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Future Trend and New Engine Technologies to Meet Emission Regulations

HANYANG UNIVERSITY

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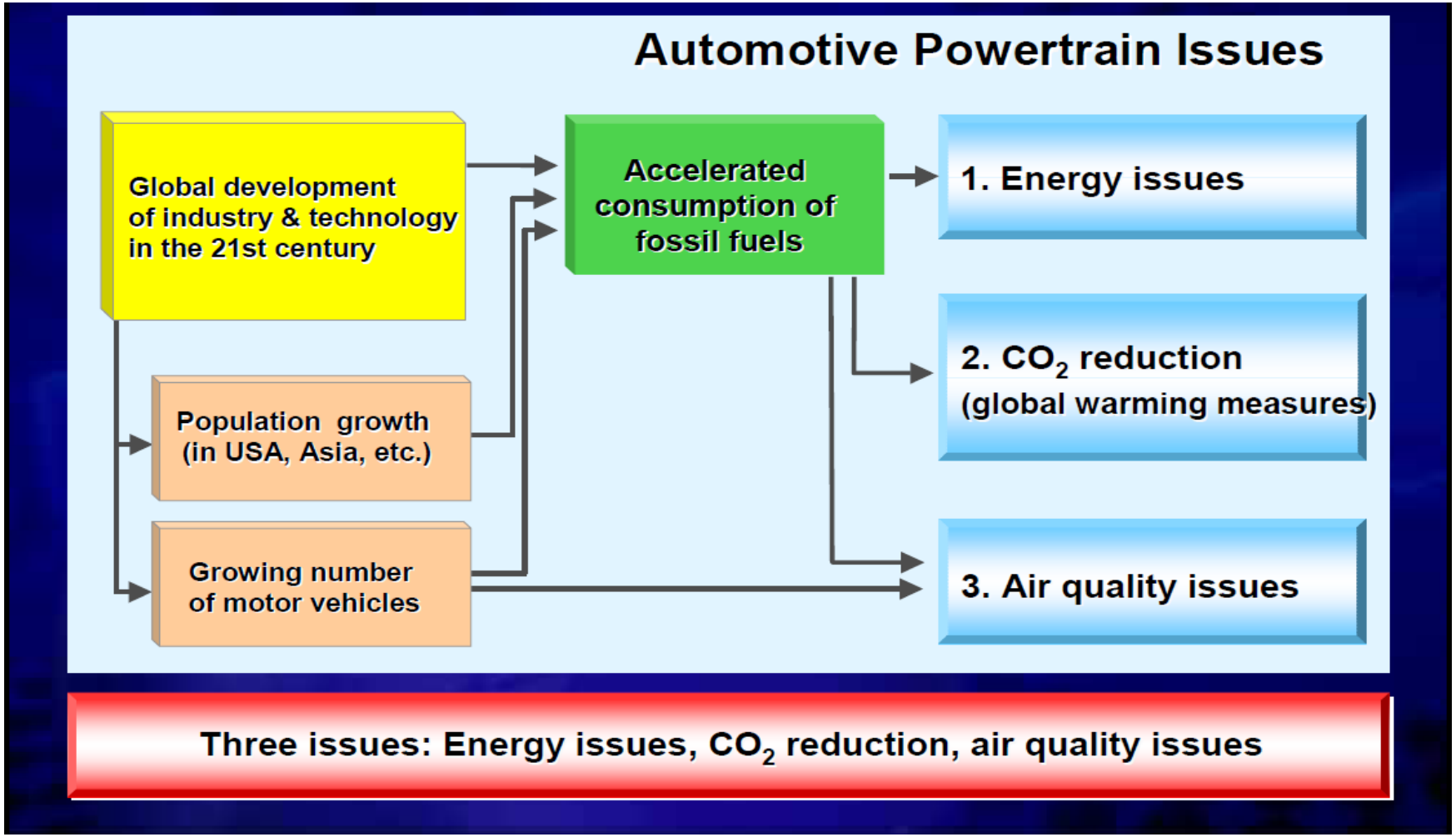
Global megatrends impacting our business

Automated mobility
Urban mobility
Connected services
Electrification
Efficient combustion engines
Comfortable travel
Recharging infrastructure
Near Zero Impact on Air Quality
Hybrid powertrains
Connected mobility
Alternative fuels
Efficient transport and logistics
Affordable mobility
Driving pleasure with powerful performance
Electromobility

Source: BOSCH

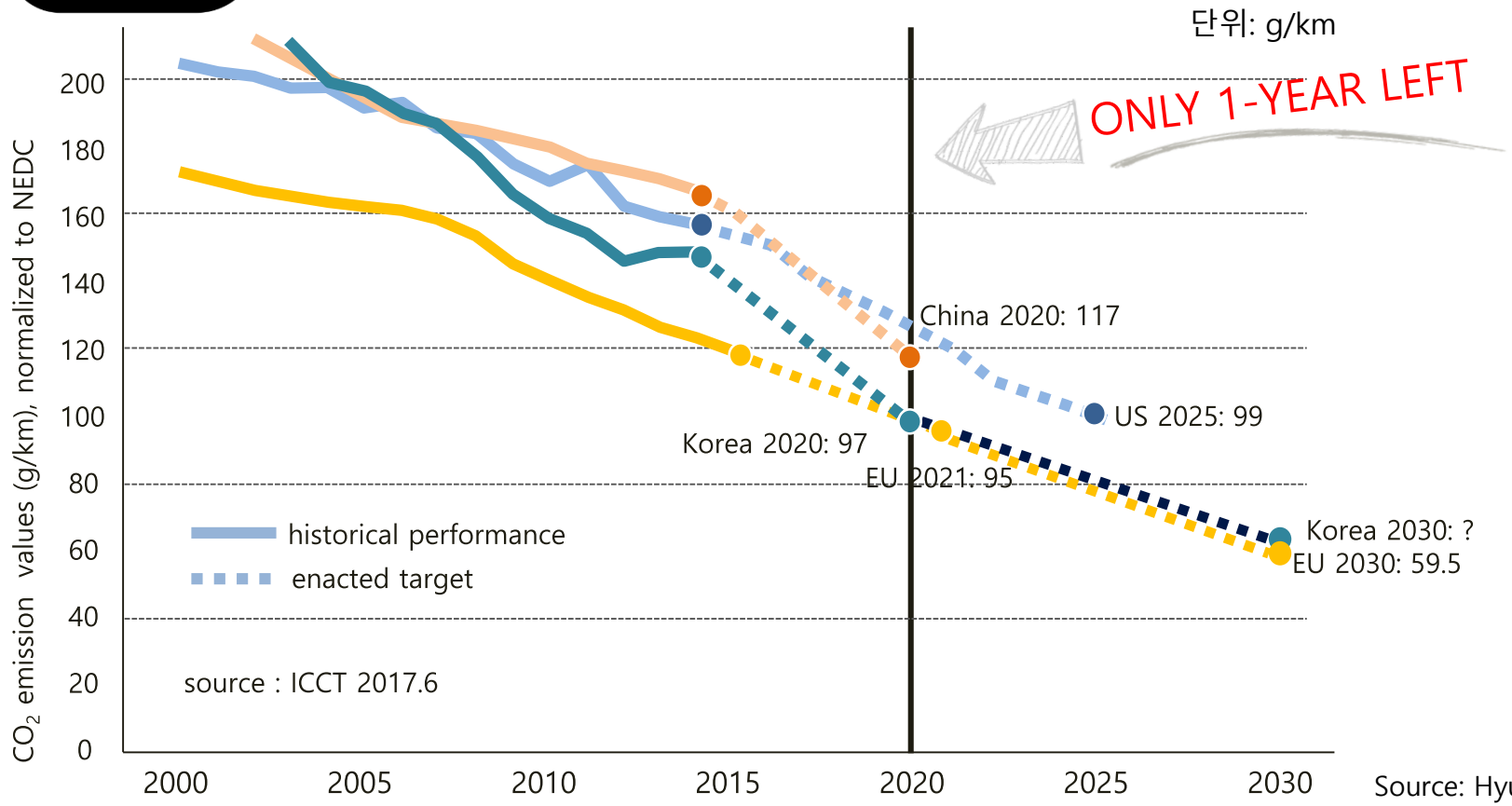
Awareness of Issues



Source : Toyota

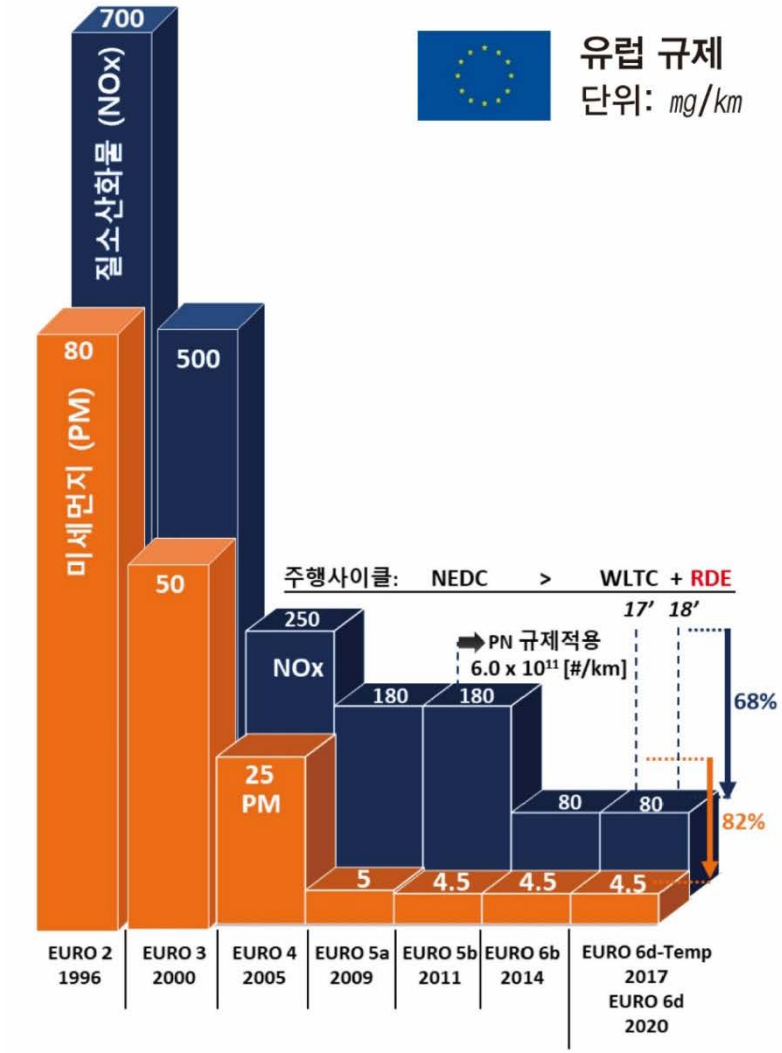
CO_2 Regulation for various countries

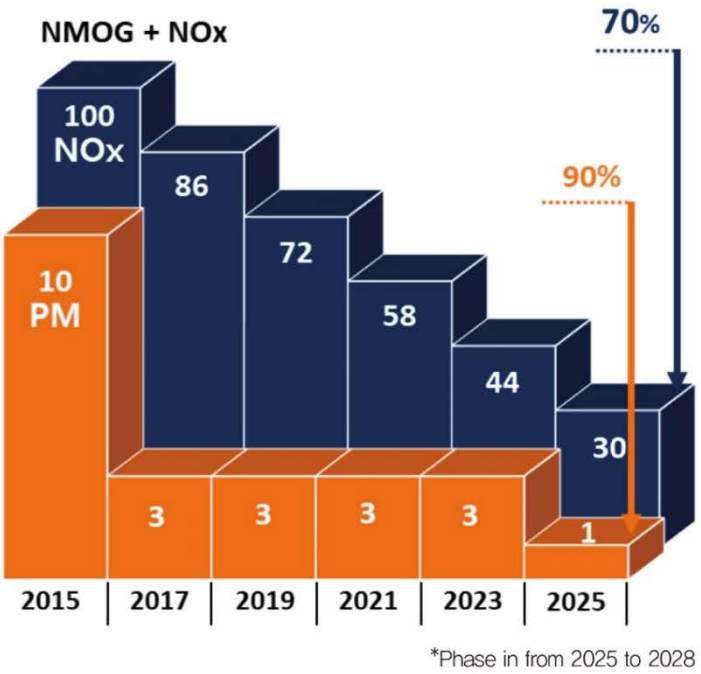
- EU 2030년, 2021년 대비 37.5% 감축 결정 (~ 60g/km)
- USA: 40 (2017) → 56 mpg (2025)
- China: 6.4 (2017) → 4.0 L/100km (2025)
- Korea: 140 (2017) → 82 g/km (2025)



Source: Hyundai

Exhaust Emission Regulations(PM, NOx)





How to prepare for 2030 ?

- Improvement of thermal efficiency for current engines
- Find the new powertrain source for 2030

Source: Hyundai

Powertrain trend beyond 2025

High energy battery
Increase mileage
Building Infrastructures
Cost competitiveness

Improve engine efficiency
Increased engine performance
Synthetic fuel development
Component Quality Management

Diversification of power sources

Electric vehicle

Plug-in hybrid

ICE

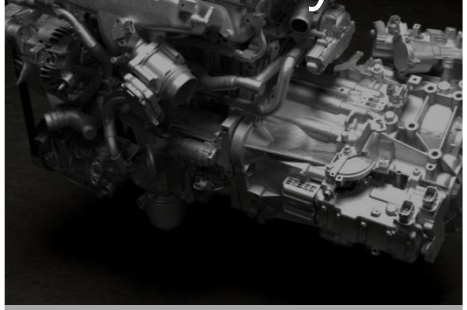
Renewable energy

Source: Hyundai

Trend of Powertrain - key strategy for 2030

CO_2 0 %

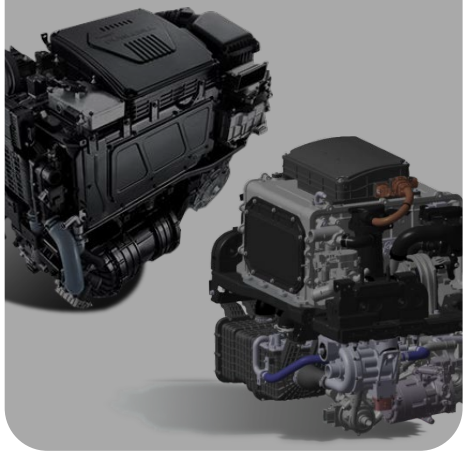
Improve powertrain efficiency



Renewable energy

MHEV, PHEV
HEV, EV

Fuel cell EV

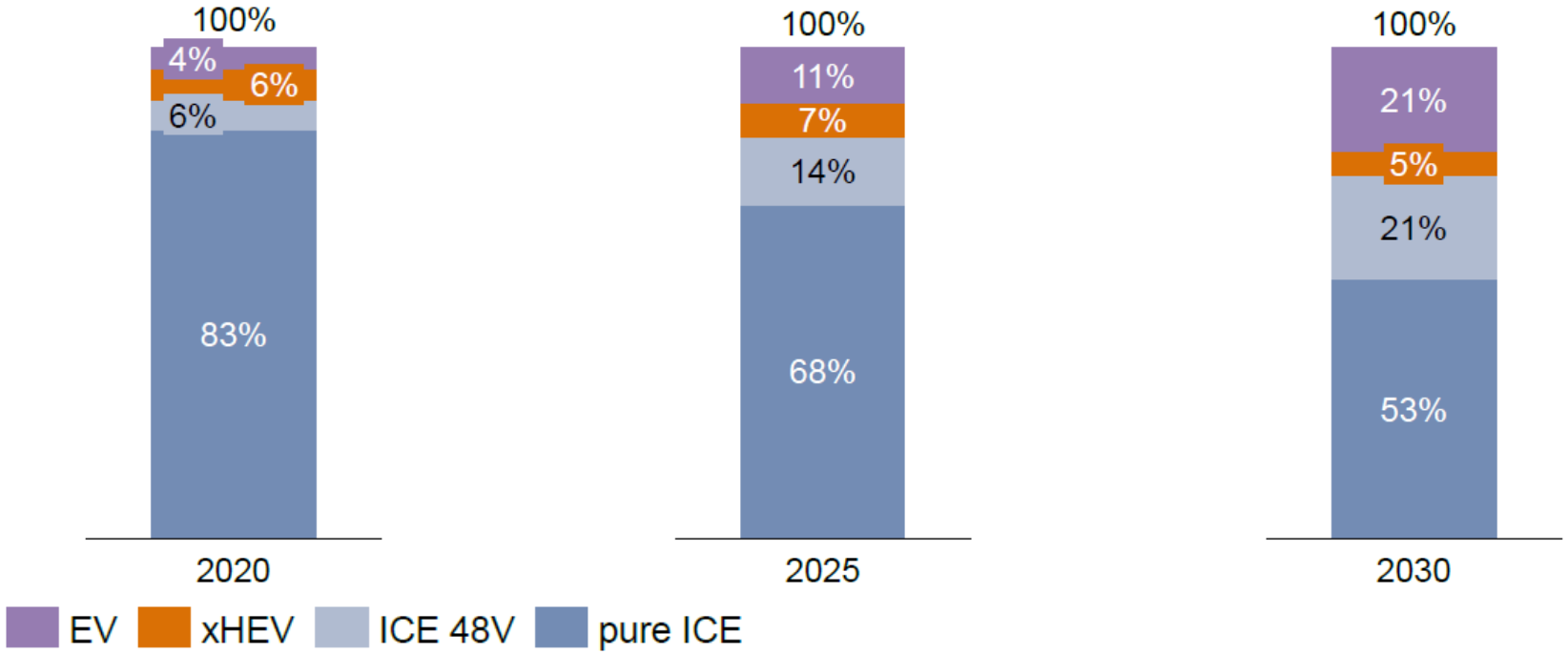


100 % Dependency on Petroleum

Source: Hyundai

Outlook for powertrain type

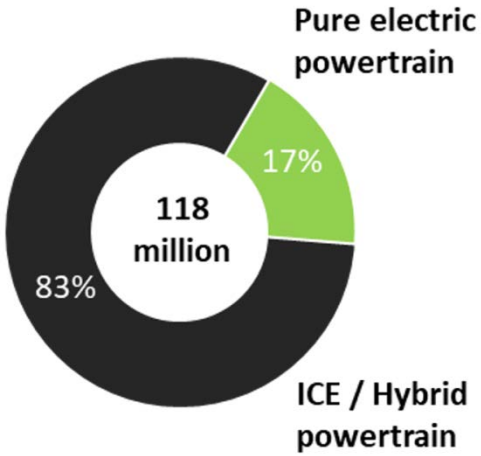
- ✓ Internal combustion engine in 2030 still dominating propulsion system
- ✓ Hybridization and electrification will proceed – increased electric range pushed by legislation



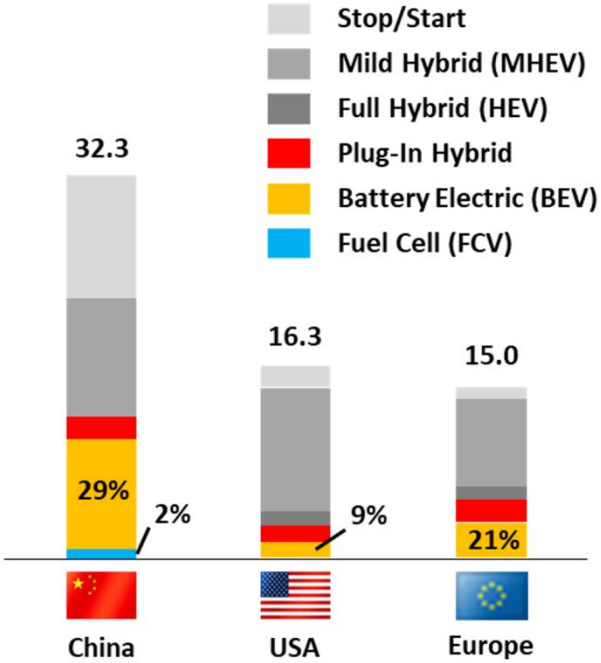
Bosch expects growing market penetration of 48V systems in all vehicle segments.
Drivers: CO_2 reduction, growing electrical power demand (comfort functions), highly-automated driving.

Source: BOSCH

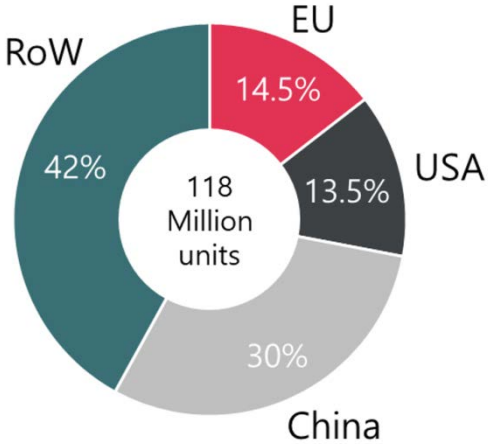
Expected global sales volume in 2030



Expected global sales volume in 2030
(# Base scenario; vehicle sales include passenger cars and light commercial vehicles up to 3.5 tons)



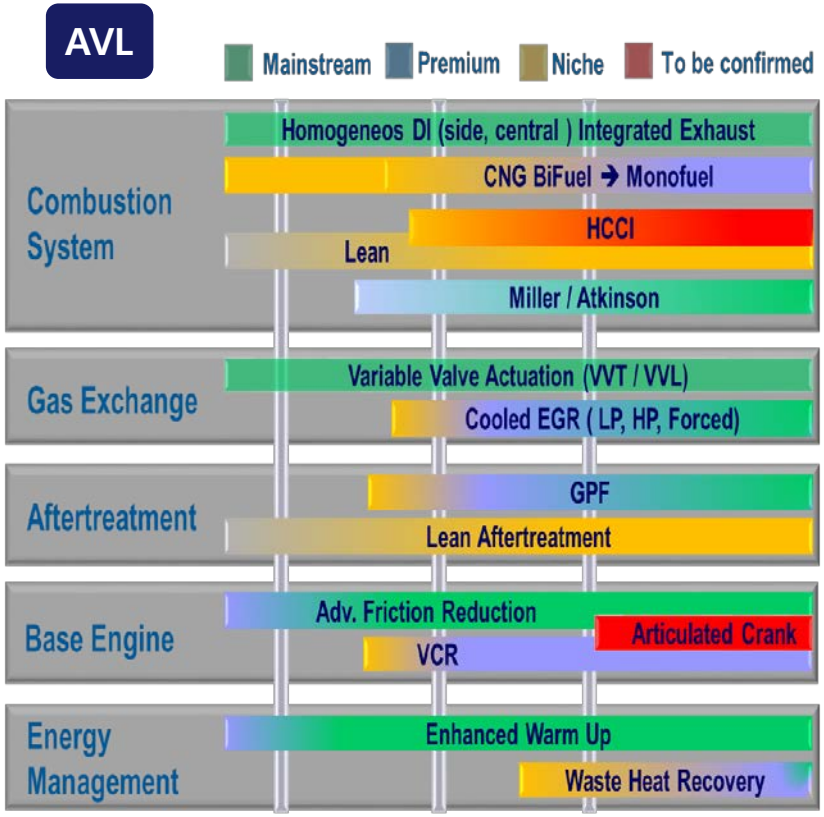
Passenger car powertrain type forecast for 2030 in million units
(# Base scenario;)

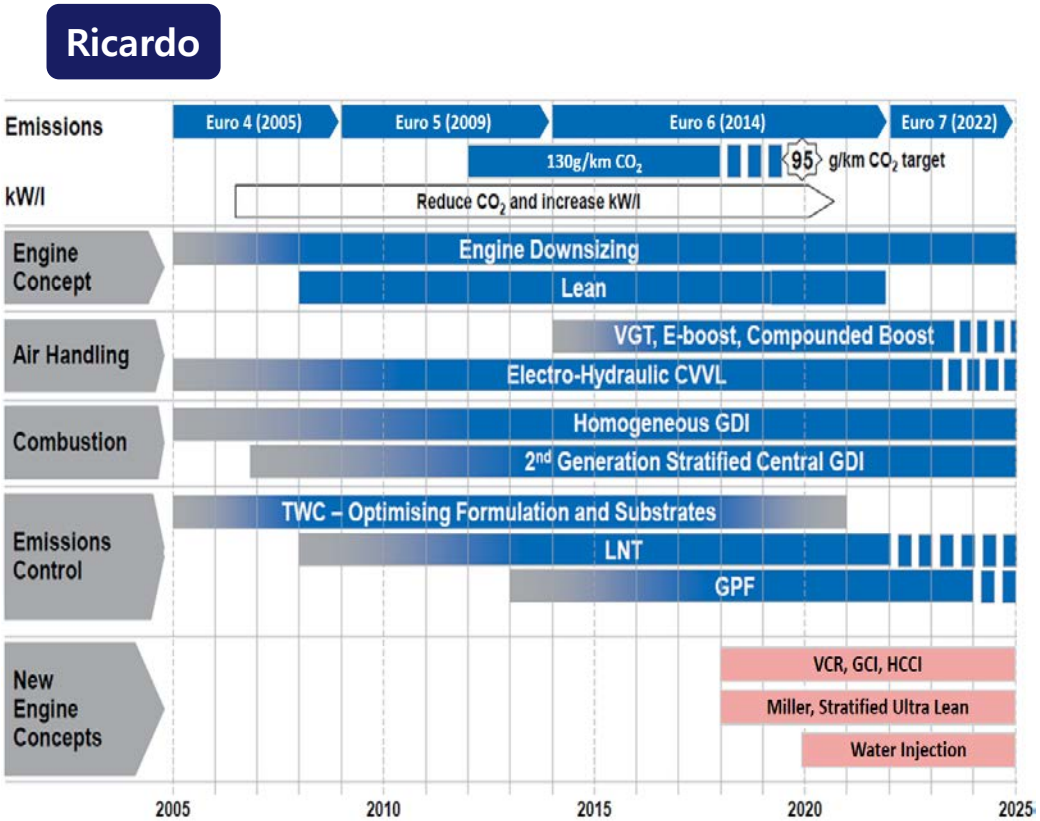


2030 light-duty vehicles sales
(#Base scenario)

Source: FEV

Powertrain Technology Trends



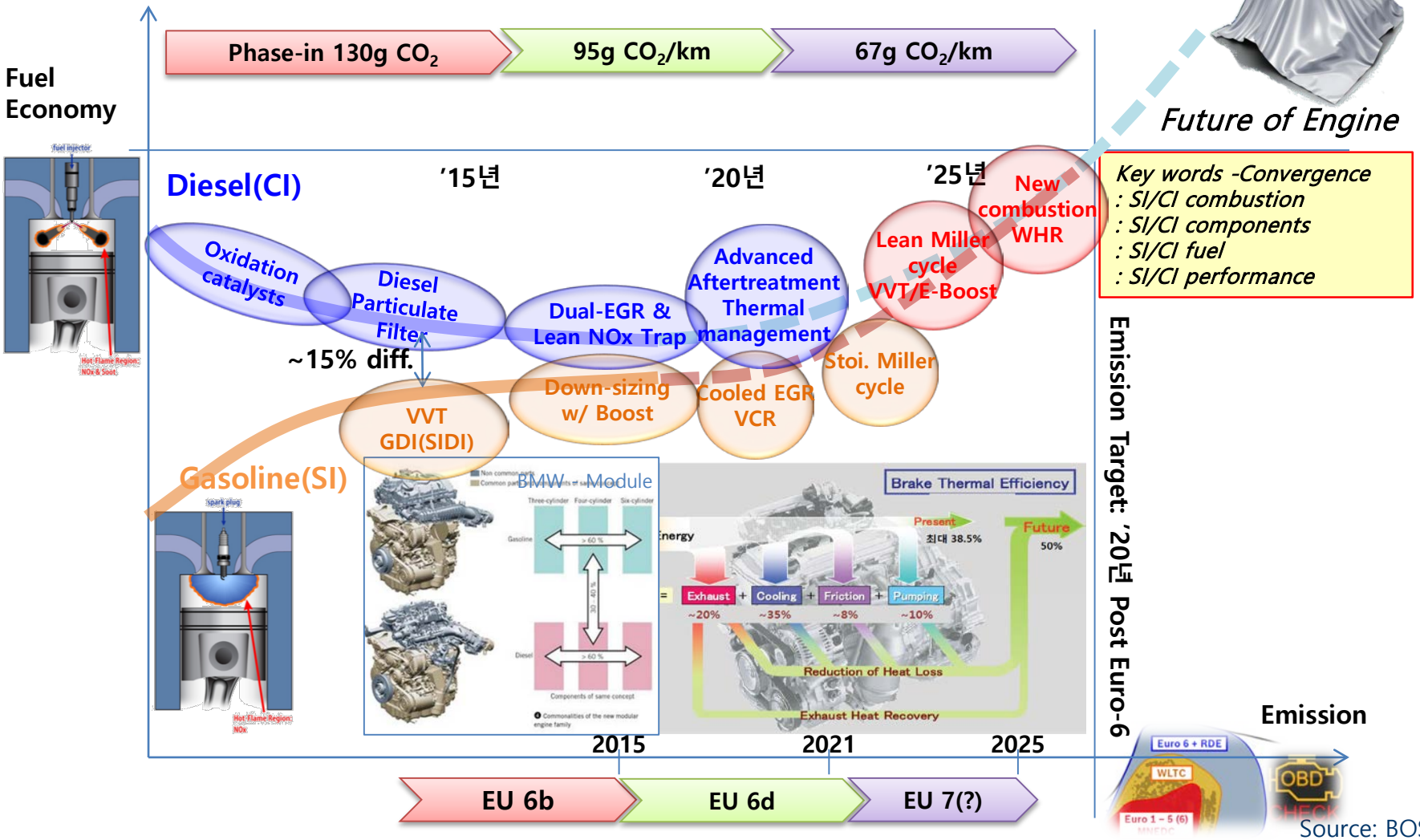


In common, researches on improvement of fuel economy by optimizing the valve system.

- **VVT / VVL is applied to achieve optimal intake and exhaust efficiency in all operating conditions.**
- **The thermal efficiency is increased by applying the Miller cycle.**

Scenario for Accomplishing Target of Engines

Fuel Economy Target: '30년 50% Thermal Efficiency(Engine)

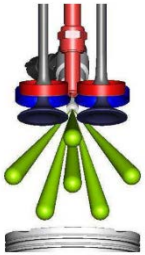


Source: BOSCH

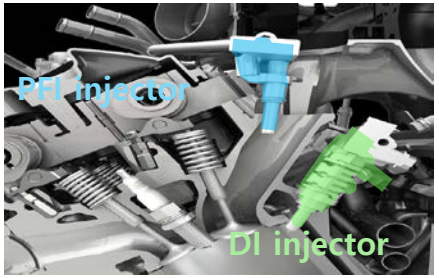
New Technologies applied to Gasoline Engines

Gasoline Engine(GDI)

High Pres. Inj. & Spray Pattern

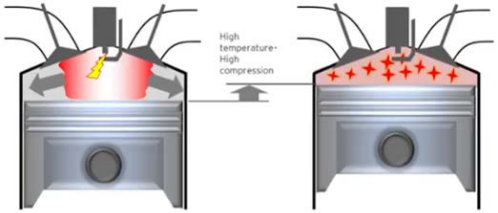


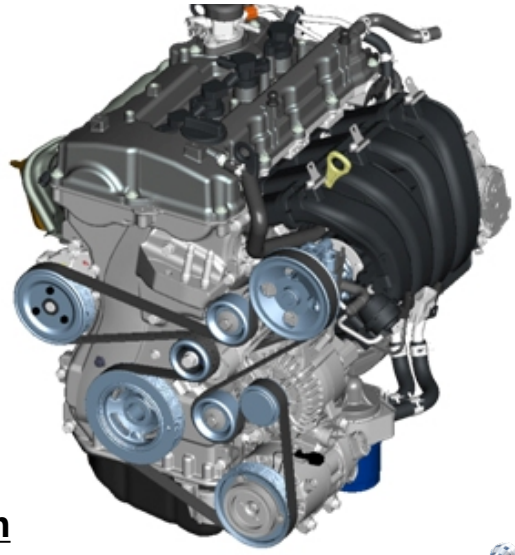
Dual Injection



Variable Compression Ratio

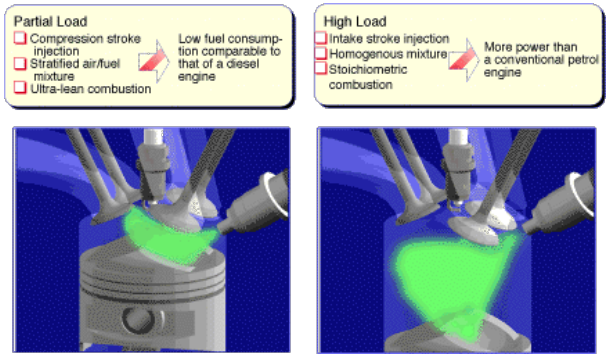
New Combustion(GCI)





High-efficiency ignition

Injection strategy



CVVT/CVVL

Electrification

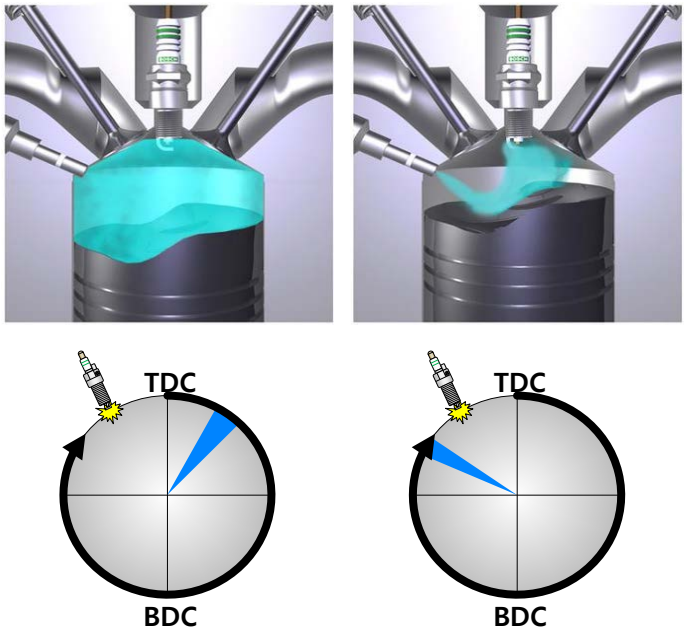
e-Supercharger

Lean Burn Technology

Lean Burn – Concept of Lean Burn Engine (GDI)

- Advantage: Intake more air than theoretically needed air , Reduce pumping loss
- Disadvantage: Combustion instability, reduced efficiency of three-way catalyst (increased NOx emissions)

Homogeneous Stratified



Lean Burn

- Under normal operating conditions, gasoline engine operate at equivalent ratio of 1.0, which is the stoichiometric air-fuel ratio.
-In case of lean burn, the fuel is stratified around the spark plug so as to stably burn even under lean conditions.

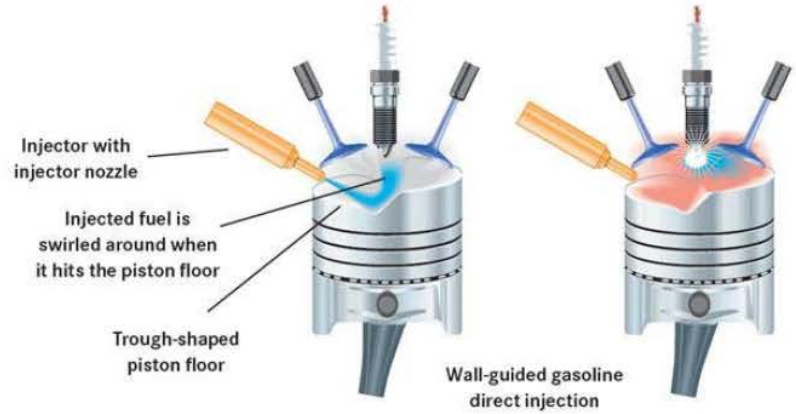
Application Method

-The fuel is injected in the late period of the compression stroke so that fuel is not mixed with air.
-Multi-stage injection can also be applied to form a suitable mixture for combustion.

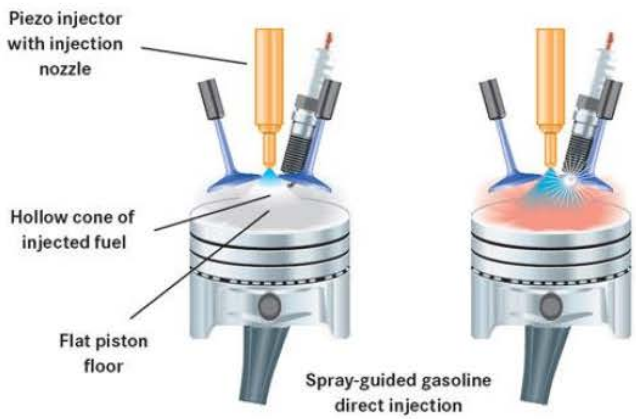
Fuel Injection Systems for GDI Engine

Side-mounted: Wall-guided

- Relies heavily on in-cylinder motion and piston-bowl geometry
- *Solenoid actuated injector*
- Liner, piston wetting → PM, HC ↑



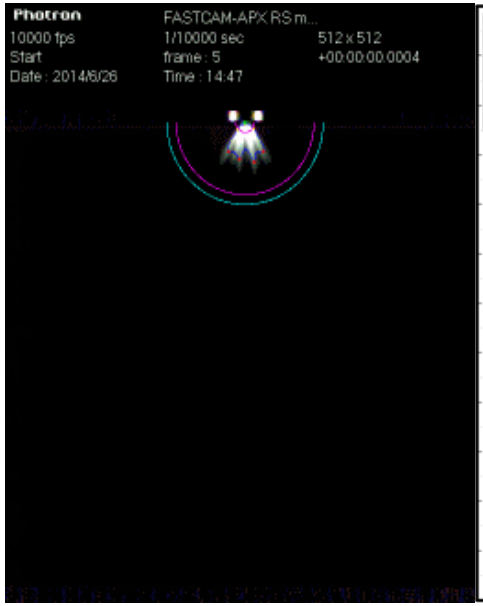
Central-mounted: Spray-guided

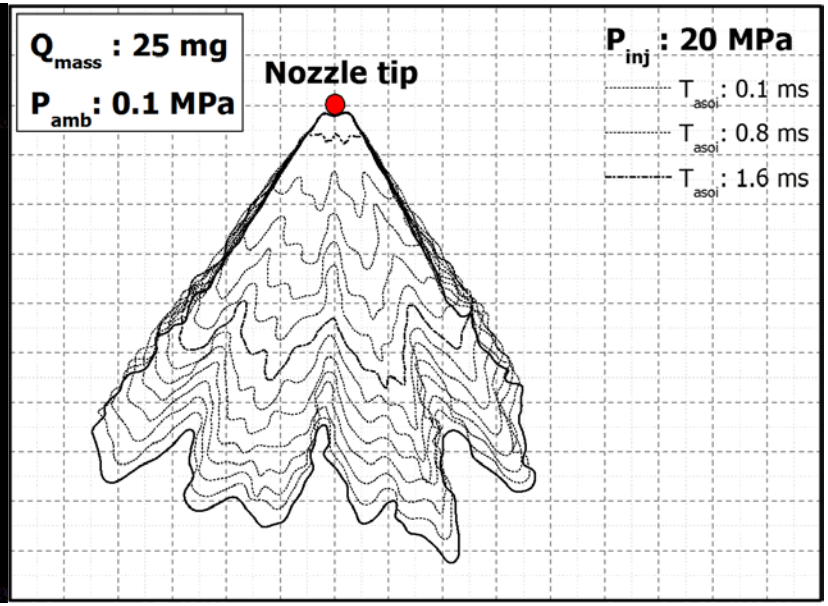


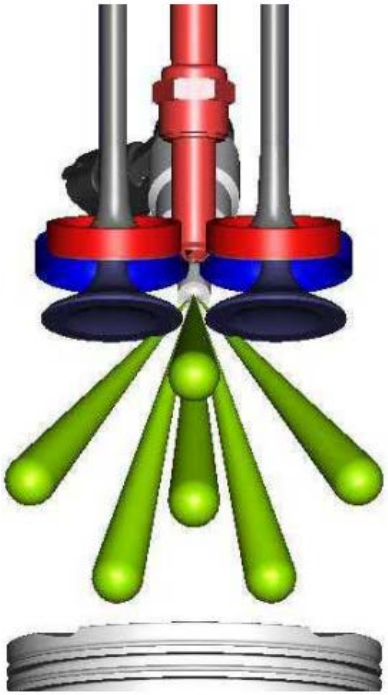
- Relies heavily on spray momentum
- *Piezo-electric actuated injector*
- Ignitability → Effect on COV, misfire

Spray characteristics of GDI Injector

Fuel injection system







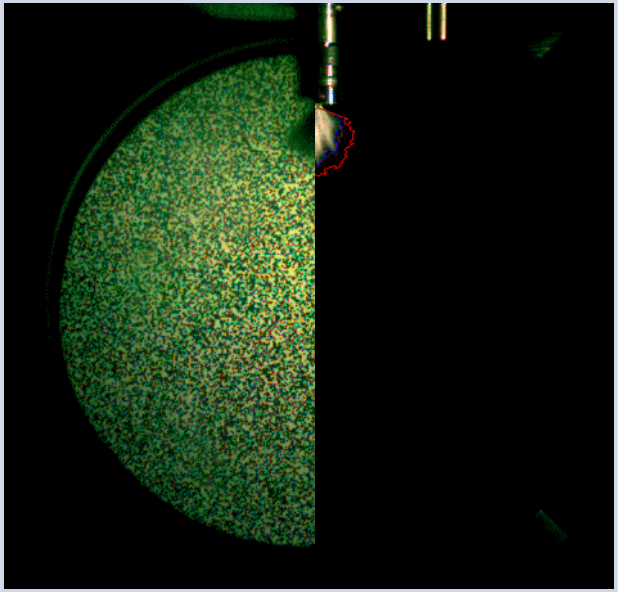
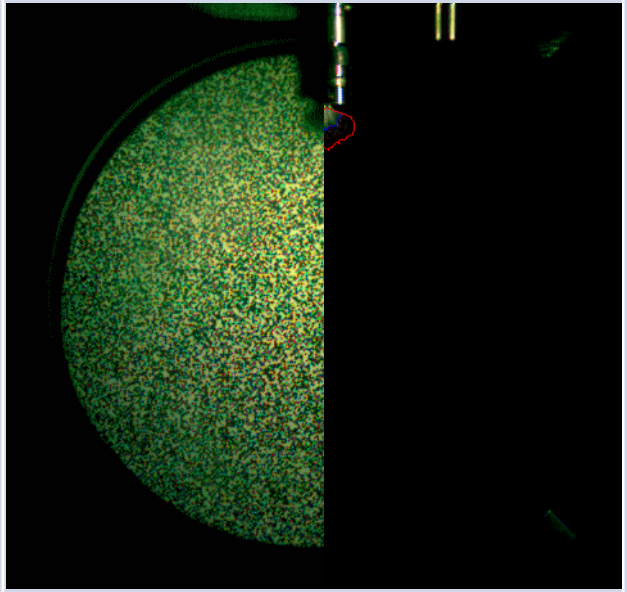
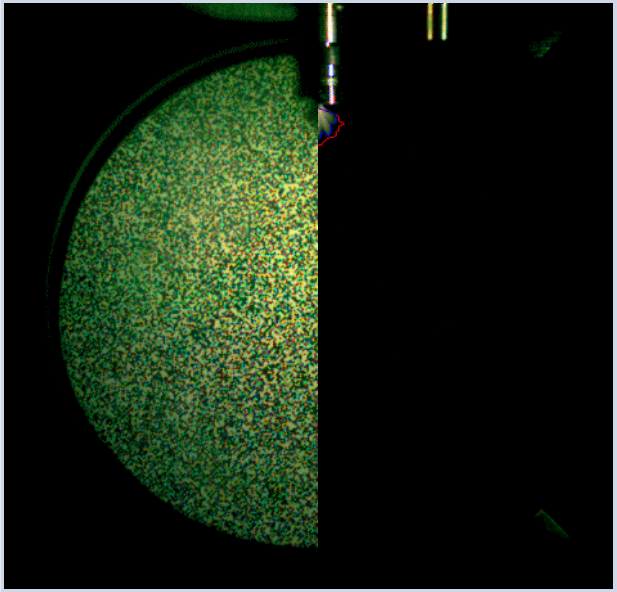
Multi injection

- Hole type fuel injection can actively utilize swirl or tumble flow for homogenous mixture formation
- The multi-hole solenoid type is most commonly used for GDI injectors.

Comparison of Spray Images

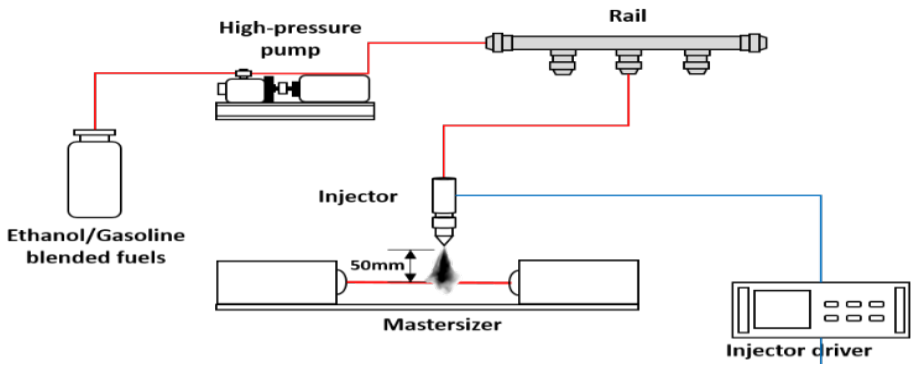
- **Spray Images according to Ethanol/Gasoline Mixture Ratios**

P_{inj} : 250 bar, P_{amb} : 5 bar, T_{amb} : 120C°

E0	E50	E100
		

Comparison of Spray Diameter(SMD)

➢ **Experimental system for SMD measurement of ethanol / gasoline mixed fuel**

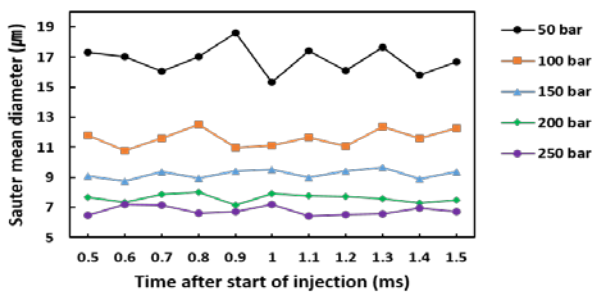


Test Fuels	E0, E50, E100
Injection pressure (bar)	50, 100, 150, 200, 250
Injection duration (ms)	1.5
Ambient pressure (bar)	1
Measuring point	50 mm

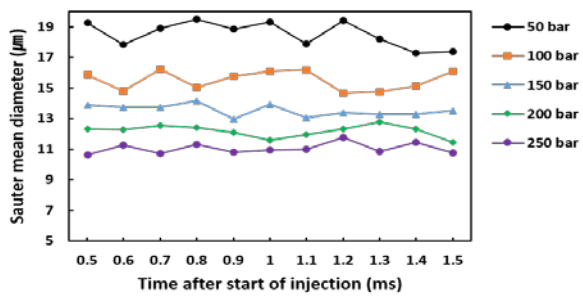
➢ **Measurement of ethanol/gasoline blended fuels**

- The higher the injection pressure, the smaller the SMD
- Fuels with a higher ethanol content have a greater SMD
- SMD is affected by viscosity, density and surface tension

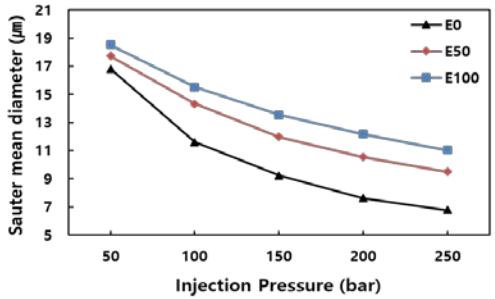
E0



E100

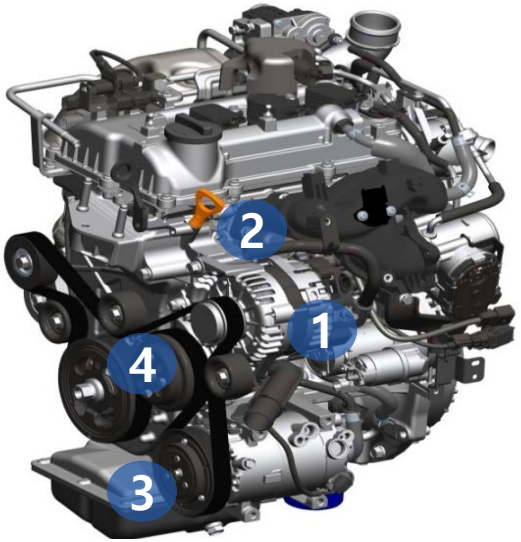


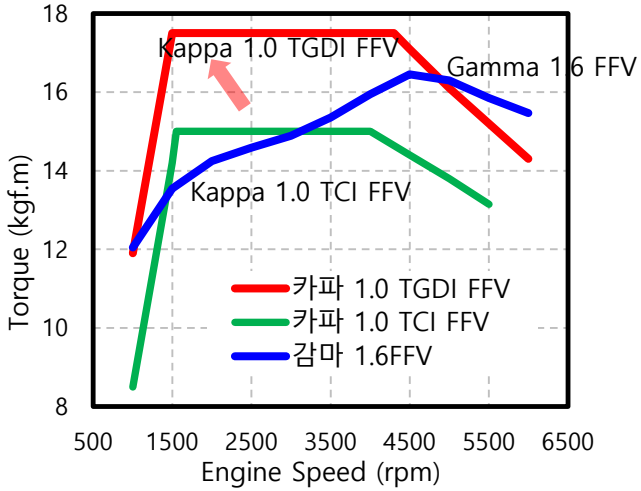
Comparison



Development of Turbo GDI FFV Engine

➢ Developed TGI FFV Engine





	Components	1.0 T-GDI FFV Engine (Modified)	1.0 T-GDI Engine (Conventional)
①	High Pressure Injector	250bar	200bar
②	Turbo Charger	터빈 전단 배압 저감 (개선율19%)	Base
③	Piston	압축비 10.5 용	압축비 10.0 용
④	Valve/Seat/ Piston material	내부식성 재질 (Cr, Ni 보강)	Base
⑤	Intake	흡압 개선 사양 (최대 0.2kPa)	Base
⑥	EMS	T-GDI FFV 엔진용 (에탄올 제어 로직 / 에탄올 센서 적용 로직 개발)	T-GDI 엔진 전용

New Combustion Concept (Gasoline Engine)

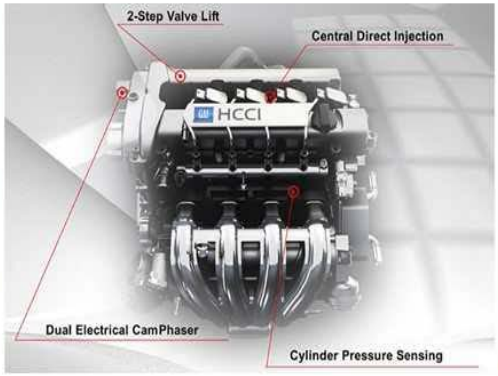
GCI(Gasoline Compression Ignition)

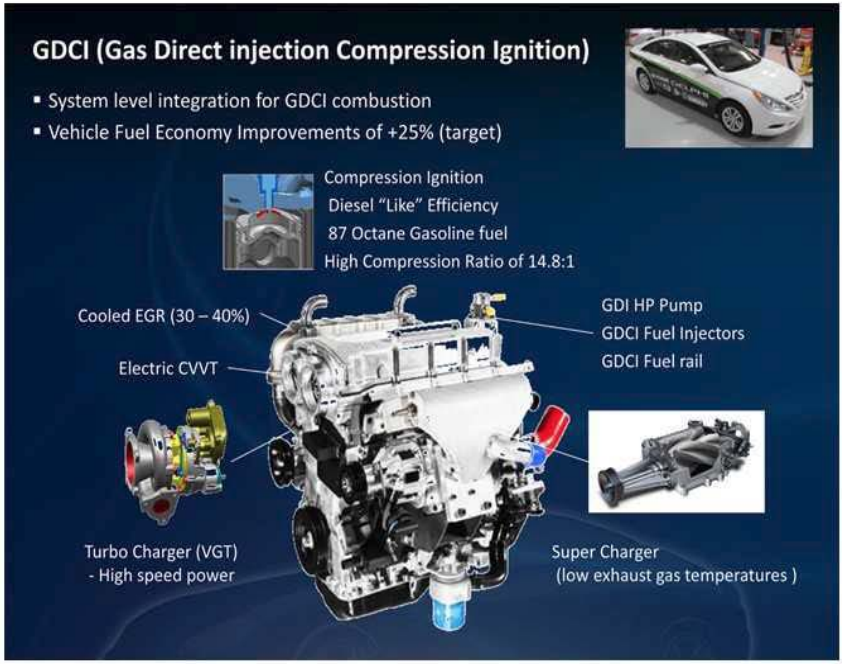
- Apply diesel combustion to GDI gasoline engines
- Without spark plugs, self-ignition of the gasoline mixture is used for combustion
  - Advantage: Decreased Soot and NOx, Improve fuel economy (Decrease pumping loss)
  - Disadvantage: Low self-ignitability (low certain number) makes combustion difficult

GM-Saturn Aura
[2008 ~]

• Saturn Aura Engine Features
- Operating mode: HCCI mode @ from idle up to 55 miles per hour
  SI Mode @ higher speeds or during heavy engine load
- 2-Step Valve Lift
- Dual Cam Phaser
- Cylinder Pressure Sensor
- GDI Injector
- Fuel economy: up to 15% fuel savings

Engine	2.2L Ecotec + HCCI
Power	179 hp
Torque	230 N-m



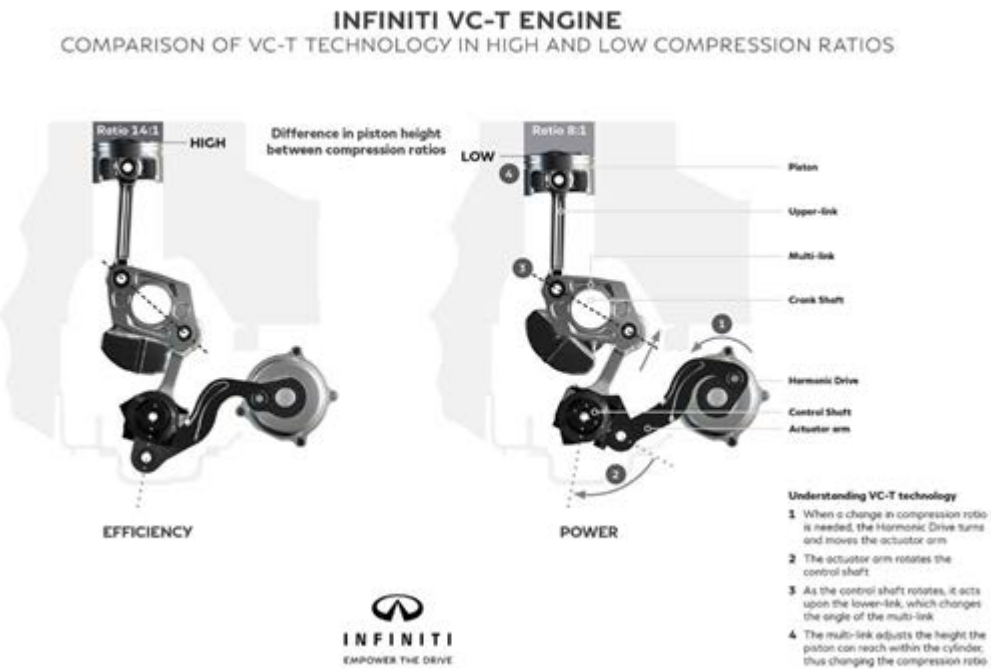


Source: Delphi

Variable Compression Ratio

VCR(Variable Compression Ratio) – Nissan(Infiniti)

- ➢ **The compression ratio can be mechanically changed while engine is running**
- ➢ **The compression ratio can be changed according to operating conditions**
- **Purpose: Increase the efficiency by increasing compression ratio in low load**
  Reduce compression ratio in high load to prevent knocking



Technology Benefits

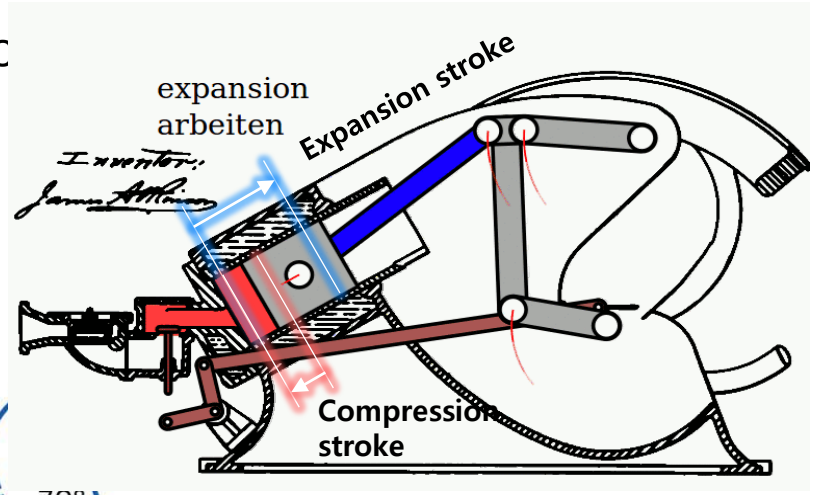
- Significant **engine mass reduction** over the base engine while exceeding its output levels.
- 33% **lesser vibration** over an I4 engine, eliminates the need of balancer shaft
- 44% **lesser cylinder friction**, eliminates the need of cylinder liners
- Dual injection (MPI & GDI) – **Minimized particulate emissions.**

VC-T(Variable Compression-Turbocharged) – Nissan Infiniti

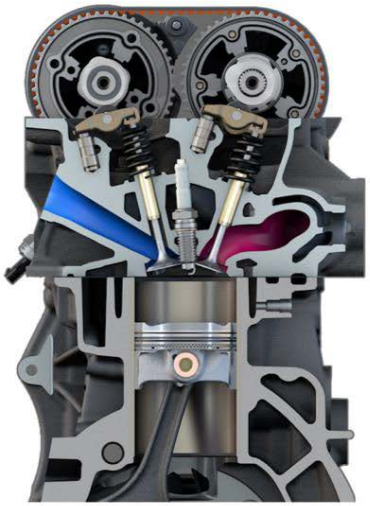
- **Changeable Range: 8:1~14:1**
- **Fuel economy increased by 30%**
- **4 Cylinder 2.0 Liter**

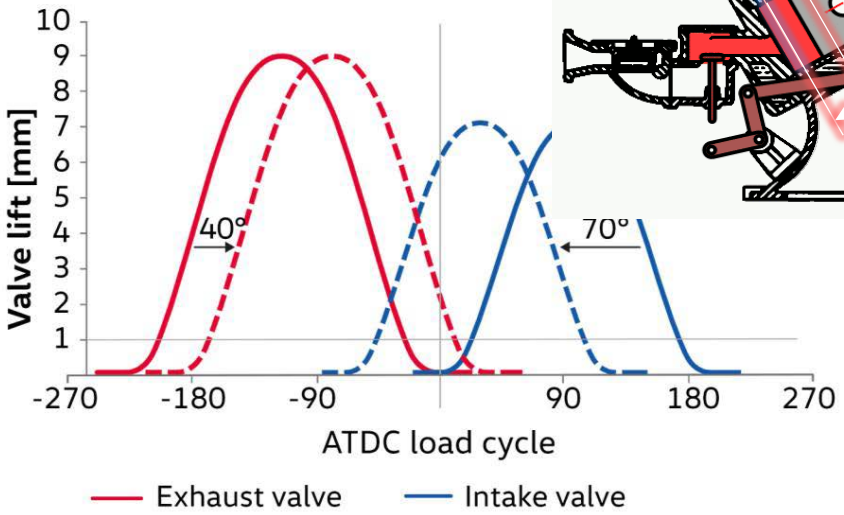
Miller Cycle and Variable Valve System

- Miller Cycle
- Compression ratio 12.5:1 → Improved efficiency
- Early intake valve closing → Lower Temperature
- Optimized charge motion → Rapid flame pro



1887.08.02 US Patent 367496

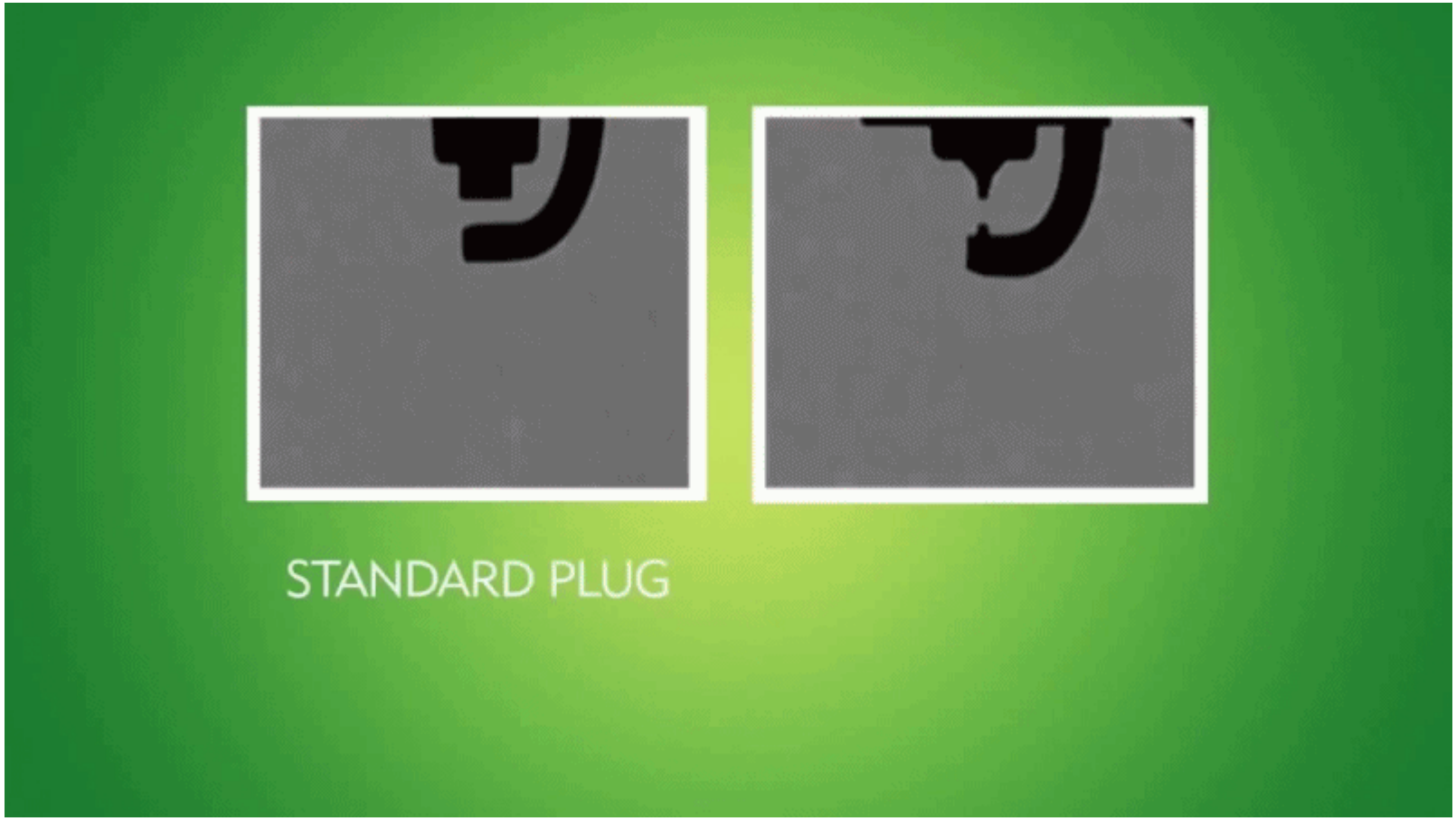




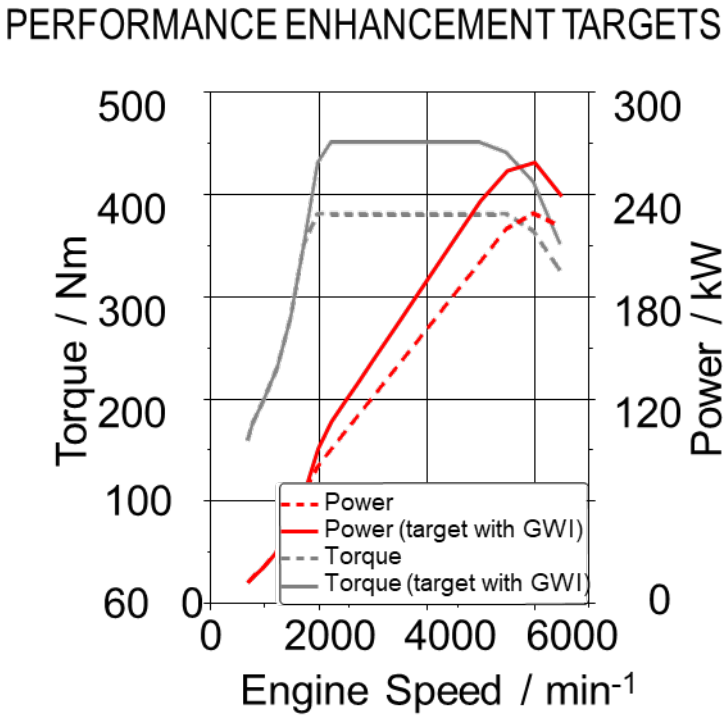
Source: VW

New Ignition System

Comparison of ignition systems



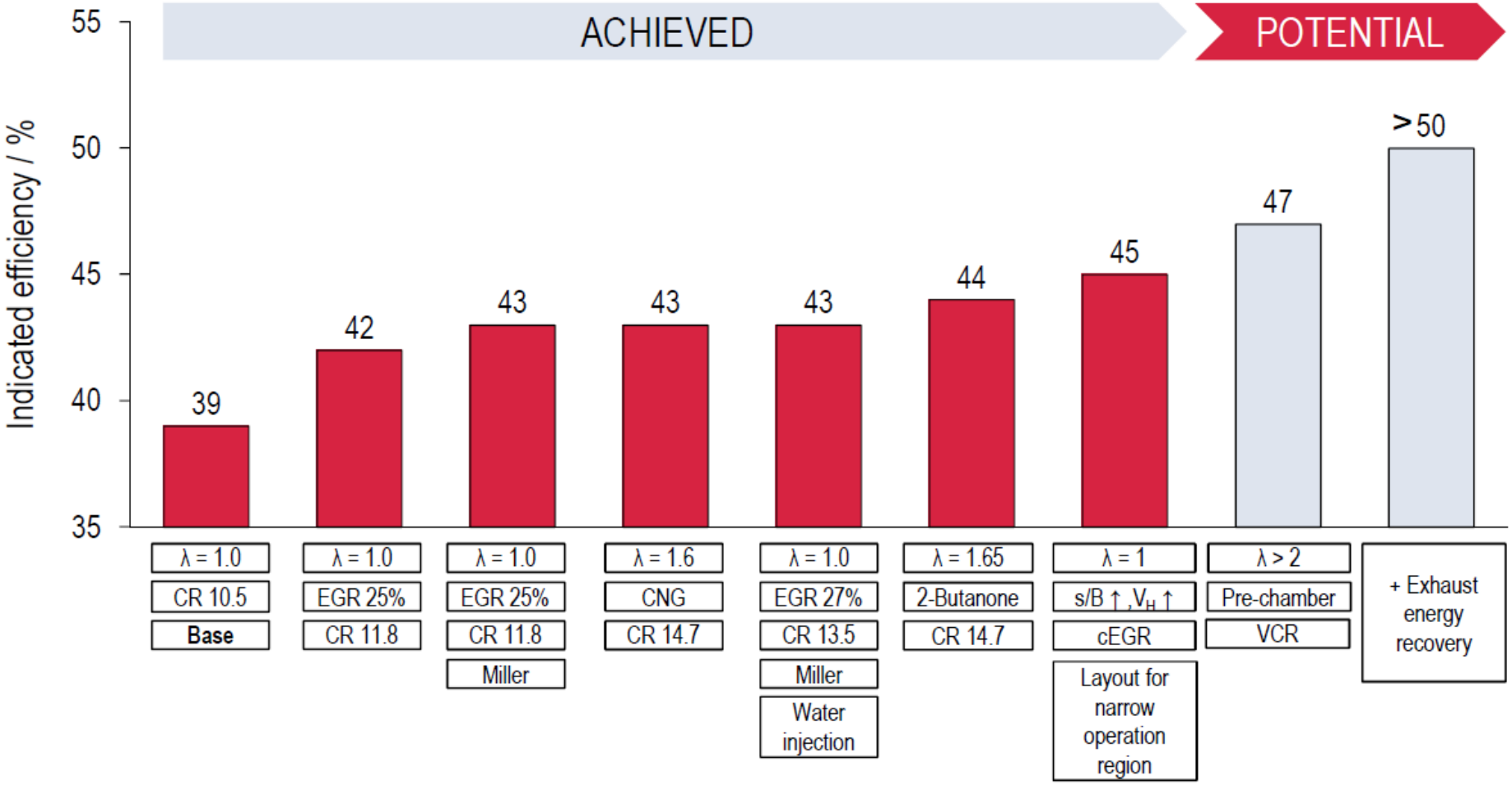
Water Injection Technology



Source : Toyota

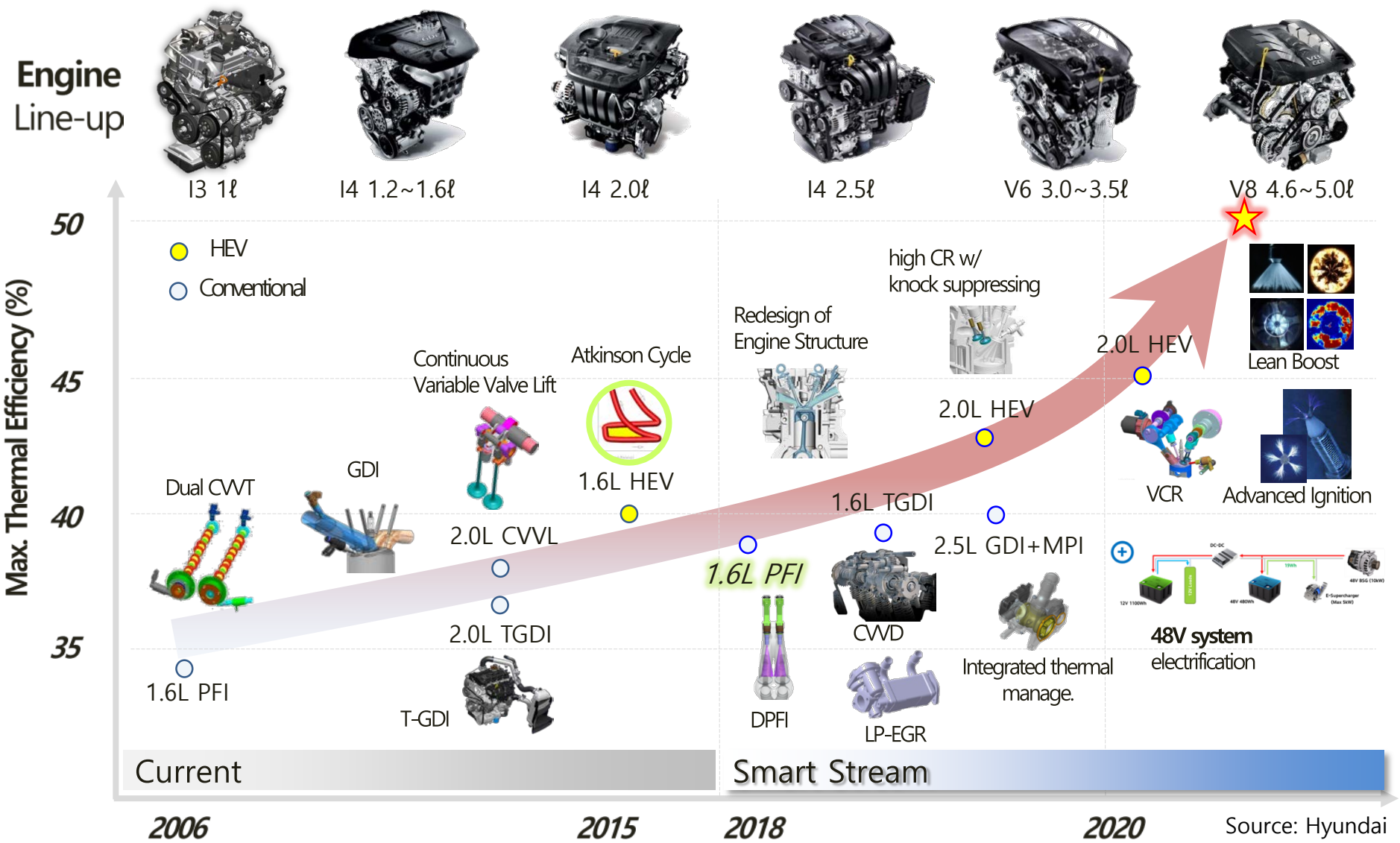
⇒ Technology for improving thermal efficiency through injection fuel and water simultaneously

Improvement of Efficiency for Various Technologies



Source: FEV

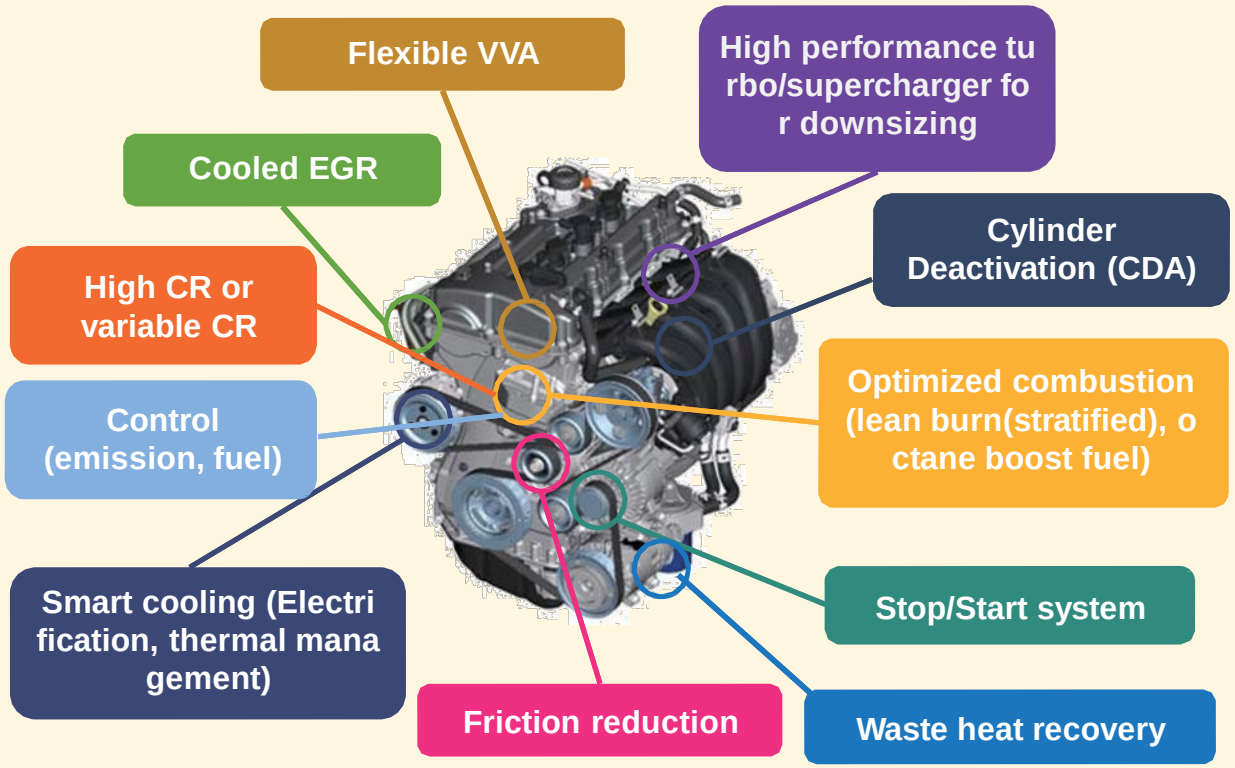
Engine Technology Roadmap(Hyundai)



Source: Hyundai

Methods for challenging emission / fuel economy regulations

Future gasoline engine technology



Emissions

- Optimized combustion
- Cooled EGR
- Flexible VVA

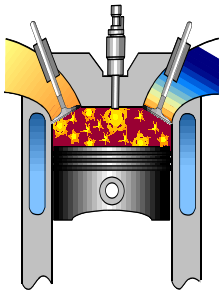
Fuel Economy

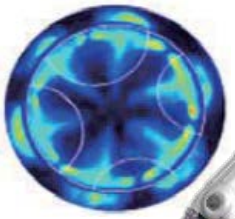
- High CR
- Flexible VVA
- Friction reduction
- Waste heat recovery
- Stop/Start system
- Cylinder Deactivation

New Technologies applied to Diesel Engines

Diesel Engine

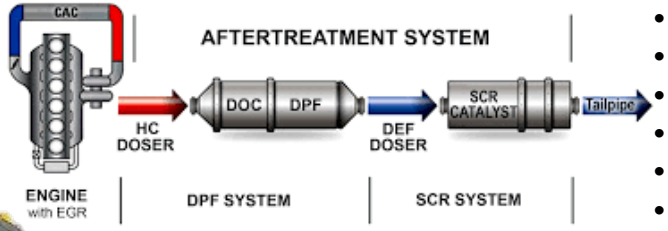
New Combustion(HCCI)





Piston Shape Optimization

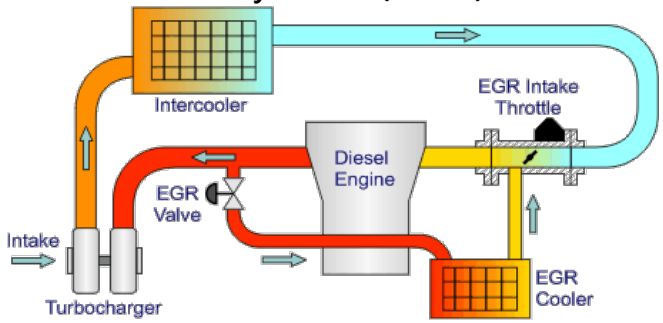
High efficiency & low cost after treatment system



- DOC
- CPF
- CRT
- DPF
- SCR
- LNT

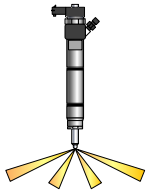
EGR control optimization

-Hybrid EGR(HP+LP)-

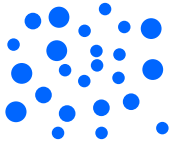


High Pressure Injection

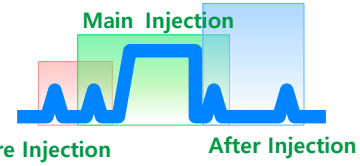
High Pressure Injection



Promoting fuel atomization

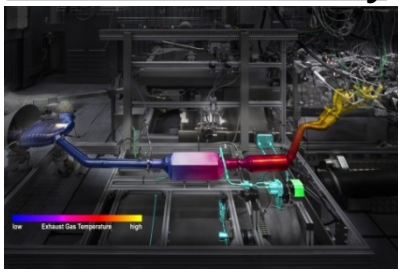


Multiple Injection



Turbo Chager

Waste Heat Recovery



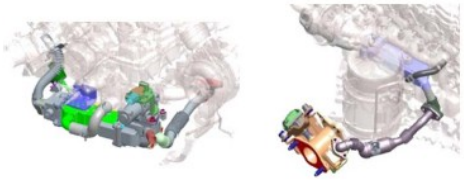
Strategy for improving fuel economy in diesel engines

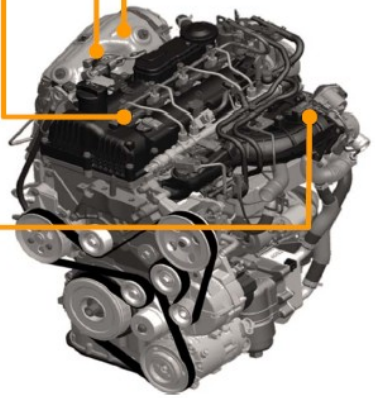
- Develop low end torque and highly responsive air management systems
- Define cost effective aftertreatment systems based on engine and vehicle boundary conditions

Low inertia, low friction
Highly responsive turbocharger

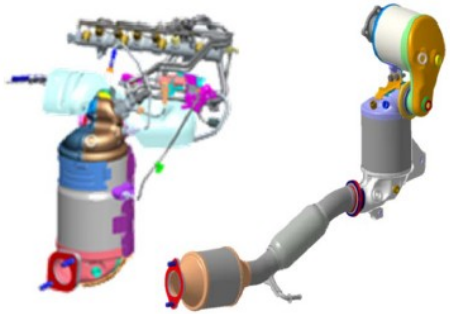
High pressure fuel injection system (> 2000 bar)

Dual loop EGR System
HP + LP EGR system





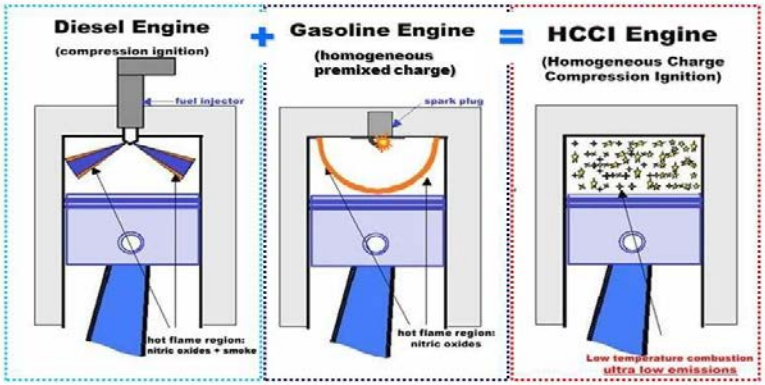
Exhaust aftertreatment system (DPF, LNT, SCR systems)



Friction reduction / Thermal Management systems

Source : Toyota

Renault & Cummins — Diesel HCCI/PCCI



Reference : KAIST Engine Laboratory

Renault VelSatis (HCCI w. NADI™ Concept)

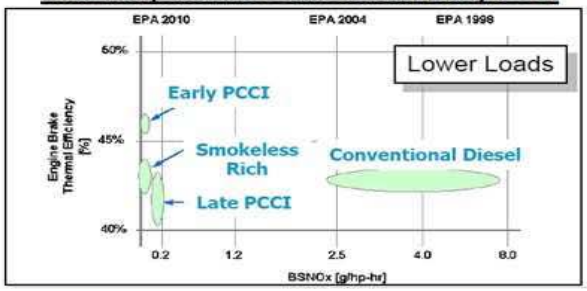
- 4 cylinder, light-duty direct injection Diesel engine
- 2.2 litre (87 mm bore and 92 mm stroke)
- Combustion chamber designed for NADI concept
- Compression ratio of 14:1

- Developed by IFP with Faurecia and Valeo
- Redefinition of the air and EGR loop with dedicated cooling circuit using low temperature water and EGR exchanger bypass

Cummins-HECC* (PCCI Concept)
[2010]

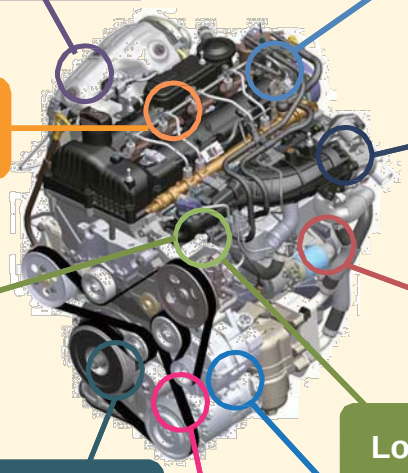
HECC*: High Efficient Clean Combustion

Low Temperature Combustion: Early PCCI



Method for challenging emission / fuel economy regulations

Future Diesel Engine Technology



After treatment system (LNT/SCR) & fuel efficiency

VVA (CVVT w/wo VVL)

High pressure injection system (>2000 bar)

Enhancing transient control logic (Air system + T/C + EGR) In-cylinder based / Model based control

Advanced combustion (LTC, dual fuel)

Hybrid EGR (HP + LP), intercooler efficiency

Low compression ratio (14~16)

Smart engine thermal management with exhaust gas

Waste heat recovery

Friction reduction

Emissions

- After treatment
- Hybrid EGR
- VVA (CVVT/CVVL)
- High press injection
- Advanced combustion

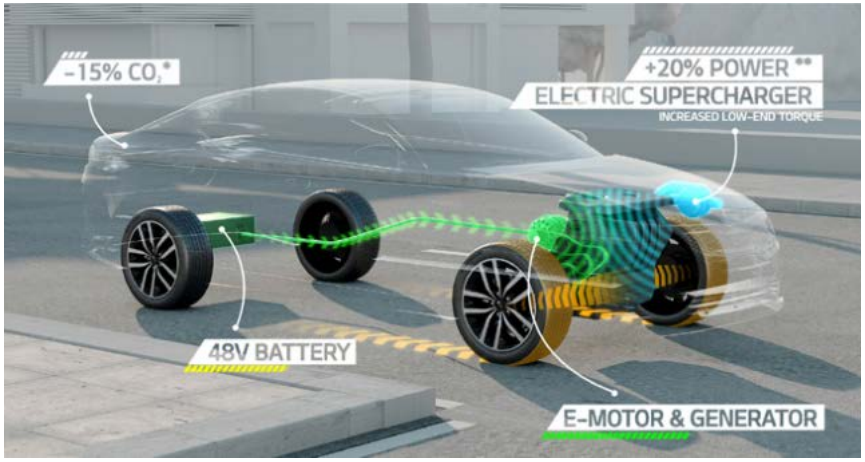
Fuel economy

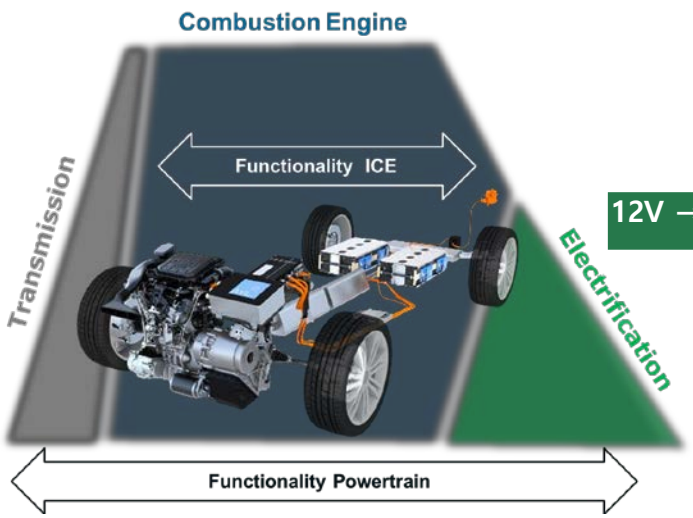
- VVA (CVVT/CVVL)
- Advanced combustion
- thermal management

Future Outlook of ICE's Evolution(48V System)

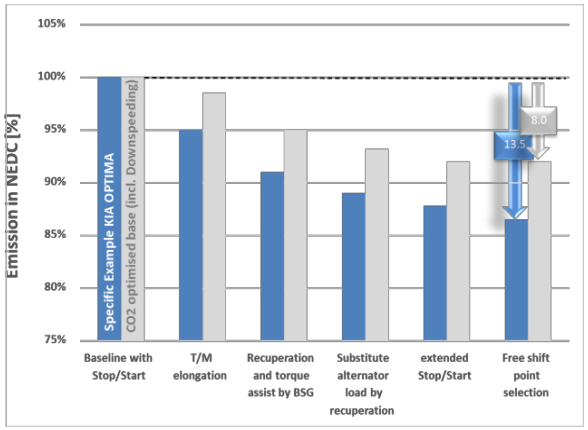
- Synergies between Hybrid and combustion engine enable further fuel economy / emission benefits
- Transient response and torque assist functionality
- Reduce emission through shaving of dynamic torque peaks

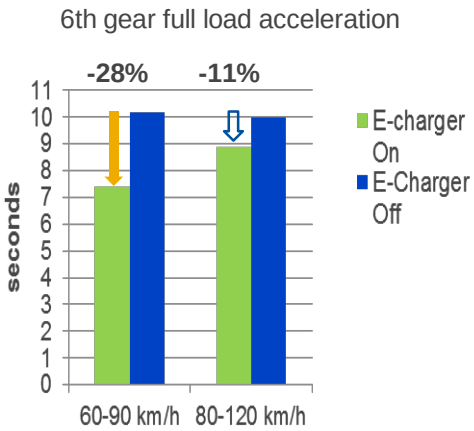
Schematic of 48V System



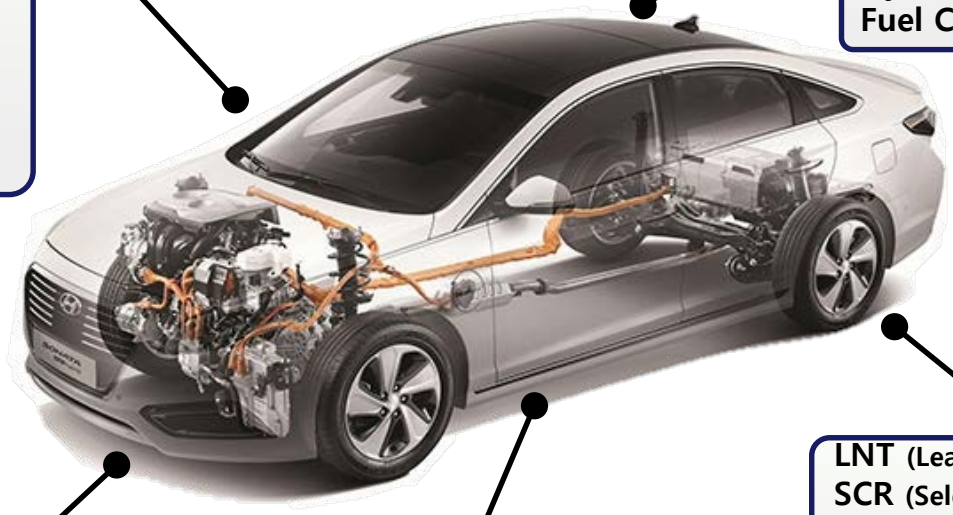


12V → 48V





Strategies for Emission and Fuel Economy Regulation



Combustion

- High pressure Injection
- Multi-Stage Injection
- Lean Burn
- Alternative Fuel (CNG, LPG, Ethanol)
- HCCI
- Gasoline Direct Injection

Eco-Friendly

- Electric Vehicle (EV)
- Hybrid Electric Vehicle (HEV)
- Fuel Cell Electric Vehicle (FCEV)

Down Sizing

- Turbo / Super Charger
- Gasoline Direct Injection

Engine Control & Valve System

- Idle Stop Go (ISG)
- Coasting Function
- Cylinder Deactivation (CDA)
- CVVT / CVVL
- Atkinson Cycle

After Treatment

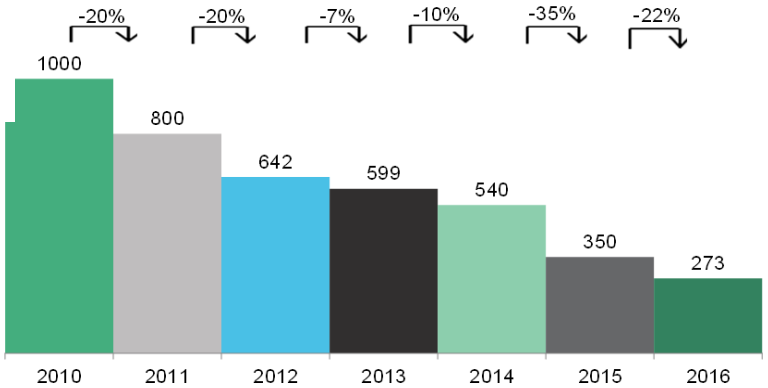
- LNT (Lean NO_x Trap)
- SCR (Selective Catalytic Reduction)
- DPF / GPF (Particulate Filter)
- DOC (Diesel Oxidation Catalyst)
- TWC (Three Way Catalyst)

Success Factor of EV(1) – decrease of battery cost

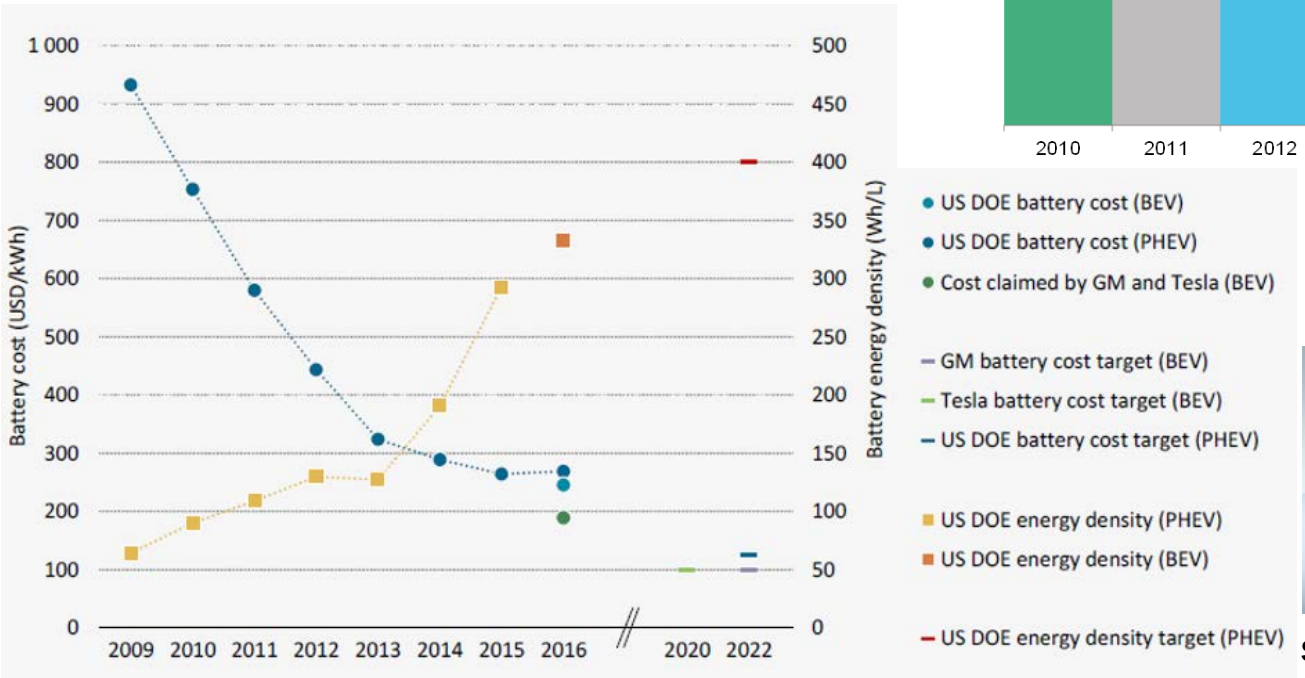
❖ **Battery cost gradually decreased** due to increase of EV sales volume

Source: Bloomberg New Energy Finance, 2017

Li Battery Cost [$/kWh], 2010~2016



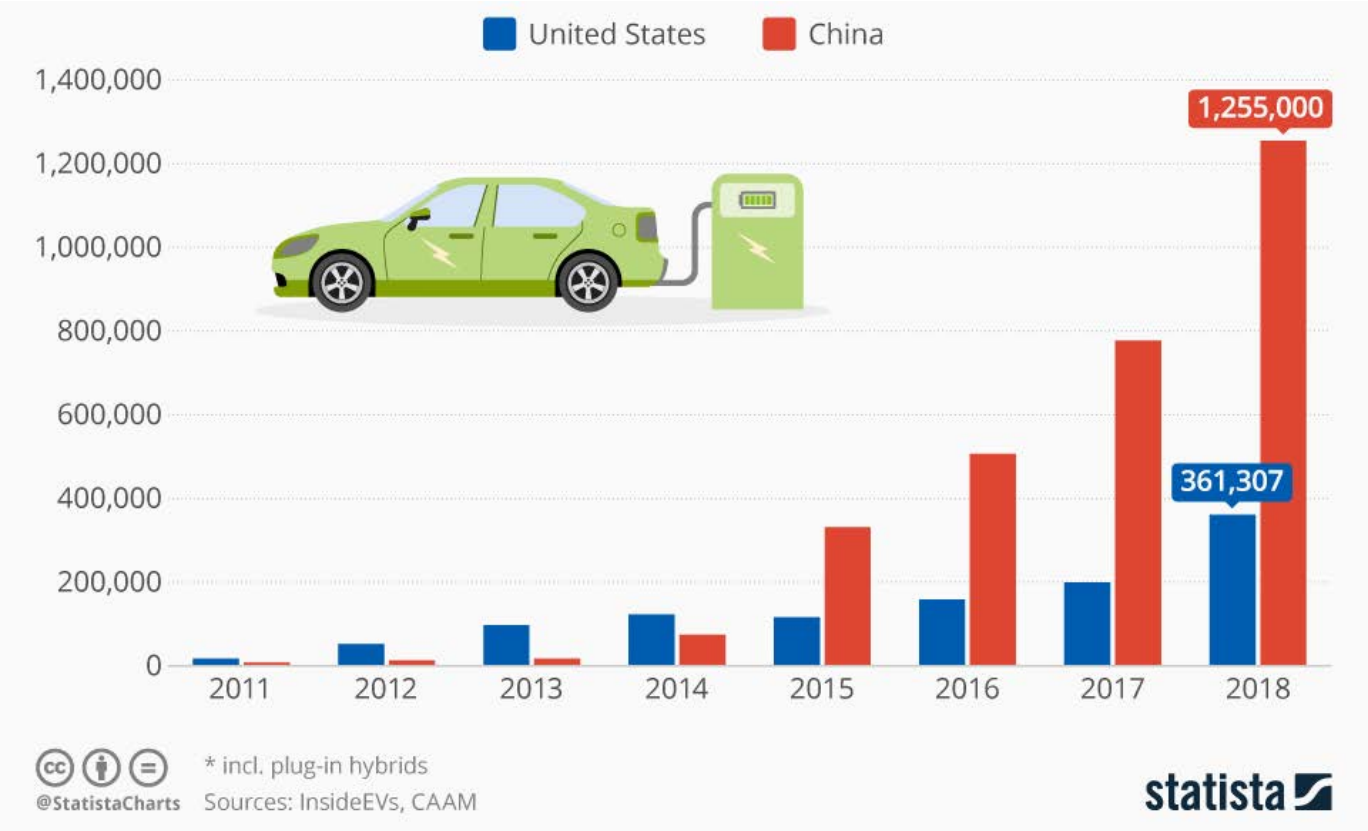
❖ **Li Battery Cost and Energy Density**



Source : Global EV Outlook 2017, IEA

Success Factor of EV(2) – Subsidy system by government

❖ **Sales volume of BEV in Chana and USA**



❖ 중국과 미국은 세계 전기차 시장을 선도하고 있음.

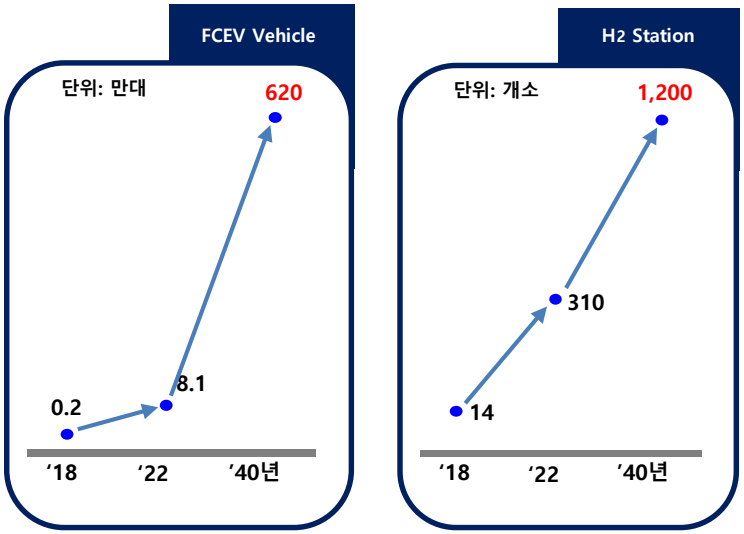
❖ 중국은 신 에너지차 크레딧 의무제, 전기차 보조금 정책, 내연기관 번호판 발급 제한 등으로 배터리 전기차의 수급을 조절하고 있음.

Expected Global Sales Volume of FCEV

(DOE, 2018)

Country	'18. 10
USA	5,715
Japan	3,359
Europe	926
Korea	794
Total	10,795

< Prospective number of Korea >



< Proprietary technologies in Hyundai >

Source : 현대자동차 수소 연료전지, NH 투자증권 리서치 본부

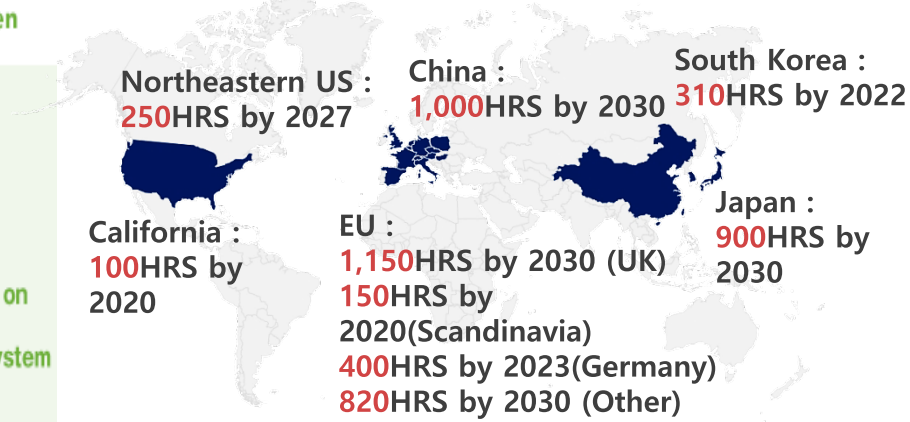
Road map of Hydrogen Supply System

❖ Roadmap of Japan

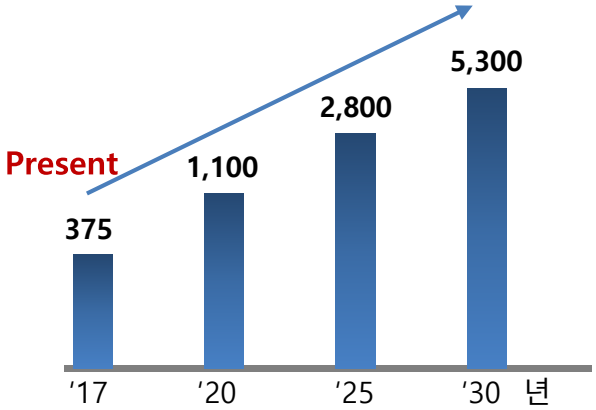
	Phase:1	Phase:2	Phase:3
	Installation Fuel Cell	H2 Power Plant/ Mass Supply Chain	CO2-free Hydrogen
2020 Tokyo Olympic /Paralympics	2009: Residential FC/2014: FCV **2017:** Stationary FC **around 2020:** - FCV fuel cost ≦ HEV fuel cost - **40,000 FCVs, 160 HRSs** **around 2025:** - FCV in main market seg. FCV cost competitive ≧ HEV - **200,000 FCVs, 320 HRSs** **2nd half of 2020's:** - Self-sustaining business of HRS	- Accelerate RD&D - Realize reasonable H2 Price	- Planned R&D based on the outlook for the hydrogens supply system
2030	**around 2030:** - 800,000 FCVs	**2nd half of 2020's:** - H2 Cost (CIF): JPY30/Nm^3 - Enhance Supply Chain in Japan **around 2030:** - Import H2 from overseas - Full Scale H2 Power Plant	
2040	FCV: Fuel Cell Vehicle HEV: Hybrid Electric Vehicle HRS: Hydrogen Refueling Station		**around 2040:** - Full Scale CO2-free H2 (w/ Renewable Energy, CCS, etc)

Source : Hydrogen Energy Navi, 2019

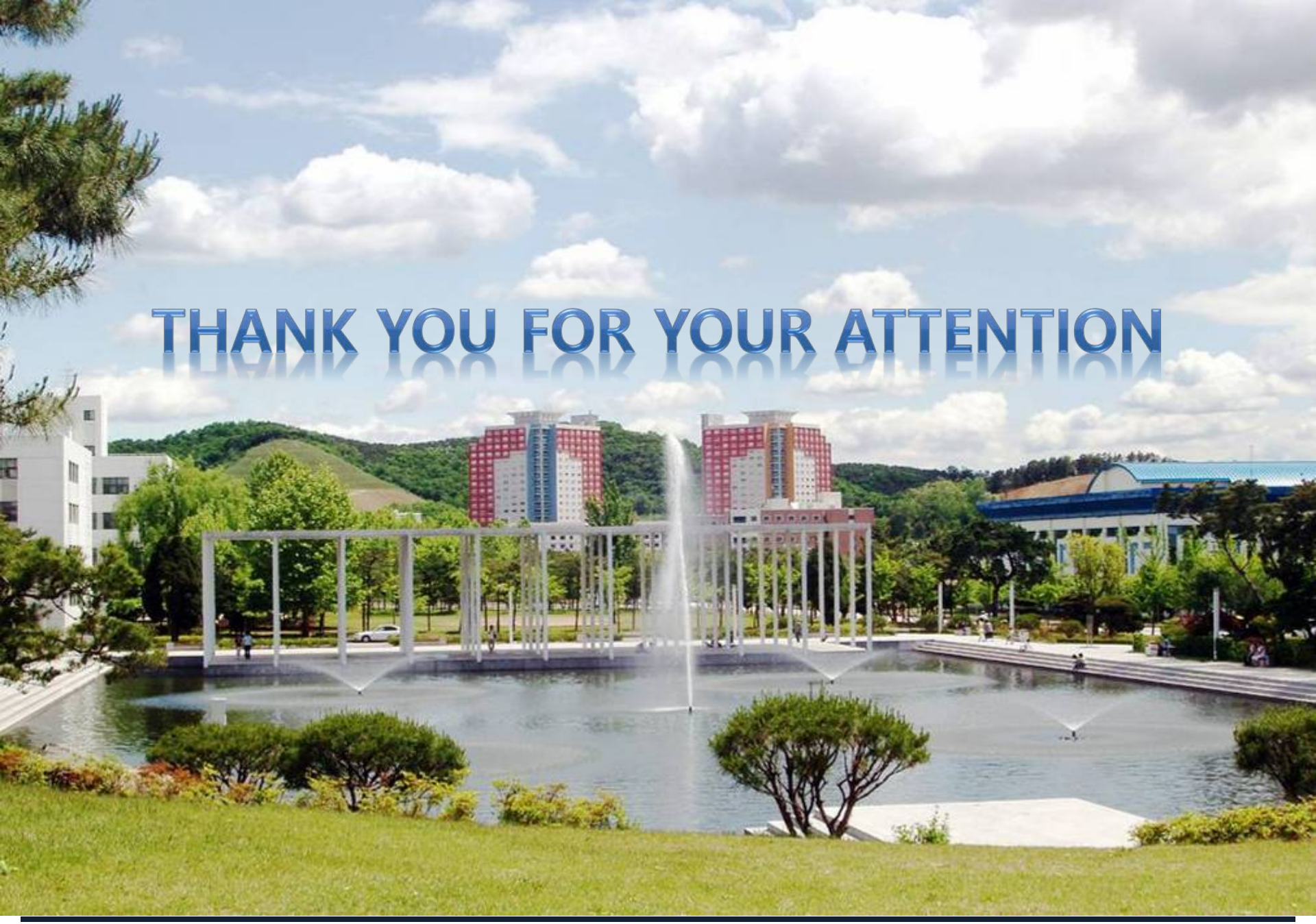
Expected Global Hydrogen Station



*HRS: Hydrogen Refueling Station



참고자료 : 환경부, 미국 에너지부 보고서(2018), IHS



THANK YOU FOR YOUR ATTENTION