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Joint Symposium

Future Fuels and Energy towards Electrifying Vehicles in Japan

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Waseda University

Serious Issues associated with mobility

< Environment >

Air pollution

Global warming

< Energy >

Oil dependence

Renewables

< Traffic Congestion >

< Traffic Accidents >

< Disasters >

Three important measures to resolve or mitigate vehicle-related environmental and energy issues

1. Reducing exhaust gas emissions and improving fuel economy in conventional gasoline and diesel vehicles

2. Developing and disseminating alternative power systems, fuels and energy, including hybrids, EVs, plug-in hybrids, FCVs, etc.

3. Changing the way we use the automobile, by means of ITS, ICT, automated drive, modal shift using mass transit, eco-drive, social and community planning for mobility, etc.

"How should automotive power systems be towards 2050?" (Future Power Systems Committee, JSAE, March, 2016) 1/2

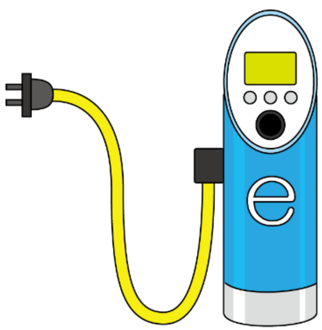
(1) The future combination of the IC engine and oil

- ❑Oil is the best fuel for IC engines used in motor vehicles. The value of oil will depend on its availability and/or the energy and environmental policies made by the individual countries in the future. Oil consumers should be ready for decreased oil production and supply and its increased prices.

- ❑The ultimately high engine efficiency should be achieved.
- ❑The use of the following alternative fuels will substantially be limited due to both their supply amounts and costs.
  - ･Bio-fuels, Natural gas, CTL, GTL, BTL, Hydrogen, Ammonia, e-fuel, etc.

(2) Alternative power systems and non-oil

- ❑Sales of FCVs will be limited due to difficulties with reducing vehicle and hydrogen costs, producing hydrogen and locating hydrogen stations even in 2050.
- ❑EVs will be a more realistic alternative because of diversified electricity sources and inexpensive recharging stations. EVs will mainly be used for short and medium range drives due to limited battery energy densities and high battery costs.



"How should automotive power systems be towards 2050?" (Future Power Systems Committee, JSAE, March, 2016) 2/2

(3) Power systems for id and long term

- Plug-in HVs are one of the most realistic options in place of IC engine vehicles and HVs. This is because the transitions from oil to electricity and/or hydrogen should be conducted smoothly taking into account the fact that ordinary vehicle's lifetime is ten to fifteen years.
- More renewable electricity and hydrogen must be utilized for these transitions along with improving the battery's performance and reducing the costs. Thus, the transitions will require one to two decades.

(4) Issues on future mobility

- To mitigate the shortage of energy and global warming, not only disseminating next generation vehicles but also realizing a mobility society with lower energy consumption.
- Developed countries should support motorizing countries with providing appropriate policies and technologies based on "Mobility Innovations."

Greenhouse Gases Reduction by each Country according to the Paris Agreement, Nov., 2015

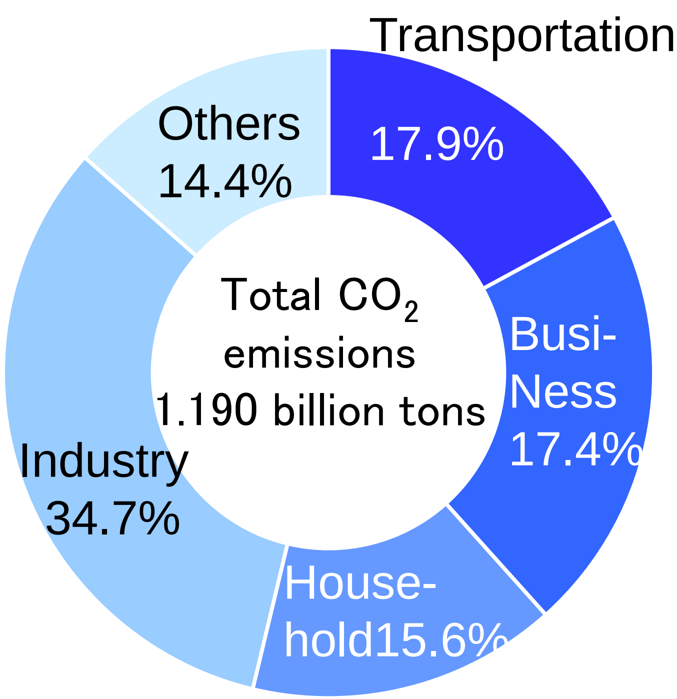
Country	Reduction		Reference
China	per GDP 60 - 65 %	by 2030	2005
E U	40 %	by 2030	1990
India	per GDP 33 - 35 %	by 2030	2005
Japan	26 %	by 2030	2013
Russia	70 - 75 %	by 2030	1990
USA	26 - 28 %	by 2025	2005

☆President Trump announced that the United States would withdraw from the agreement on June 1st, 2017.

☆Each developed country is supposed to reduce its GHGs by 80% by 2050 compared to the present levels to achieve a 50% reduction in global GHGs.

CO_2 Emisions in the Transportation Sector in Japan, FY2017 （MLIT, 2018）

Emission in Each Sector



Transportation	Million tons	%
Motor vehicles	183.88	86.2
Passenger cars	98.50	46.2
Private trucks	35.32	16.6
Professional trucks	42.40	19.2
Buses	4.17	2.0
Taxes	2.69	1.3
Motorcycles	0.80	0.4
Aviation	10.40	4.9
Costal shipping	10.25	4.8
Railways	8.67	4.8
Total	213.00	100.0

★ CO_2 emitted from motor vehicles: 15.4% of total emissons

Energy Related CO_2 Emission Reductions in 2030 for the Paris Agreement, Japan

[Unit: Million t-CO_2]

Sector	2013 （2005）	2030 ／ Reduction % 2013（2005）
Industry	429 (457)	401 ／ ▲6.5 (▲12.3)
Business, etc.	279 (239)	168 ／ ▲39.8 (▲29.7)
Household	201 (180)	122 ／ ▲39.3 (▲32.2)
Transportation	225 (240)	163 ／ ▲27.6 (▲32.1)
Energy Conversion	101 (104)	73 ／ ▲27.7 (▲29.8)
Total	1,235 (1,219)	927 ／ ▲24.9 (▲24.0)

Comparison of LDV Fuel Economy Standards based on NEDC, ICCT 2015

Country	Year	km/L	L/100 km	CO_2 g/km
Japan	2020	22.1	4.52	105
E U	2021 (2030)	24.4 (38.6)	4.10 (2.59)	95 (60)
USA	2025	22.5	4.44	103
China	2020 (2025)	19.8 (25.0)	5.05 (4.00)	117 (93)
India	2021	20.5	4.88	113

( ): Proposed

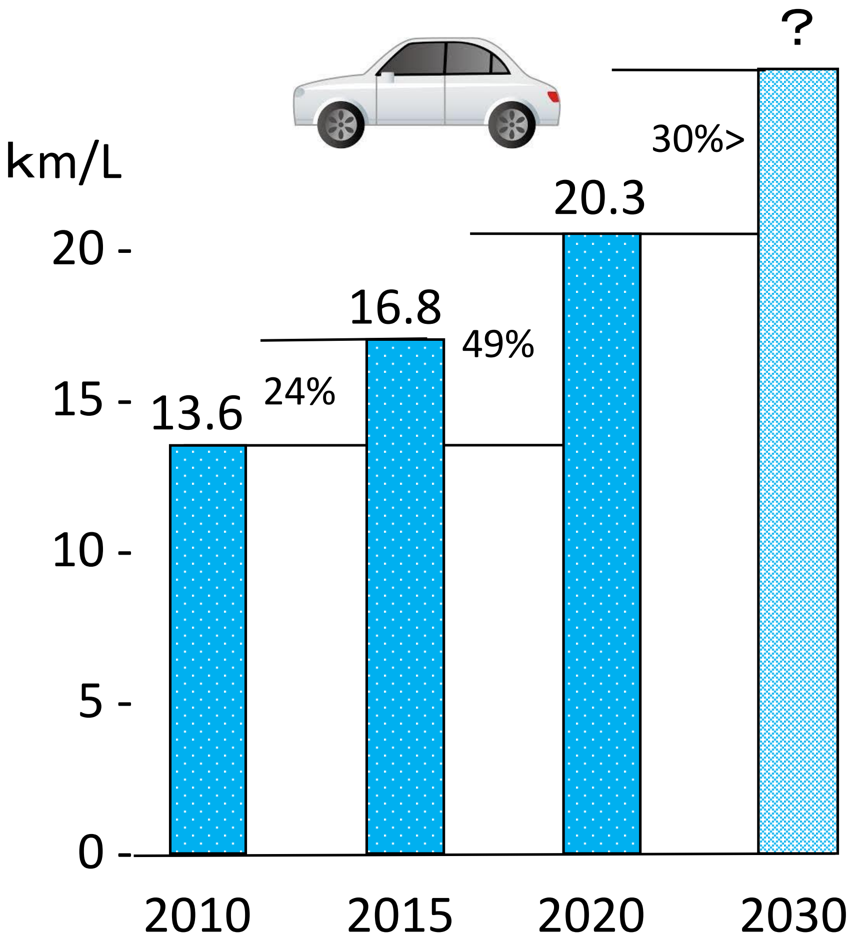
* President Trump is trying to abolish the 2025 standards.

NEDC: New European Driving Cycle

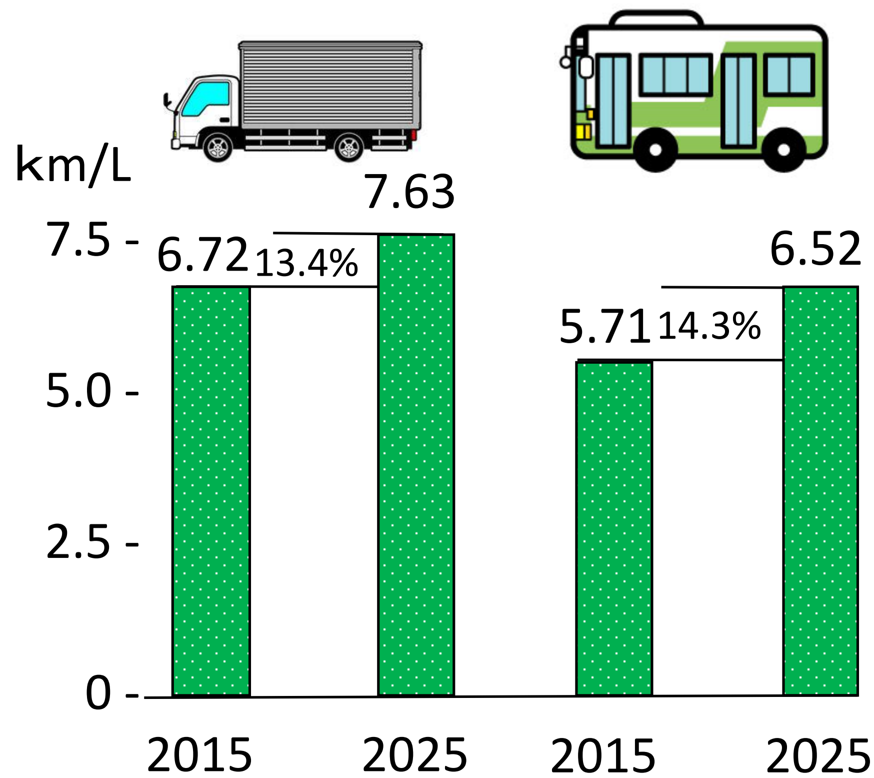
ICCT: The International Council on Clean Transportation

Fuel Economy Standards (average) in Japan

★Standards in 2015 required 12% fuel economy improvement compared to the level in 2002.



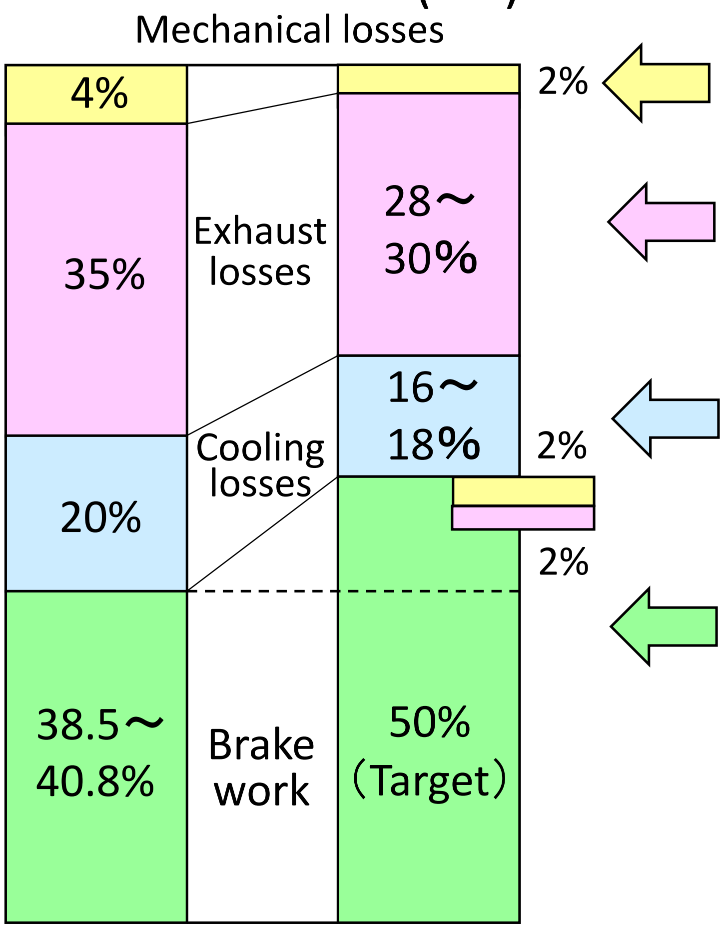
＜Passenger Cars＞
（Corporate Average Fuel Economy）



＜Trucks＞ ＜Buses＞
≪Heavy-duty Vehicles≫

Solutions to Achieve a 50% Brake Thermal Efficiency in Passenger Car Engines

Innovative Combustion Technologies in the Strategic Innovation Program (SIP) in FY2014-2018, with ¥10 billion budget



≪Energy Balance≫

✓Reducing mechanical losses by 50%

✓Utilizing exhaust gas energy
- Increasing turbocharging efficiency
- Using a thermoelectric device

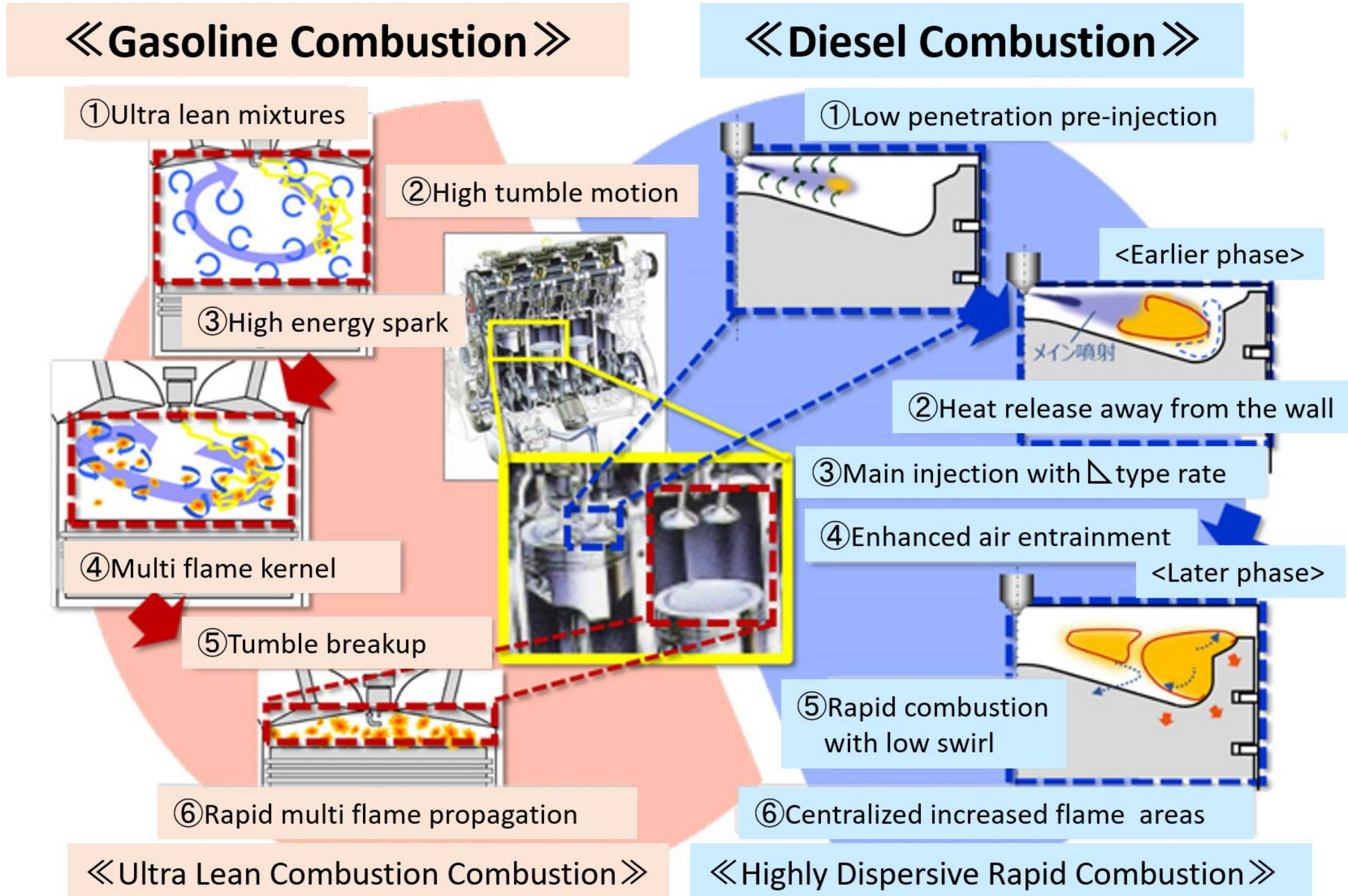
✓Reducing heat losses by improving combustion

✓Enhancing indicated work by improving combustion in both engines

★ Brake Thermal Efficiency Baseline:
Gasoline engines ⇒ 38.5%
Diesel engines ⇒ 40.8%

☆The high efficiency engine is essential also for increasing hybrids' fuel economy.

SIP's "Innovative Combustion Technologies"



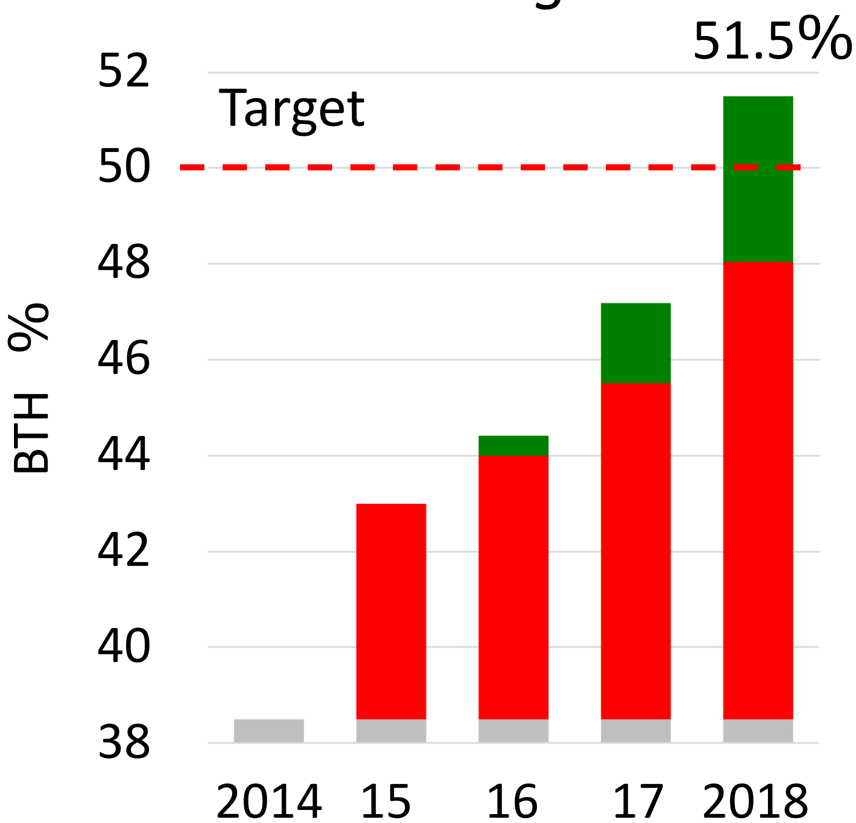
- Utilizing Waste Heat Recovery: Improving turbocharging efficiency, Use of thermoelectric device,
- Reducing Mechanical Losses

Brake Thermal Efficiency: 51.5%

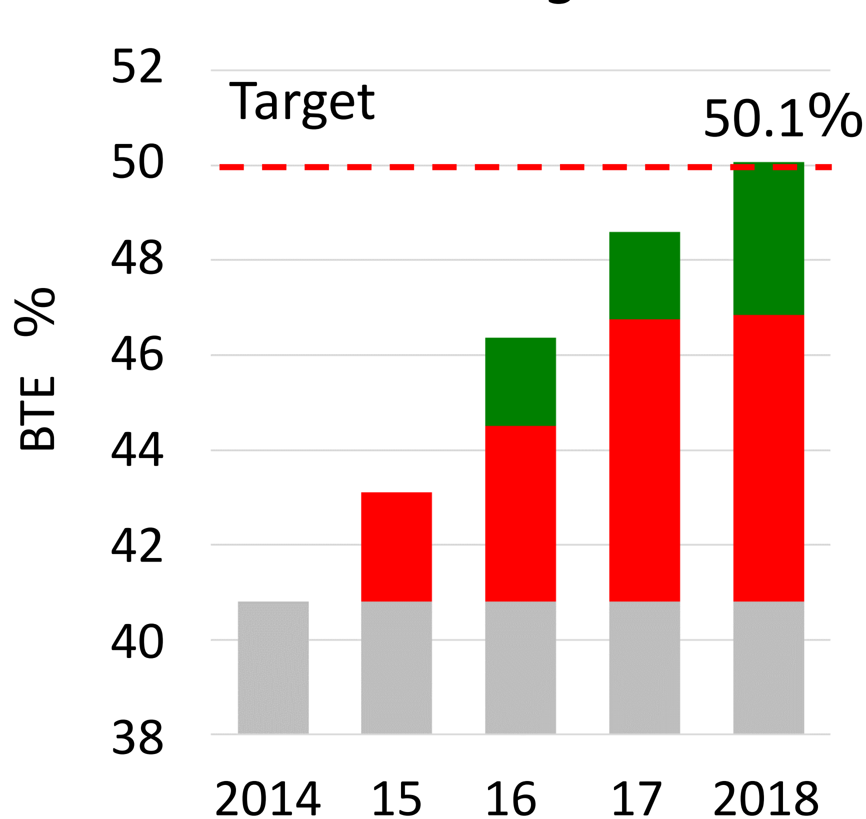
Brake Thermal Efficiency: 50.1%

Achievements in Brake Thermal Efficiencies in Gasoline and Diesel Engines (January, 2019)

<Gasoline Engine>



<Diesel Engine>

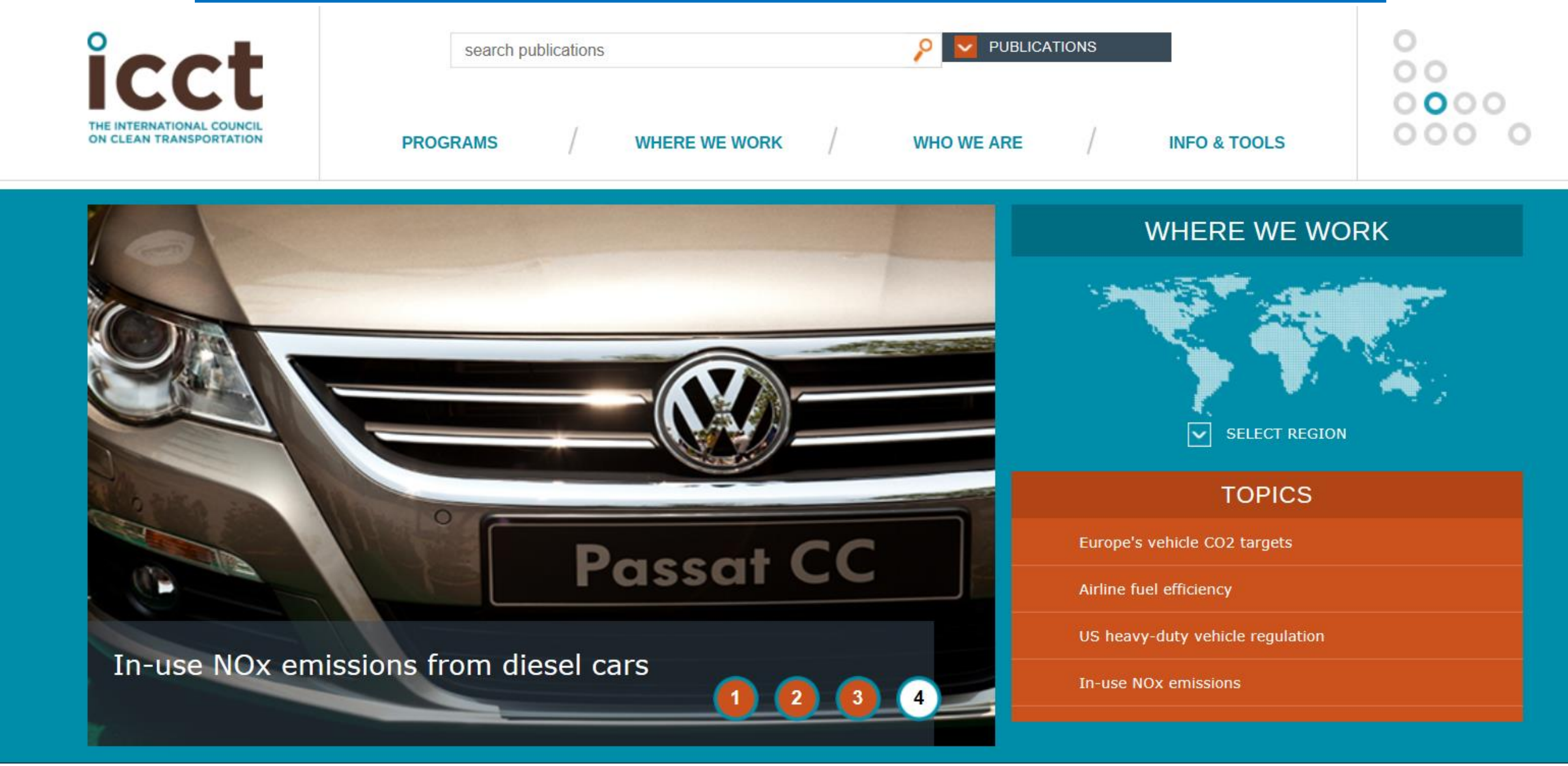


Combustion improvements

Loss Reductions

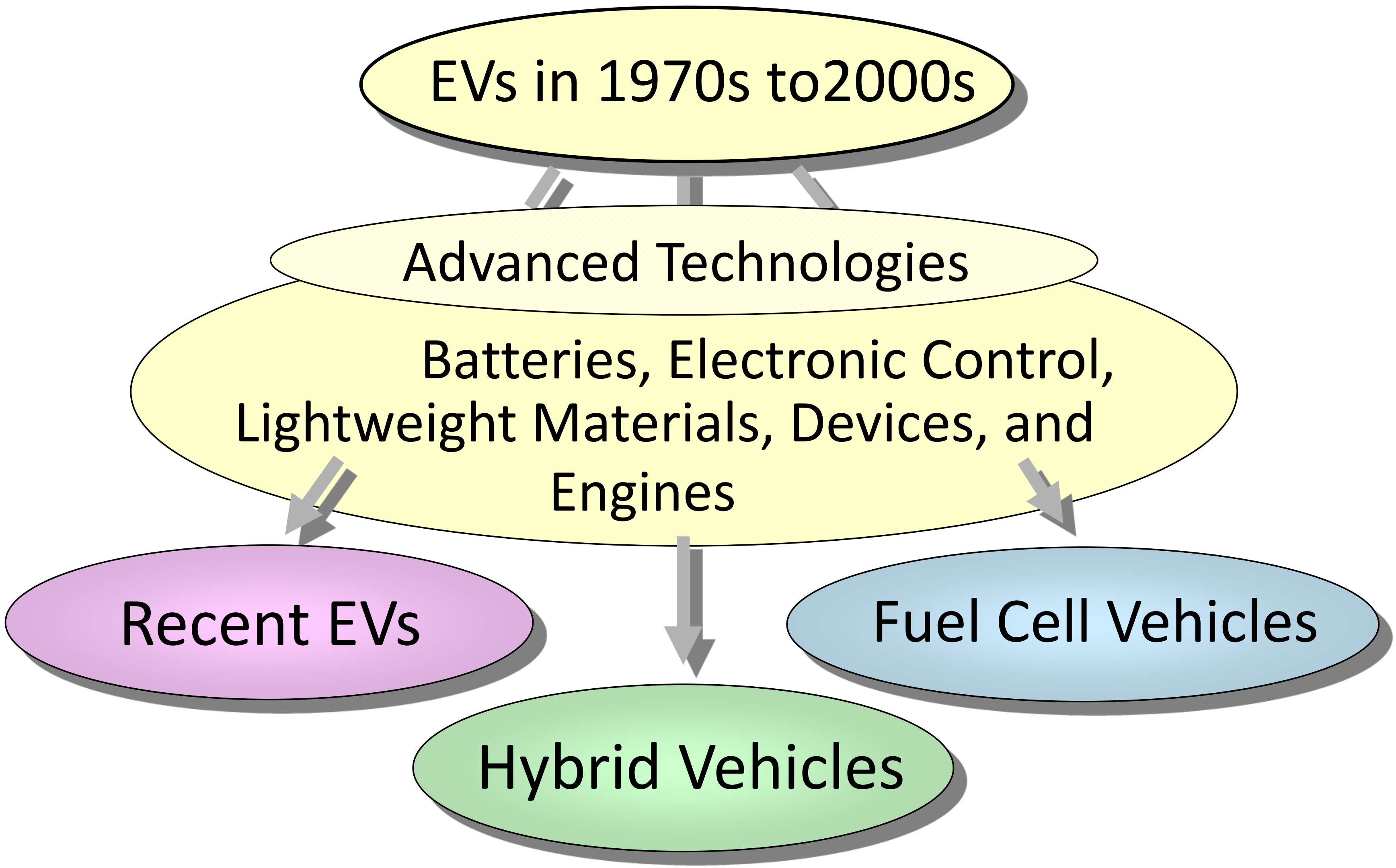
- ❑Turbocharging efficiency: 69%
- ❑Thermoelectric device: 262W×4
- ❑Mechanical loss reductions: 55.5%

The Volkswagen emissions scandal called "Dieselgate" announced on Sept. 18th , 2015, by U.S.EPA



The International Council on Clean Transportation

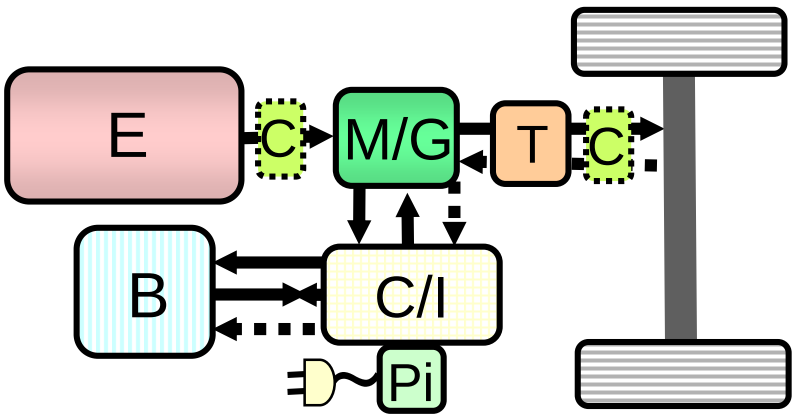
Variations of Electrified Vehicles



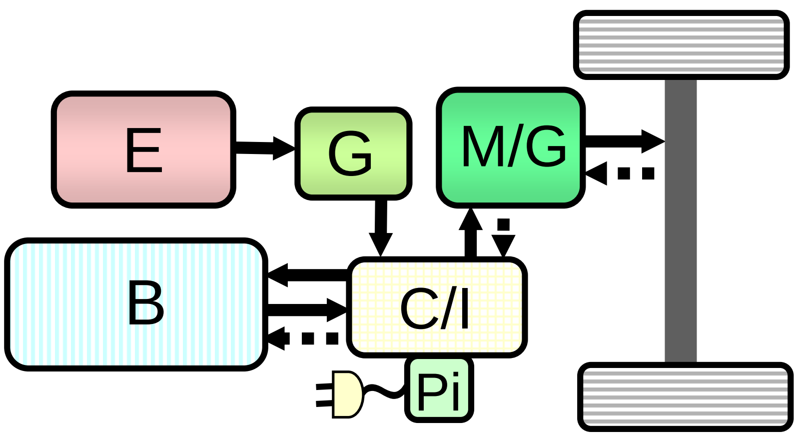
Three Hybrid Systems

<Hybrid type>
【Improved fuel economy, %】

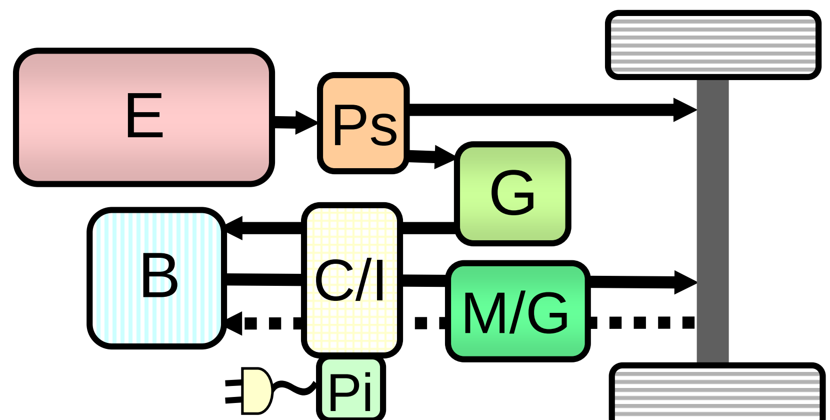
M: Motor G: Generator
C/I: Controller / Inverter
B: Battery unit
T: Transmission C：Clutch
Ps: Power splitter
Pi: Plug-in
: Drive / Power generation
: Regeneration



<Parallel (Mild)>
【20-50%】



<Series（Full）>
【50-100%】



<Series/Parallel (Full)>
【50-100%】

A Variety of Latest HEVs in Japan

Prius, Toyota

Plug-in Prius, Toyota

Plug-in Outlander, Mitsubishi

Solio, Mild hybrid (ISG) Suzuki

Note, e-Power, Series Hybrid, Nissan

Fit Hybrid, Dual Clutch Transmission Honda

Diesel Parallel Hybrid Truck, Isuzu

Diesel Parallel Hybrid Bus, Hino

A Variety of Electric Vehicles in 2017-2019

Chevrolet Bolt, GM

i3, BMW

E-Golf, VW

Leaf, Nissan

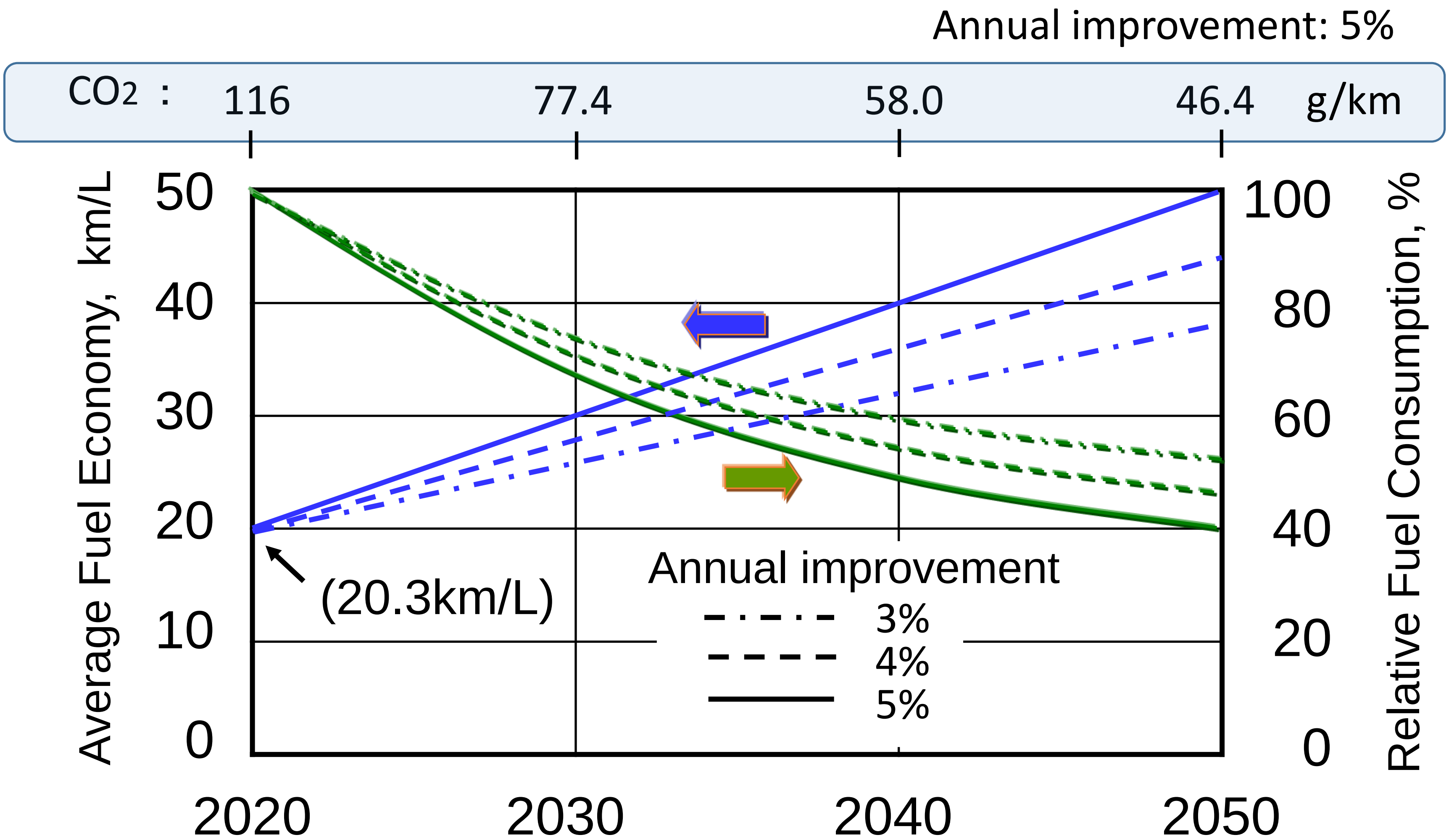
Model 3, Tesla

Honda Urban EV Concept

E-Canter, Mitsubishi

Semi in 2019?, Tesla

Future Passenger Car Fuel Economy Targets by Y. Daisho



ZEV and NEV policies will lead the global EV market.

❑ZEV regulations is tightened in California.

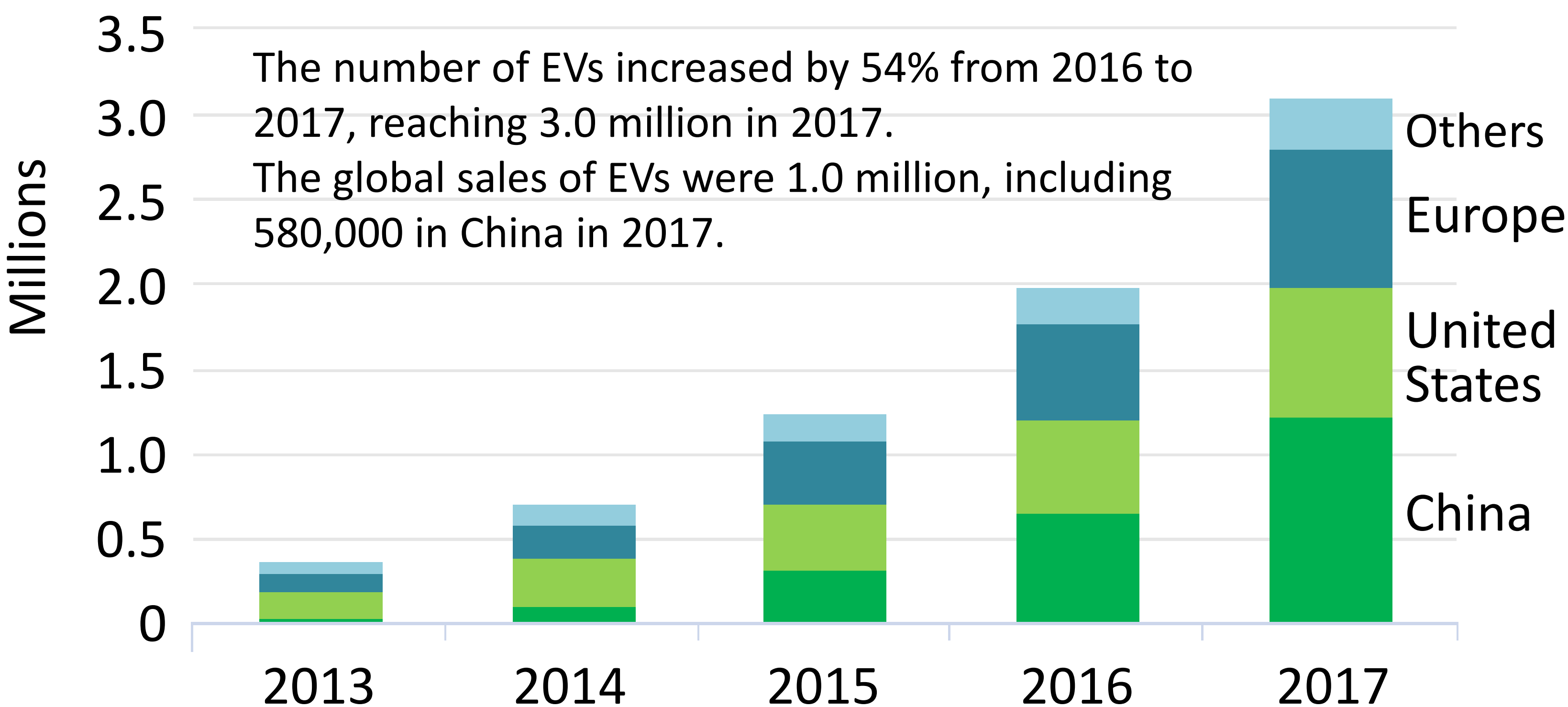
- ZEV sales: 4.5% in 2018, stepwisely 22% in 2025
- GM, Ford, FCA, Toyota, Honda, Nissan, VW, BMW, Daimler, Hyundai/Kia and Mazda have to comply.
- ZEVs include BEVs, FCVs, TZEVs (Transitional ZEV, PHV) excluding hybrids.
- Nine statess follow California.
- President Trump is insisting that the program should be abolished.

❑NEV（New Energy Vehicle）policy starts in China.

- ZEVs sales: 10% in 2019, 12% in 2020
- Hybrids are excluded.
- PHEVs having longer than 50 km EV range are included.
- EV and battery technologies are expected to advance.
- Will EV sales decrease after EV's purchase incentives are expired in 2020?
- China will become the mightiest EV nation, producing 7 million EVs out of 35 million vehicle production along with "Made in China 2025."
- Disseminating EVs will not have any significant effect on reducing CO_2 or improving air pollution in all megacities in China.

Number of EVs in Circulation

（Source：Global EV Outlook 2018, IEA）



❑It is predicted that the sales of EVs will be 4.0 million in 2020, and 21. 5 million in 2030 based on each country's BAU policy for disseminating EVs. Thus, owned EVs will be 13 million in 2020, and 125 million in 2030, accounting for 10% of global LDVs on the road.

Nissan's New "LEAF" (Sept., 2017)

- Drive range: 400 km by "e-Powertrain" ・Energy consumption: 10km/kWh
- "e-Pedal" is adopted to reduce driver's pedaling load.
- "Pro-pilot" is installed for driver's assistance.
- A connected technology "Apple CarPlay" is adopted.1
- CO_2 emission: 48.6 g/km（TEPCP: 486g/kWh in 2016)
- Real drive energy consumption: 7km/kWh
- "e+ version" was released having 62 kWh battery capacity in January, 2019
  The capacity is increased by 25%, drive range by 40%.

Domestic sales stock: 100,00
Global sales stock: 400,000
in 2018

L×W×H×WB	4,480×1,790×1,540×2,700 mm
VW/GVW	1,490–1,520 kg/1,765–1,795 kg
Battery type/Capacity	Li–ion/40 kWh (30 kWh)
Motor type/name	PM synchronous/EM57
Max. power （80 kW)	110kW/3,283～9,795rpm
Max. torque（280Nm)	320 N・m/0～3,283 rpm
Drive range（JC08 mode)	400 km（280 km)
Slow recharging time	16 hours（3 kW）/8 hours（6 kW)
Rapid recharging time	40 min. for 80% SOC

- Battery cell anode: NiMnCo
- Cell energy density: 240 Wh/kg
- Cell mass: 167kg
- Package mass: 300kg

Recharging Spots for EVs and PHV in Japan (October, 2018)

- Total Recharging Spots: 29,700
  - Major Rapid Recharging Spots as below: 7,600 (6-50 kW)

Nissan's Dealers: 1,890

Convenience stores: 1,040

Shopping malls: 900

Municipal areas: 460

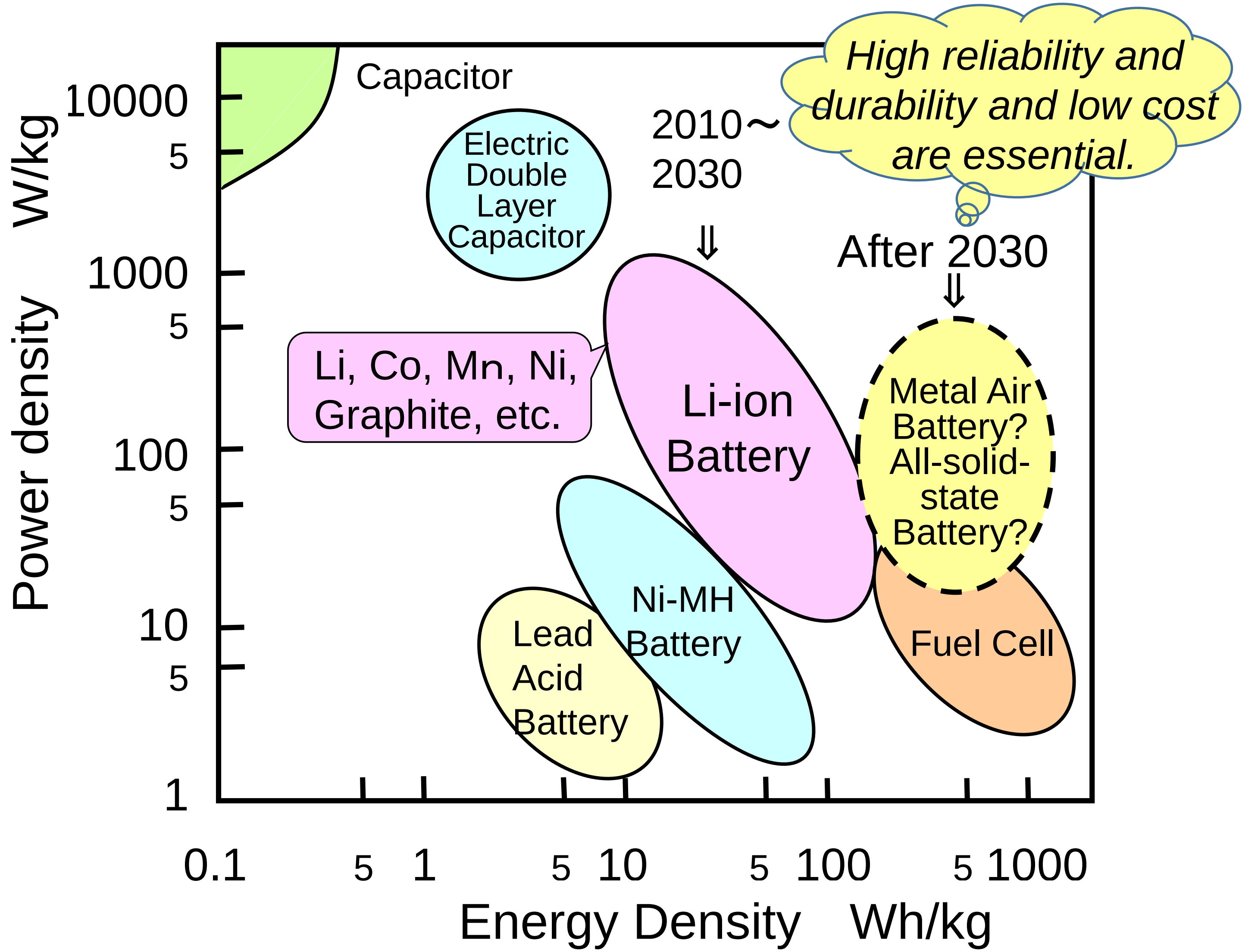
Road-side stations: 860

Express highway PAs: 410

  - Slow Recharging Spots: 22,100 (1-3 kW)

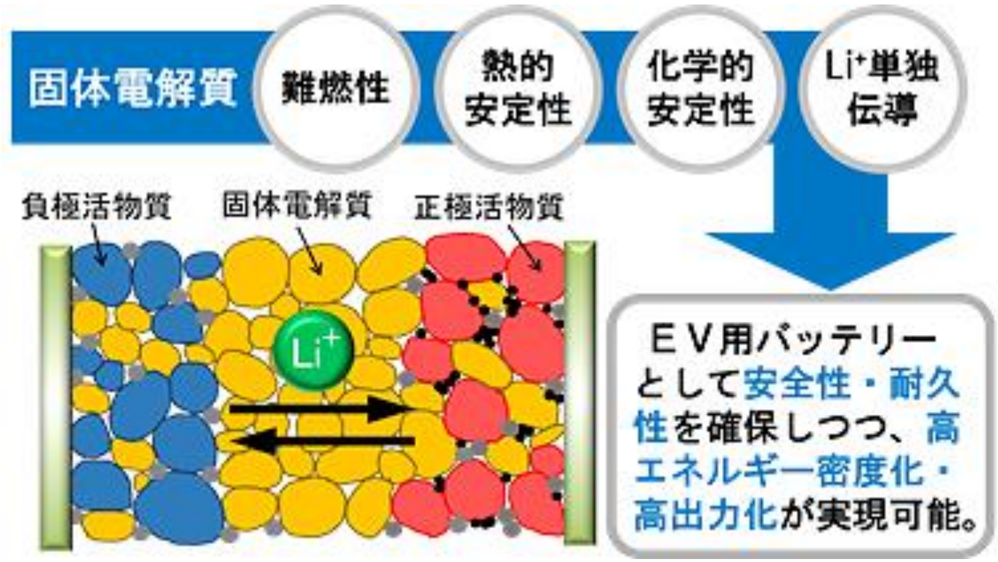
- Gas Stations: 30,747 (in March, 2017)

Devices for Storing Electricity



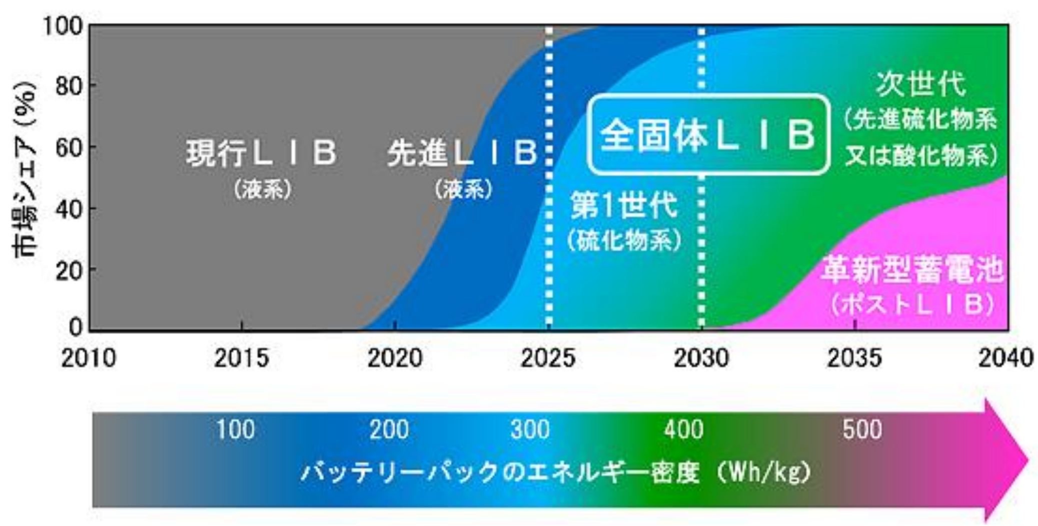
（Professor T. Osaka, Waseda University)

All Solid-State Lithium-ion Battery Development Project Phase 2 Started (NEDO, June 15, 2018)



Industry-academia-government collaboration project FY2018-FY2022, Budget: ¥10 billion

☚Structure of an all solid–state Li–ion battery



☚Assumed shift of EV battery technologies

Mid and Long Term Targets for Developing Battery Packages for PHVs and EVs

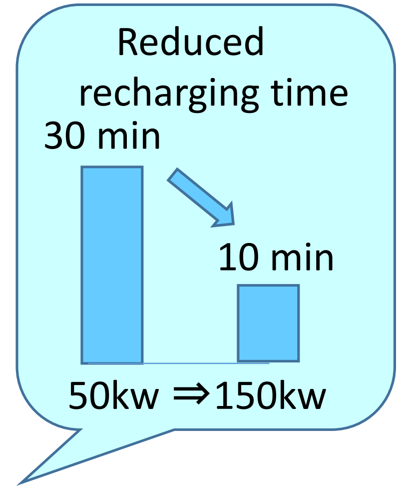
Type	Term	Drive range, km	Mass, kg	Capacity, kWh	Cost, ¥
PHV	2020～2030	60	50	10	200,000
EV	2040～2050	700	80	56	260,000

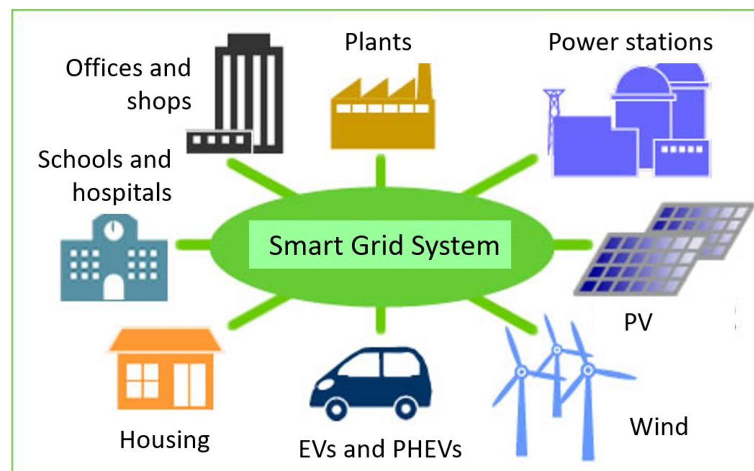
Source: Roadmaps on Developing Secondary Batteries for Motor Vehicles 2013
(NEDO, August, 2013, Reviewed in June, 2018)

Issues on Rapid Recharging Systems for EVs and PHEVs in Japan

❑ The effect of stopping all nuclear power stations in March 2011 on increased CO_2 emissions in Japan
- 340g/kWh in 2010
- 610g/kWh（1.8 times） in 2014 (average)

❑ Revised CHADEMO standards for rapid EV recharging, announced in March 2017
- Increasing power capacity for Evs and reducing recharging: 50 kW ⇒ 150kW (2017) ⇒ 350kW (2020)
- Issues on how to manage electricity supply and demand for transportation, business and household sectors
  - ✓ Smart grid and demand response systems are necessary.
  - ✓ Power management systems are also necessary to store and generate electricity





SHIZUKI ELECTRIC CO.

Considering EV's Electricity Consumption

- Annual electricy consumption, Wt：797,100GWh （FY2015）
- EV's real drive energy consumption: 7km/kWh （Leaf's case）
- Data ・Daily drive distance: 23.4km （MLIT）
  - ・Annual drive distance: 8,540km
  - ・Annual electricity consumption: 1,220kWh
  - ・Annual electricity cost: ¥30,500円 (¥25/kWh)
- EVs' annual electricity consumption, We （We/Wt）
  - ・1.0 million EVs: 1220GWh (0.153%)
  - ・5.0 million : 6100GWh (0.765%)
  - ・10 million ：12,200GWh (1.531%)
- A typical 1.0 million W nuclear powerplant can provide 7,010 GWh at 80% operation to be used for 5.75 million EVs.
- If 20,000 EVs are simultaneously charged at 50 kW recharging stations, a nuclear poerplant is necessary.
- Taxation on EVs will be based on annual drive distance and ownership.

Comparison of Electricity Sources in Japan

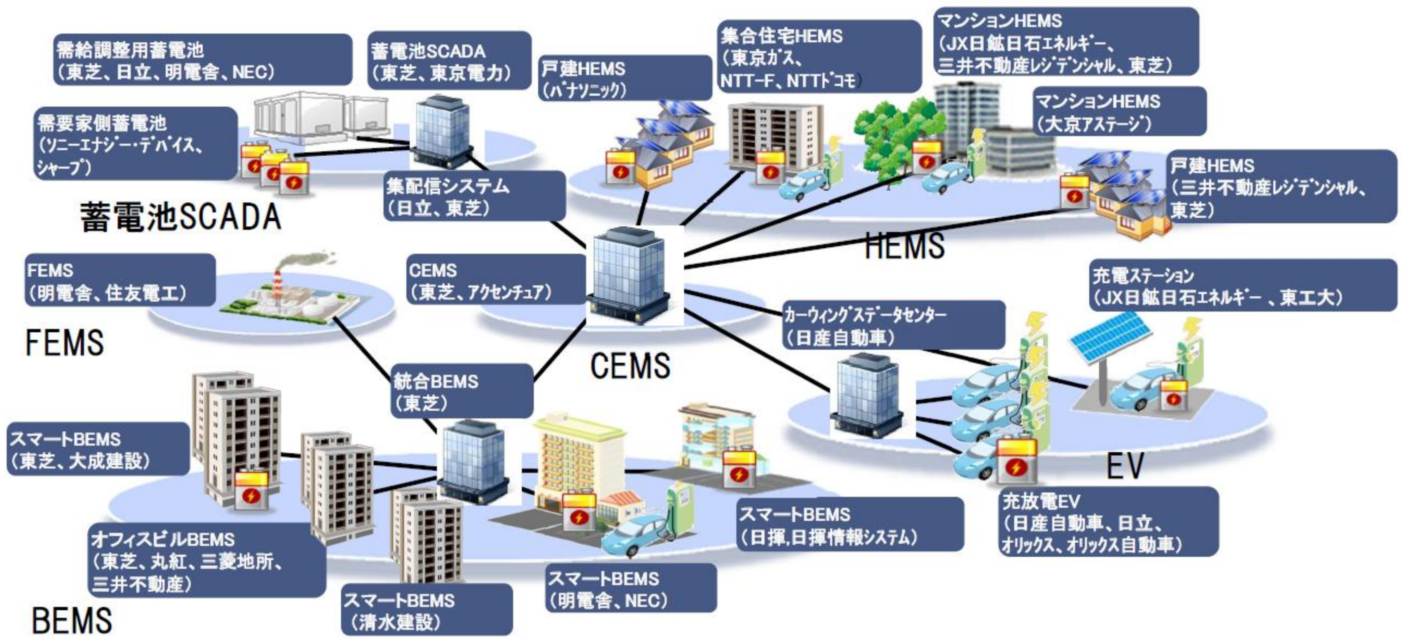
Source	Plant CO_2 emission g/kWh*	Cost ¥/kWh (predicted for 2030)	Operation %	Life time year
Coal	943	12.9	70	40
Oil	738	28.9～41.7	10～30	40
LNG	599	13.4	70	40
Solar	38	12.5～16.4	12	20
Wind	25	13.6～21.5 (inland) 30.3～34.7 (off shore)	20 (←) 30 (←)	20
Nuclear	20	10.3～	70	40
Geothermal	13	16.8	10～80	40
Hydraulic	11	11.0	45～60	40～60
Biomass	10～	29.7 (dedicated) 13.2 (mixed)	80	30～40
Average	540	24	-	-

Based on sources from METI and CRIEPI

*: including facility and operation costs

Yokohama Smart City Project (YSCP) (METI, FY2010-FY2014) reported in March, 2015

(Achievements/targets)
HEMS (4,230/4,000 households), PV (37/27 MW), EVs (2,300/2,000)
CO_2 reduction (39,000/30,000 tons), (29/25%)



- ❑Toyota, Keihanna and Kita-Kyushu Cities also joined in their own ways.
- ❑V2X (X： Grid, Home, Building, ect.) projects have been conducted after YSCP.

A Variety of Toyota's FCVs, 2014-2018

"Mirai" December, 2014

FC Forklift, January, 2017

FC Bus with two Mirai's FC systems sold to the Tokyo Metropolitan Government, February, 2017

FC Truck , in U.S. California bay areas April, 2017

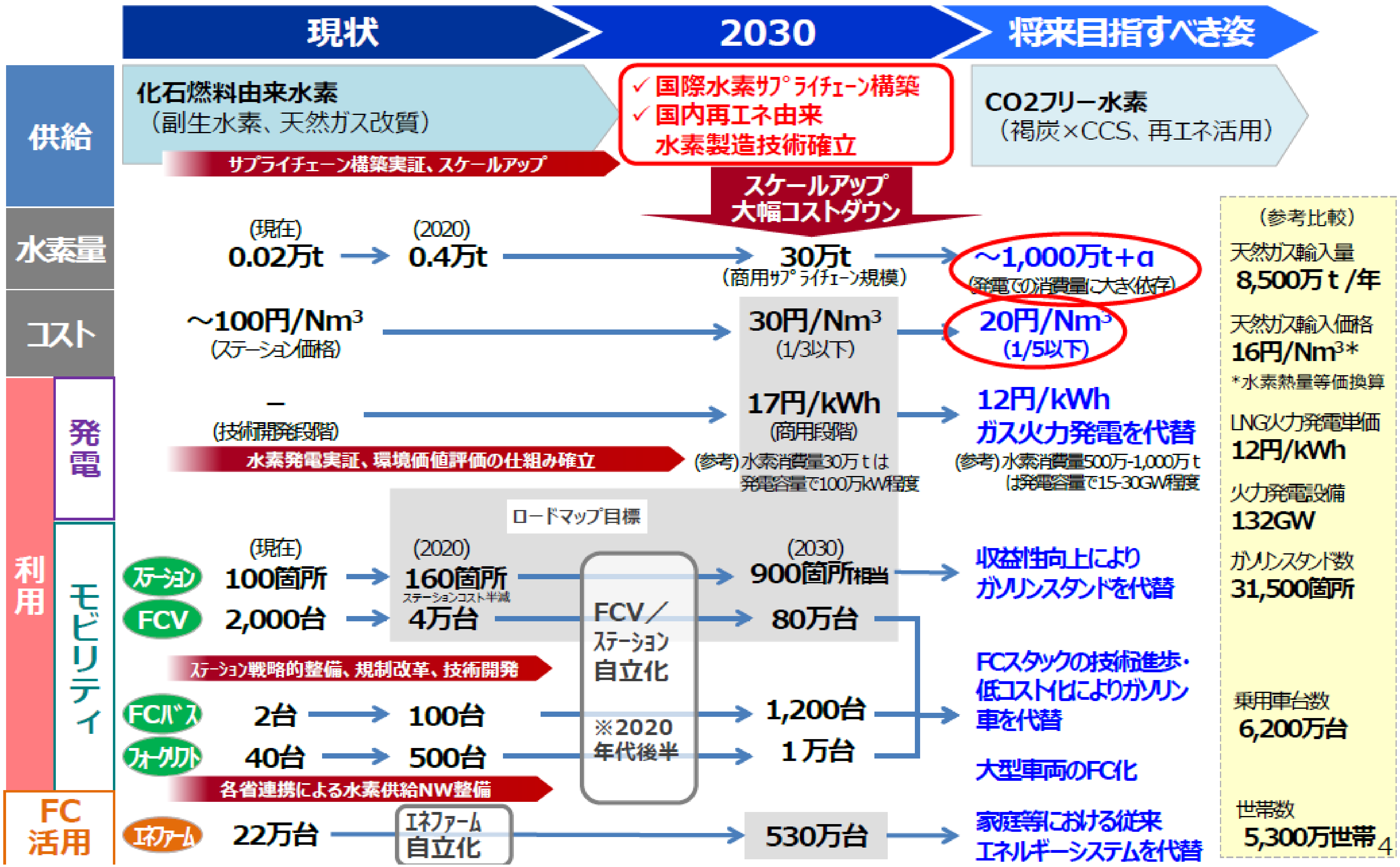
The truck has two "Mirai`s FC systems, 12 kWh battery unit and 500 kW power motor unit with 1,800 N･m torque. The gross vehicle weight is 36 tons.

Two delivery FC Trucks will be used for Seven-Eleven stores starting in 2019. Their drive range is about 200 km. (June 6, 2018)

Other automakers are expected to follow or collaborate with Toyota.

Scenarios on “Basic Hydrogen Strategies”

(Ministerial Meeting on Renewable Energy and Hydrogen (December 26, 2017)



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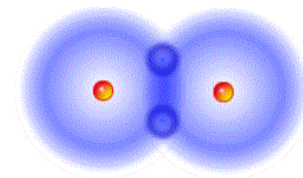
A Roadmap for Disseminating Hydrogen Fuel Cell Vehicles in Japan (METI, 2016-2017)

❑Number of registered FCVs:

・**40,000 by 2020** ・**200,000 by 2025** ・**800,000 by 2030**

(・3-6 million in 2040 ・8-16 million in 2050)

❑FCVs should include not only passenger cars but also forklifts, trucks, buses, vessels, etc.



❑Number of hydrogen stations:

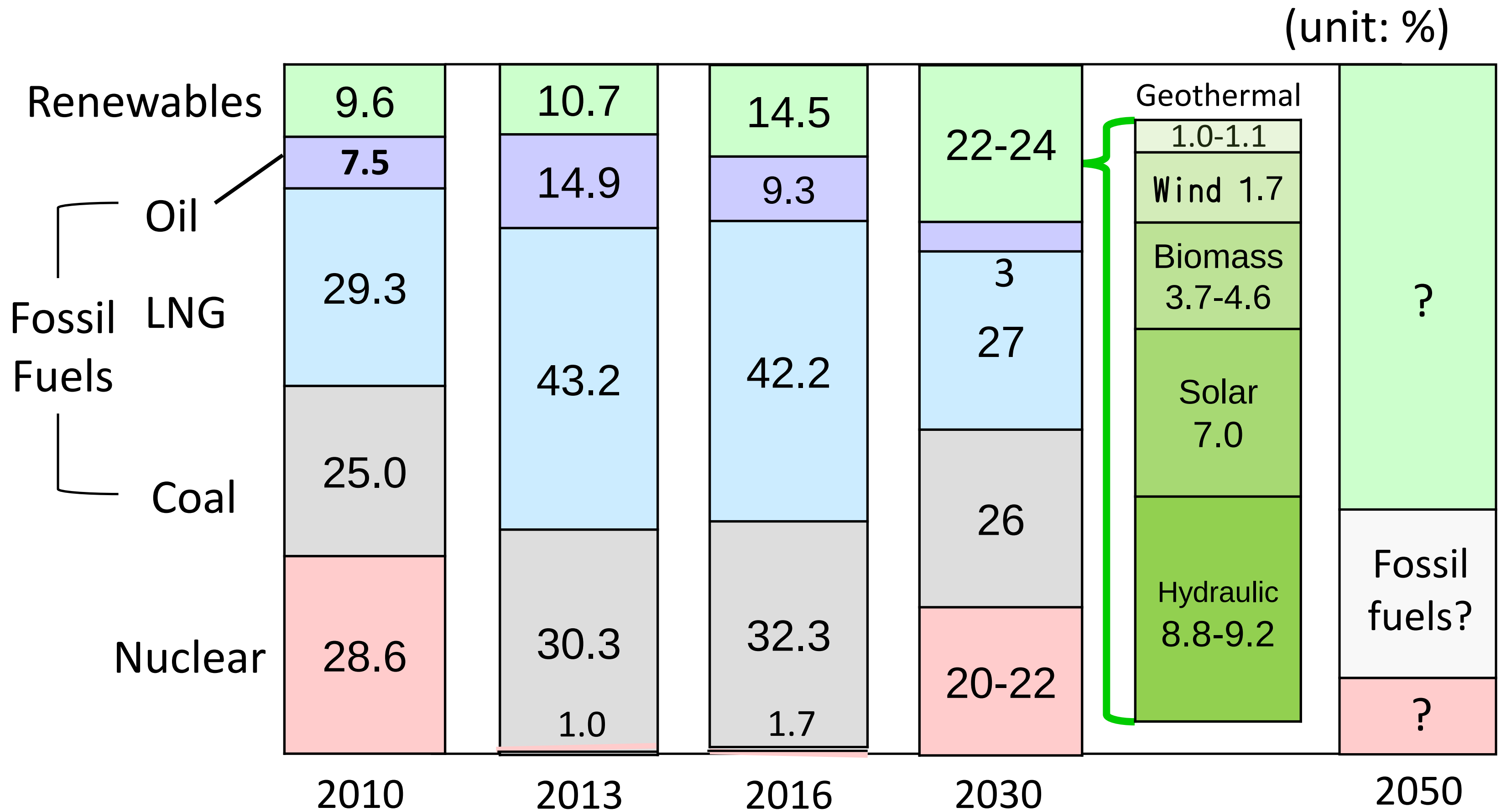
・**160 by 2020** ・**320 by 2025** (・720 in 2030)

❑Hydrogen should be CO_2 free in terms of production, transportation, storage and usage by 2040.

❑Hydrogen carriers including organic hydride, ammonia and liquefaction are the most promising measures to store and transport hydrogen. (SIP)

❑Technological and economical issues should be discussed and overcome to introduce renewable hydrogen.

Electricity Sources Proposed for the Paris Agreement by METI, Japan, 2015, 2018



☆Reducing the consumption of fossil fuels in electric power plants is effective to decrease CO_2 emission from all sectors.

Comparison of Enery Consumed by EVs and FCVs

Item	EV "L"	FCV "M"
Real Drive energy consumption	7 km/kWh	100 km/kg-H_2
Annual energy consumption	1,220 kWh	85.4 kg
Annual energy expense (Present)	¥30,500	¥85,400
Energy cost (present)	¥25/kWh	¥1,000/kg-H_2
Future energy cost target	¥12/kWh	¥20/Nm^3
Electricity fraction required for one million vehicles	0.153%	0.52%

- Average drive distance: 23.4 km/day, 8,540 km/year (MLIT, 2016)
- Electricity required for producing 1 kg hydrogen: 140 MJ/kg=38.9 kWh/kg
- Electricity required for driving an FCV in a year: 3,320 kWh
  (If electrolysis efficiency is 80%, 4,150 kWh is necessary.)

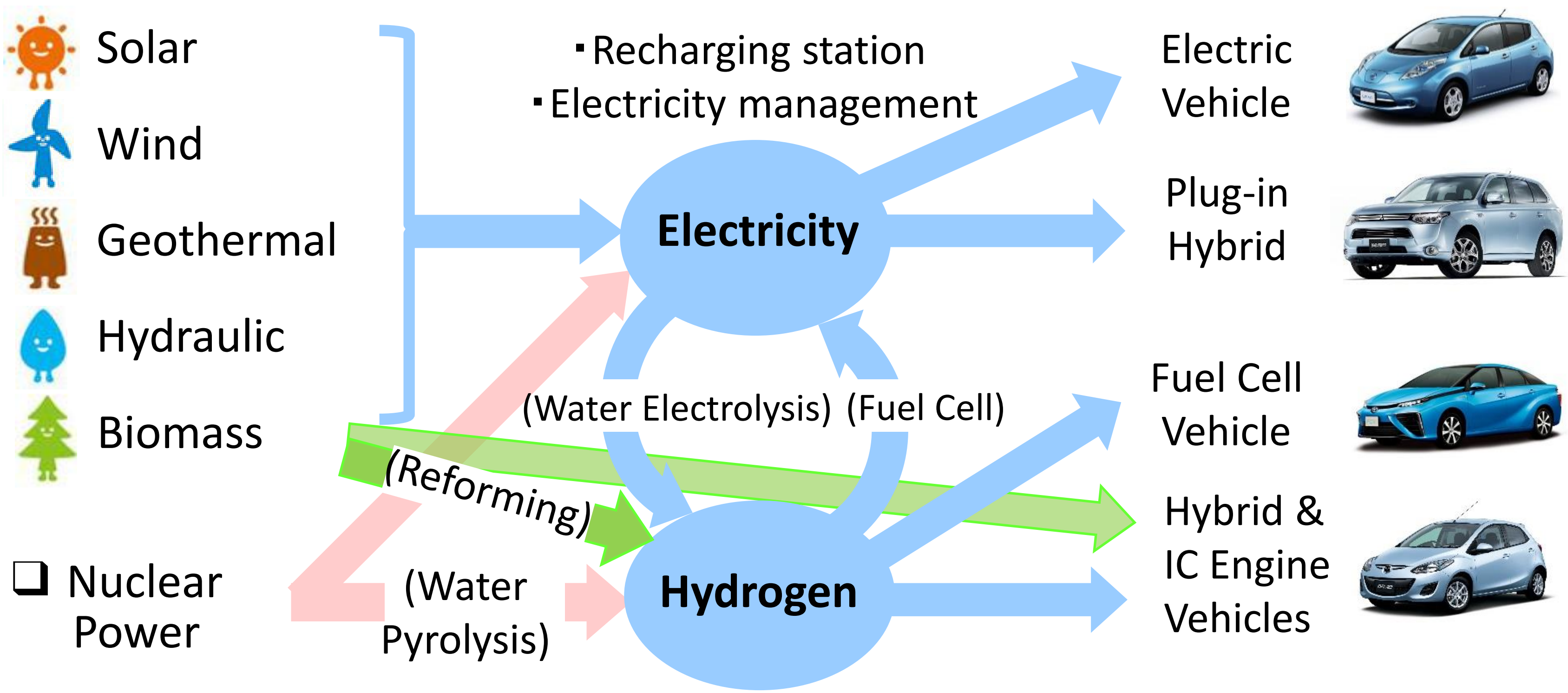
Future Competition of EV vs FCV

Item	EV	FCV
Vehicle cost	high battery unit cost	extremely expensive
Production process	simpler (reduced parts)	Complicated
Running cost	cheaper (<25円/kWh)	expensive
Drive range	sufficient for weekday use	long (400-700 km)
Charging time	10-15 min, required	3 min. or so
Charging infrastructure	20-50kW (¥2-4 million) ⇒150kW, 350 kW（?）	¥500 million⇒¥300 million (excluding land acquisition costs)
Energy Business	low profit	very low profit
Rare materials	Nd, Li, Co, Ni ・・・	Pt, Nd・・・
Social acceptance	favorable	awareness required

- ❑ Co-existing utilizing their own features or the survival of the fittest?
- ❑ Rapid recharging systems with smart grids VS hydrogen stations
- ❑ How much renewable energy will be produced for electricity or hydrogen in place of oil?

Options for Decarbonizing Electricity and Hydrogen

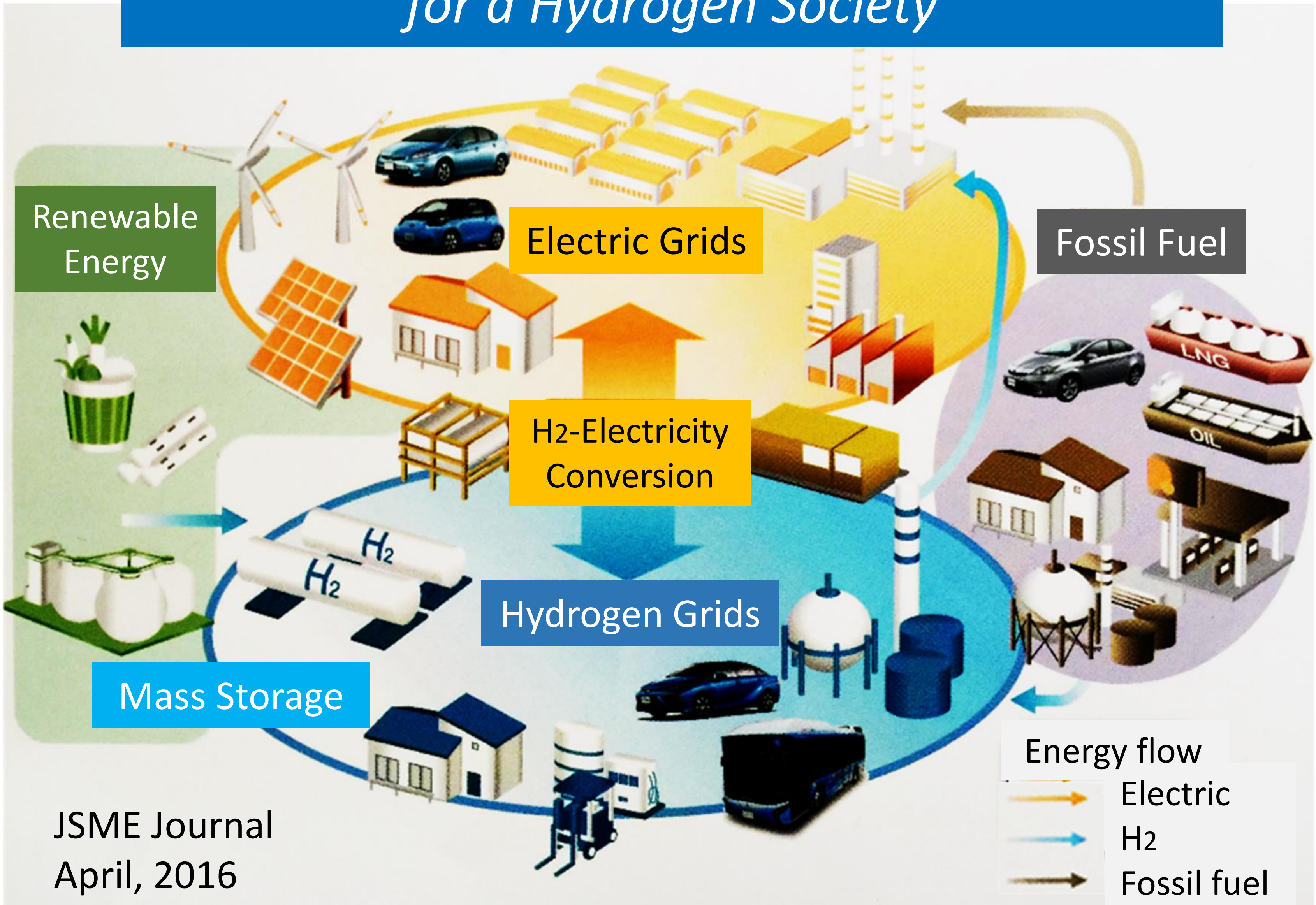
❑ Renewables



・Hydrogen handling, storage and supply

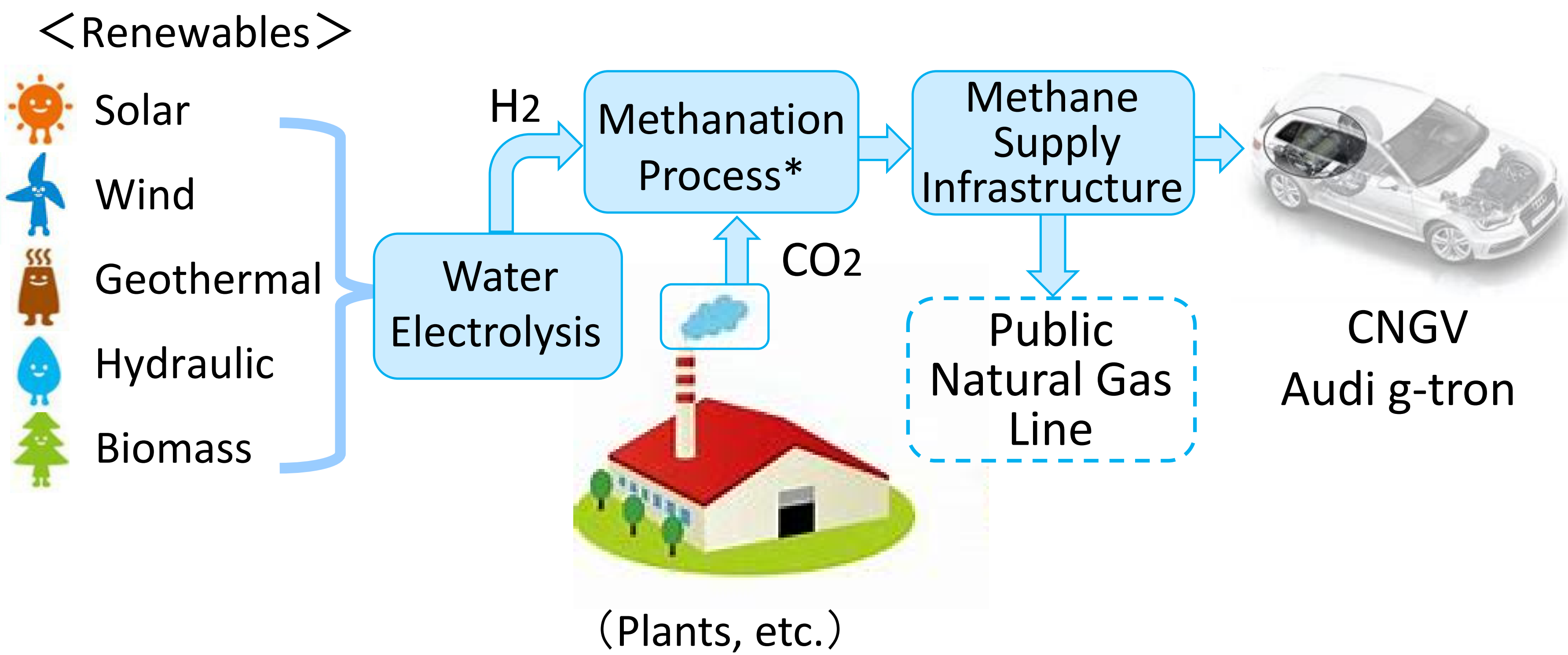
☆ Hydrogen is produced mainly from fossil fuels such as oil and natural gas.
☆ Carbon-free hydrogen must be realized by 2040 taking into production, transportation, storage and supply processes. (Japan)
☆ Overall LCA and cost evaluation should be made on these fuels and energy.

Developing Advanced Energy Technologies for a Hydrogen Society



JSME Journal
April, 2016

"e-gas" Production by Audi based on Carbon Capture & Utilization (CCU) (1/2)



- ❑ CO_2 emission can be reduced by about 80% on Well-to-Wheel basis.

Market Share Targets for Passenger Cars in 2020-2030 proposed by METI

（A Strategic Research Committee for Next Generation Vehicles, METI, 2010, The following Committee, METI, 2018）

Vehicle type		2017（data）	2020	2030
Conventional vehicles		63.97%	50～80%	30～50%
Next generation vehicles		36.02%	20～50%	50～70%
	HEV	31.2%	20～30%	30～40%
	EV / PHEV	0.41 / 0.82%	15～20%	20～30%
	FCV	0.02%	～1%	～3%
	Clean diesel	3.52%	～5%	5 ～10%

- ❑4.386 million passenger cars were sold in Japan, in 2017.
- ❑Percent market share of passenger cars is lower than 5% in the other major countries in 2017 as follows. ･USA： 4.0% ･Germany: 3.0% ･France: 4.8% ･China: 3.0% ･India： 0.03%

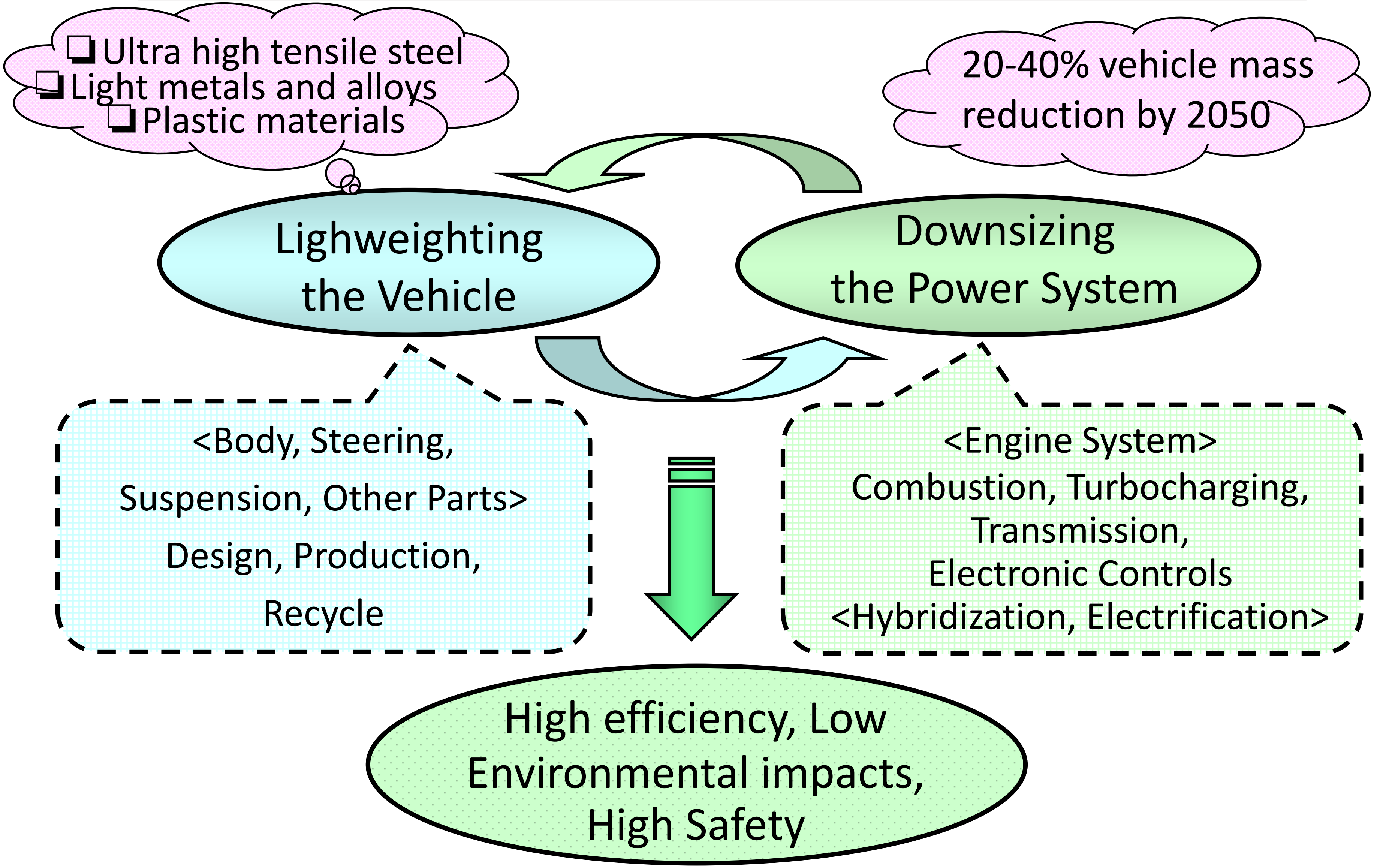
Comparison of Next Generation Vehicles at Middle Class

Type	Battery capacity kWh	Vehicle mass ratio	Fuel economy
Gasoline vehicle	（fuel: 400-500）	（1.0）	（1.0）
Diesel		1.06	1.15～1.20
HV	1～2	1.05～1.15	1.20～1.90
PHV	10～20	1.15～1.20	1.8
BEV	20～80	1.20～1.30	3～4**
FCV	1～2 (H_2: 150-170)	1.30～1.40	1.8～2.5**

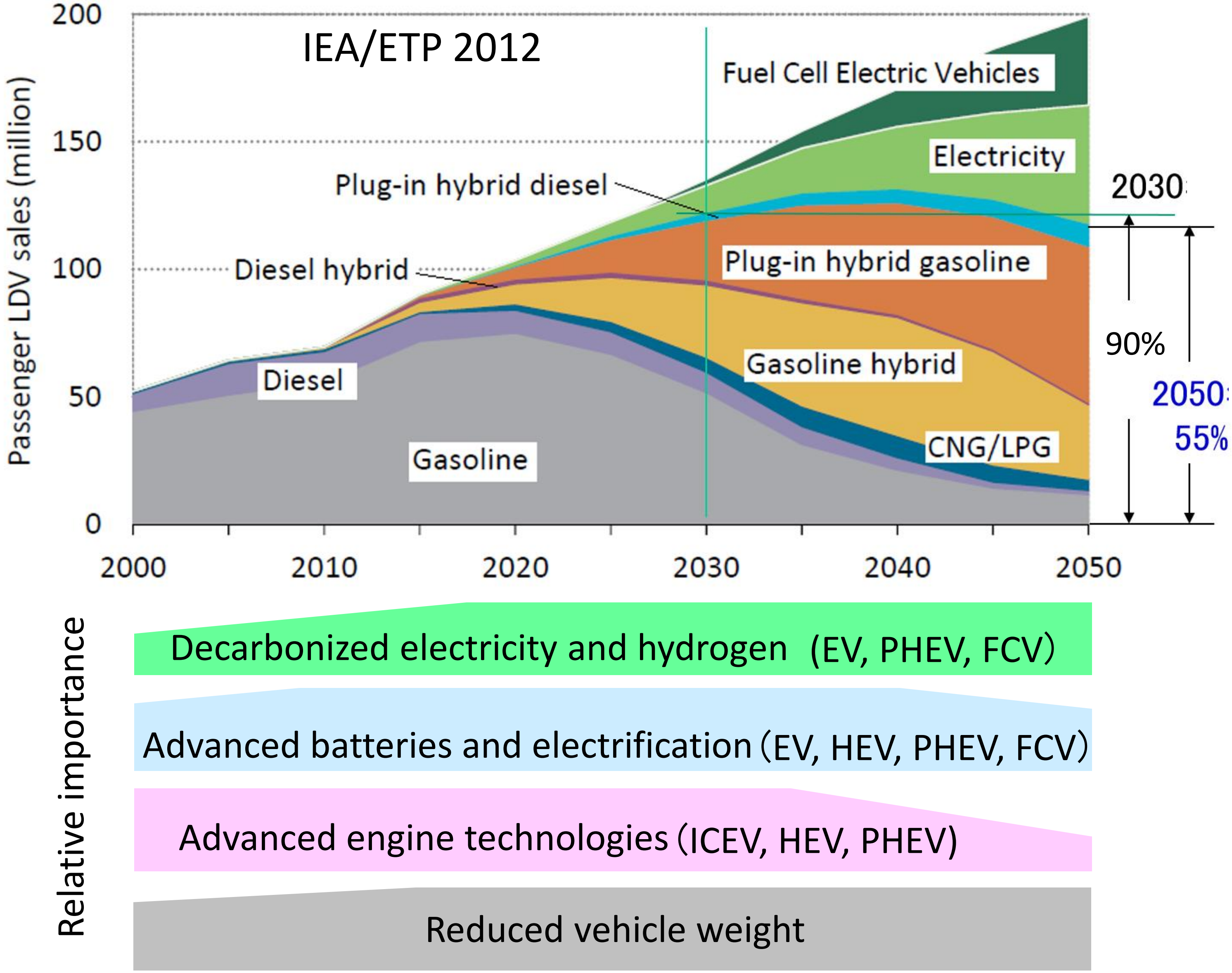
* : Relative to gasoline vehicle

**: Converted based on energy consumption (Wh/km)

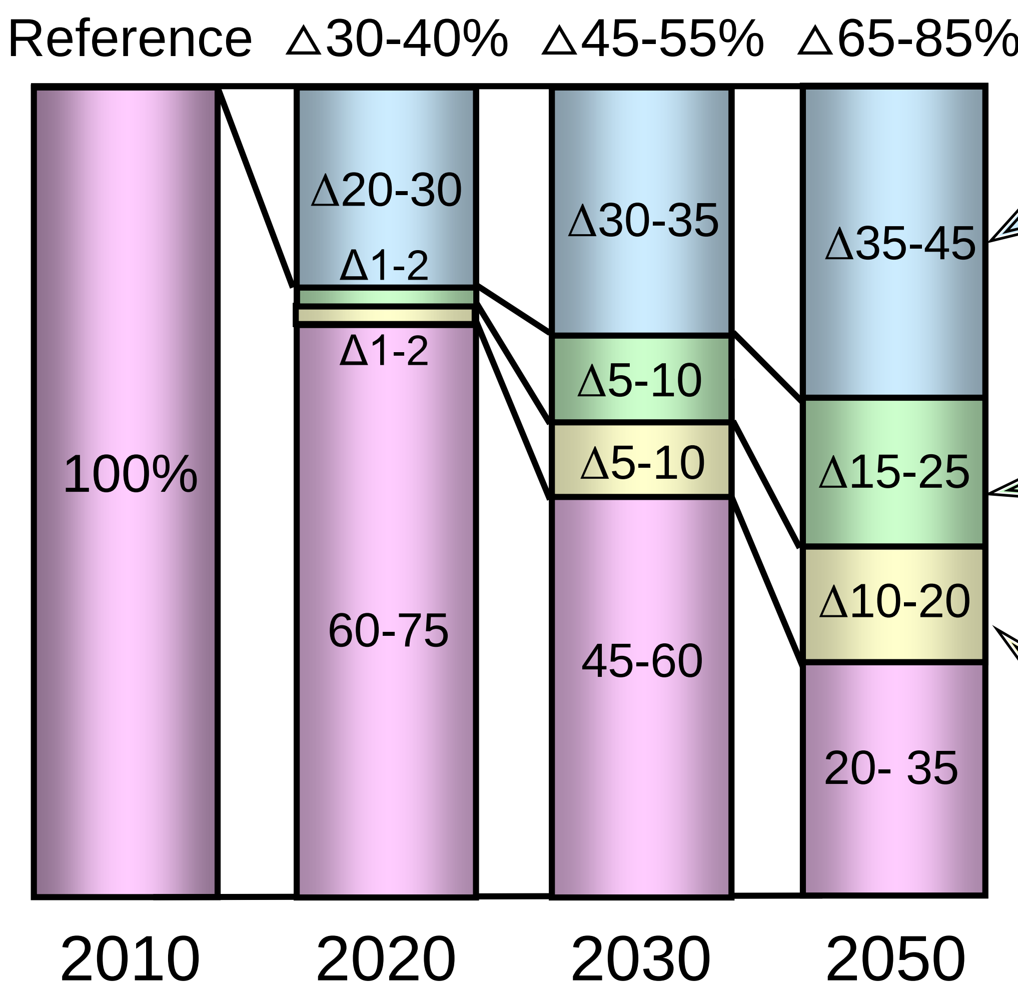
Synergetic Effects of Downsizing the Power System and Lightweighting the Vehicle



Projected Next Generation Passenger Vehicles' Share Worldwide and Relative Importance for R&D



Projected Long-term Reduction in Motor Vehicle CO_2 Emission in Japan



【 Measures 】

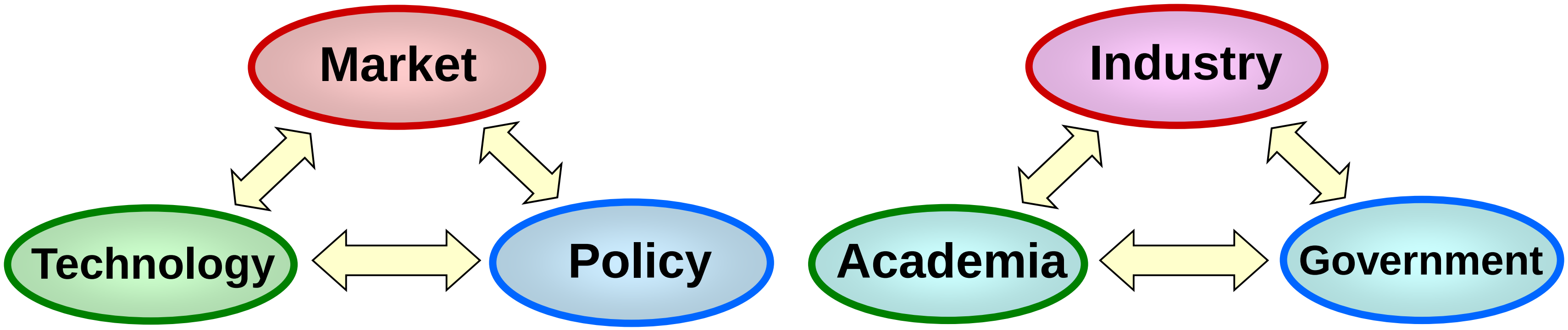
<Fuel Economy Improvements>
Efficient power systems, Hybridization, Vehicle weight reduction

<Use of Low Carbon Fuels and Energy>
Electricity, H_2, Biofuels

<Smart Vehicle Use>
ITS, ICT, Modal shift, Change in car lifestyle

(By Y. Daisho)

Issues for Developing and Disseminating Next Generation Vehicles



- Comprehensive efforts for sustainable mobility in terms of environmental protection, energy security, economy, convenience, safety, comfort and resiliency to disasters.
- Continued governmental support and collaboration between industry, academia and government for developing advanced mobility technologies
- Strengthening global competitiveness for motor vehicle-related technologies
- Developing and disseminating technologies related to low-carbon renewable fuels and energy such as electricity, bio-fuels, hydrogen etc.
- Creating new environmentally friendly car lifestyles
- Developing technologies related to ITS, IT, ICT and AI for us to drive conveniently, efficiently and safely.
- Technological and policy contributions to emerging economies