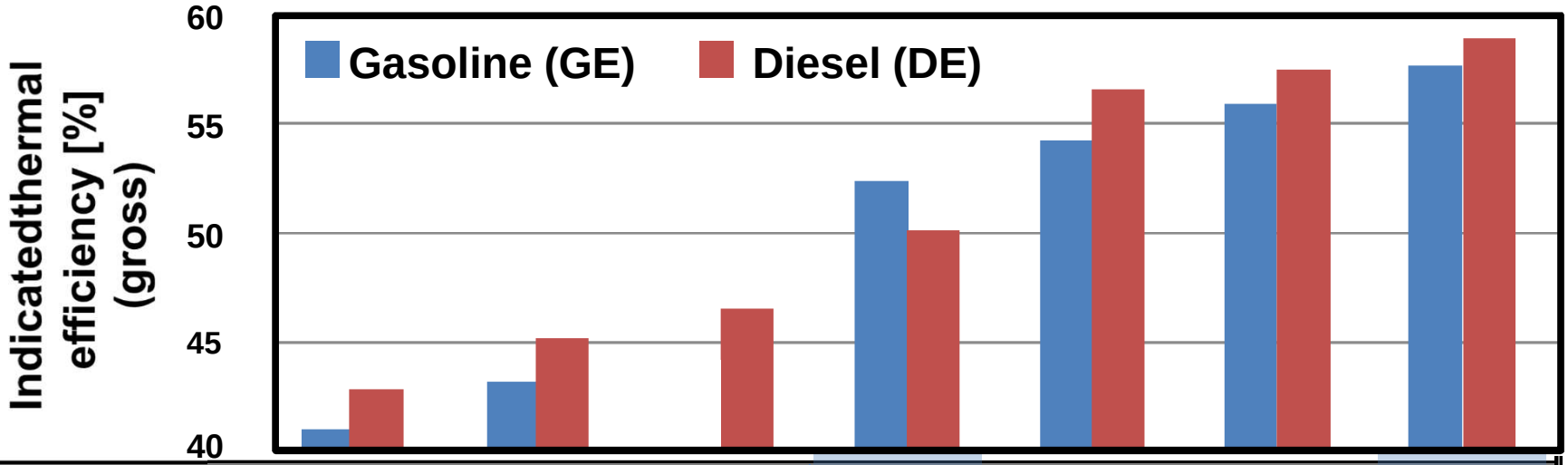
Combustion **period**	**GE:** **DE:**	75deg 40deg	30deg	←	←	←
Specific heat ratio	GE: DE:	**λ=1** Homogeneous **λ=2.8** Stratified	← ←	← **λ=2.8** Homogeneous	**λ=4**	←
Compression raio	GE: DE:	14	←	←	20	30
Wall heat transfer	GE: DE:	Base Base	← ←	← ←	← ←	0.5*GE
Intake valve close	GE: DE:	93deg ABDC 36deg ABDC	← ←	← ←	← ←	← ←

There is room for improving thermal efficiency in the light load range:
Approx. 30% for diesel engines Approx. 40% for gasoline engines

Thermal efficiency improvement

Walk of efficiency improvement

Middle load：2000rpm – IMEP940kPa



Combustion period	GE: DE:	**50deg** **75deg**	**30deg**	←	←	←	←	←
Specific heat ratio	GE: DE:	**λ=1 Homo.** **λ=1.6 Strat.**	← ←	← **λ=1.6 Homogeneous**	**λ=4** **λ=4**	**λ=1** **λ=1.6**	**λ=2** **λ=2**	**λ=4** **λ=4**
Compression raio	GE: DE:	**14**	←	←	**20**	**30**	←	←
Wall heat transfer	GE: DE:	**Base**	⇇	⇇	⇇	0.5*GE	←	←
Intake valve close	GE: DE:	85deg 36deg	⇇	⇇	36deg ABDC	←	←	←

In the mid-and-high load ranges, there is room for improving thermal efficiency by approx. 40% for both the diesel and gasoline engines.

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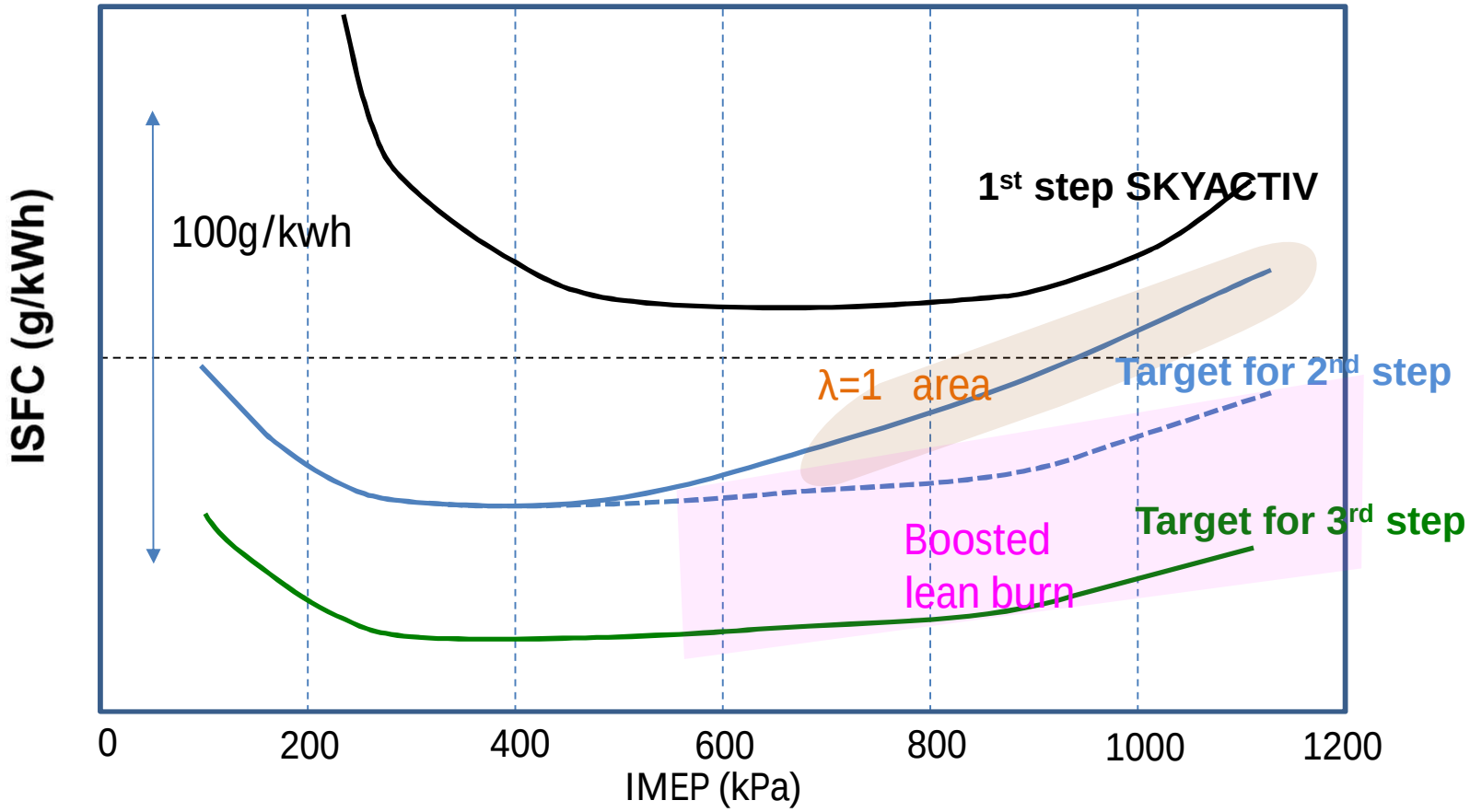
Will ICE vehicles catch up with EVs?

Indicated Specific Fuel Consumption



Targeted ISFC improvements

Light-and-mid load: 30% in the 2nd step & 40% in the 3rd step

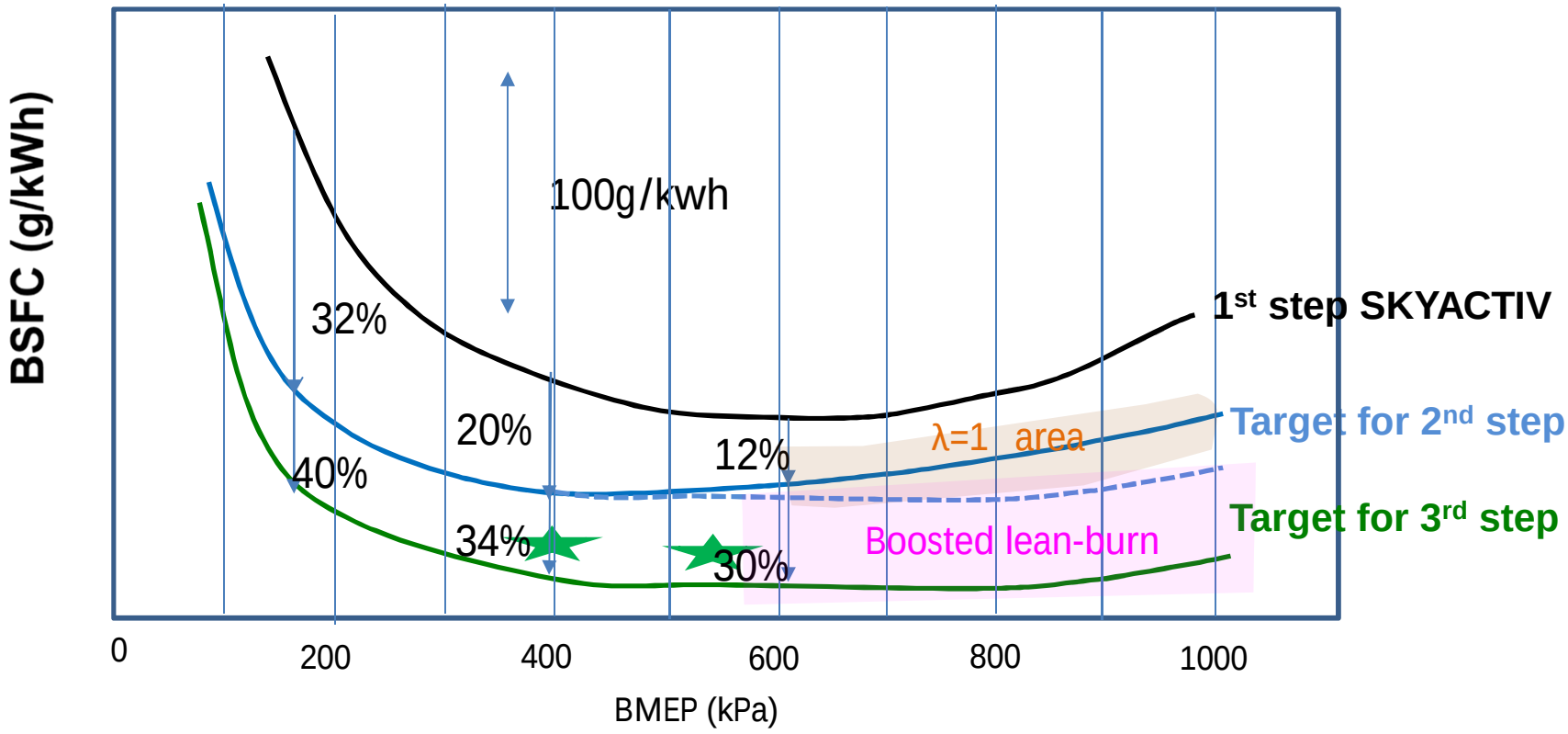
High load rang : 10% in the 2nd step under **λ=1**.

20% in the 2nd step & 35% in the 3rd step under boosted lean burn

Will ICE vehicles catch up with EVs?

Brake Specific Fuel Consumption

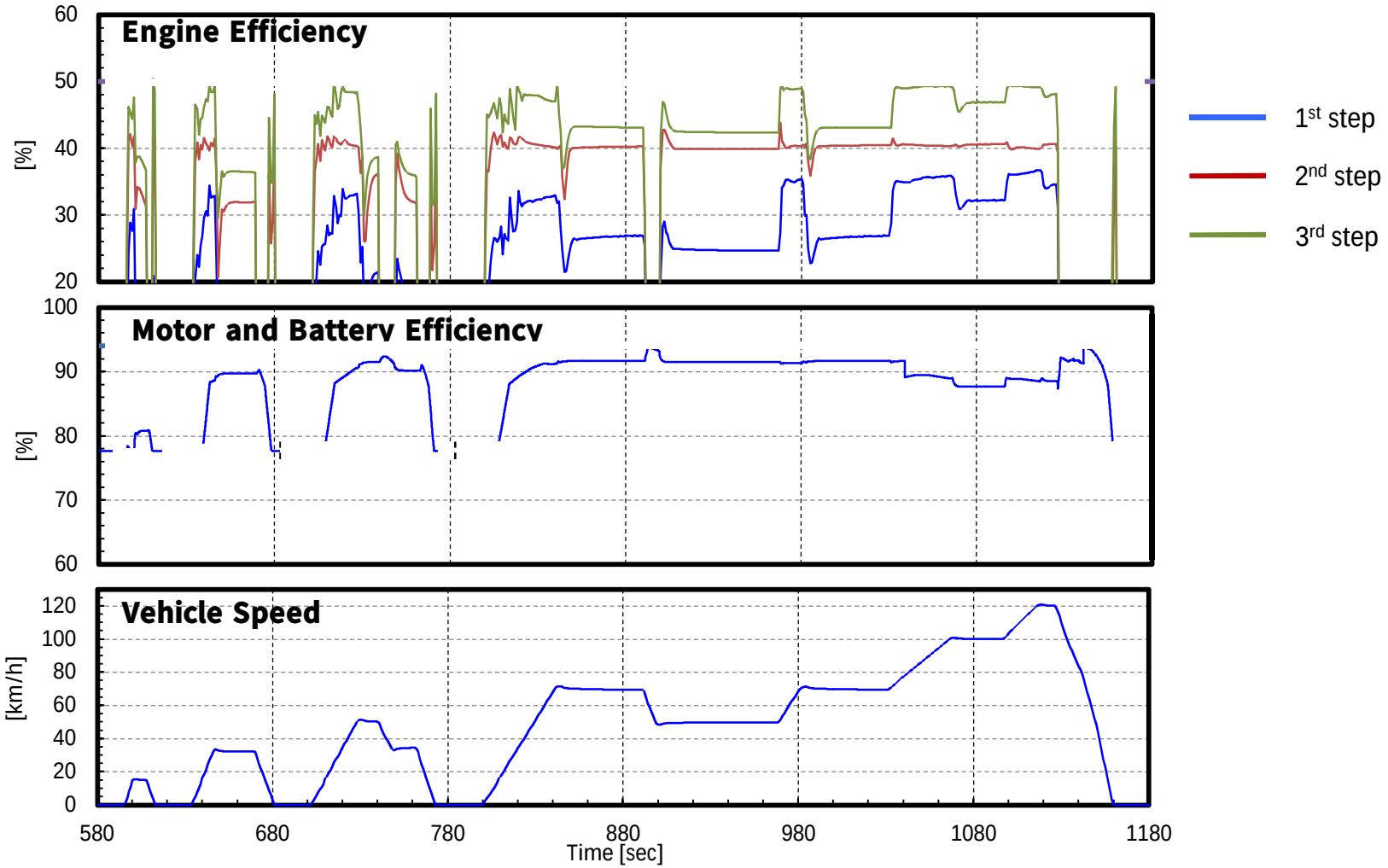
Target for Mazda 3 5.2L/100km → 3.8L-4.2L/100km
around 25% fuel consumption reduction required



It seems possible for ICEs to attain a 25% fuel economy improvement, which is the target to to attain the EV level CO2

Will ICE vehicles catch up with EVs?

Comparison of thermal efficiency improvement during driving



ICE vehicles will be able to attain the CO2 level of EVs based on mode simulation.
Efficiency improvement for EVs is nearing its limit.

Contents

Conclusions

Approach to reduce CO2 emissions

	Gasoline	*Diesel*
Light-and–mid load	Lean burn + fast burn + high compression ratio HCCI	More homogeneous lean burn + high compression ratio
Mid-and-high load	Lean burn +high compression ratio	More homogeneous lean burn + high compression ratio + fast burn

Heat insulation + high compression ratio

Enabler Technologies to mix fuel and air quickly.

Conclusions

1. The annual volume of auto sales in the world will approximately double by 2050 mainly because of increasing sales volume in non-OECD countries.

2. In order for ICE vehicles to attain the well-to-wheel CO2 level of EVs, approx. 25 % improvement in real-world fuel economy is required.

3. If both the gasoline and diesel engines achieve more homogeneous lean-burn, heat insulation and high compression ratio, it is possible for them to attain the CO2 level of EVs.

Questions for you

Despite the fact that lean burn is required to drastically improve thermal efficiency, do you still think that downsizing engines have a future?

Even though the much electricity is generated by coal-fired power plants, will you continue to advance the zero CO2 scheme of electricity?

Thank you for your attention!