Toyota's Challenge for Energy Efficiency Improvement in Automobiles

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TOYOTA MOTOR CORPORATION

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1. Circumstances of Automotive Society

- Energy Sources and Global Warming

2. Improvement of Thermal Efficiency of Engines

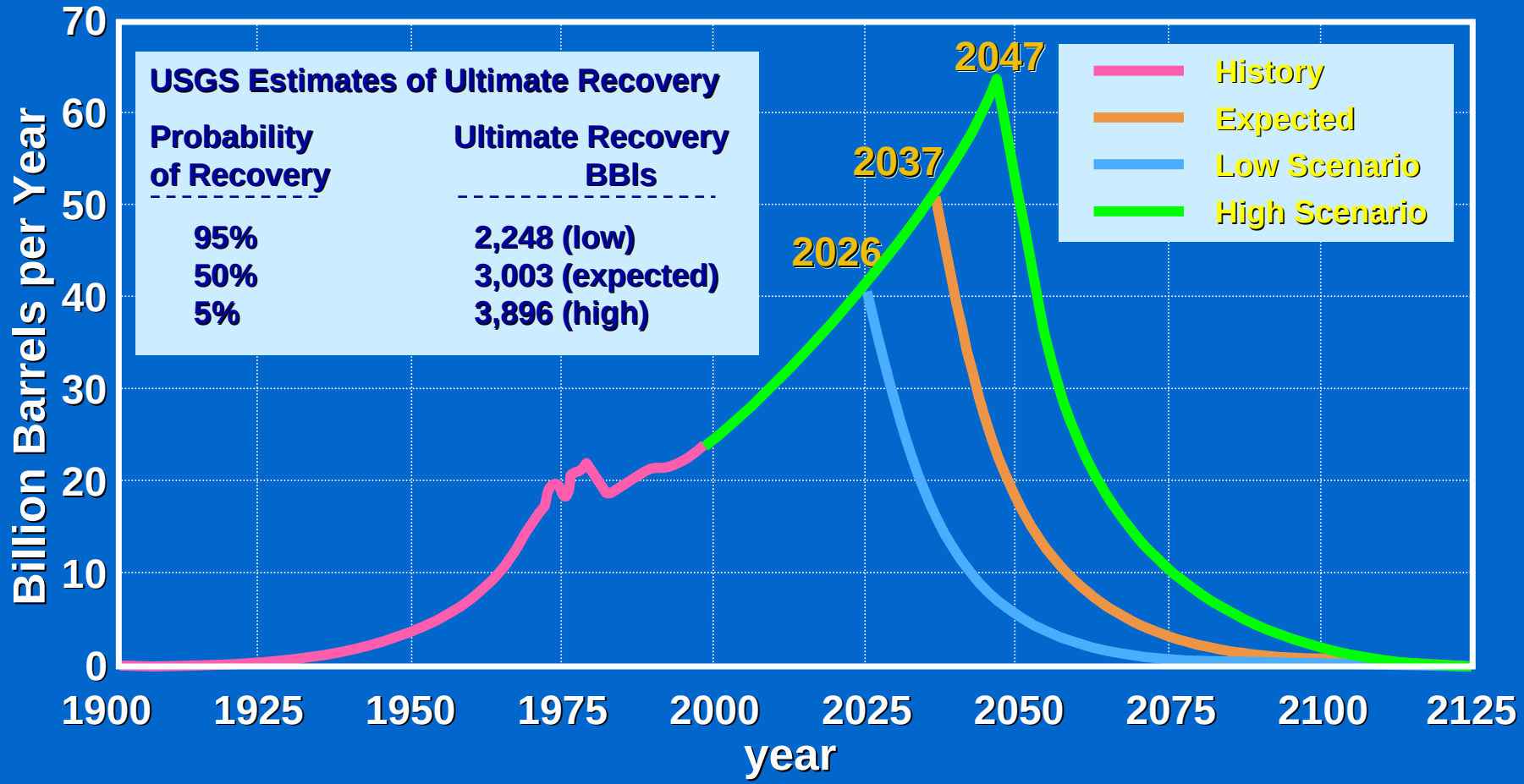
- Internal Combustion Engine (Gasoline, Diesel)
- Alternative Fuels
- Fuel Cell
- Weight Saving

3. Effective Energy Utilization

- Hybrid Technology
- Improvement of Traffic Situations

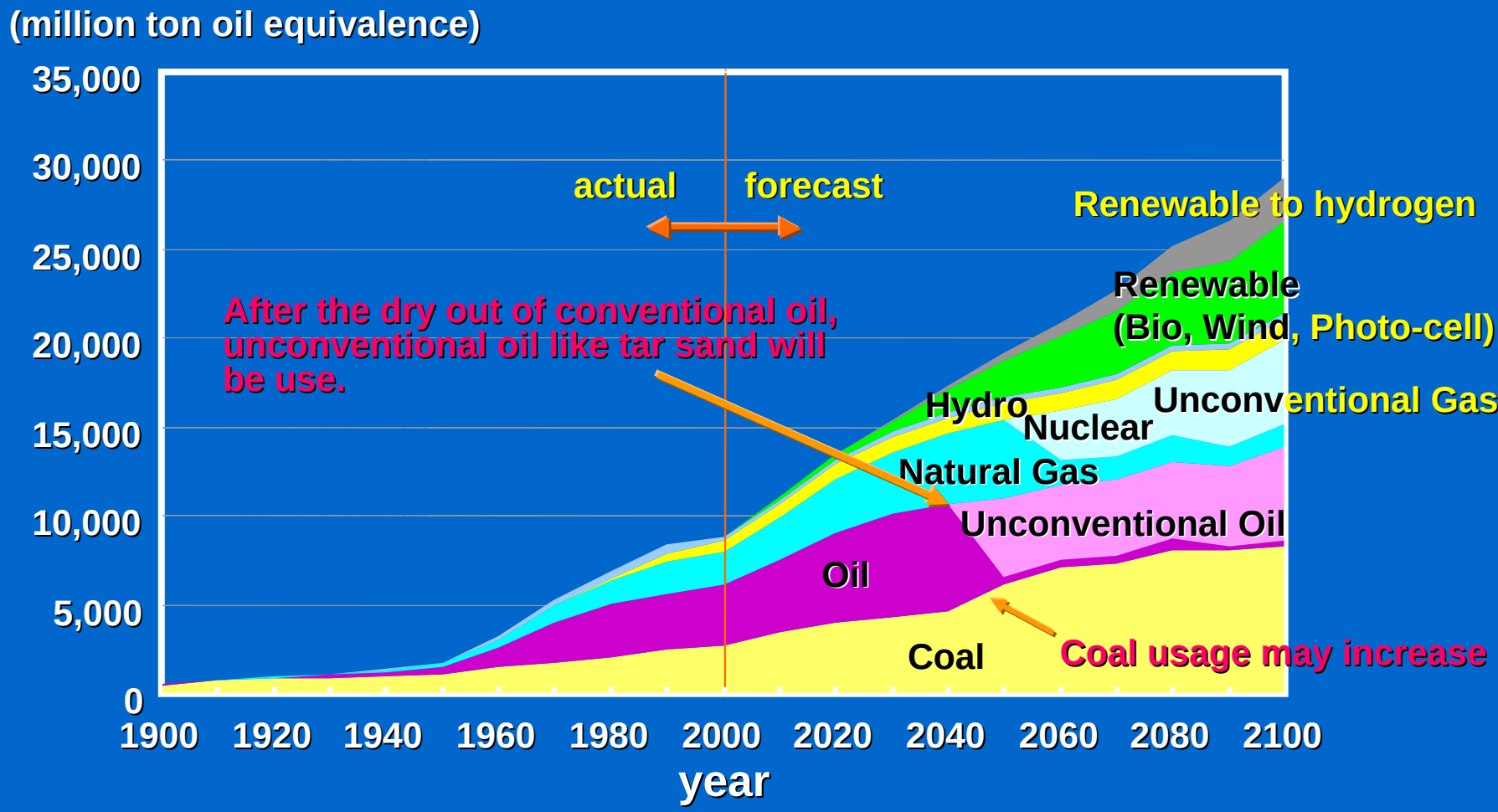
Prospect of Crude Oil Production

When will Crude Oil run dry ? ..... 20xx ?



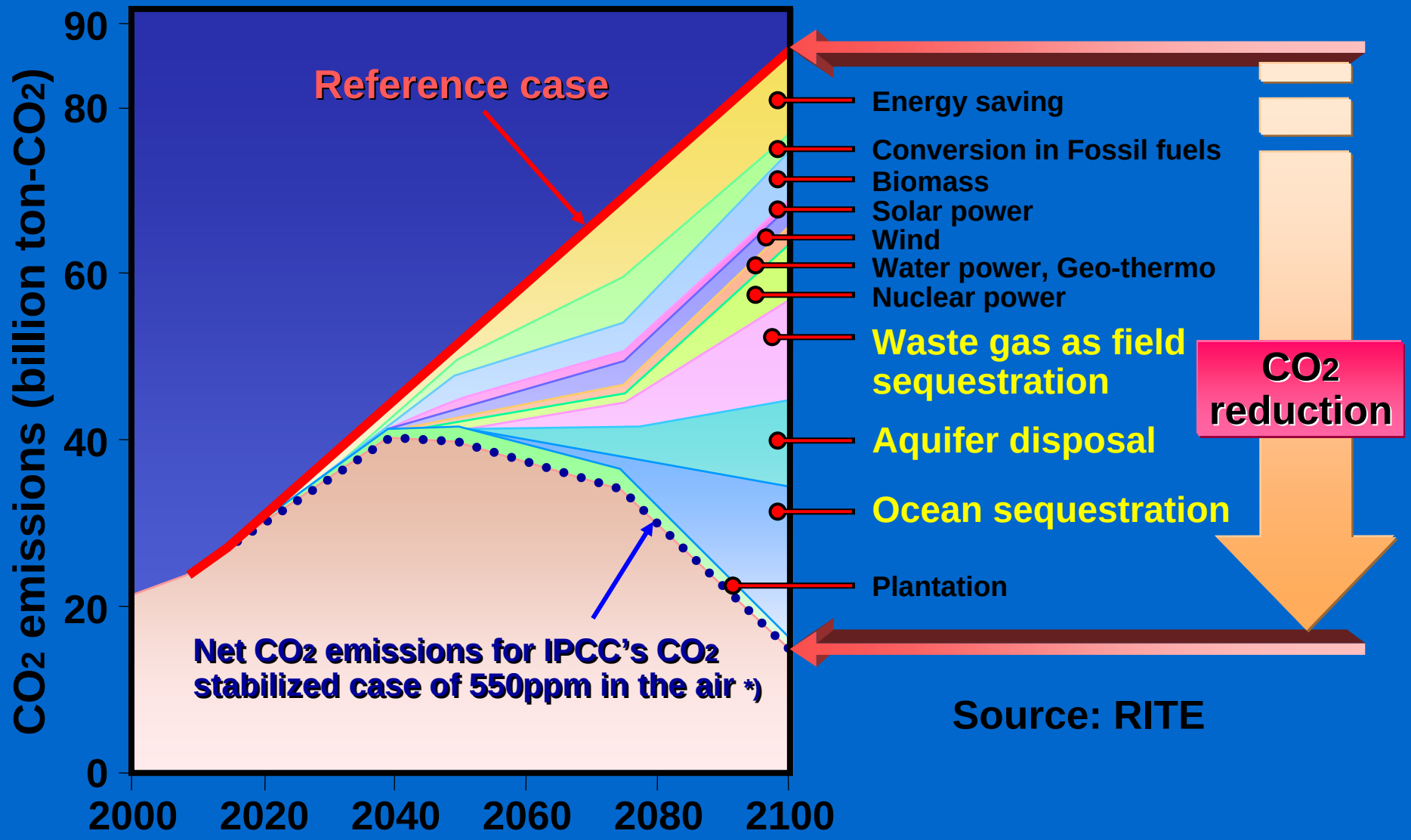
Notes: U.S. volumes were added to the USGS foreign volumes to obtain world totals.
Assumption: Growth rate of oil demand: 2 % / year

Prospect of World's Primary Energy Supply



Source: The Institute of Energy Economics, Japan

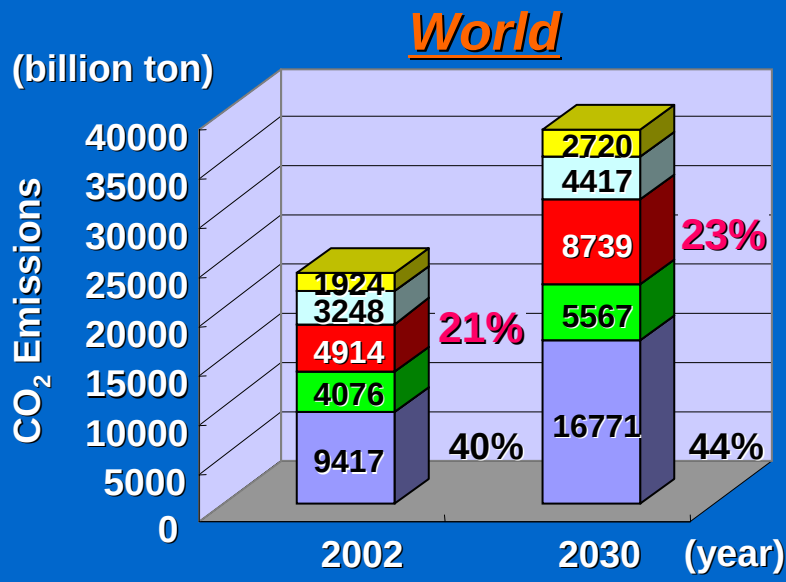
CO_2 Scenario



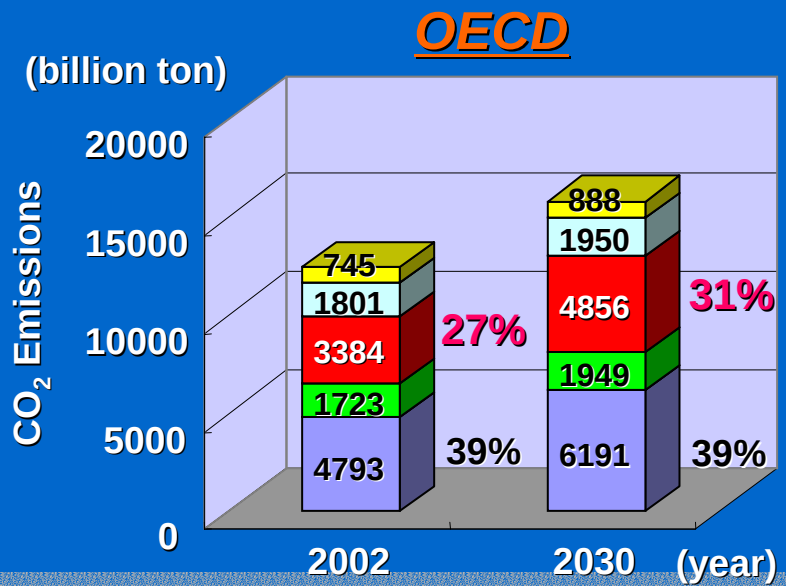
Source: RITE

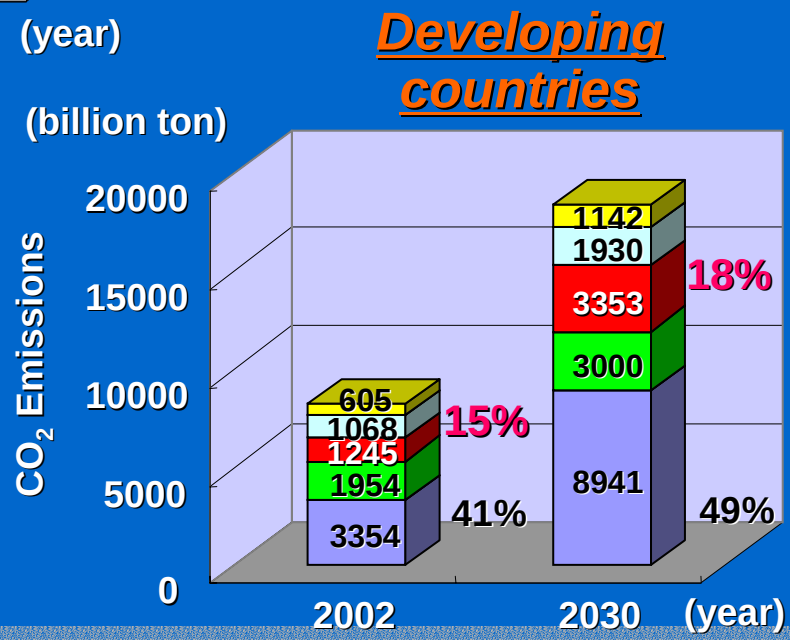
*) IPCC: Intergovernmental Panel for Climate Change

Exhaust of CO_2 Emissions



Source: World Energy Outlook,2004





Approach to CO_2 Reduction

Selection of Energy Source

- Crude Oil — ICE (SI,CI)
- Synthetic Fuel — ICE (CI)
- Bio Fuel — ICE (SI,CI)
- Natural Gas — ICE (SI)
- Hydrogen — FC / FCHV
- Electric Power — EV / HV / Plug-in HV

Improvement of Vehicles

- Weight Reduction
- Reducing Friction
- Idling Stop — HV
- Regeneration — HV / EV

Improvement of Engines

- Lower Friction Loss
- Higher Compression Ratio
- Boosting
- Variable Valve System
- Heat Management

→ ICE (SI, CI)

Improvement of Traffic Flow

- Road Improvement
- VICS
- Park & Ride

1. Circumstances of Automotive Society

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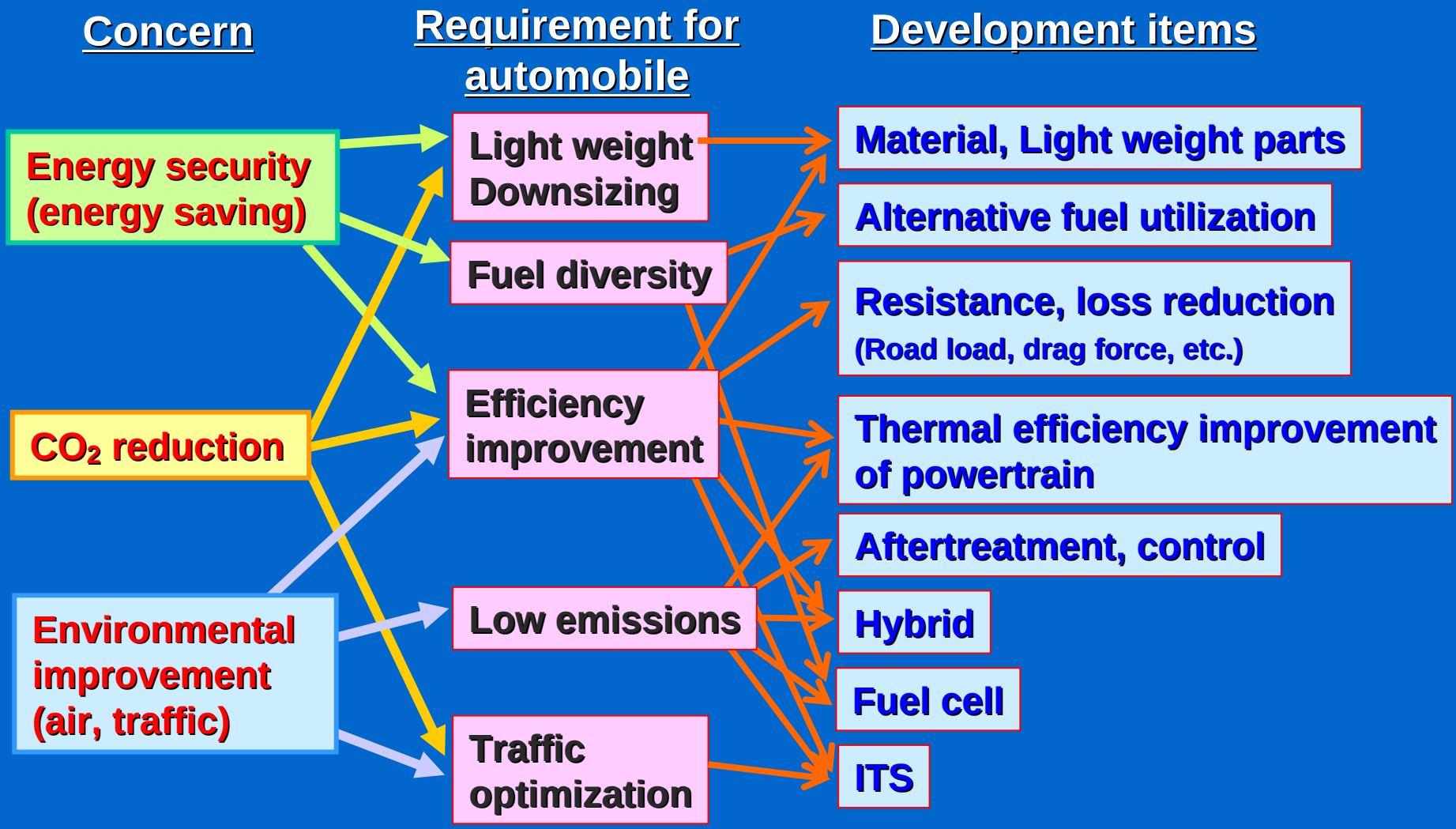
Directions of Development of Automobile Technologies



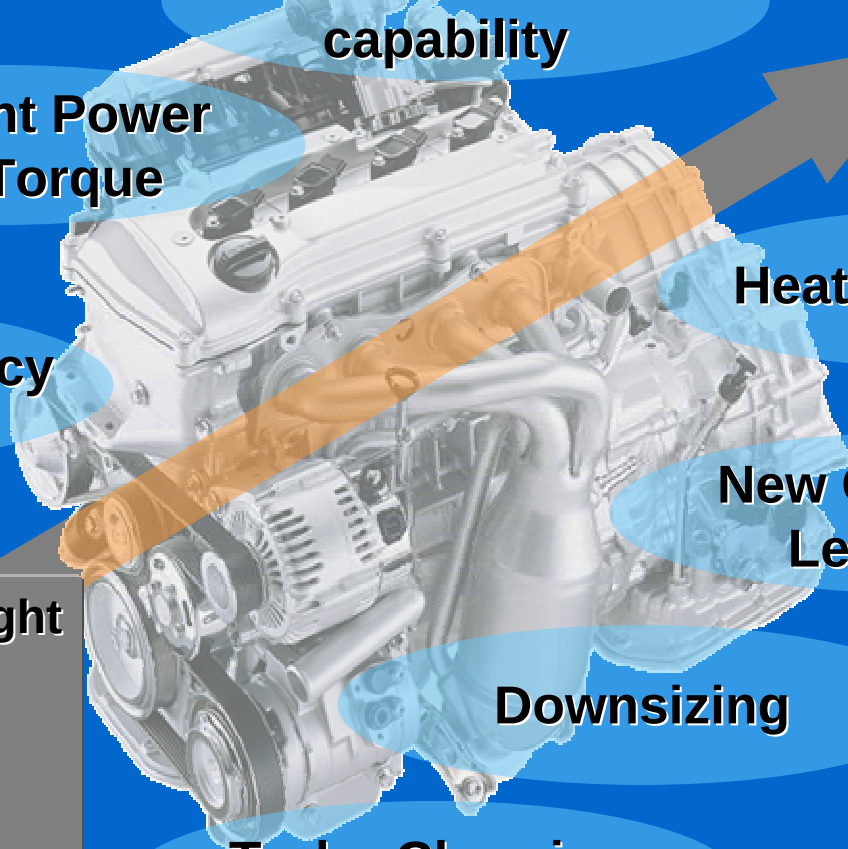
Engine Technologies

Comparison of Internal Combustion Engines

		Gasoline	Diesel	Problems
Fuel consumption#1		5.5L/100km/ton	4.0L/100km/ton	Efficiency improvement (esp. gasoline)
Thermal efficiency		35%	42%	
Specific power		65kW/L	60kW/L	<Gasoline> Torque enlargement => Boosting
Specific torque		105Nm/L	175Nm/L	
Emissions	λ=1 (stoich.)	Good	NOx PM	<Gasoline lean burn> NOx reduction <Diesel> NOx, PM reduction
	Lean	NOx		
Noise, vibration		Good	Level	
Weight		1.0	1.3 - 1.4	
Cost		1.0	1.3 - 1.5	

#1 : 10-15 mode 2 - 3L Passenger car Vehicle wt. = 1.5 - 1.75ton

Technical Trends of SI Engines



Alternative fuel capability

Efficient Power and Torque

Heat Management

Thermal Efficiency > 40%

New Generation Lean Burn

Downsizing

Turbo Charging with λ1

- Compact and Light weight
- Direct Injection
- Variable Valve System
- Nearly Zero Emission
- Low Friction Losses

Next Gen. Gasoline Technologies

Fuel

- Fuel Flexibility
- Hydrogen application

Power

- Knock Free Combustion
- Turbocharging

Fuel Consumption

- Downsizing
- High Compression Ratio
- Variable Valve Actuation
- Next generation DI
- Lean Burn
- Low Friction Component

Emissions

- High Efficiency
  - Three-way Catalyst
  - Lean NOx Catalyst
- Quick Warm Up
- Combustion Improvement

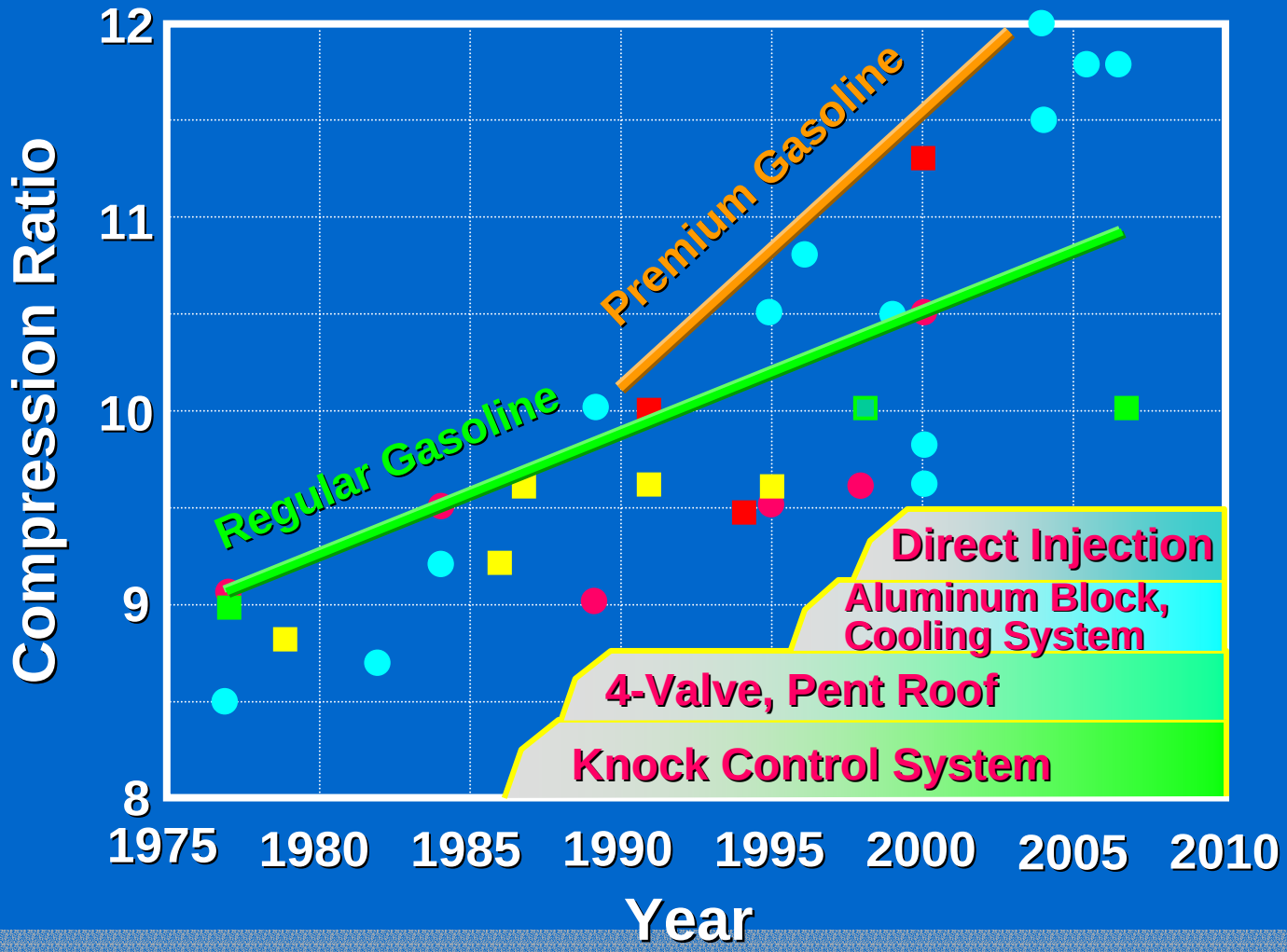
Weight / Compactness

- Downsizing
- Light Weight Materials

Noise/Vibration

Cost

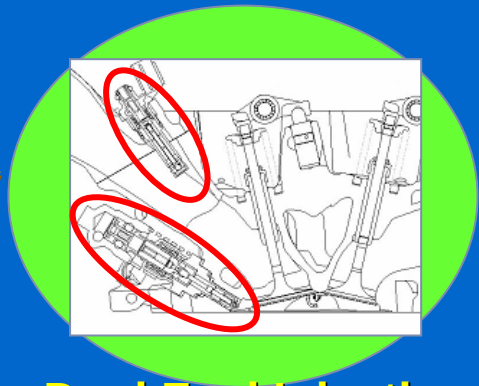
History of Compression Ratio (Toyota Gasoline Engines)



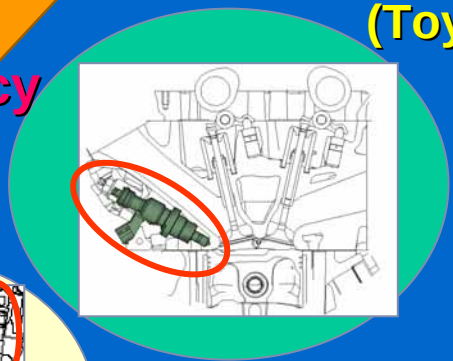
Technology Innovation in Fuel System (DISI engines in Toyota)

High Power & efficiency

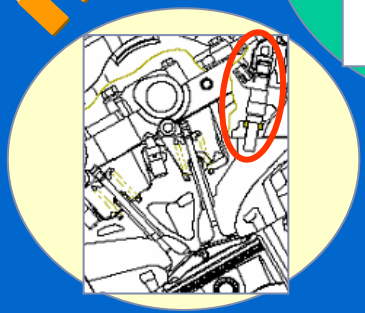
High Efficiency



Dual Fuel Injection
(Toyota D-4S)



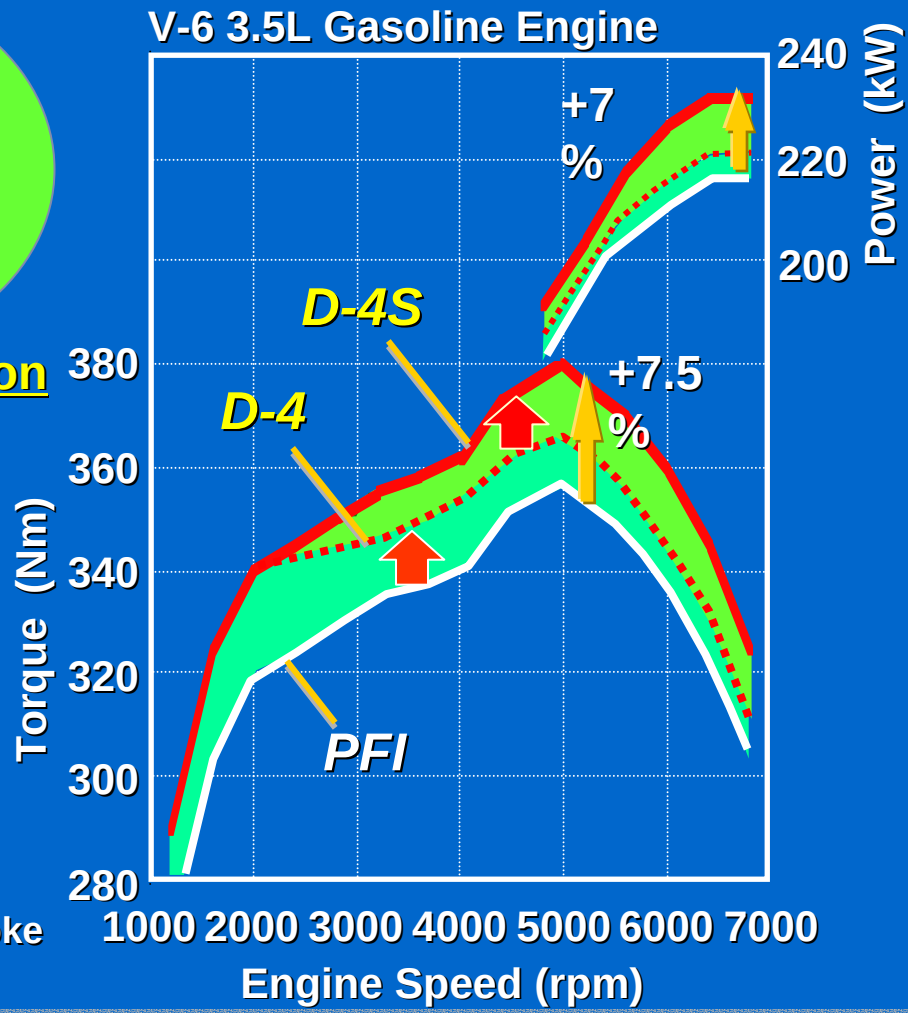
Direct Fuel Injection
(Toyota D-4)



Port Fuel Injection

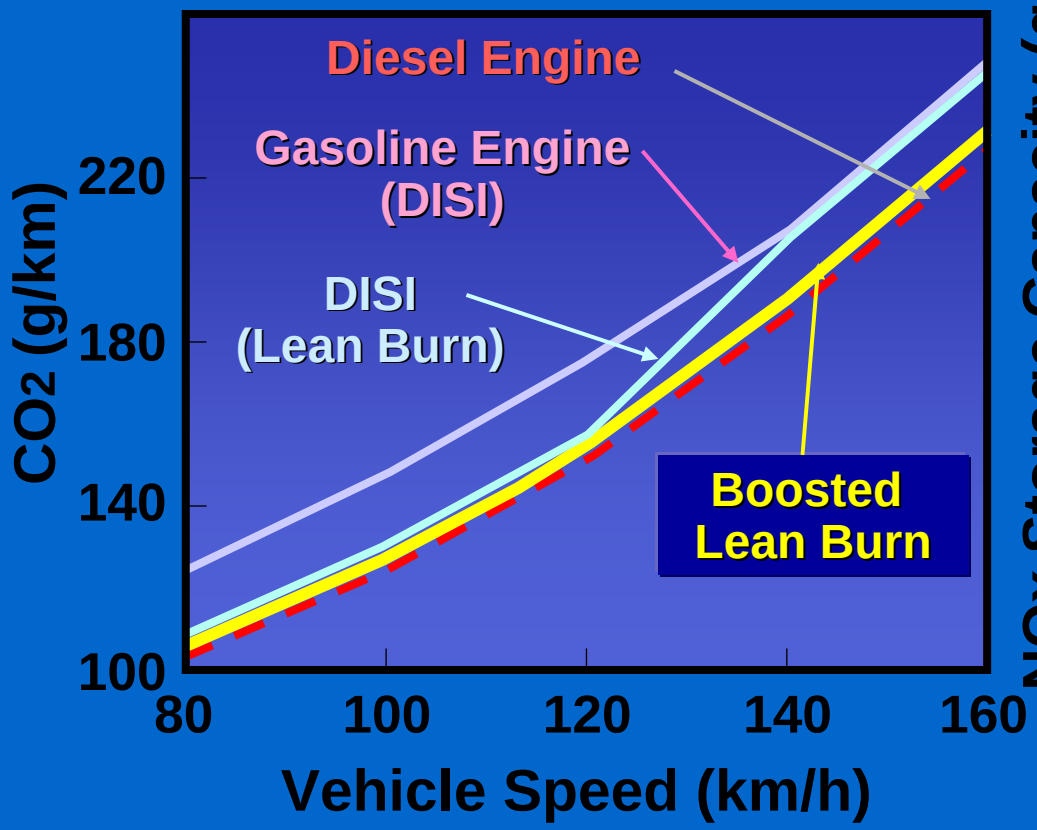
D-4: Direct injection 4-stroke gasoline engine

S : Superior

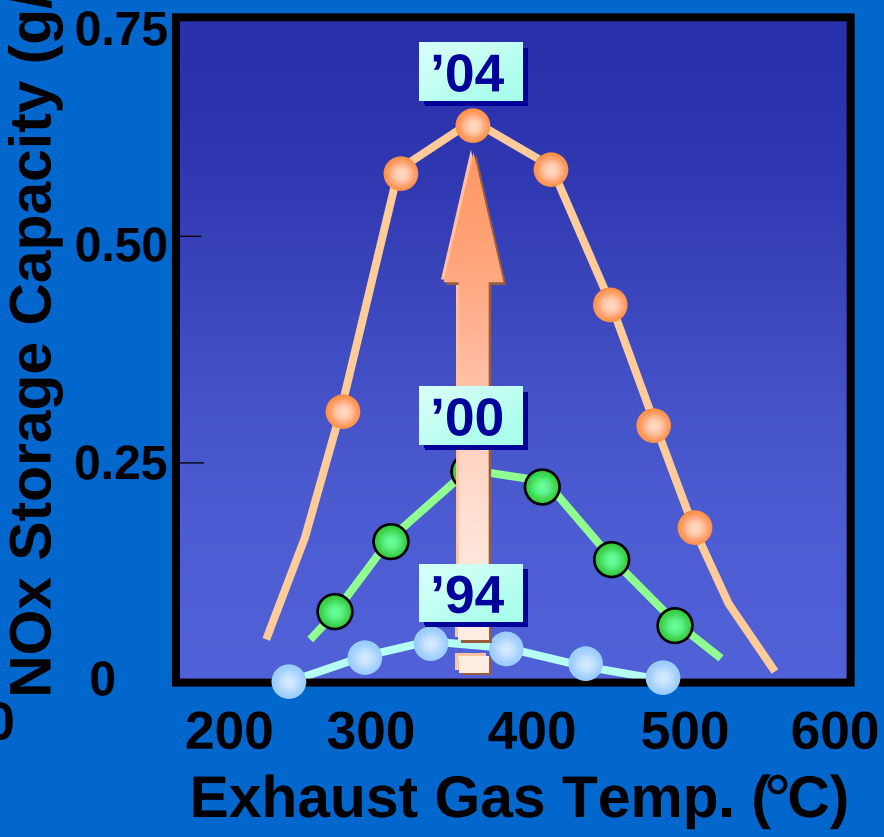


Evolution of DISI
(Boosted Lean Burn)

Effect of CO_2 Reduction



NSR Catalyst Performance

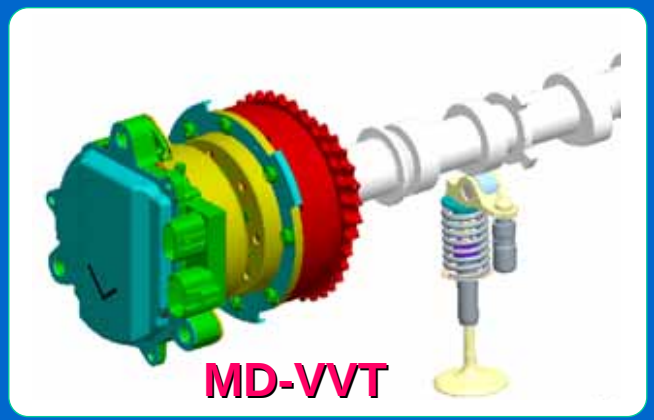


Development Issues

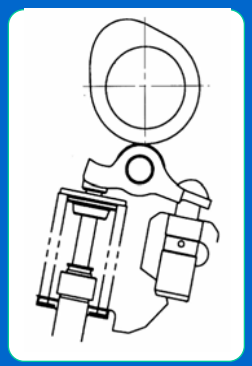
- Reduction of Engine Out Emission
- Improvement of NSR Catalyst

Technology Innovation in Valve System

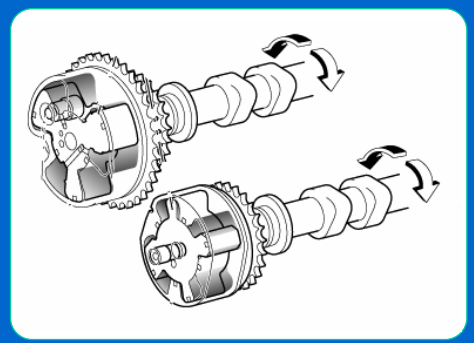
Original Technology



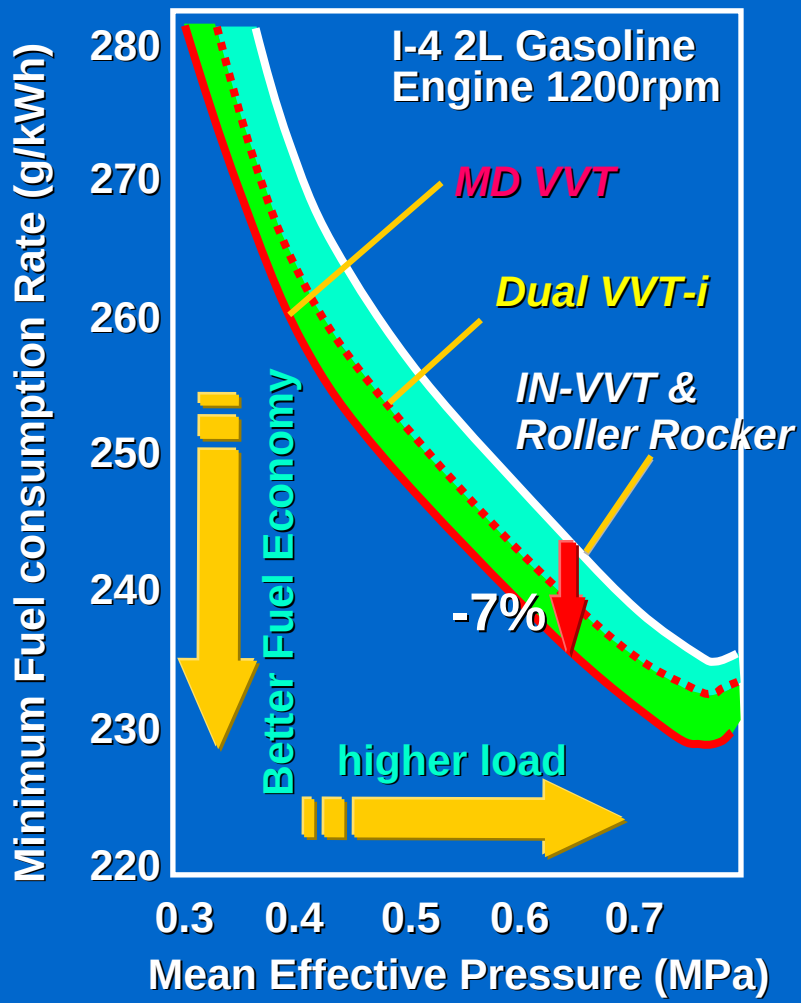
Standard Technologies



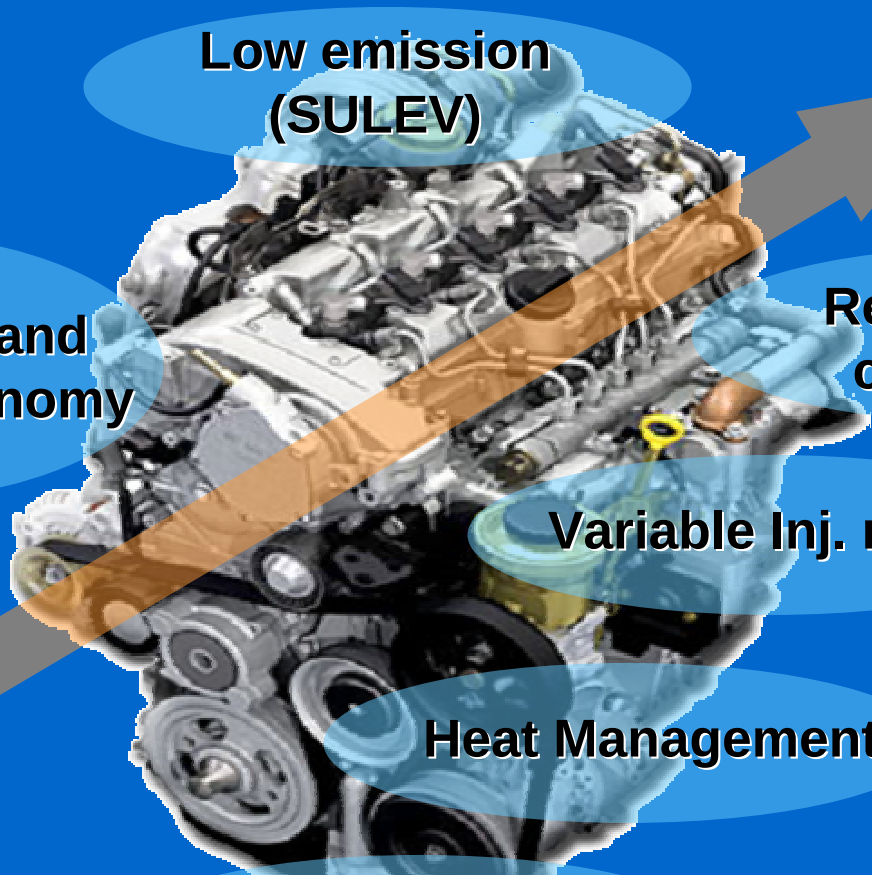
Roller Rocker Arm



Dual VVT-i



Technical Trends of CI Engines



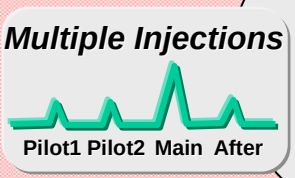
- Piezo Common rail
- Low Comp. Ratio
- 4-valve DOHC
- Variable Nozzle Turbo-charger
- Cooled EGR
- 4-way catalyst

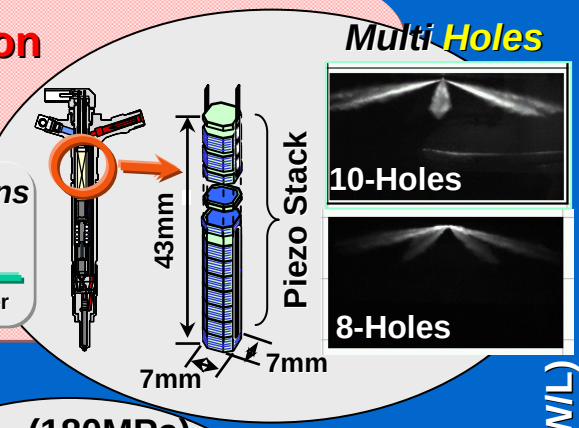
Progress of Diesel Engine Technologies

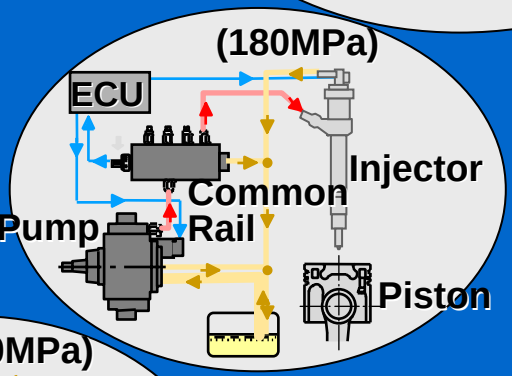
World Premiere

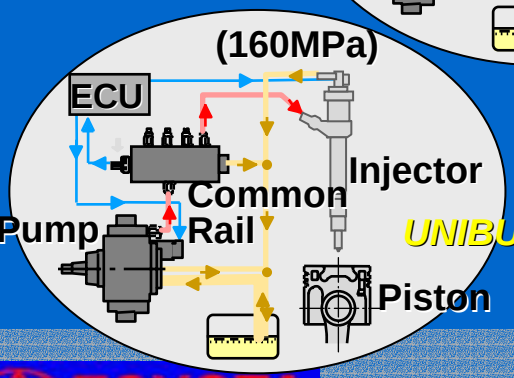
Low Compression Ratio (15.8)
+ Piezo Injector

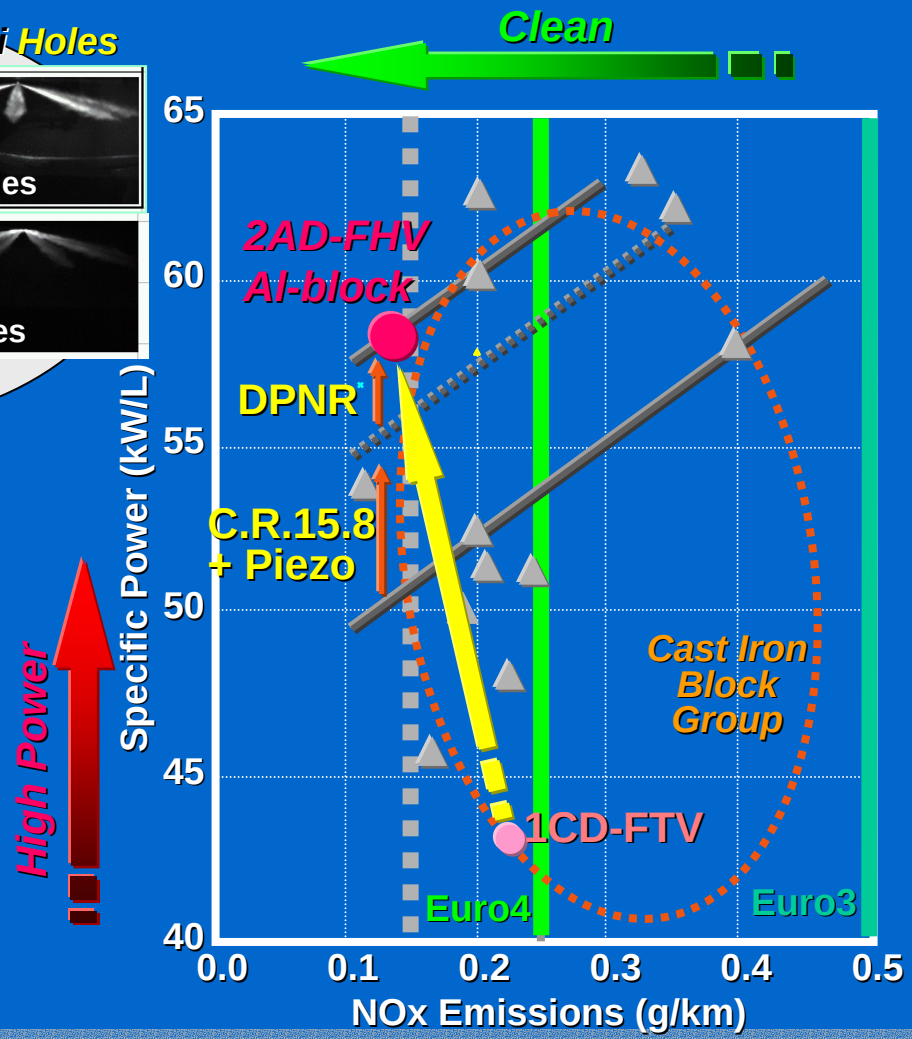
Multiple Injections



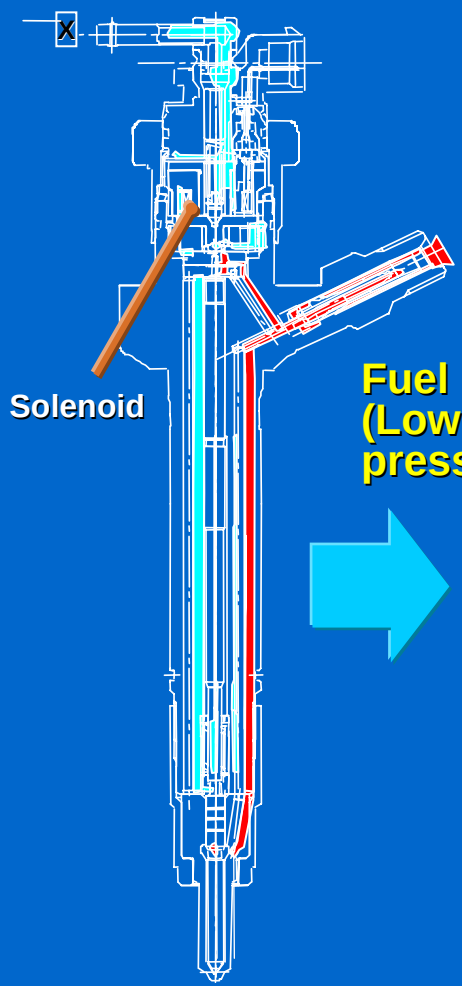




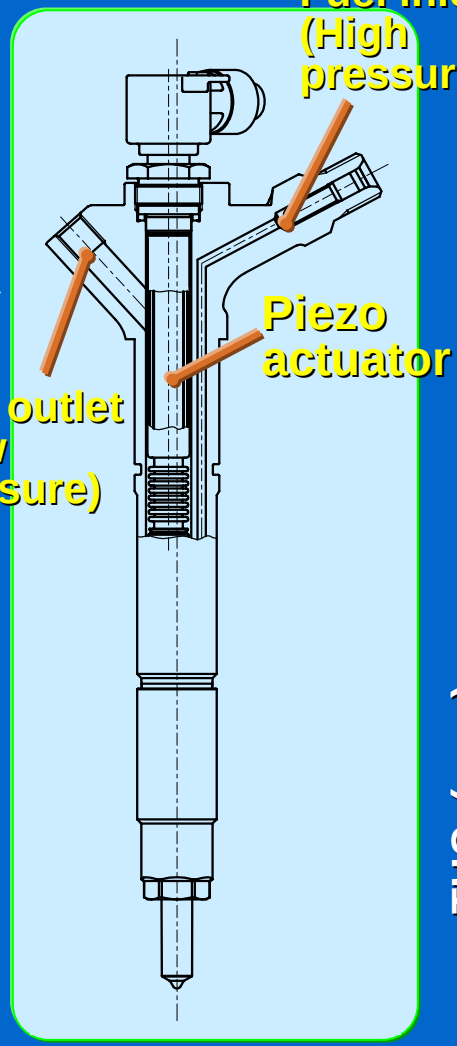




Progress of Diesel Injector

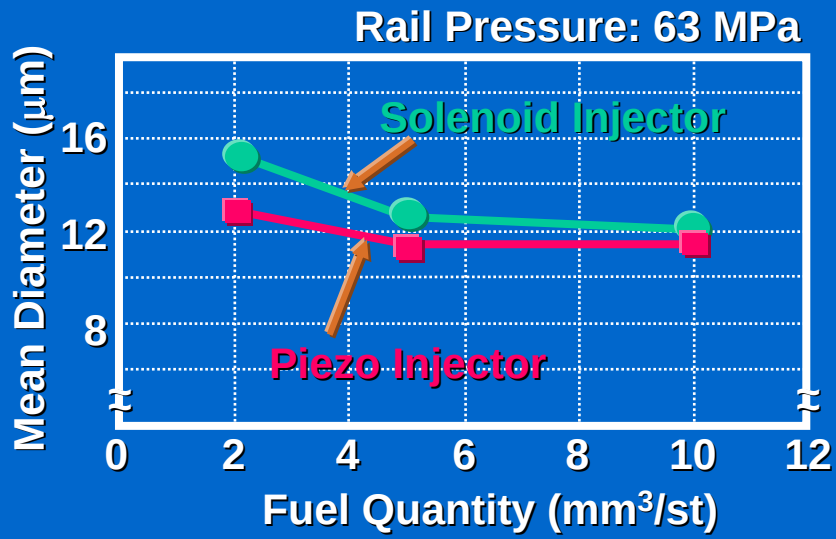


Solenoid Injector

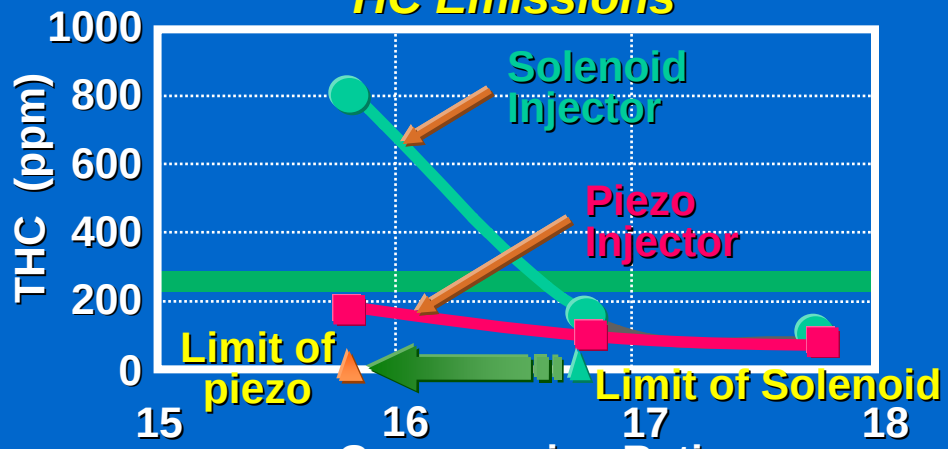


Piezo Injector

Spray Mean Diameters

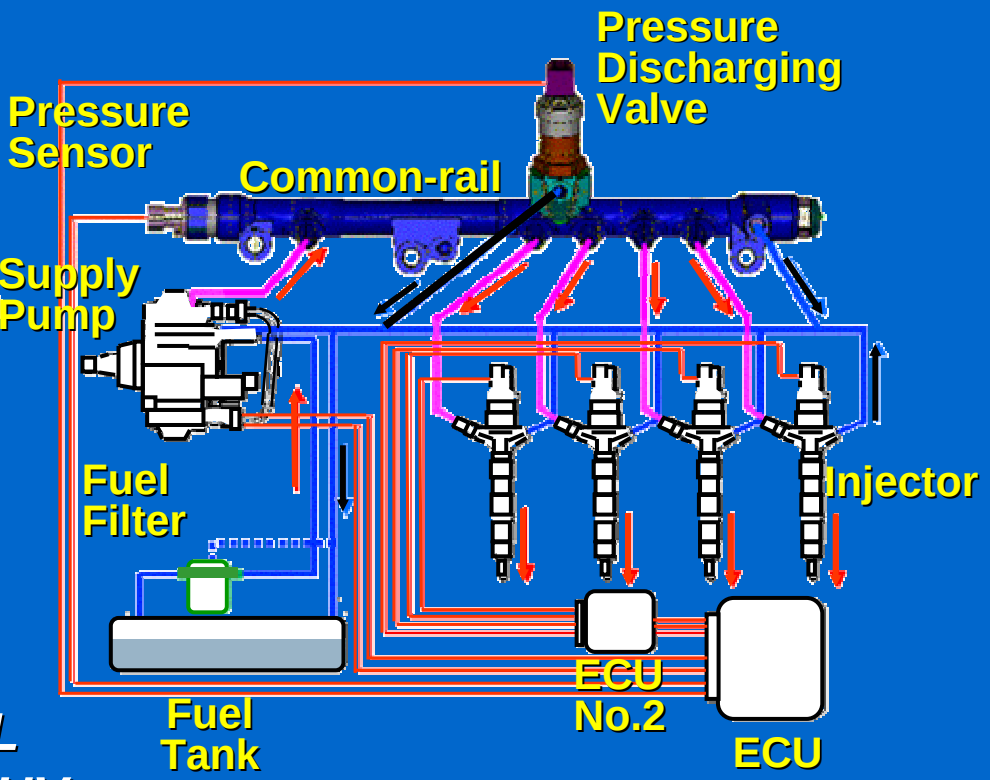


HC Emissions



New Diesel Engine

Common-rail injection system



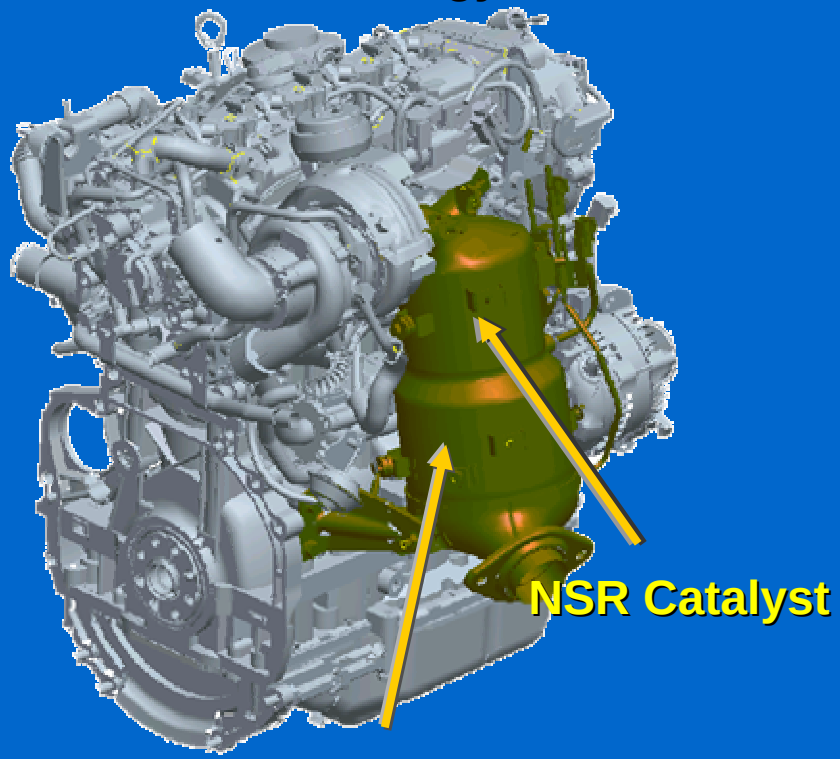
I-4 2.2L

2AD-FHV

- Piezo Injector 10-Hole Nozzle
- Fuel Pressure : 180 MPa
- Compression Ratio : 15.8
- DPNR (D-CAT)

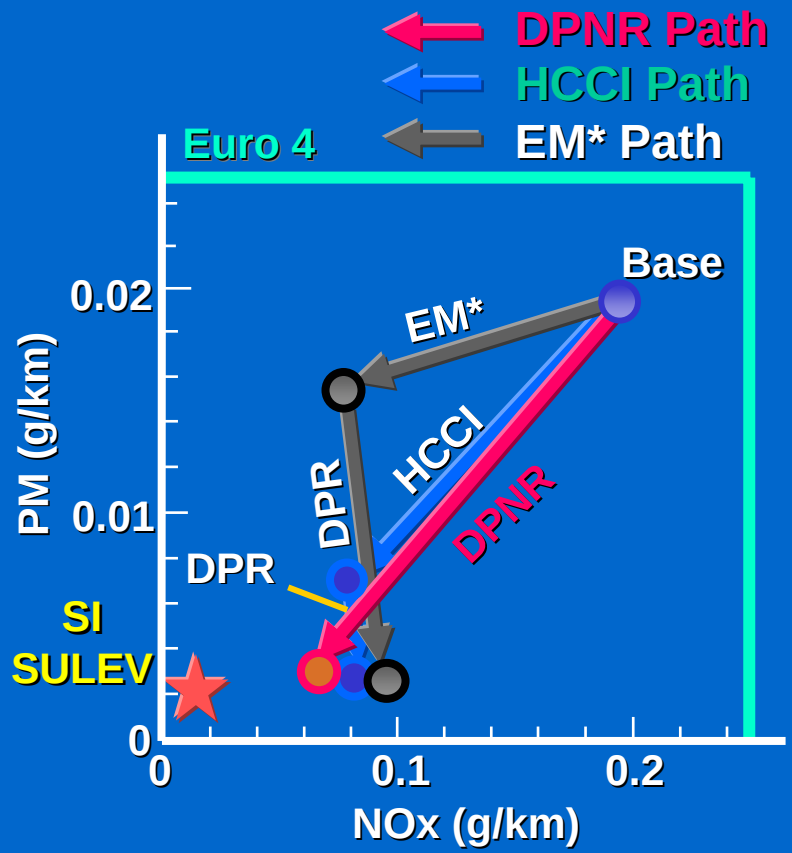
Diesel Aftertreatment (D-CAT)

D-CAT: Diesel-Clean Advanced Technology



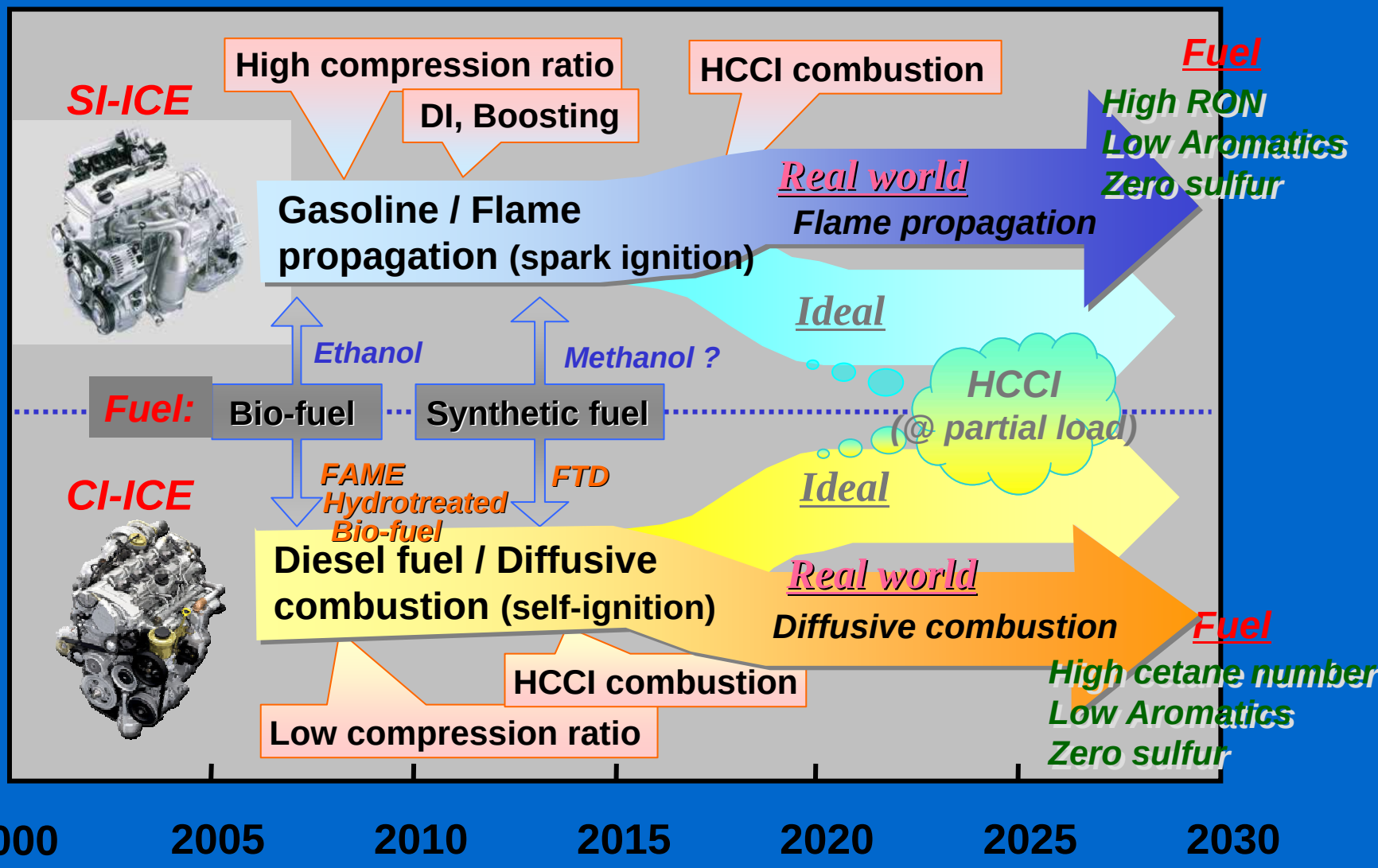
NSR : NOx Strage Reduction
DPNR : Diesel Particulate NOx Reduction

Diesel Low Emission Concept



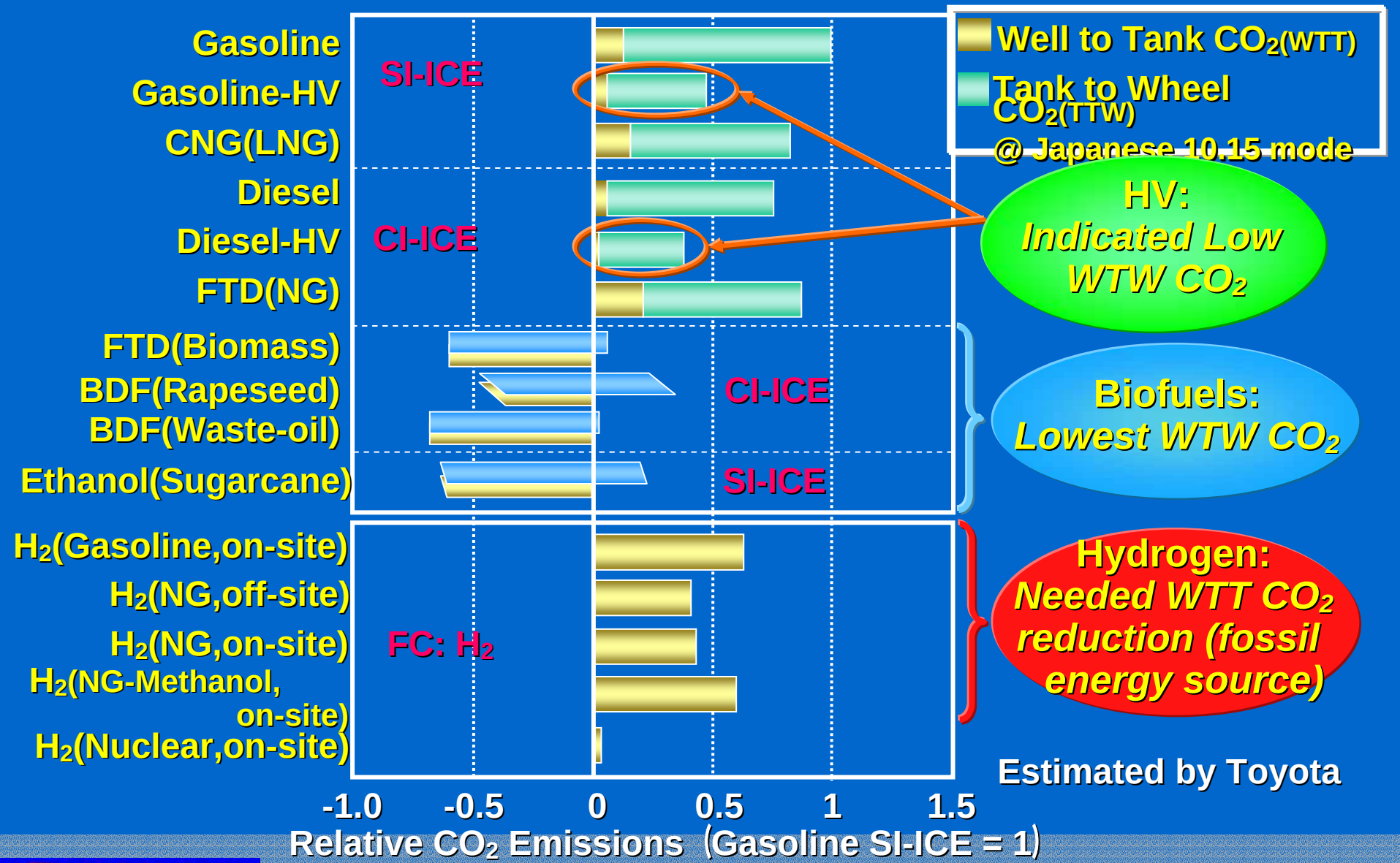
EM* : Engine Modification
Low Compression Ratio
+ Large EGR Cooler

Future Outlook of ICE's Evolution

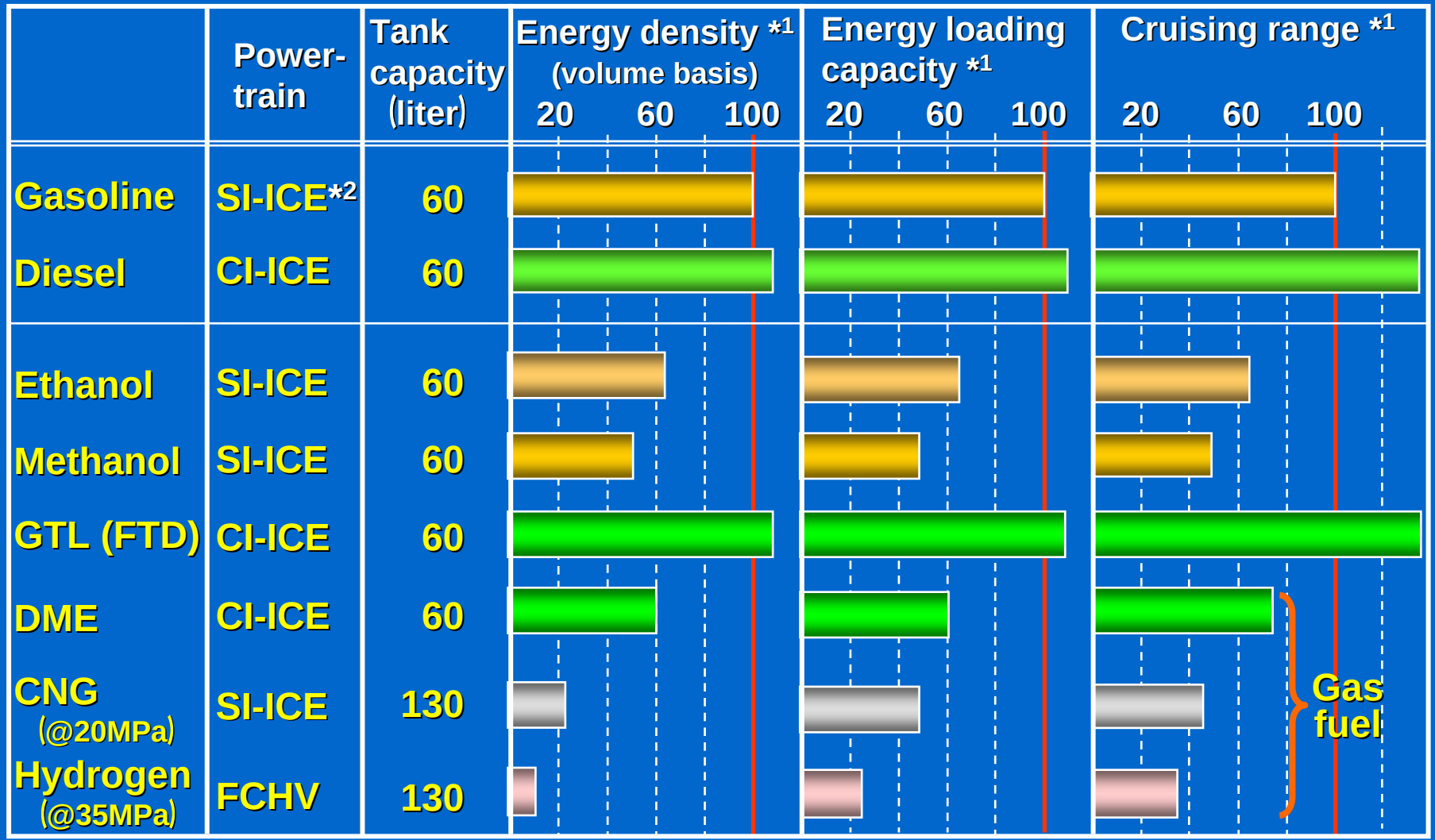


Utilization of Alternative Fuels

Well to Wheel CO_2 in Japan



Mileage of Alternative Fuel Vehicles

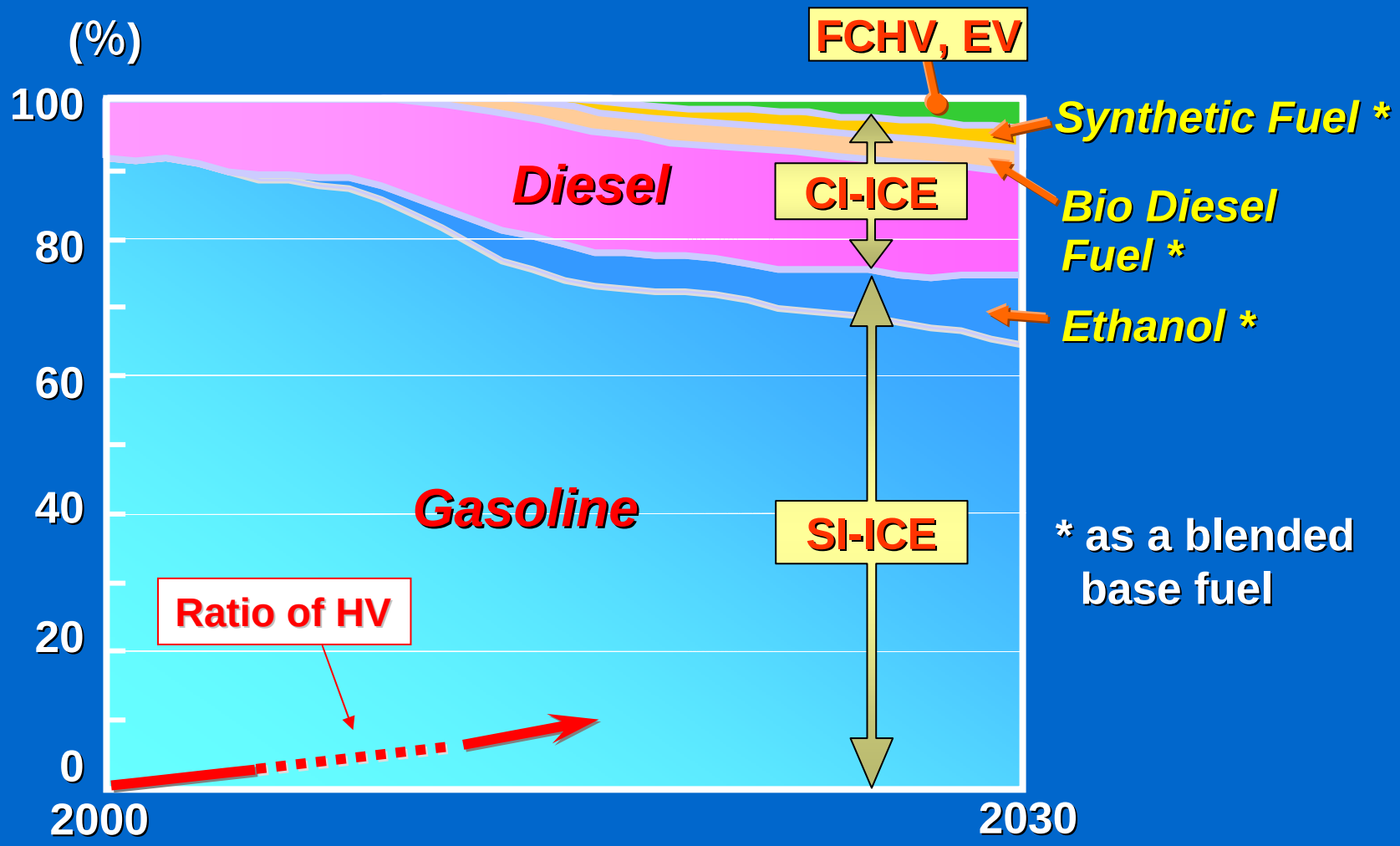


*1 relative value based on gasoline (= 100)

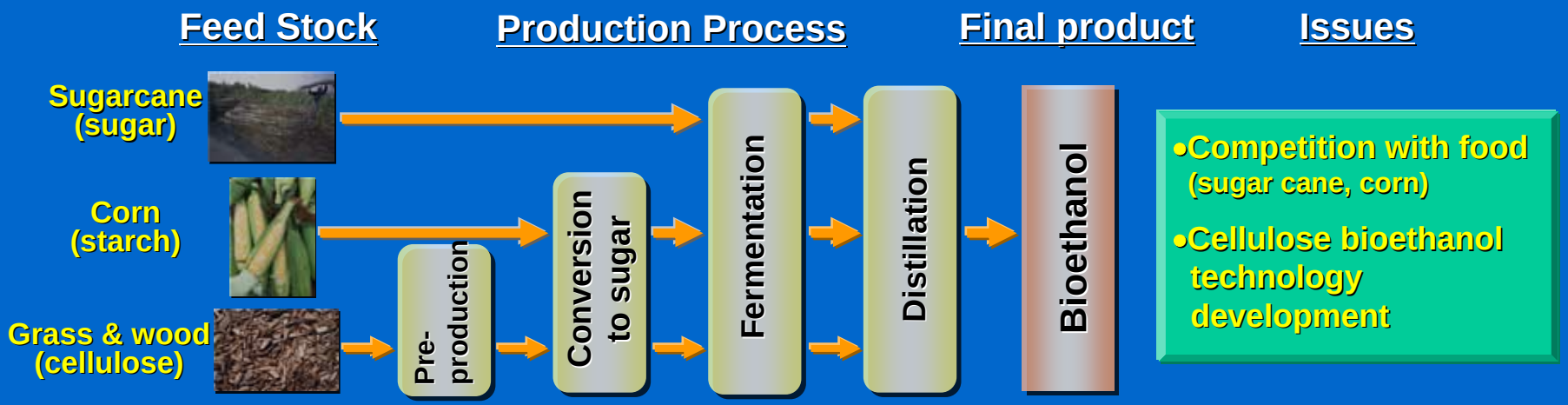
*2 ICE : 2 liter engine for passenger car with 1.5 ton inertia weight

Estimated by Toyota

Forecast of Powertrain and Fuels in Toyota Global Production



Steps to Introduce Bioethanol

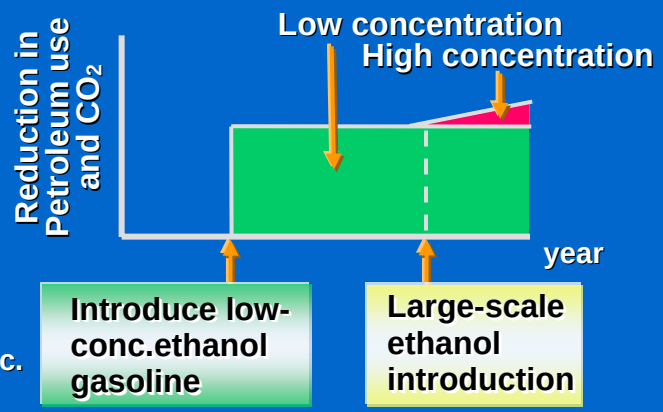


Measures needed to handle bioethanol fuel

	Low concentration (up to E10)	High concentration
Vehicle	Already prepared	•Need to develop special vehicles •Worsening of fuel economy
Filling stations	Use existing pumps	Install special pumps

Issues Vehicle; Fuel tube corrosion, rubber part expansion, start up in cold, etc.
Filling stations; Hose deterioration, rubber seal expansion, etc.

Ideal format for bioethanol introduction



Bioethanol is suited to low-concentration blends for the time being

Steps to Introduce Bio-Diesel

FeedStock

Biomass (vegetable oils)

Rapeseed

Palm

Jatropha, sunflower…

Production process

Methanol → Trans-esterification → Fatty acid methyl ester (FAME)

Glycerin

Hydrogen → Hydro-cracking → Hydro-cracked oil

H_2O, CO_2, methane, etc.

Toyota in joint research with Nippon Oil Corp.

Final product

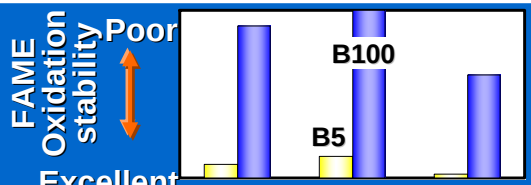
Issues
- Each country has own standards
- Need unified standards

Issues
- Water content, low-temperature viscosity

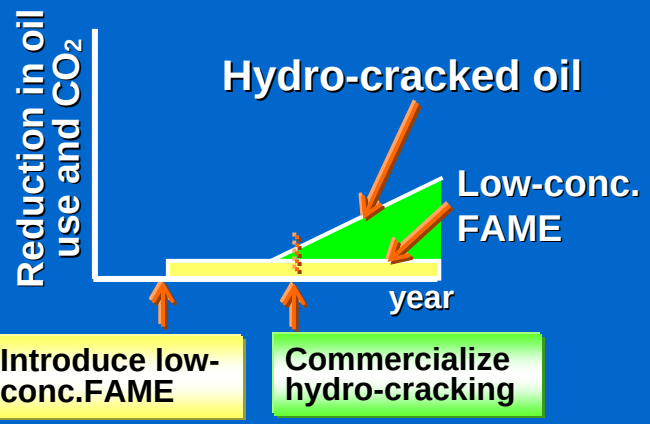
Bio-diesel characteristics

	Hydro-cracked vegetable oils	FAME	
		Low conc.(~B5)	High concentration
Oxidation stability	Excellent	Good	Poor Not suitable for vehicles
Other	Properties close to diesel		Impurity precipitation

Processed at oil refinery



The image for bio-diesel introduction



Biomass is suited to low-concentration FAME & hydrocracked vegetable oil applications

Fuel Cell

Significance of Fuel Cell

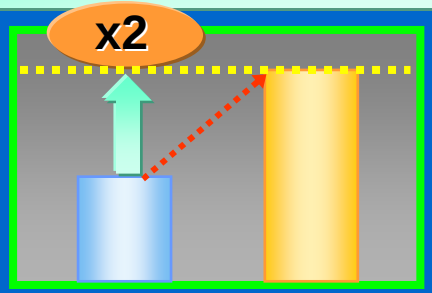
20th c.
Era of mass consumption of fossil oil

21st c.
Variation of energy source
Renewable energy society

- ***High efficiency*** — Higher efficiency than gasoline engine (in case of hydrogen)
- ***Zero emission*** — CO_2, NOx, HC, CO never exhausted
- ***Energy security*** — Variety of hydrogen supply (not only from crude oil)
- ***Low noise*** — No moving parts, no combustion

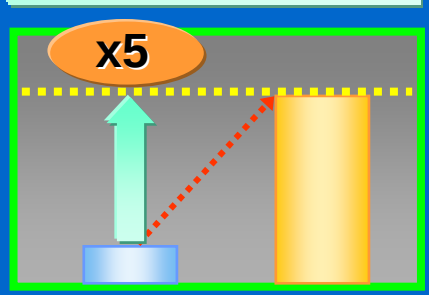
Technical Problems of Fuel Cell Vehicle

Power density



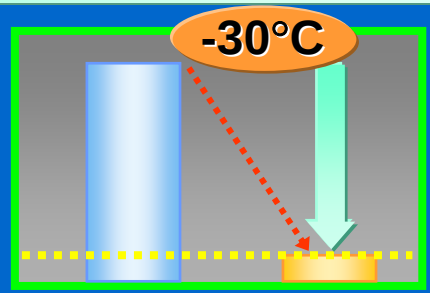
Current Target

Durability



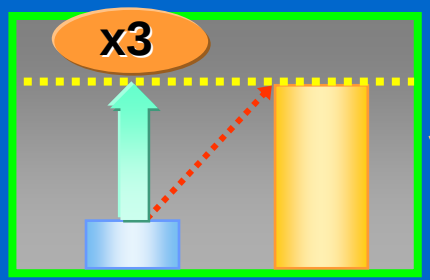
Current Target

Cold startability



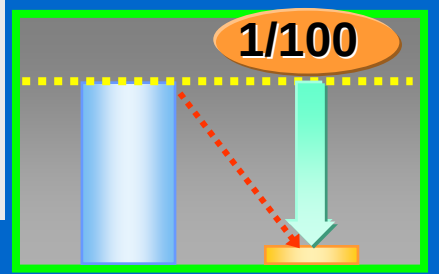
Current Target

Driving range



Current Target

Cost



Current Target

TOYOTA

Hydrogen Storage Technologies

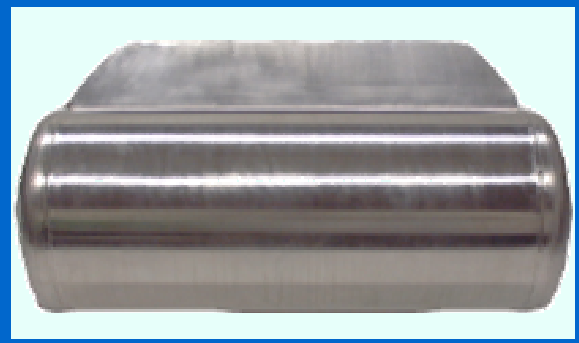
High pres. H_2 tank

Capacity

H_2 absorption alloy tank

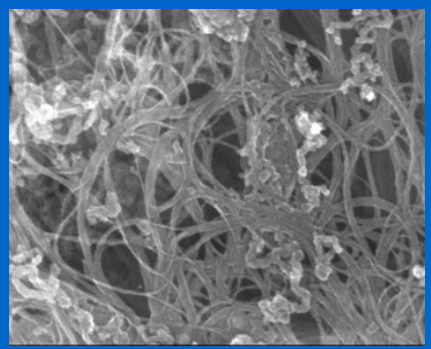
Weight

Liquid H_2 tank



Vaporization

Carbon nano tube



Potential

Chemical hydride

Hydroxide boron sodium (NaBH4)

Decalin ($C_{10}H_{18}$)

- H_2

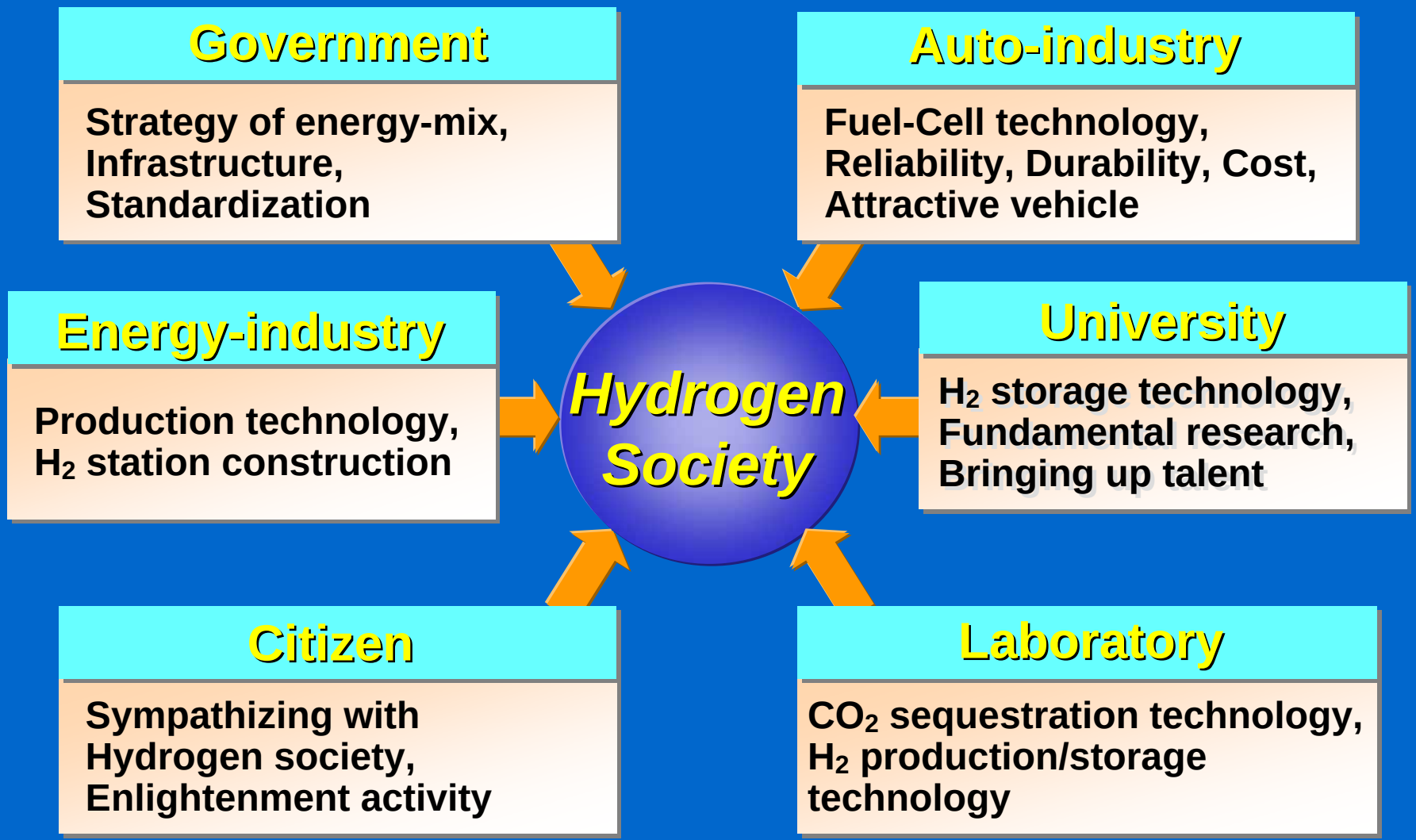
Catalyst

+ H_2

Naphthalene ($C_{10}H_8$)

Recycle

Challenge to Hydrogen Society

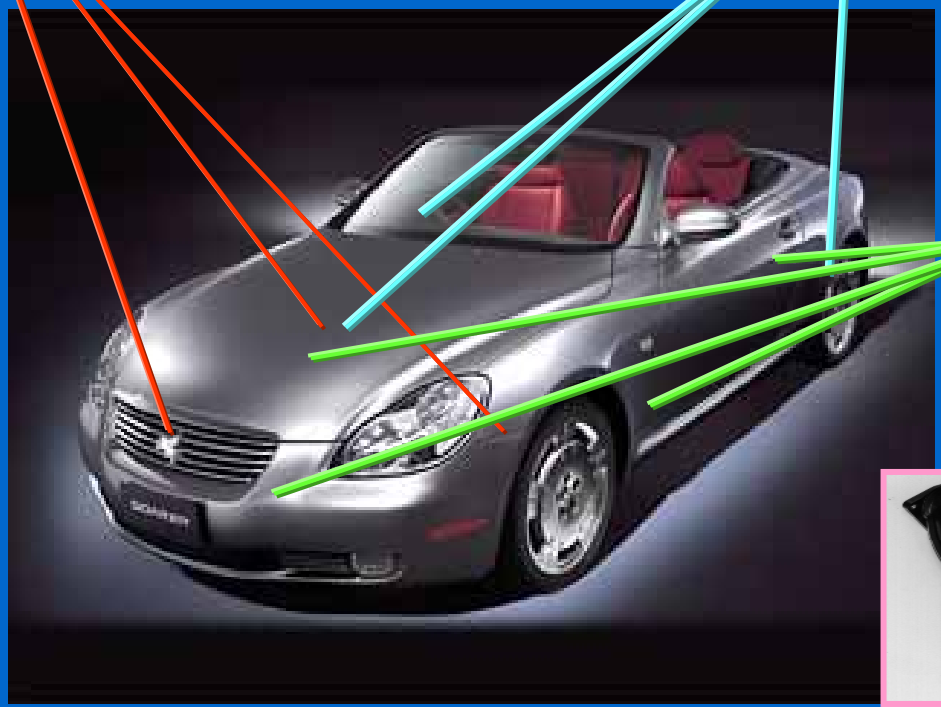


Weight Saving

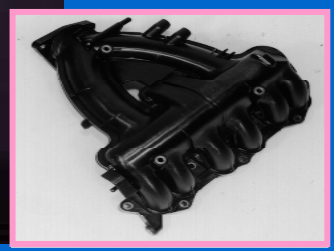
Examples of Weight Saving

Aluminum : Cylinder block,
Radiator,
Suspension member

Magnesium : Cylinder head-cover,
Steering wheel core,
Disc wheel



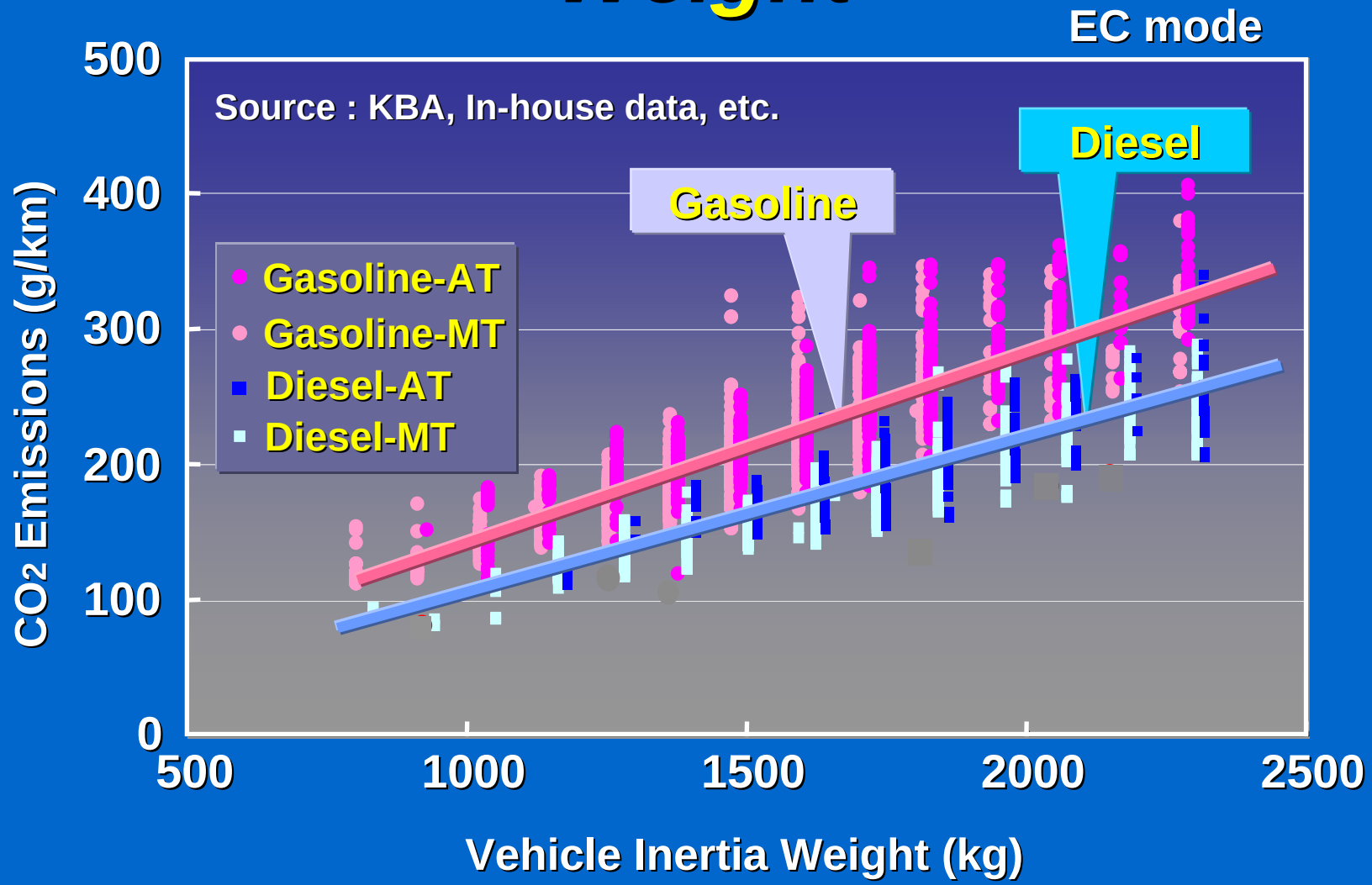
Plastic : Intake manifold,
Bumper,
Propeller shaft,
Fuel tank



Plastic intake manifold :
Weight –25%

Plastic fuel tank :
Weight –27%

Relation between CO_2 and Vehicle Weight



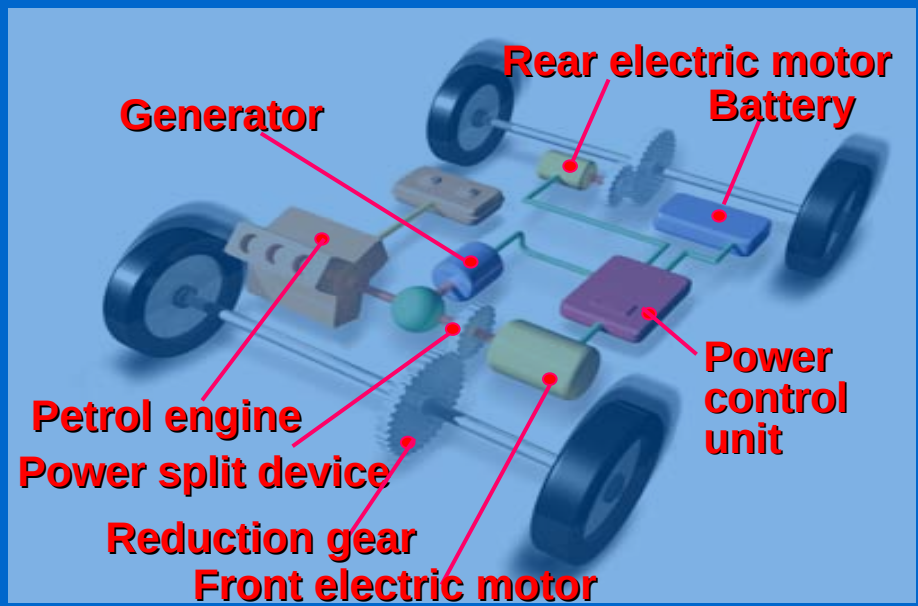
1. Circumstances of Automotive Society
   - Energy Sources and Global Warming
2. Improvement of Thermal Efficiency of Engines
   - Internal Combustion Engine (Gasoline, Diesel)
   - Alternative Fuels
   - Fuel Cell
   - Weight Saving
3. Effective Energy Utilization
   - Hybrid Technology
   - Improvement of Traffic Situations

Hybrid Technologies

Hybrid Vehicles (Gasoline-electric)

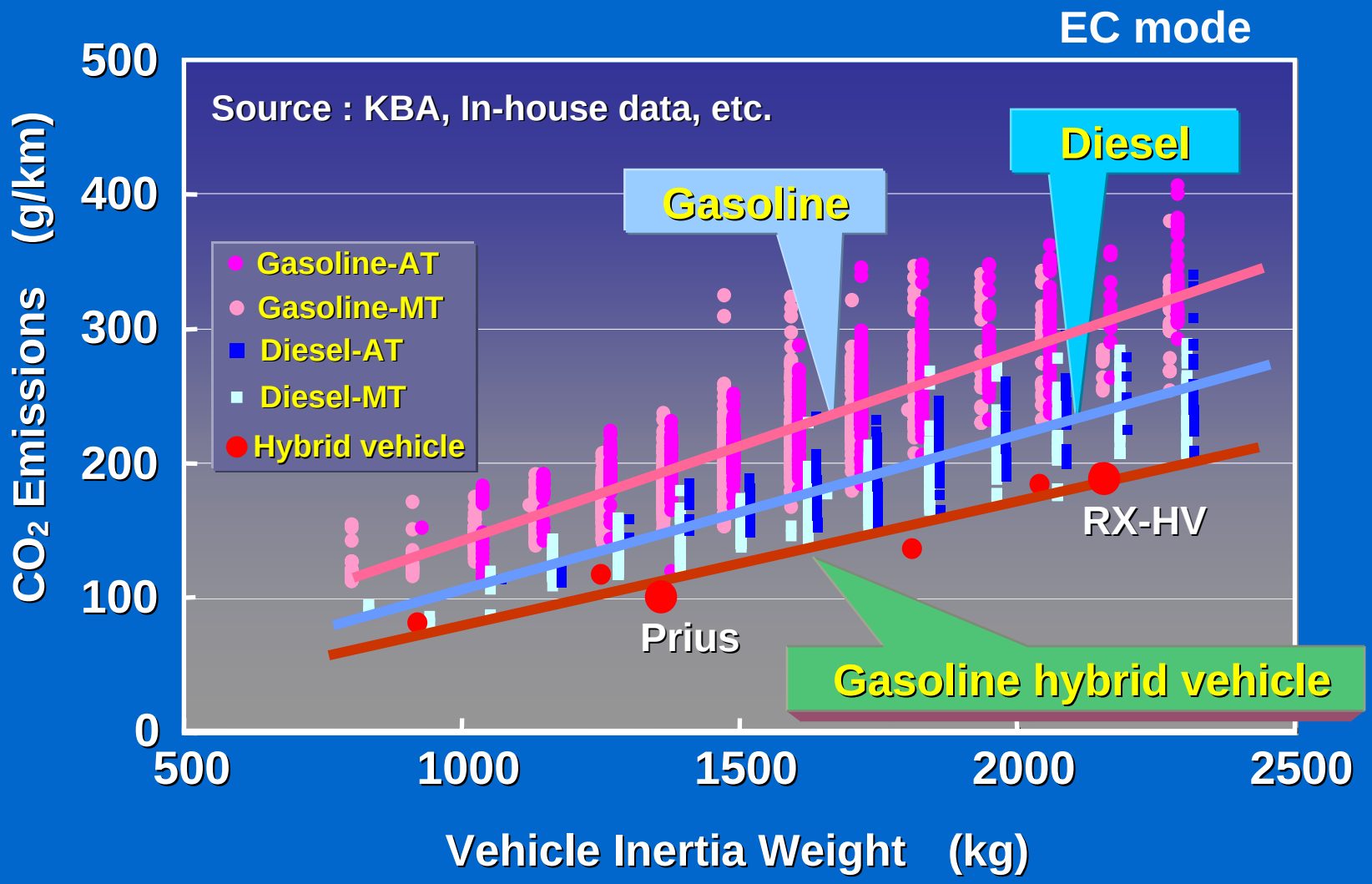
Merits of hybrid vehicle

- Fuel consumption
- Drivability
- Emissions
- Noise

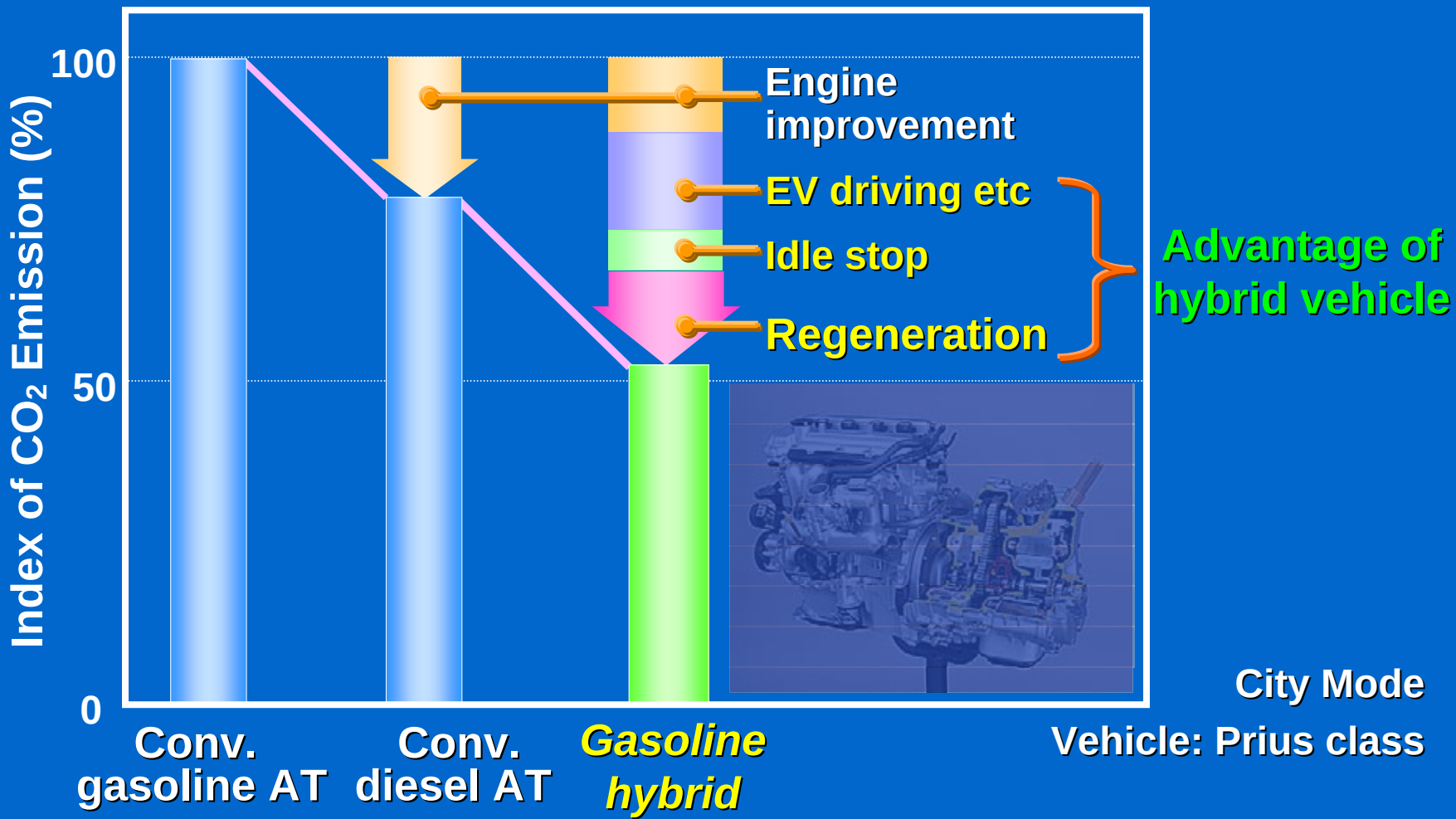


Toyota Hybrid System–II (THS-II) for V-6 SUV

CO_2 Potential of Hybrid Vehicles

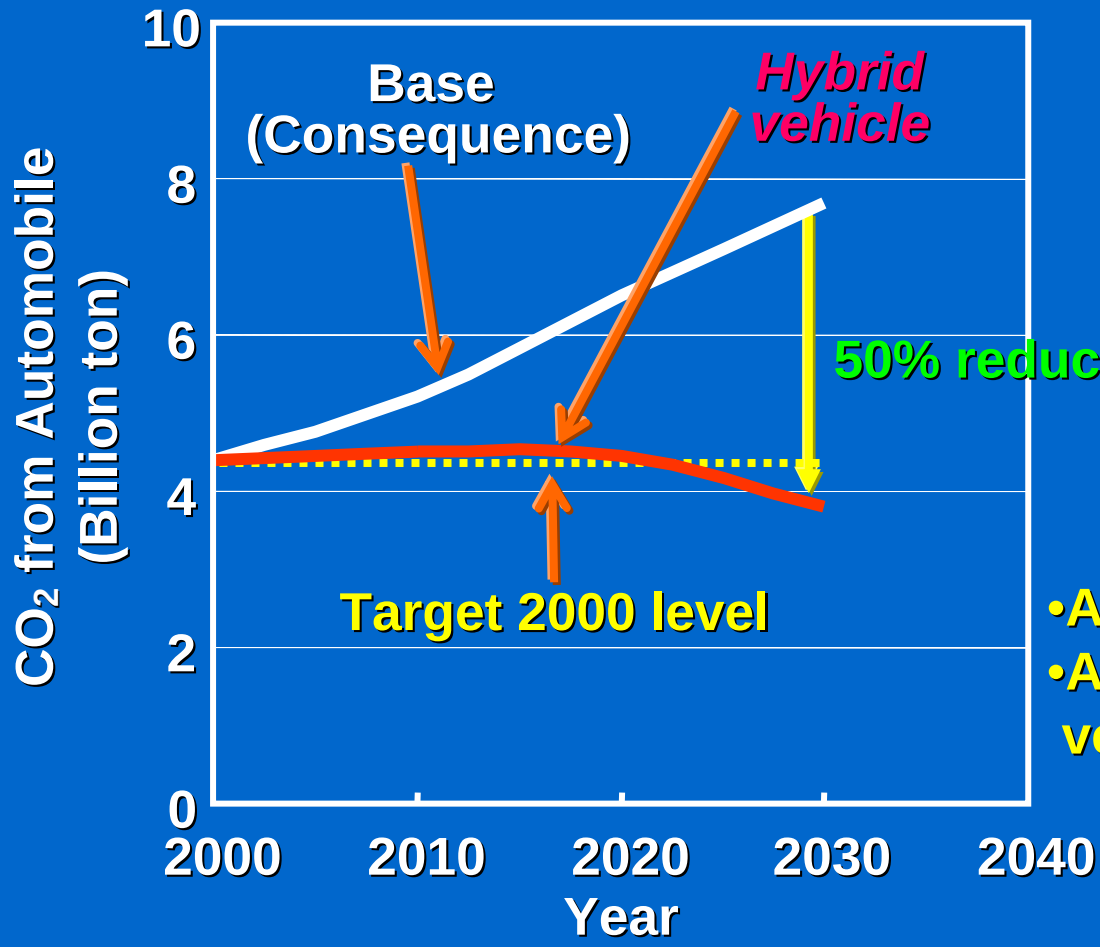


CO_2 Reduction by Hybridization



- *Hybrid vehicle has advantages to recover and minimize energy loss.*
- *50% reduction of CO_2 and improved fuel efficiency can be achieved.*

Case Study of CO_2 Reduction by Promotion of Hybridization



- All hybridized in 2030
- Added on engine and vehicle improvements

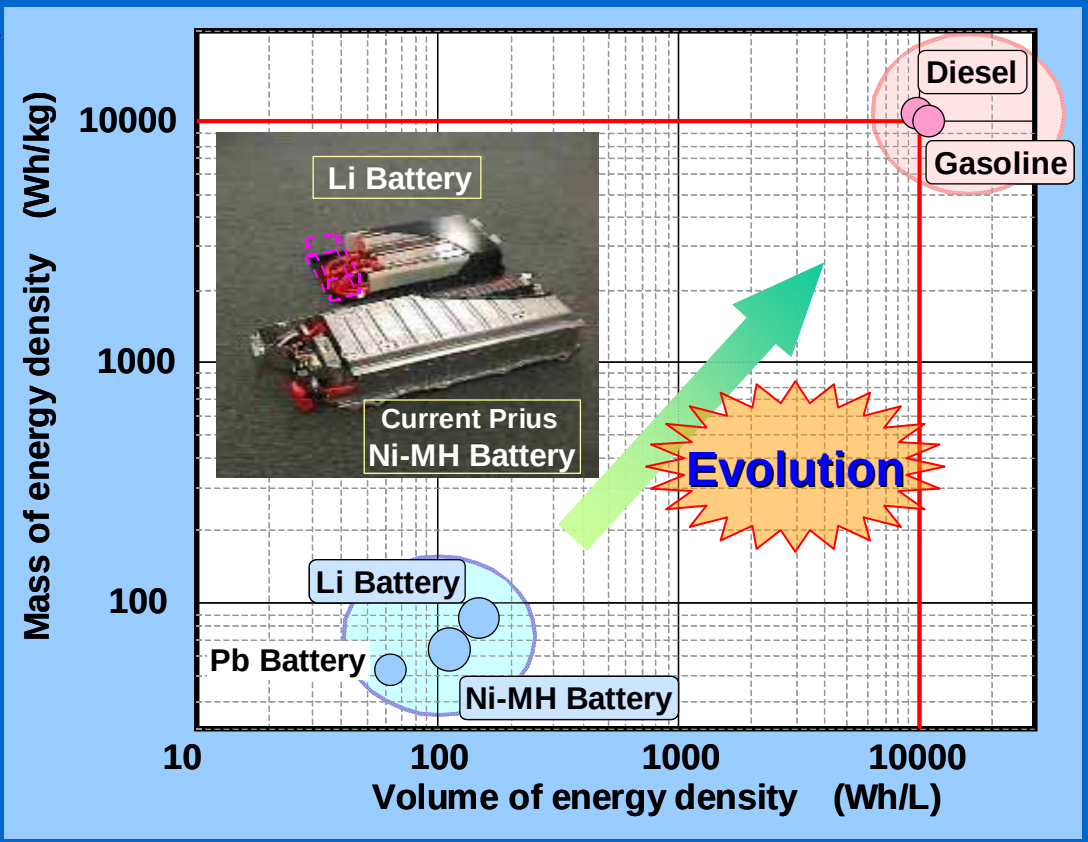
- *If all vehicles in the world were hybridized, it would be possible to reduce CO_2 to year-2000 levels.*

Evolution of Hybrid Technologies

Direction of hybrid technology improvement

- ***Battery***
  - -High energy density
  - -Size & weight reduction
- ***Motor***
  - -High power
  - -Size & weight reduction
- ***Inverter***
  - -High efficiency
  - -Size & weight reduction

Energy Density of Battery

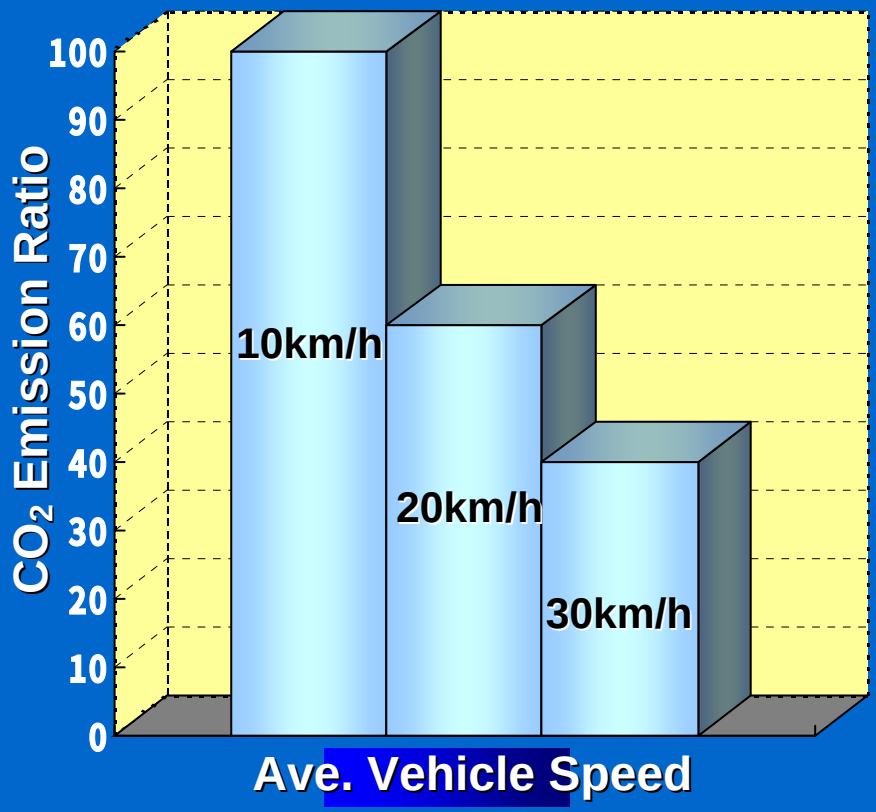


Improvement of Traffic Situations

CO_2 Reduction by Traffic Measures

Average Vehicle Speed in Test Modes

Japanese 10.15	22.7km/h
US LA#4	31.5km/h
EU	33.6km/h



(Data : Japan Automobile Research Institute)

- *Average speed in Japan is lower than EU and US.*
- *Traffic jam in city area is the main reason.*
- *Average speed increase is effective to fuel consumption.*

Effect of CO_2 Reduction in Toyota City

Toyota IC to Toyota-cho (4.2km)

	Speed(km/h)		Traffic volume (vehicles/2.5hrs)
	ave.	peak	
Before	9	6	2355
After road development	16	13	2602

CO_2 reduction (7:00 to 9:30am)

CO_2 (Kg-CO_2)	Reduction
3883	-
3230	-17%

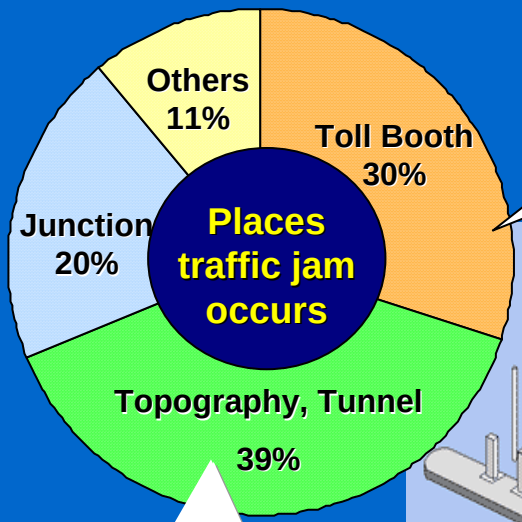
(CO_2 emission volumes were estimated using the unit of emission per speed stipulated by Public Work Research Institute of the former Ministry of Construction)

✧The data shown here reflects only one day's sampling in each instance

Average speed increased from 9 to 16km/h → *17% reduction of CO_2*

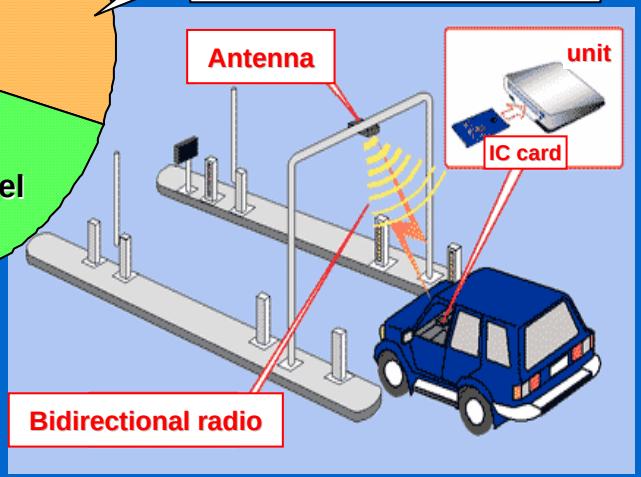
Countermeasures by ITS

Countermeasure : 1



Lack of capacity
→ ETC

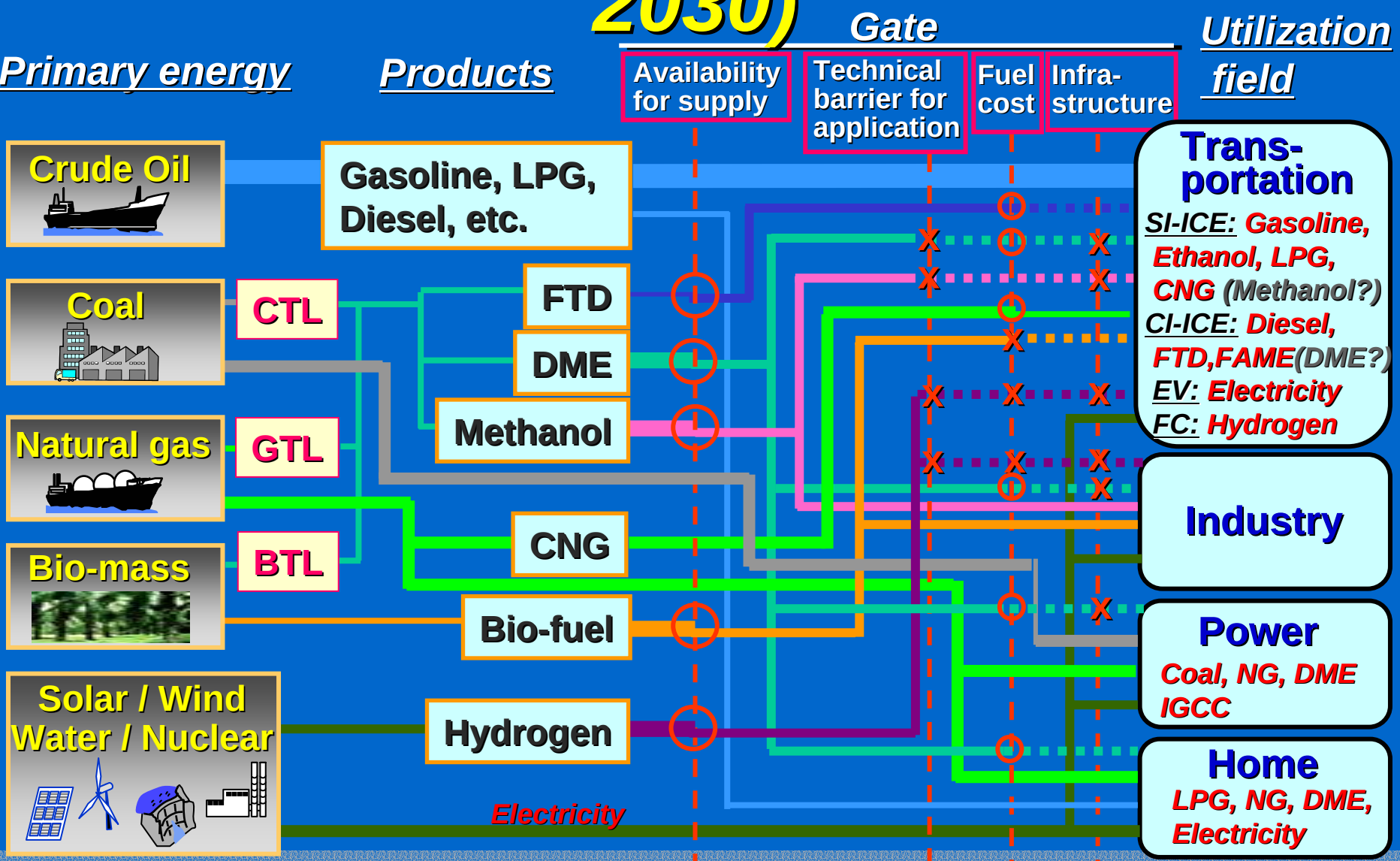
Driving assist



Countermeasure : 2

ITS : Intelligent Transport Systems

Future Energy Utilization (until 2030)




Thank you for your attention