Prospect of automotive energy strategy and powertrain technology roadmap

Playing fire seriously

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Outline

1. Demand of CO_2 emission reduction and energy security in China

2. Prospect of automotive powertrain technology roadmap

3. Paths forward to carbon neutral combustion

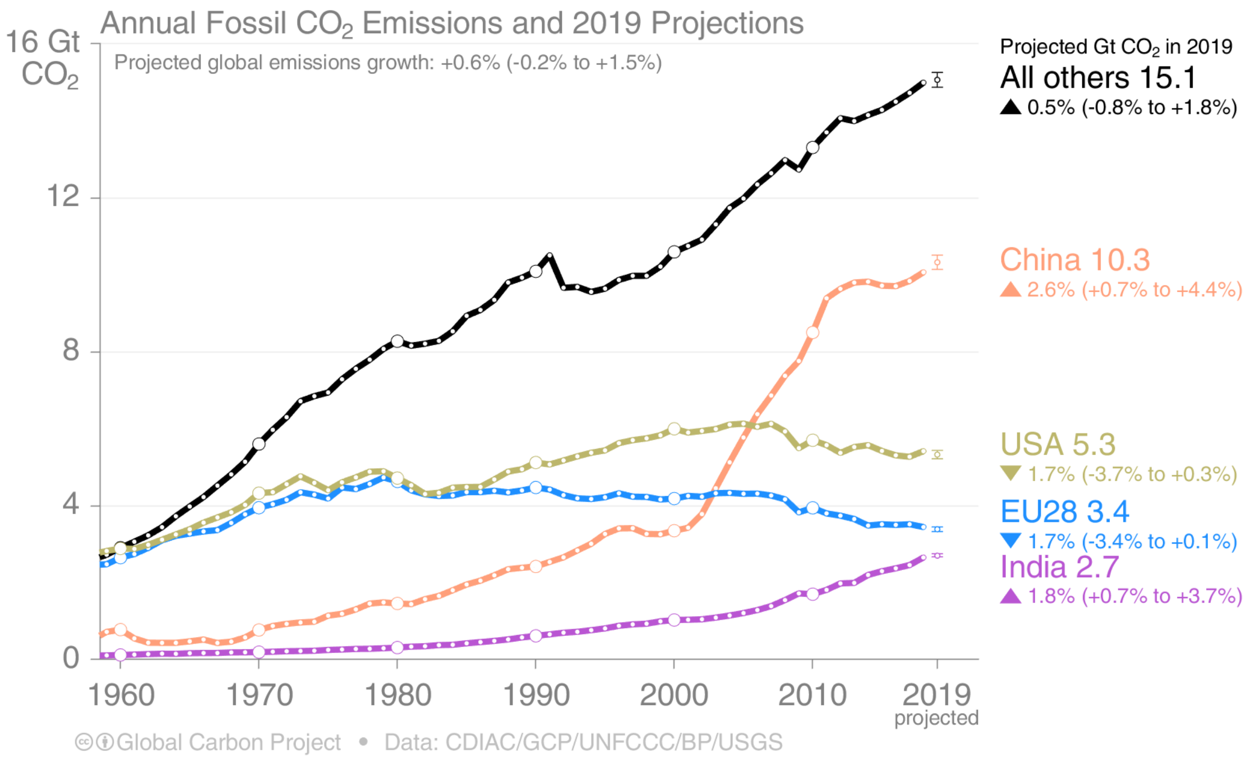
4. Prospect of internal combustion engine and fuels

5. Relation between Intelligent connected vehicles (ICV) and automated driving (AD)

6. The role of high-definition map for self-driving vehicles

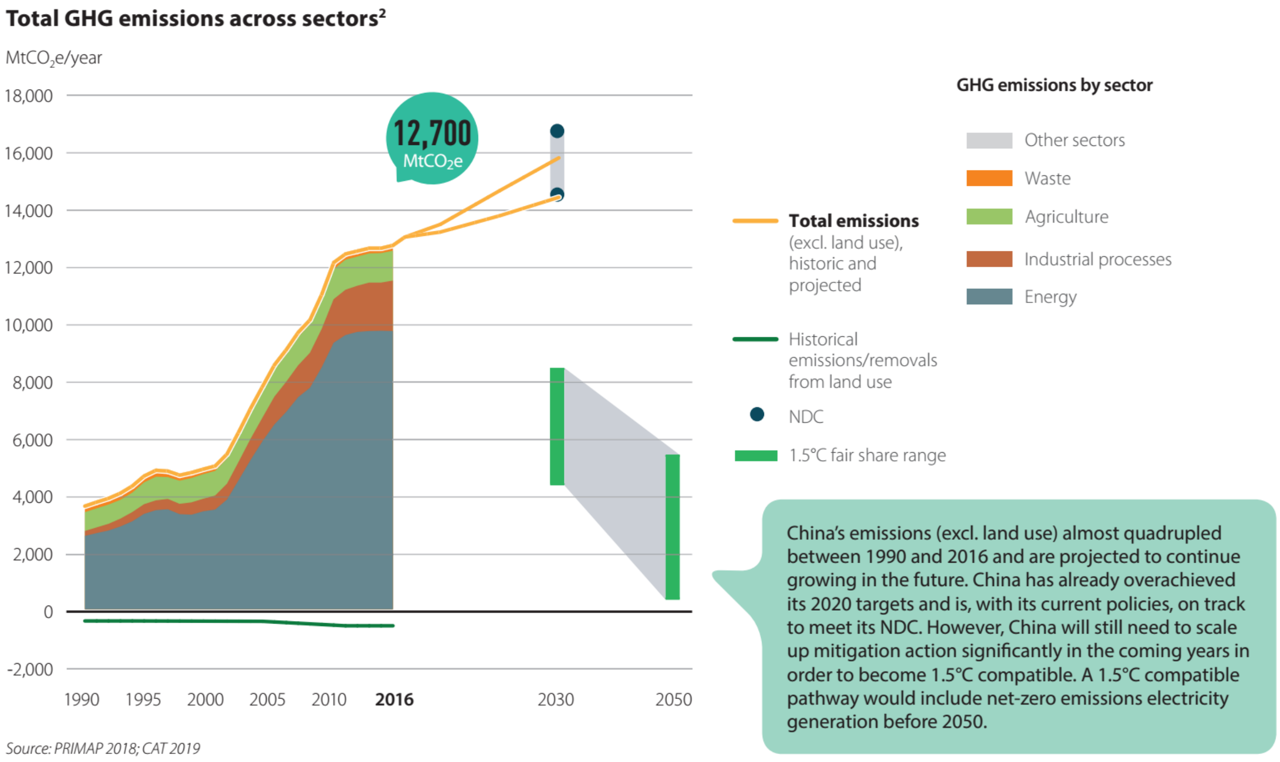
1. Demand of CO_2 emission reduction and energy security in China

CO_2 Emissions Projections for 2019



Group 1	Group 2	Group 3	Group 4	Group 5
Australia	India	Argentina	France	China
Canada	Russia	Brazil	Germany	Indonesia
Saudi Arabia	South Africa	Mexico	Italy	Japan
United States	Turkey		United Kingdom	South Korea

CO2 Emissions reduction mission by 2030



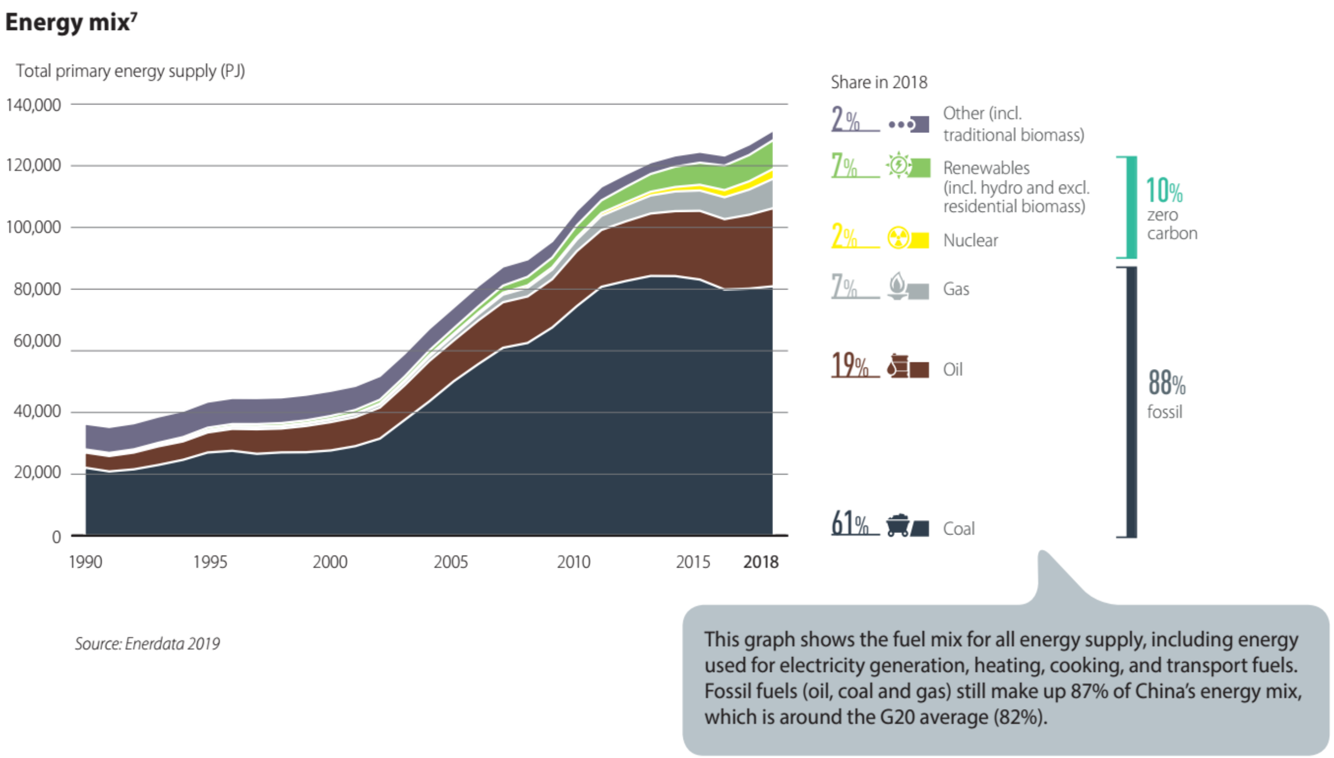
China needs to reduce its emissions to below 8.4 GtCO2e by 2030 and to below 5.4 GtCO2e by 2050 to be within its fair-share range compatible with global 1.5°C IPCC scenarios.

GtCO2e: gigatonnes of CO2 equivalent;
MtCO2e: million tonnes of carbon dioxide equivalent

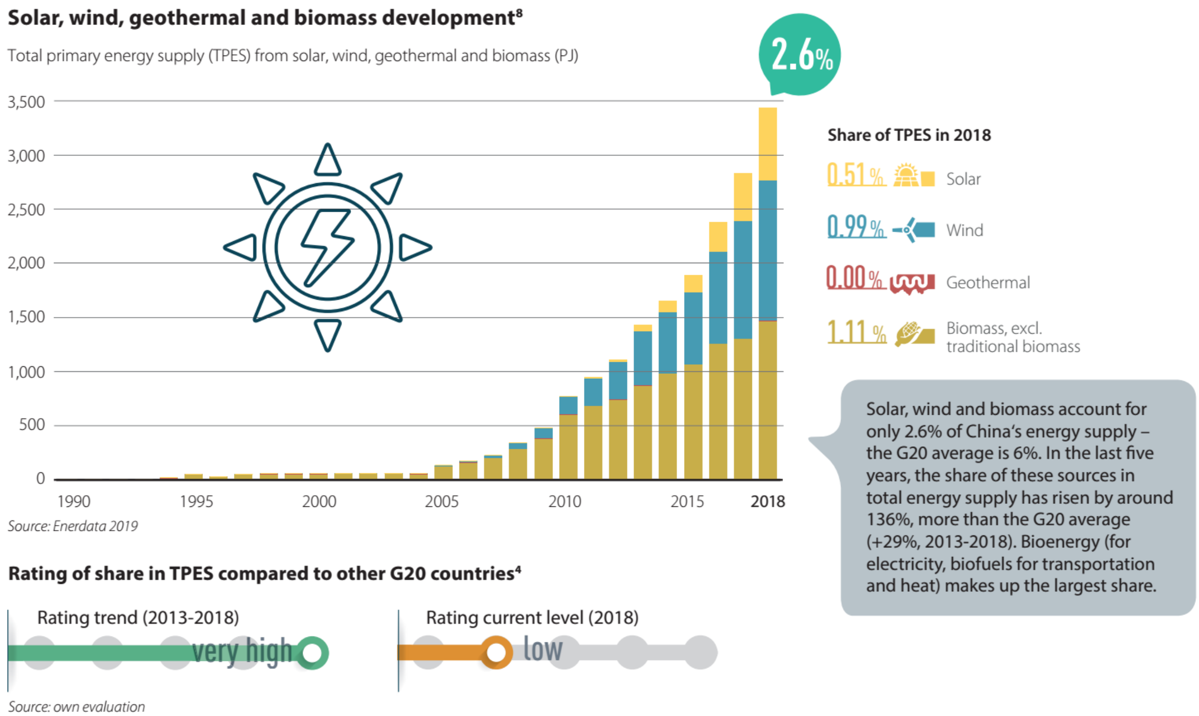
[1] Global Carbon Budget 2019
[2] Brown to Green Report 2019 China.

1. Demand of CO_2 emission reduction and energy security in China

Energy mix in China



Solar, wind, geothermal and biomass development



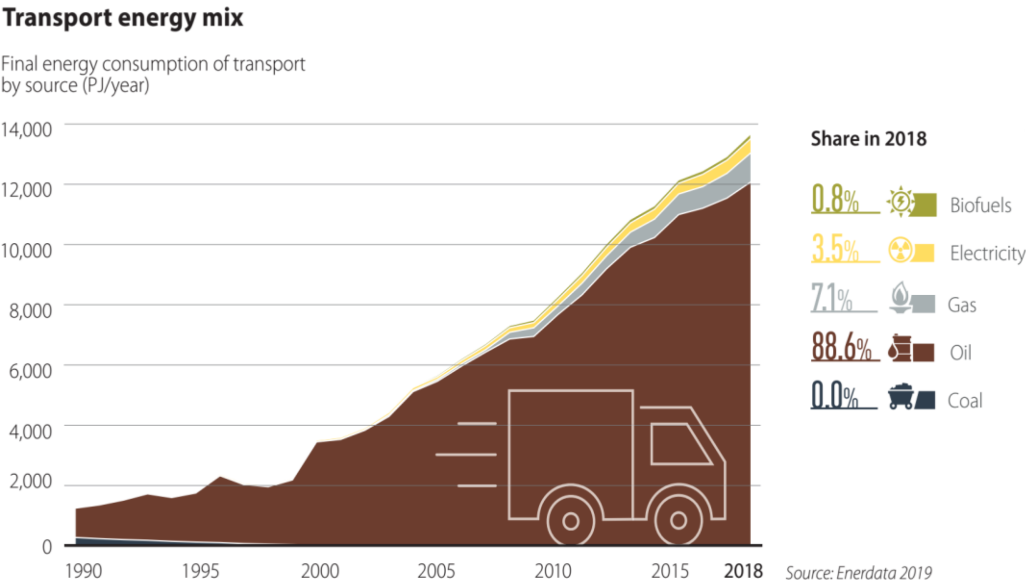
Fossil fuels still make up 87% of China's energy mix (including
power, heat, transport fuels, etc), with **coal being the predominant resource.**

Solar, wind and biomass account for only 2.6% of China's energy supply –the G20 average is 6%.

[1] Brown to Green Report 2019 China

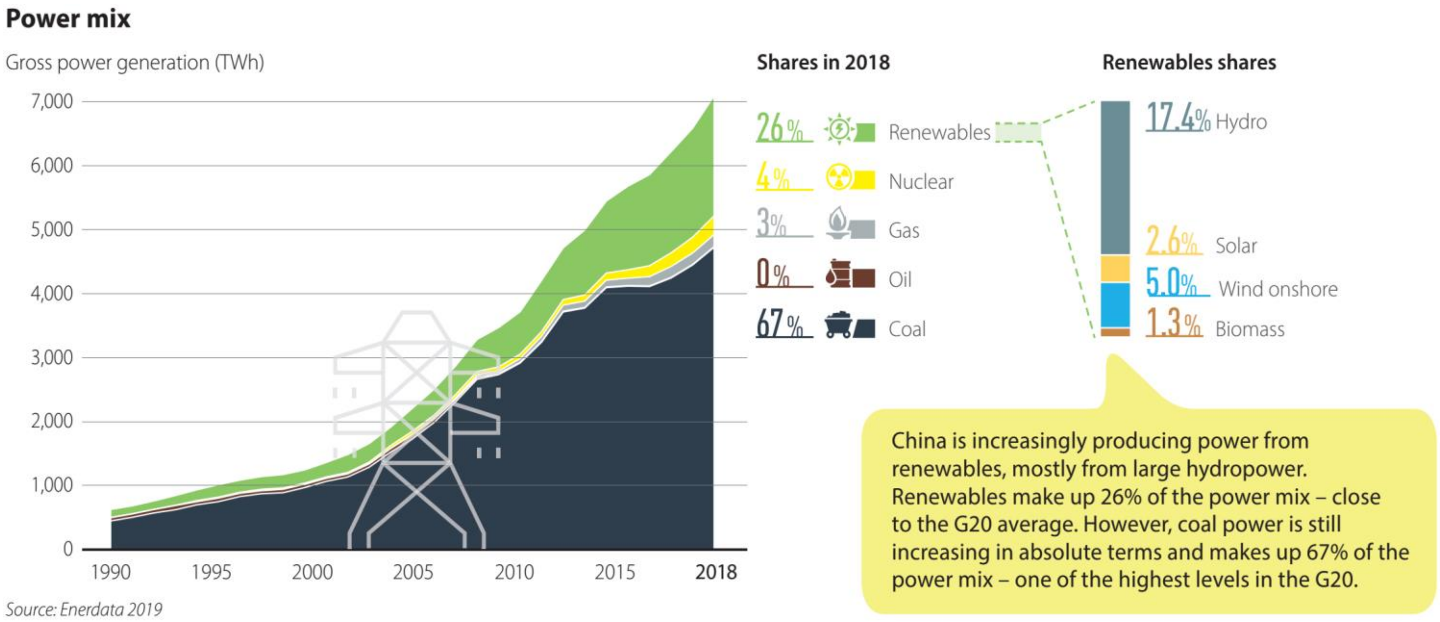
1. Demand of CO2 emission reduction and energy security in China

Transportation energy mix in China



Electricity and biofuels make up only 4% of the energy mix in transport.

Power mix in China



Coal power is still increasing in absolute terms and makes up 67% of the power mix – one of the highest levels in the G20

2. Prospect of automotive powertrain technology roadmap

Different automotive powertrain configurations

ICE powertrain | Transmission | Electric powertrai
FC powertrain | Battery

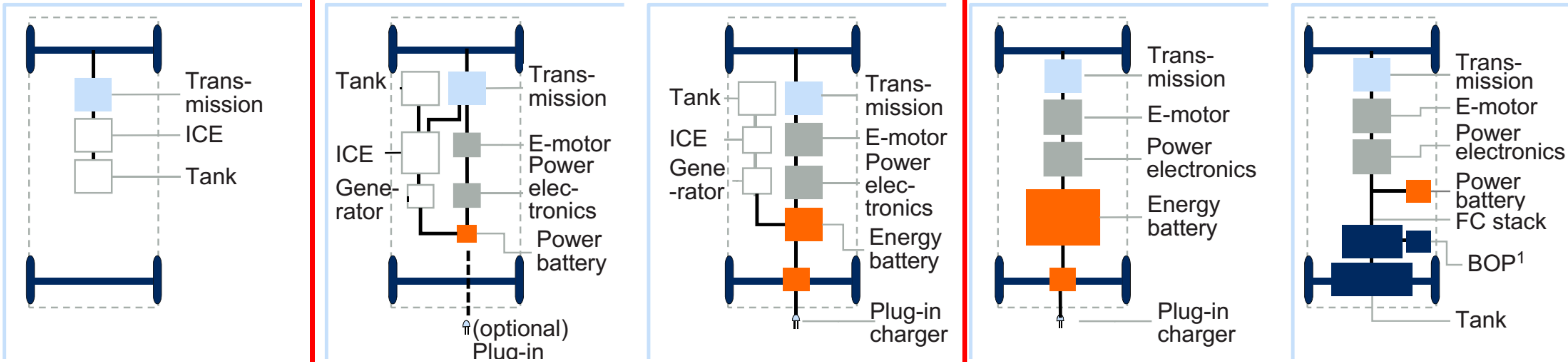
Internal combustion engine, ICE

Hybrid electric vehicle (P) HEV

Range extended electric vehicle, REEV

Battery electric vehicle, BEV

Fuel cell electric vehicle FCEV

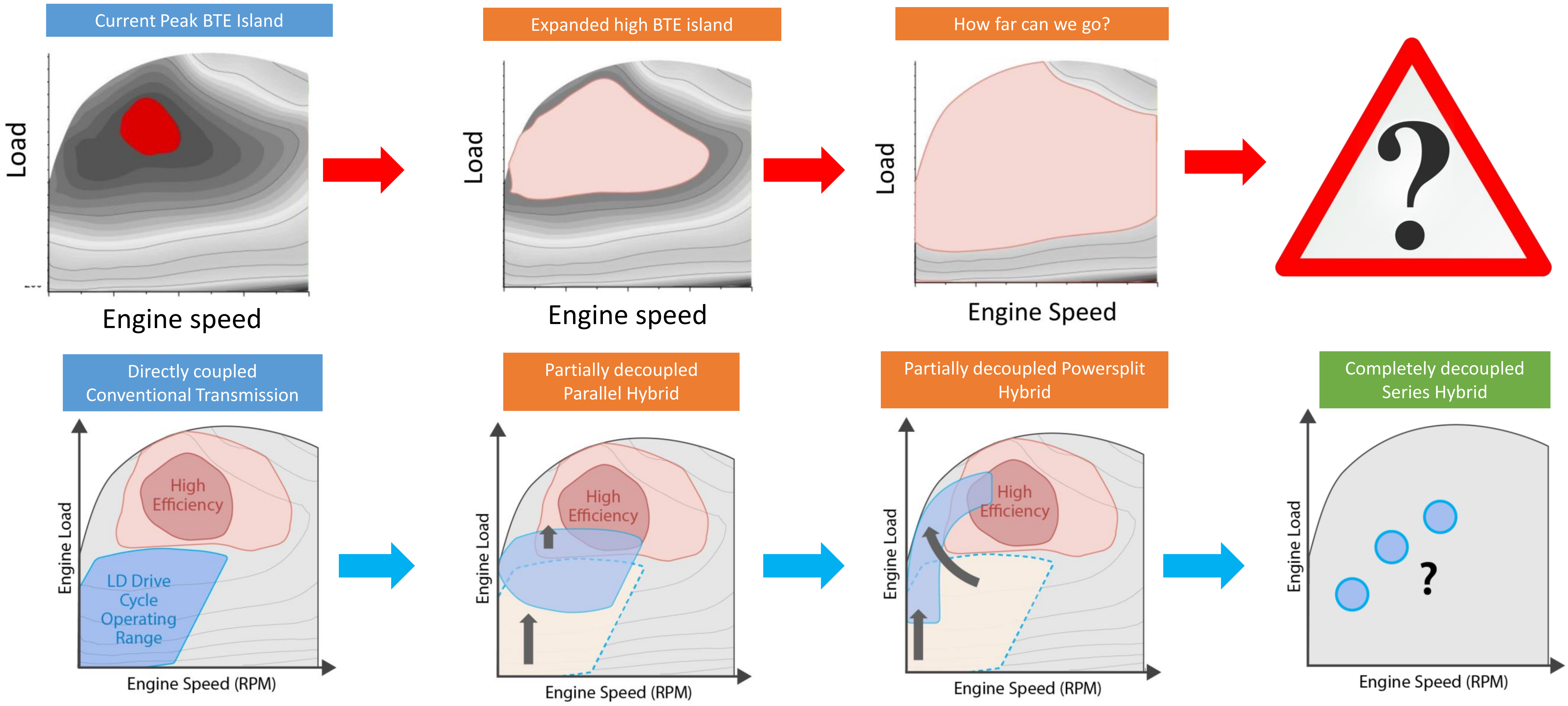


ICE primary source of propulsion

ELECTRIC MOTOR primary source of propulsion

[1] Electric vehicles in Europe: gearing up for a new phase?

2. Prospect of automotive powertrain technology roadmap



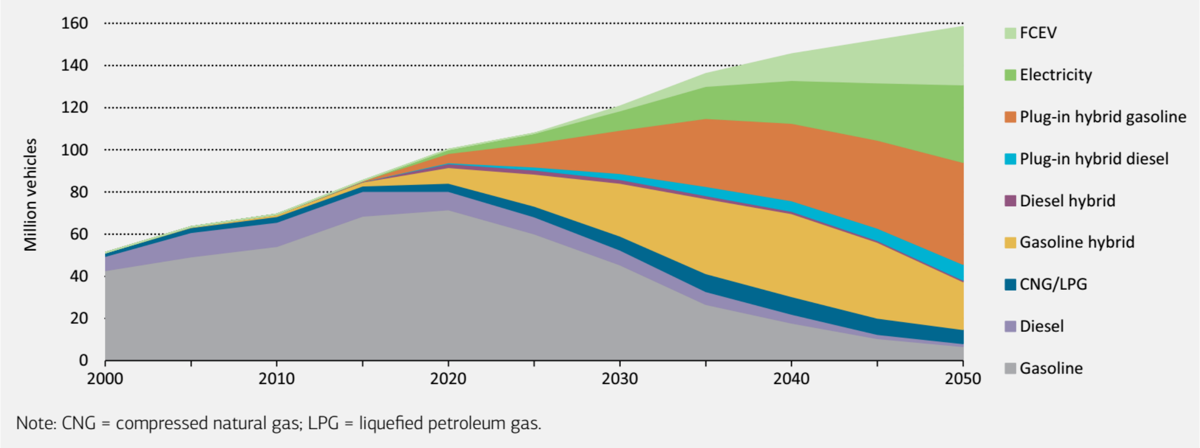
1. **Electrification** and **hybridization** decouples engine operation from vehicle power demand which enable the **engine operate under high efficiency regime**.
2. Brake thermal efficiency: 50% for spark ignition engine, 60% for compression ignition engine.

[1] Wagner RM, Curran S. The Future of the Internal Combustion Engine. 2018.

2. Prospect of automotive powertrain technology roadmap

[1] **World**

Figure 1.16 Global portfolio of technologies for PLDVs in the 2DS



Note: CNG = compressed natural gas; LPG = liquefied petroleum gas.

Key point *The 2DS sees a dramatic change in PLDV technologies, with EVs, PHEVs and FCEVs accounting for nearly three-quarters of new vehicle sales in 2050.*

[2] **US-EU-China**

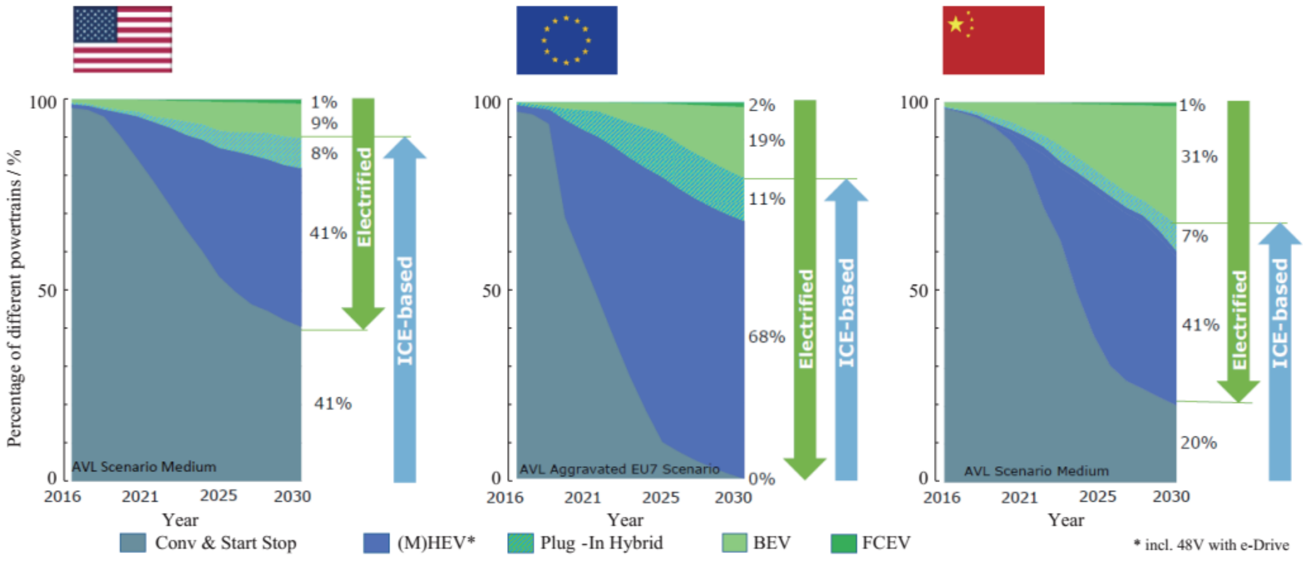


Figure 13 AVL Forecast of Possible Powertrain Technology Split [56]

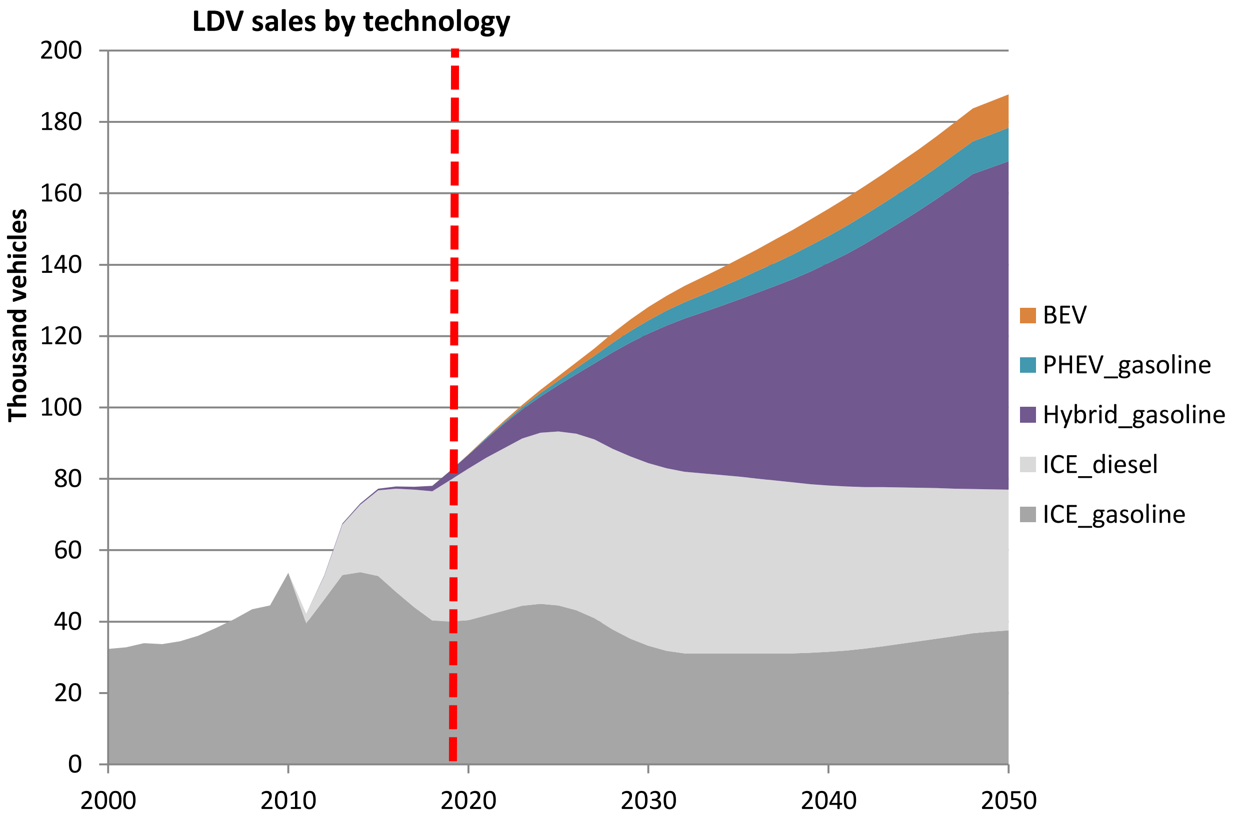
Future trend of automotive powertrain: **Power diversity** & **electrification**

[1] Energy Technology Perspectives 2015.
[2] Tian J, Bin Z, W W, A K, A A, M K, et al. Shell's View on Future Mobility Fuels: A patchwork, or "Mosaic" approach will be needed to address societies energy needs. Journal of Automotive Safety and Energy 2020;11(1):17-35

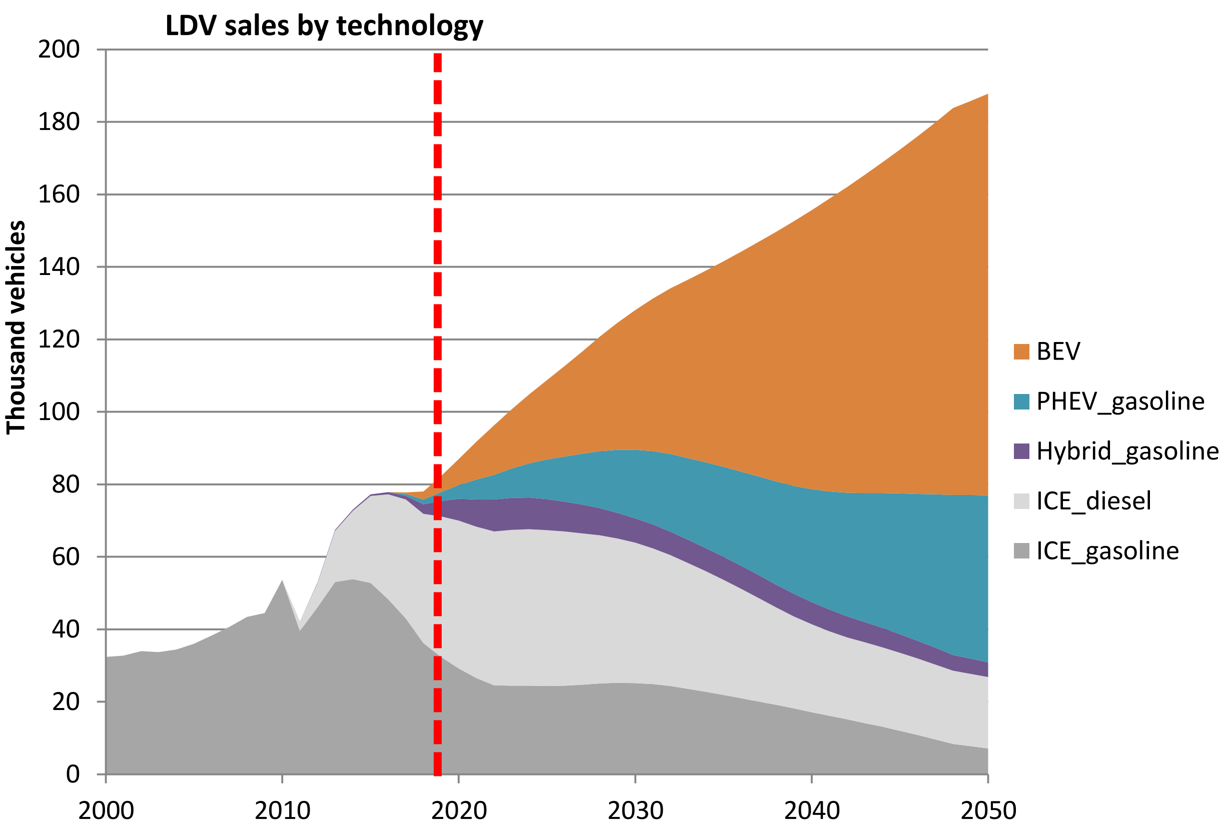
2. Prospect of automotive powertrain technology roadmap

Powertrain roadmap of light-duty vehicle

Benchmark scenario



EMOB scenario

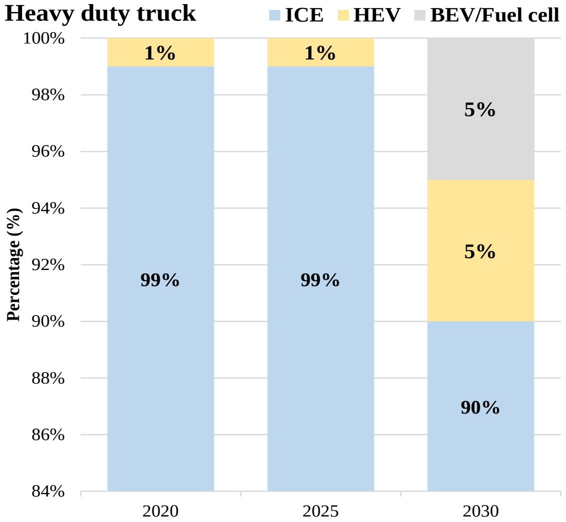


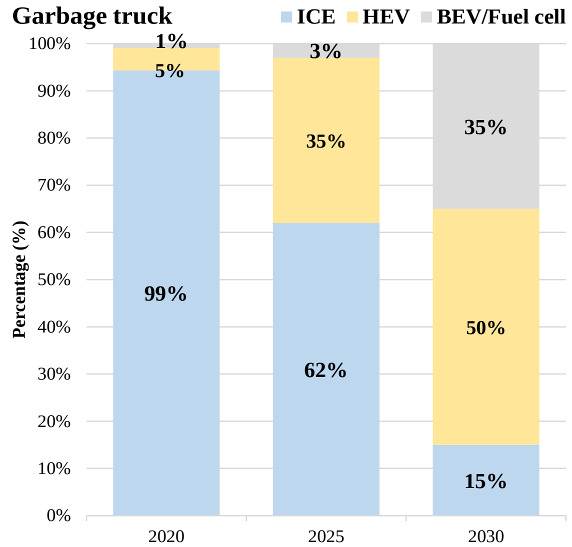
Battery electric vehicle, plug-in hybrid vehicle, gasoline engine hybrid vehicle will dominate the **light duty vehicle** market.

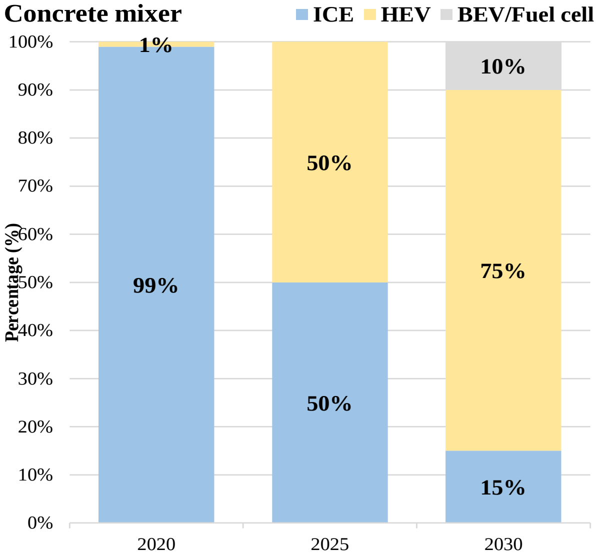
[1] The EMOB calculator

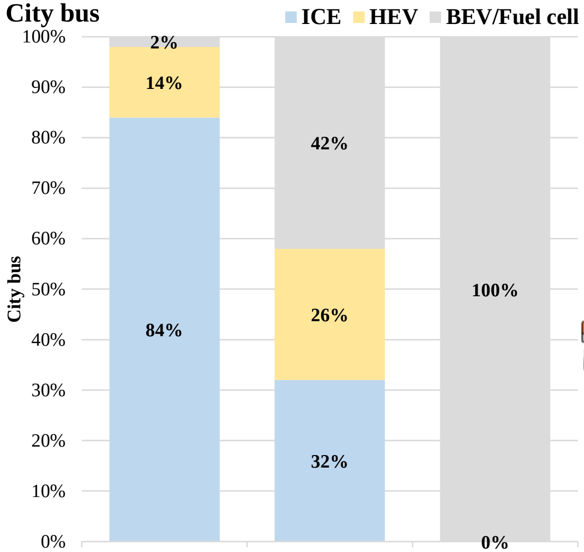
2. Prospect of automotive powertrain technology roadmap

Powertrain roadmap of heavy-duty vehicle







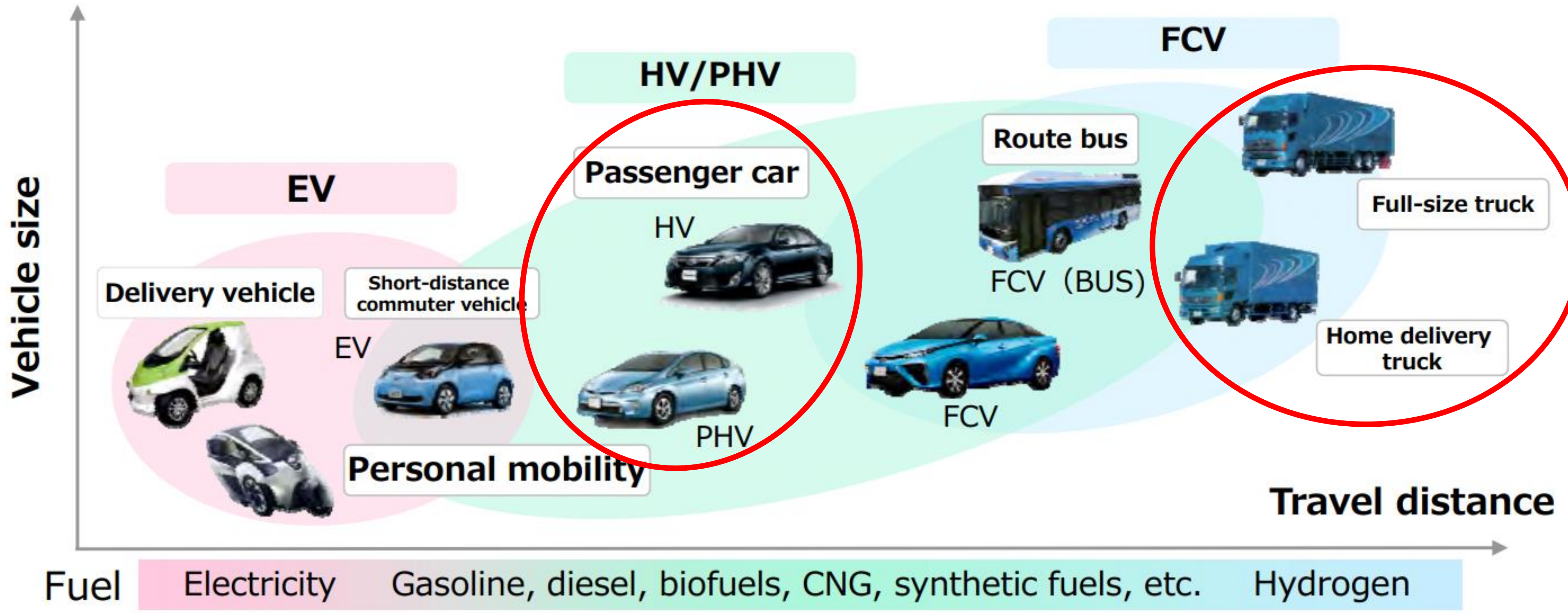


Diesel engine hybrid vehicle, fuel cell electric vehicle will dominate the **heavy-duty vehicle** market.

[1] Guangxi Yuchai Machinery Group Co., Ltd.

Prospect of automotive powertrain technology roadmap

Fuel diversity and uses

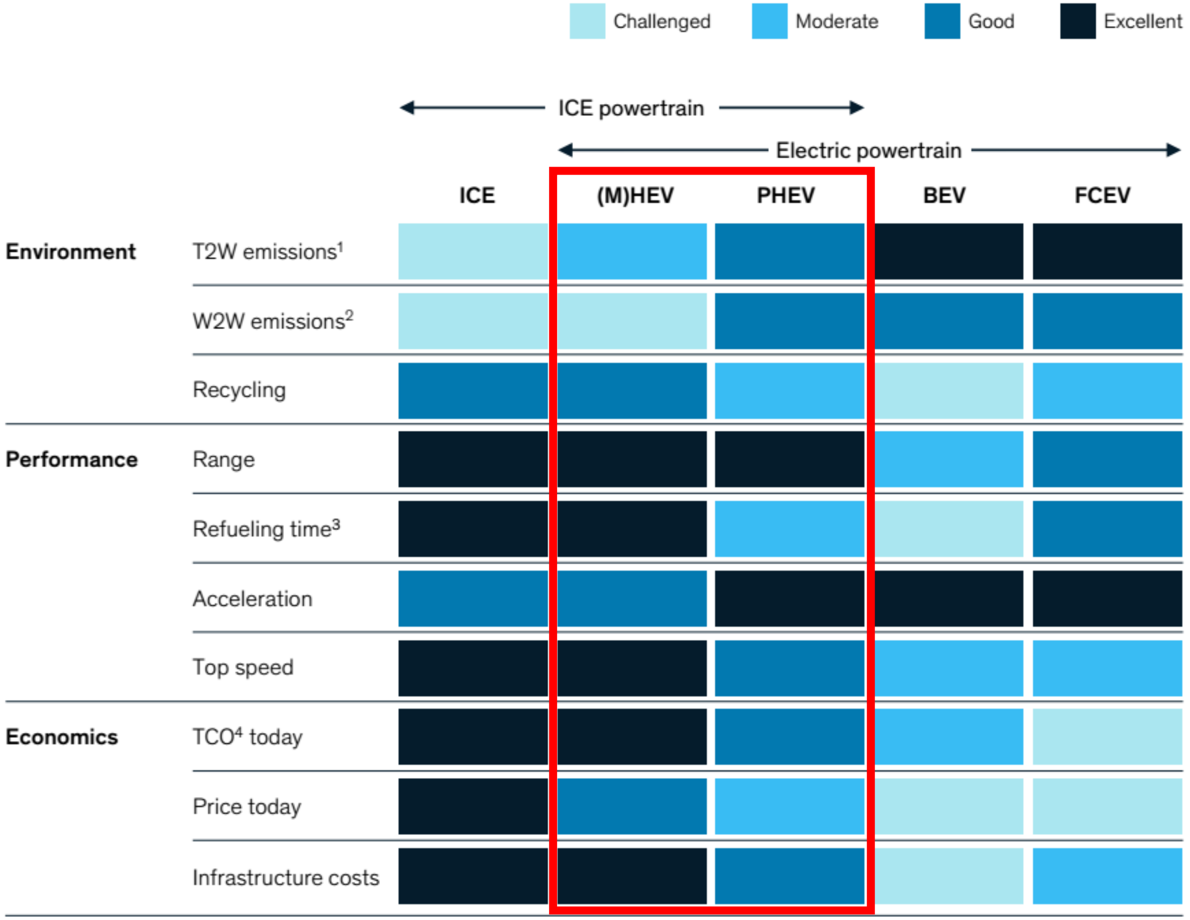


EV: Short-distance, HV & PHV: Wide-use,
FCV: Medium-to-long distance

[1] TOYOTA's Electrification Roadmap.

2. Prospect of automotive powertrain technology roadmap

Strengths and limitations of today's powertrain technologies



Key characteristics, indicative		ICE	(M)HEV	PHEV	BEV	FCEV
	ICE power, kW	50-400	50-400	50-200	–	–
	Electric power, kW	–	<25	<100	>100	>100
	Battery capacity, kWh	–	<2	<30	>40	<10
	T2W CO_2 savings, % CO_2	–	10-20	50-80[5]	100	100

Mild hybrids (MHEVs) are the entry point to electric powertrain technologies. A low-voltage (LV) system (mostly 48V) enables the use of efficient electrification elements, such as start-stop, regenerative braking, and some level of power assist the ICE.

Hybrid electric vehicles (HEVs) are designed to optimize the use of the combustion engine in interplay with a small, low-range, HV electric powertrain, e.g., for low-speed cruising or power boost.

Plug-in hybrid electric vehicles (PHEVs) have a similar architecture to HEVs, yet they have a significantly larger battery, a more powerful electric engine, and can be recharged by plugging into an external source of power. They are designed for a significant share of pure electric driving.

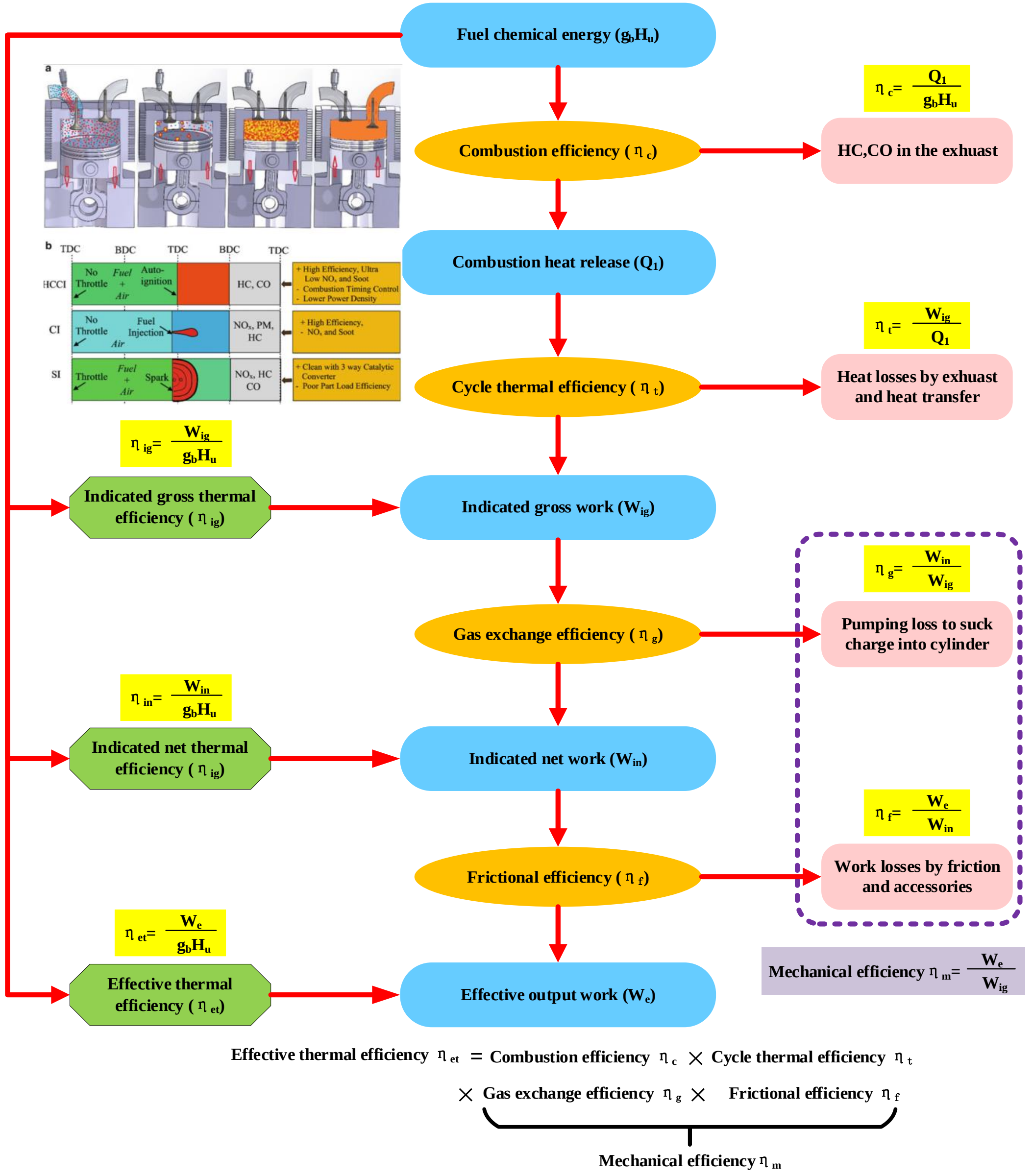
Battery electric vehicles (BEVs) replace the combustion engine with an electric engine.

Fuel cell electric vehicles (FCEVs) fundamentally function like BEVs but store energy as a pressured hydrogen gas and produce electricity from that energy with a fuel cell. The energy density of storing hydrogen is, both by volume and weight, significantly higher than in batteries. In addition, fueling speed can be in the order of a few minutes.

[1] Reboost: A Comprehensive View On The Changing Powertrain Component Market And How Suppliers Can Succeed

Prospect of automotive powertrain technology roadmap

Energy efficiency of IC engine



SI engine as range extender in electric vehicle

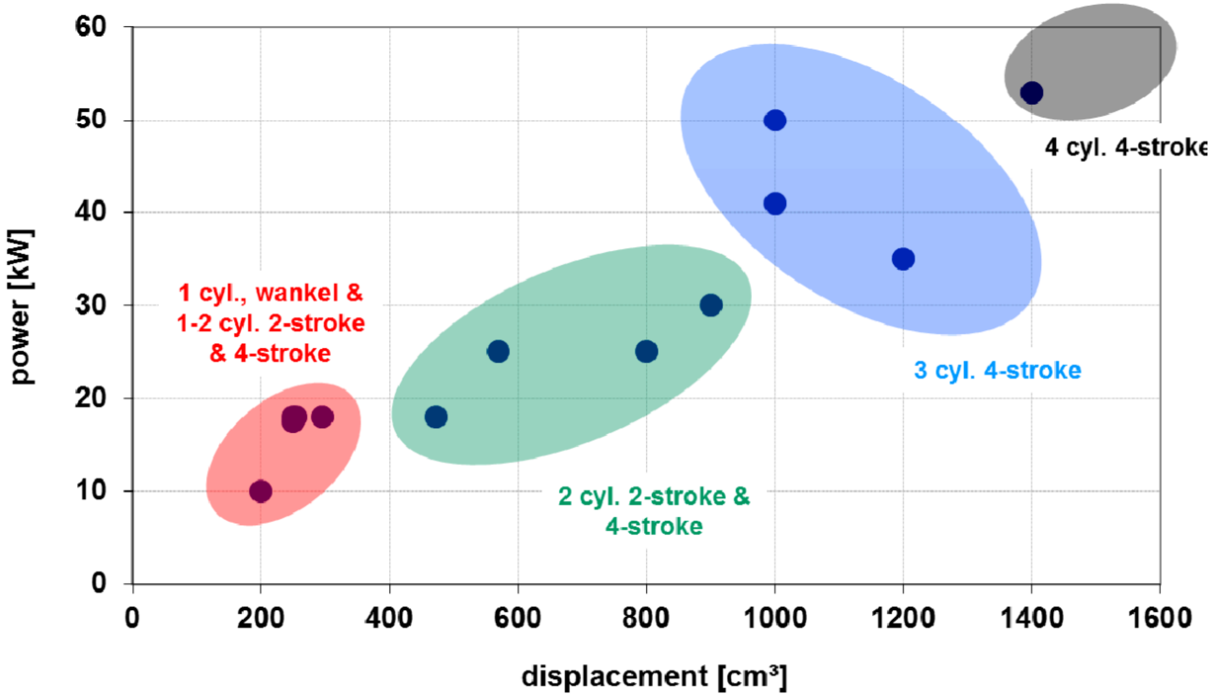


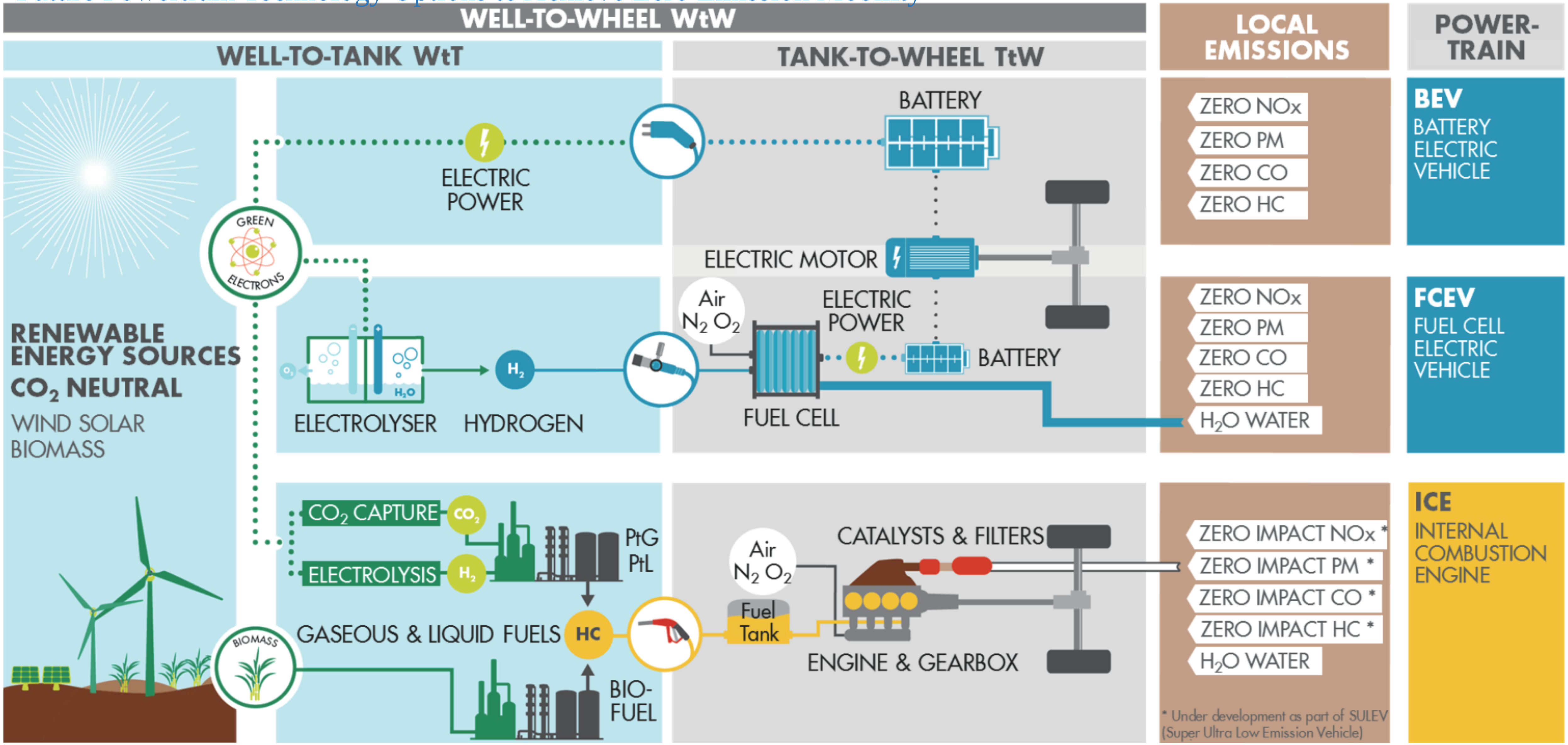
Figure 4: Maximum power of present and forthcoming on-board power plants used in REX vehicles

Spark ignition engine with small displacement and 1~4 cylinders will dominate the REX vehicle.

[1] Trattner A, Pertl P, Schmidt SP, Sato T. Novel Range Extender Concepts for 2025 with Regard to Small Engine Technologies. 2011.

2. Prospect of automotive powertrain technology roadmap

Future Powertrain Technology Options to Achieve Zero Emission Mobility



[1] Tian J, Bin Z, W W, A K, A A, M K, et al. Shell's View on Future Mobility Fuels: A patchwork, or "Mosaic" approach will be needed to address societies energy needs. Journal of Automotive Safety and Energy 2020;11(1):17-35

3. Paths forward to carbon neutral combustion

Carbon neutral fuels (eco-fuels, from renewable electricity and CO_2) & tailor-made IC engine for hybrid vehicle

Closing the Carbon Cycle

Turning carbon dioxide into eco-fuel

[1]

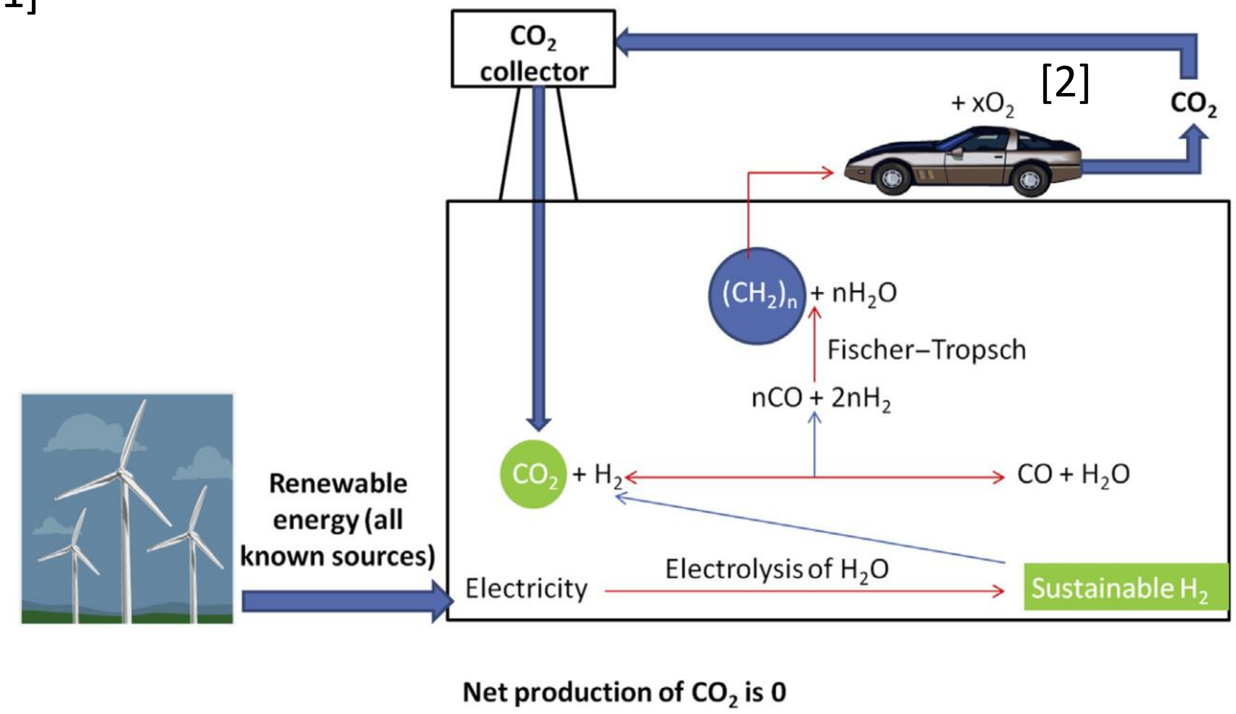
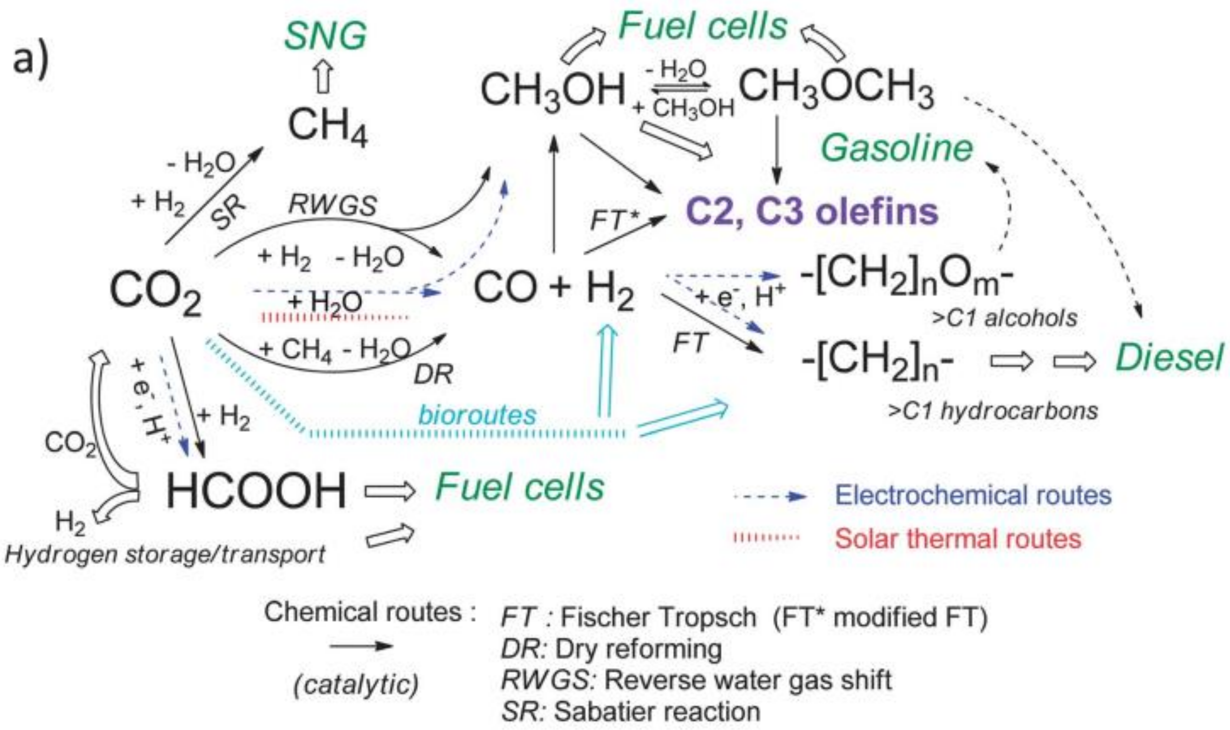


FIGURE 10.3 A representative route to achieve carbon-neutral hydrocarbon fuels by cycling CO_2 and employing renewable H_2 and energy sources.[9,15]



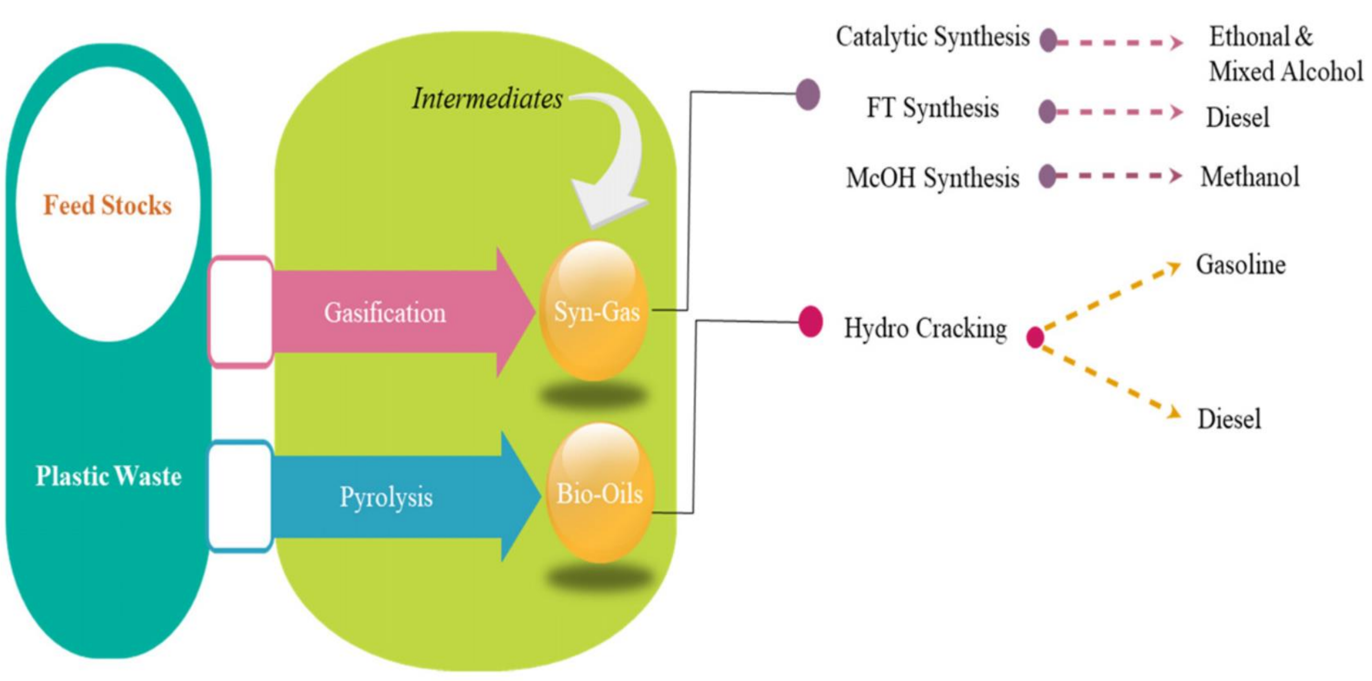
CO2 conversion routes to incorporate renewable energy in the chemical and energy chains

[1] Carbon Dioxide Utilisation-Closing the Carbon Cycle.
[2] Centi G, Quadrelli EA, Perathoner S. Catalysis for CO2 conversion: a key technology for rapid introduction of renewable energy in the value chain of chemical industries. Energy & Environmental Science 2013;6(6).

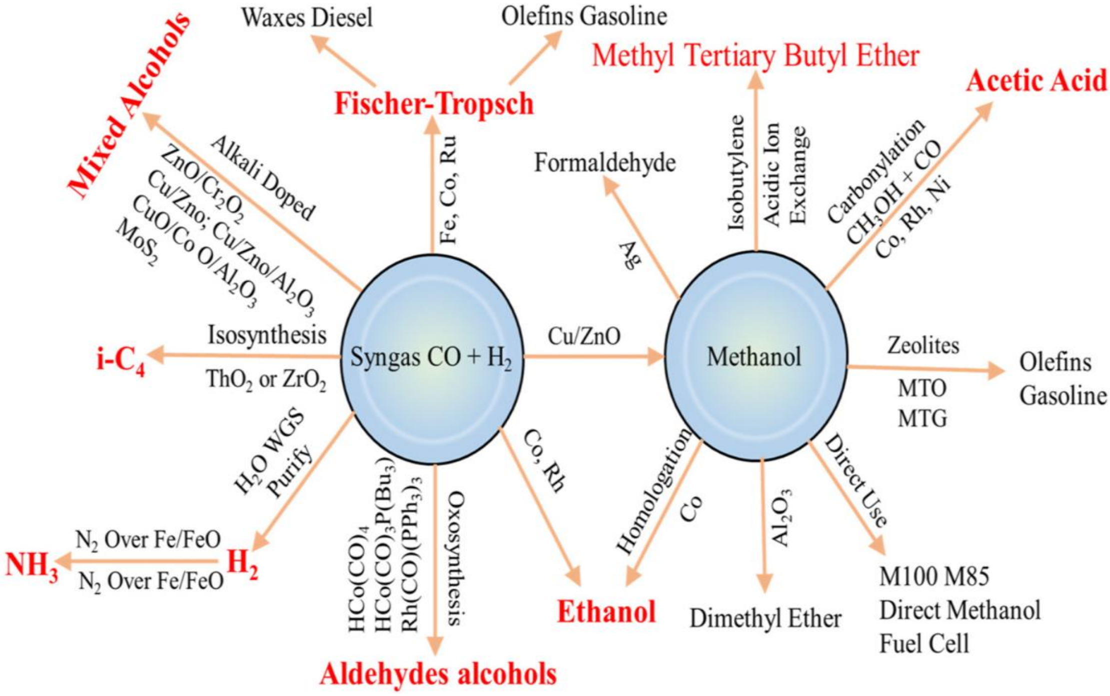
3. Paths forward to carbon neutral combustion

Carbon neutral fuels (eco-fuels, from plastic waste) & tailor-made IC engine for hybrid vehicle

Thermochemical recycling techniques

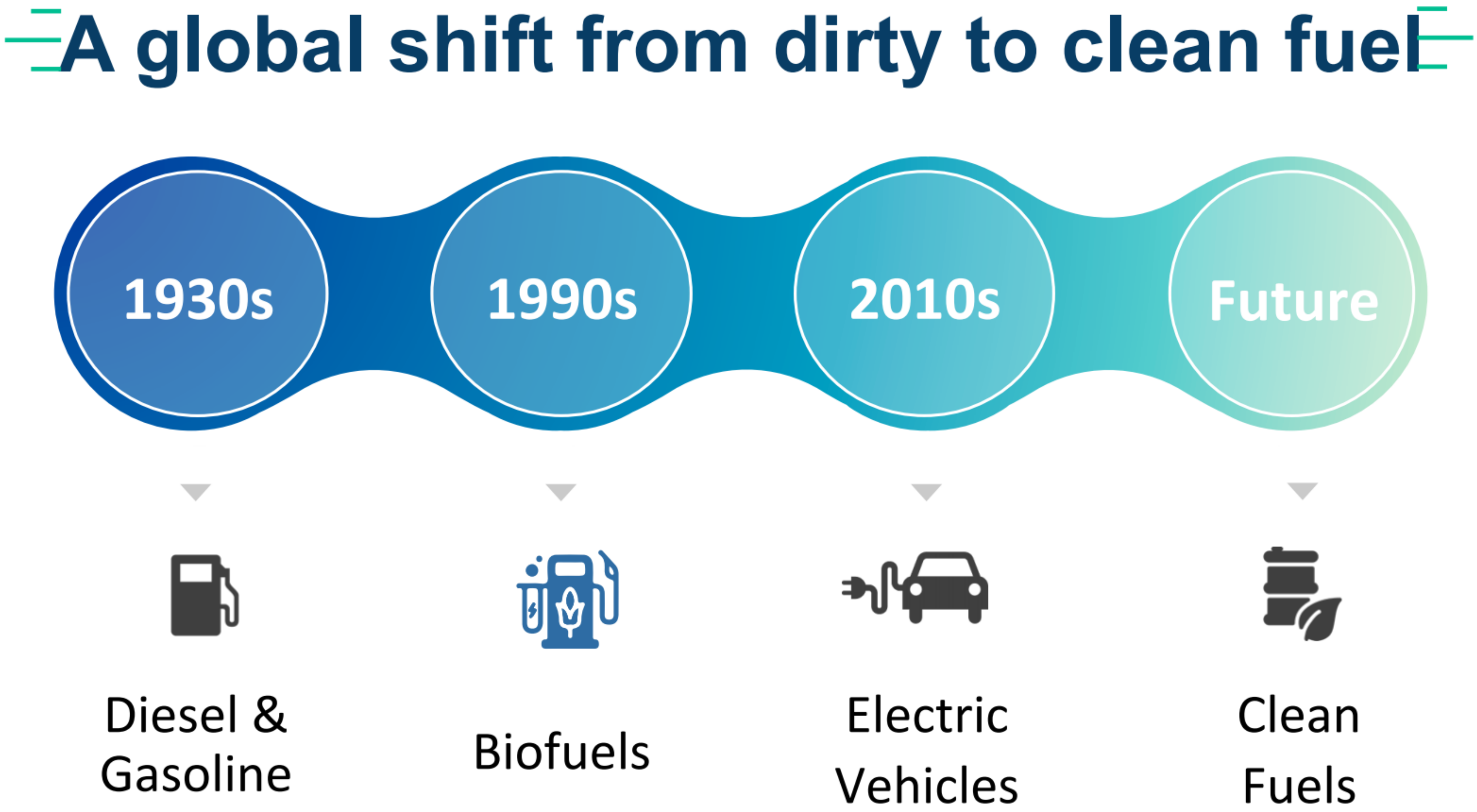


Transform syngas into liquid fuel



[1] Banu JR, Sharmila VG, Ushani U, Amudha V, Kumar G. Impervious and influence in the liquid fuel production from municipal plastic waste through thermo-chemical biomass conversion technologies - A review. Sci Total Environ 2020;718:137287.

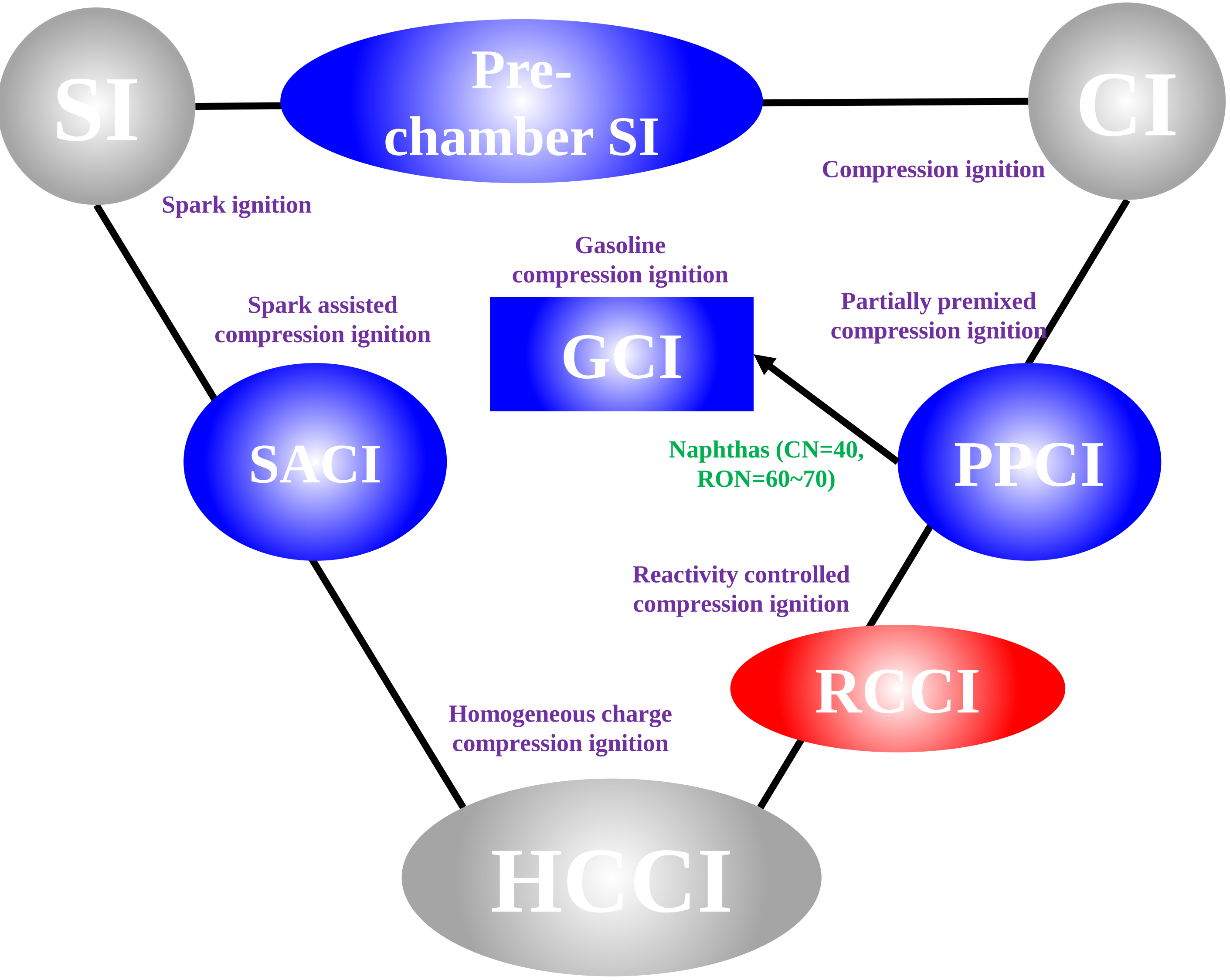
4. Prospect of internal combustion engine and fuels

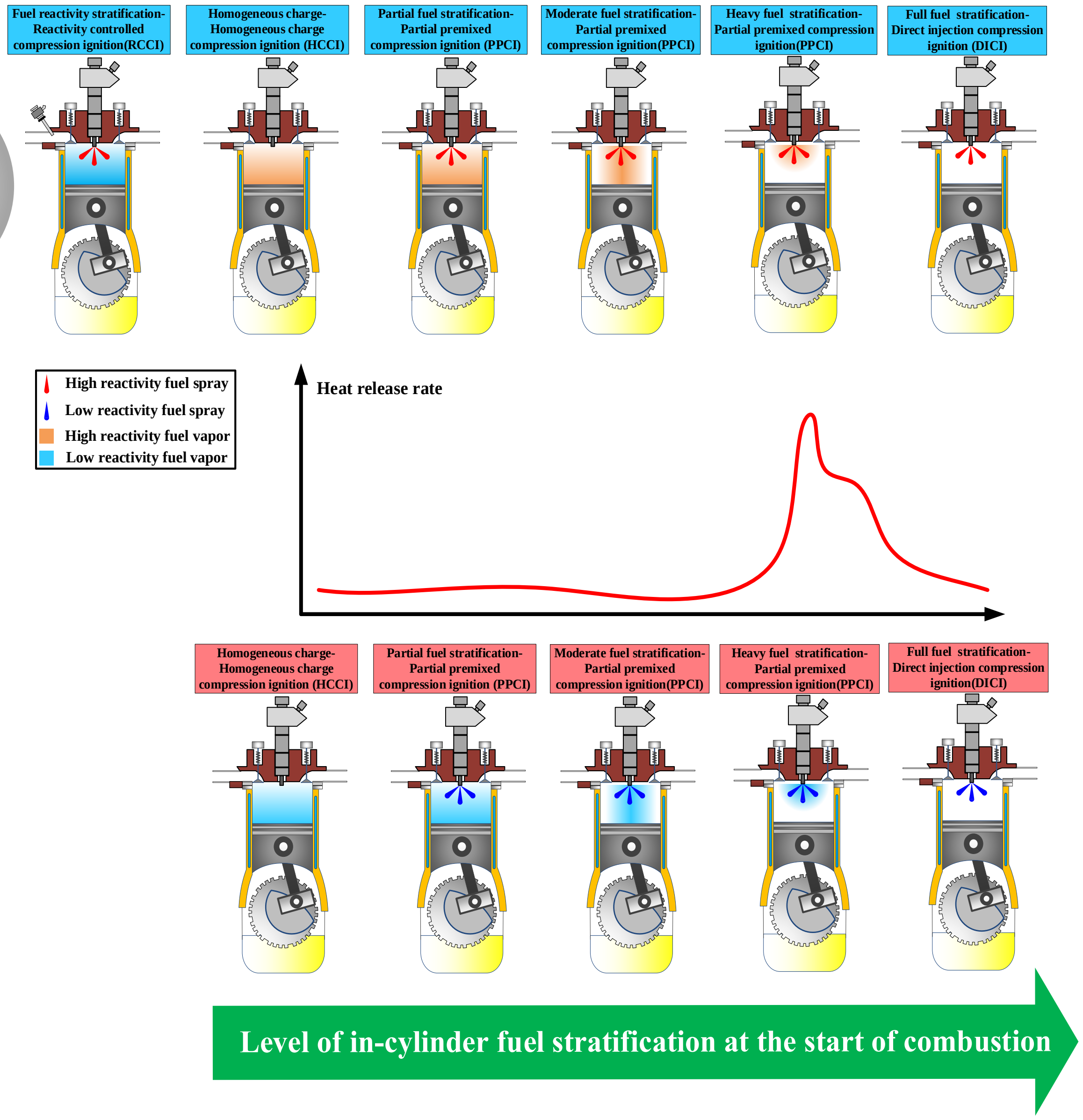


[1] Clean Combustion Technologies that Valorize CO2, KAUST

4. Prospect of internal combustion engine and fuels

IC engine combustion modes

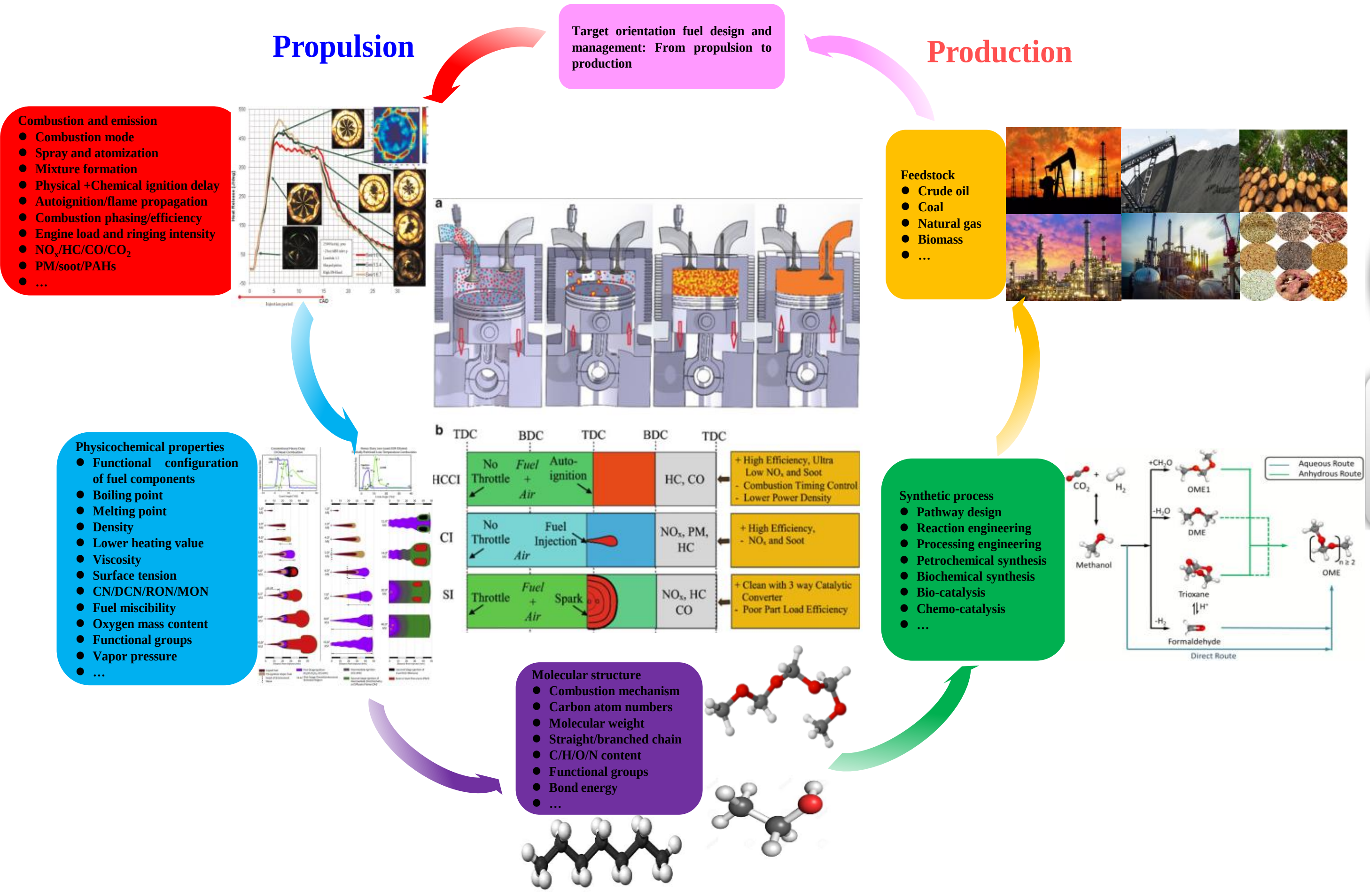


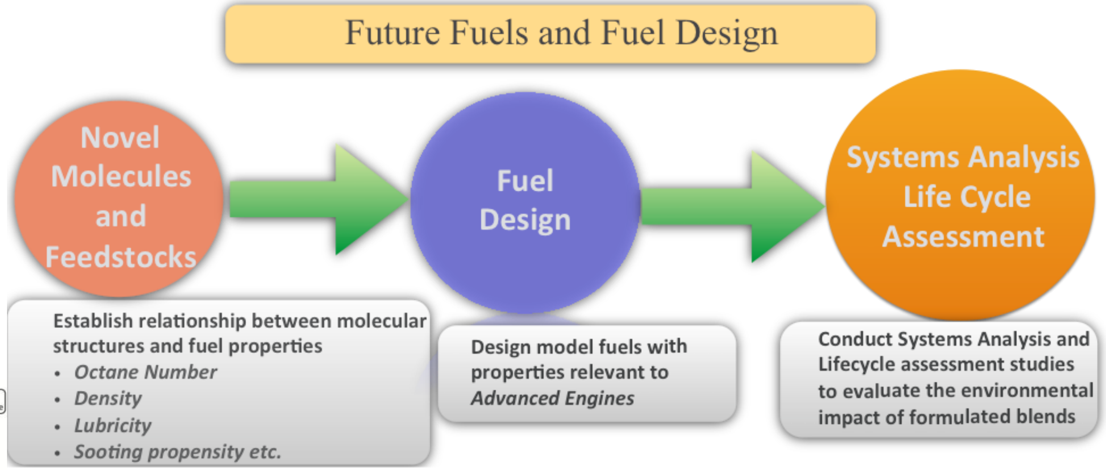


1. Low temperature combustion; 2. lean burn; 3. high charge density; 4. stratified combustion; 5. compression ignition

4. Prospect of internal combustion engine and fuels

Property-oriented fuel design





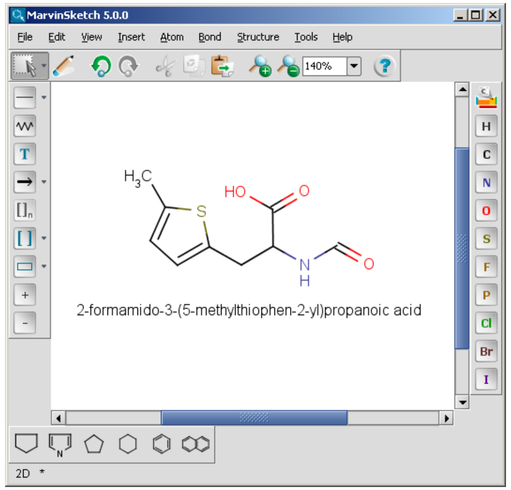
Innovative **fuel formulation** is required for advanced combustion modes, but the rules is still less understanding.

Tailor-made fuels to co-optimize fuels and engines

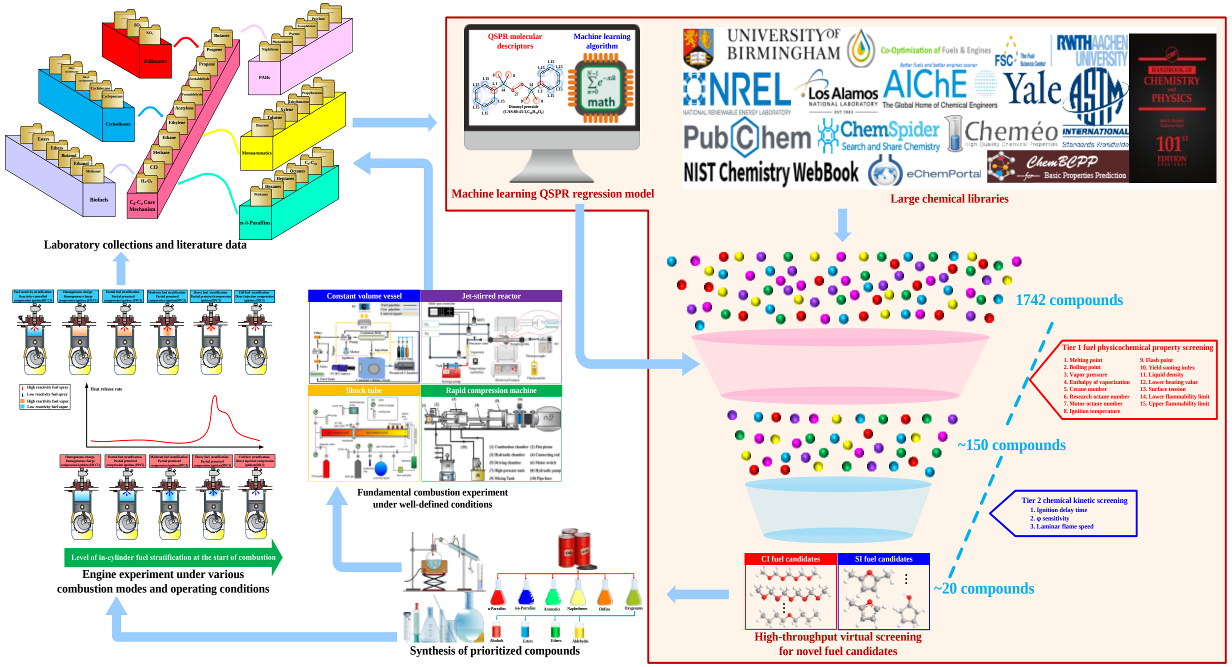
[1] Li R, Liu Z, Han Y, Cai Y, Wang X, Zheng J, et al. Target-Oriented Fuel Design for the Homogeneous Charge Autoignition Combustion Mode: A Case Study of a n-Heptane–PODE3–Ethanol Mixture. 2. Identification of a Functional Configuration of Fuel Components. Energy & Fuels 2018;33(1):31-49.

Prospect of internal combustion engine and fuels

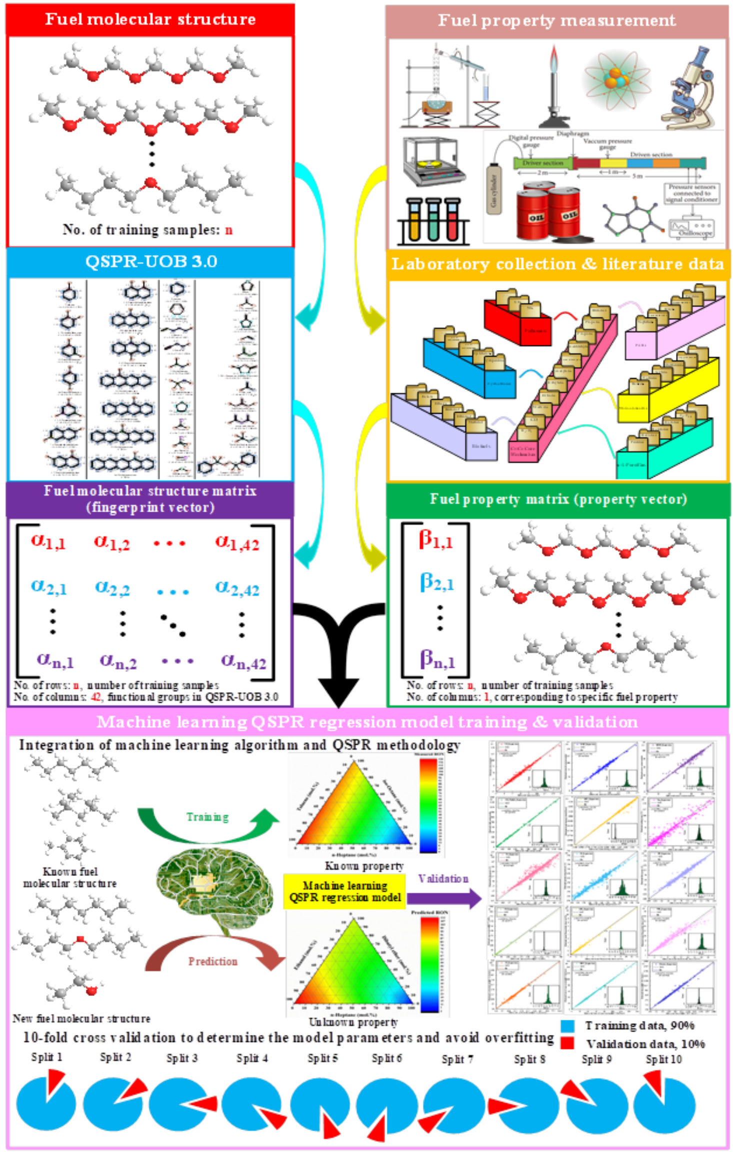
Molecular structure generator: MOLGEN



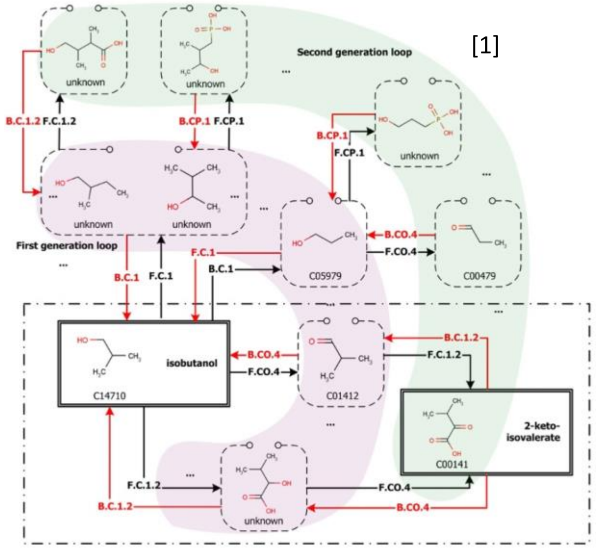
High throughput fuel screening tool



Machine learning QSPR models

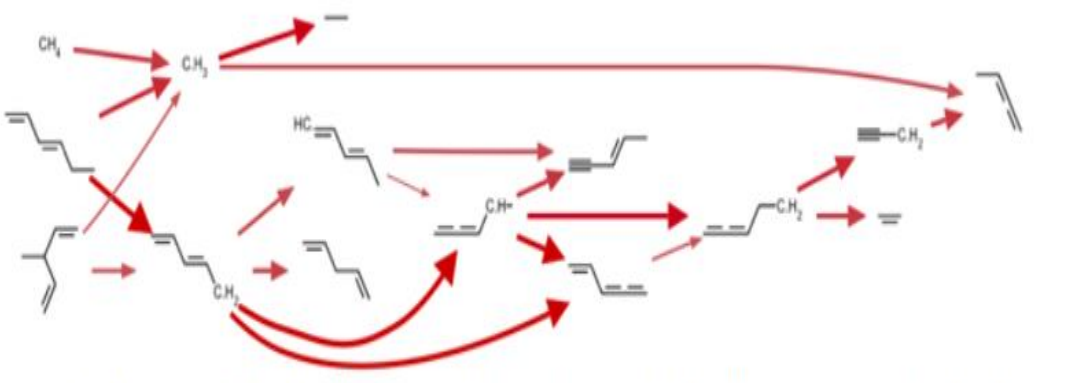


Retrosynthesis tool



[1]

Reaction Mechanism Generator (RMG)



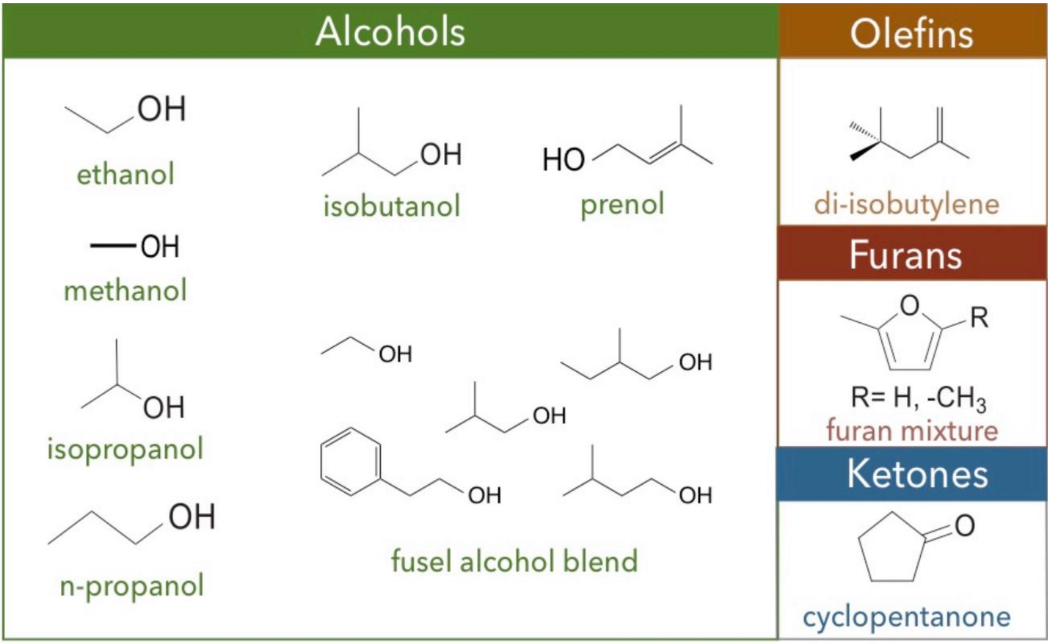
Flux diagram for the pyrolysis of 1,3-hexadiene, an example model generated with RMG, showing the net carbon flux at an instant near the end of the simulation.

[1] Cho A, Yun H, Park JH, Lee SY, Park S. Prediction of novel synthetic pathways for the production of desired chemicals. BMC Syst Biol 2010;4:35.

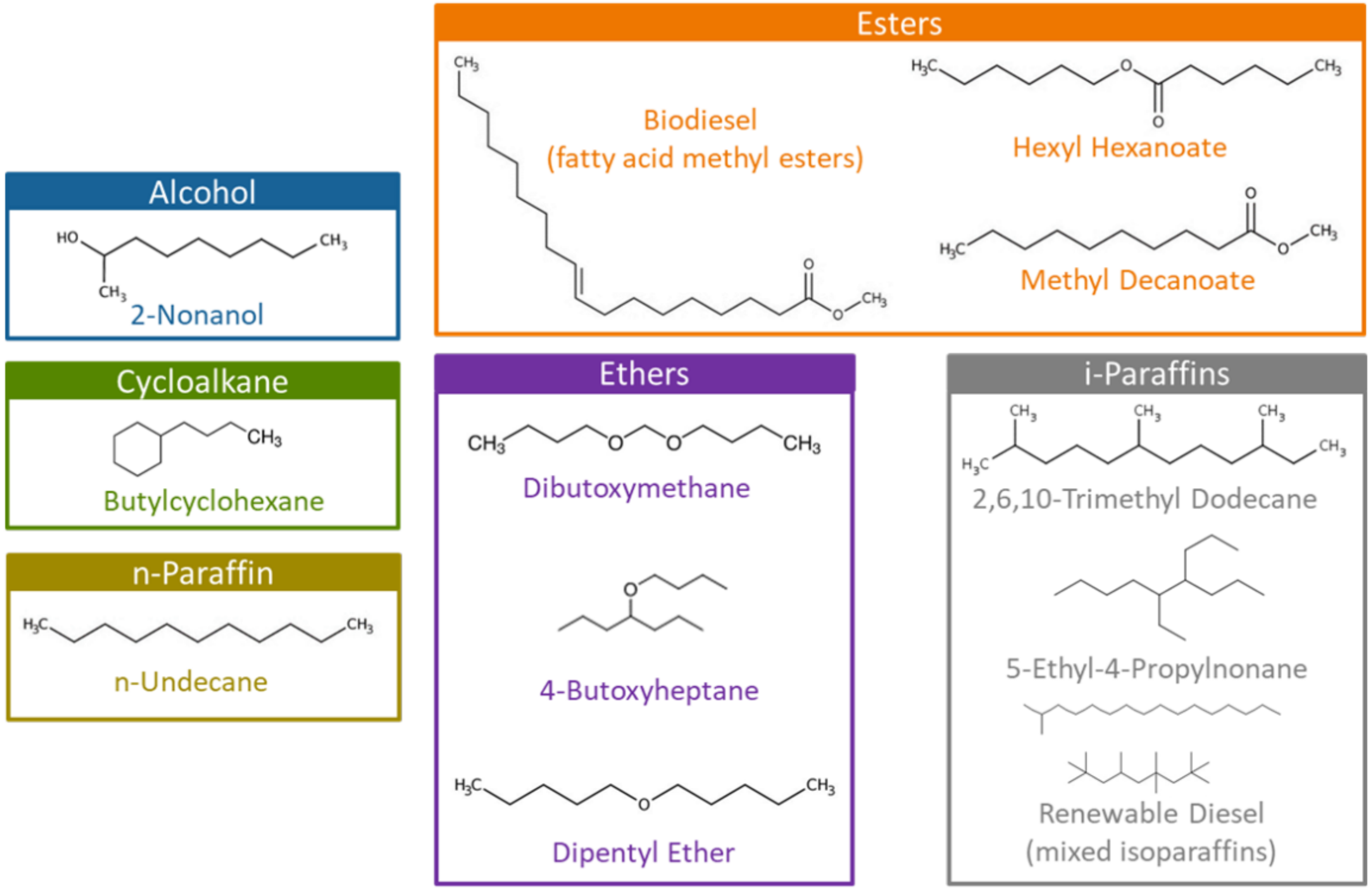
4. Prospect of internal combustion engine and fuels

Top 10 blendstocks for SI engines

Top 12 blendstocks for CI engines



Top Ten Performing Blendstocks According to Merit Function Score.

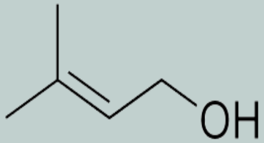


Chemical structures of MCCI biofuel candidates meeting the property requirements for blending into conventional diesel. Figure by Gina Fioroni, NREL

[1] Top Ten Blendstocks for Turbocharged gasoline engine. https://wwwostigov/servlets/purl/1567705 2019.
[2] Wagner R, Gaspar D, Bryan P, McCormick R. Co-Optimization of Fuels & Engines FY19 Year in Review. 2019;https://www.energy.gov/sites/prod/files/2020/06/f75/beto-co-optima-fy19-yir-report-june-2020.pdf.

4. Prospect of internal combustion engine and fuels

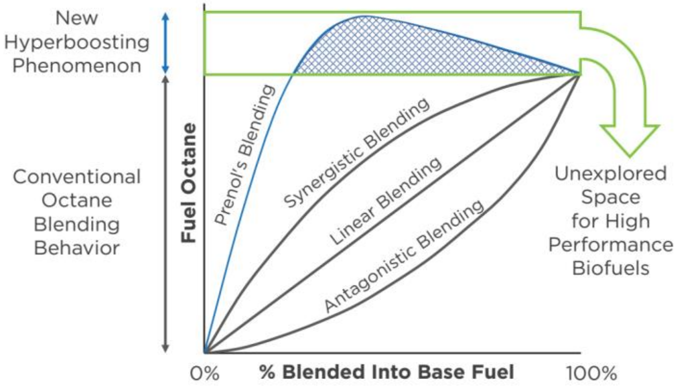
3-Methyl-2-buten-1-ol (prenol)



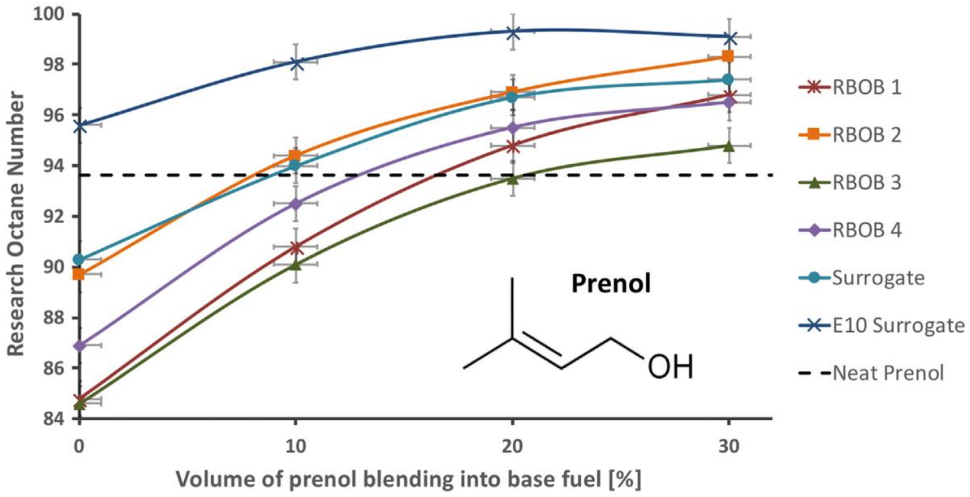
CAS #	556-82-1
Formula	C_5H_9OH
RON	93.
bRON at 20%	120
MON	74
S	19
HoV (kJ/kg)	512
LHV (MJ/kg)	34.0
YSI	47
PMI	0.93
S_L (298K; 1 bar; cm/s)	Not measured
Water sol. @ 25 °C (g/L)	46.9 g/L
Catalyst Light-Off: T_{50}	Not measured
T_{90}	Not measured
LSPI propensity	Low

	RON	MON
Base BOB	90.3	84.7
10% prenol	94.0	85.5
20% prenol	96.7	84.9
30% prenol	97.4	84.0

Hyperboost impact for octane number



Schematic of fuel octane vs. percentage of blendstock blended into base fuel, showing prenol's hyper-boosting behavior pushing the blended fuel's RON beyond the level enabled by typical synergistic blending. Figure by Anthe George and Eric Monroe, SNL



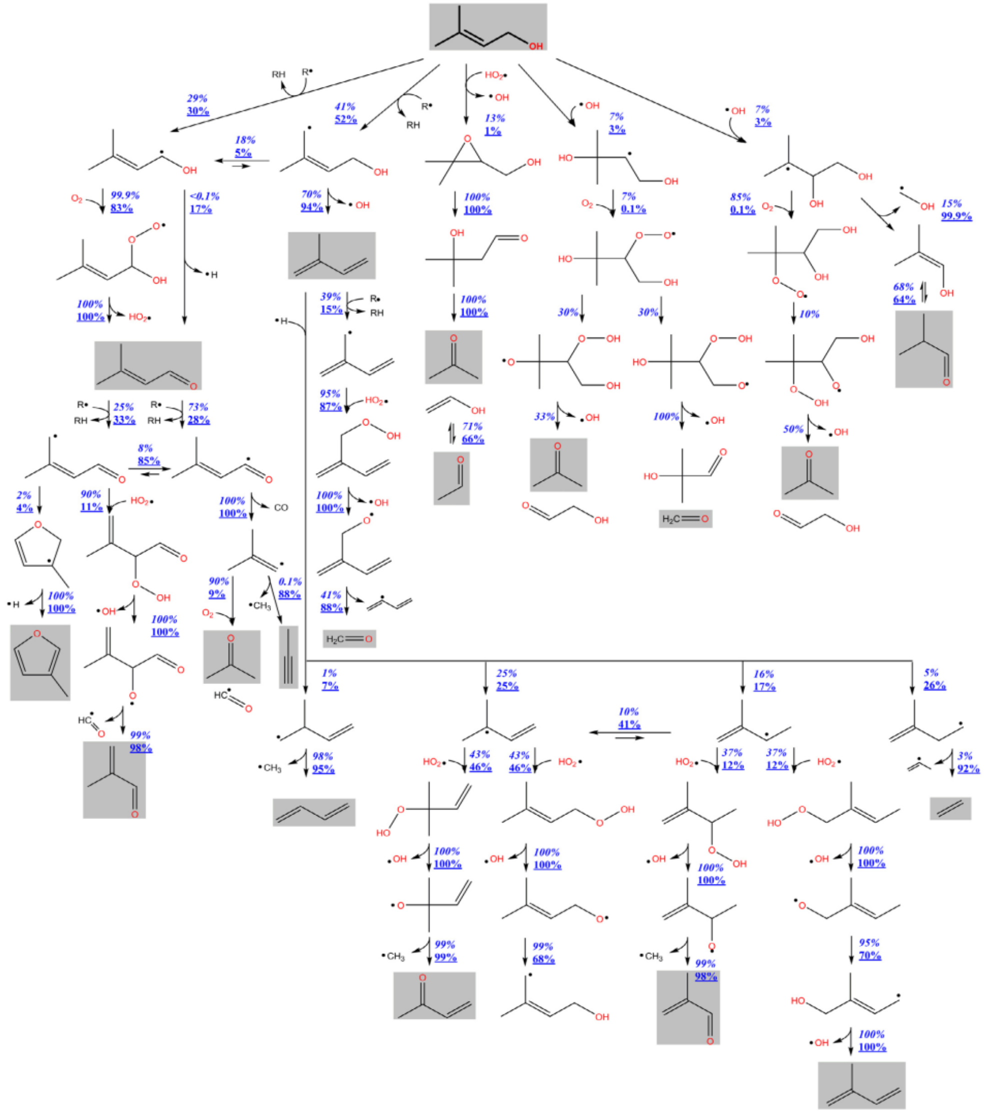


Fig. 7. Reaction path analysis for the decomposition of prenol. Operating conditions: $F_V = 4.06\ 10^{-5}\ m^3\ s^{-1}$, $\tau = 2$ s, $x_{prenol,0} = 0.008$, $\varphi = 1.0$, $T = 700$ K (blue and italic) and 900 K (red and underlined). Percentages on a reaction path represent the reaction rate relative to the total consumption rate of the reacting species. Species with a shaded background have been detected experimentally. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

[1] Top Ten Blendstocks for Turbocharged gasoline engine. https://wwwostigov/servlets/purl/1567705 2019.
[2] Farrell J, Wagner R, Gaspar D, Moen C. Co-Optimization of Fuels & Engines FY18 Year in Review. 2018;https://www.energy.gov/sites/prod/files/2019/06/f64/Co-Optima_YIR2018_FINAL_LOWRES%20190619_0.pdf.
[3] Monroe E, Gladden J, Albrecht KO, Bays JT, McCormick R, Davis RW, et al. Discovery of novel octane hyperboosting phenomenon in prenol biofuel/gasoline blends. Fuel 2019;239:1143-8.
[4] De Bruycker R, Herbinet O, Carstensen H-H, Battin-Leclerc F, Van Geem KM. Understanding the reactivity of unsaturated alcohols: Experimental and kinetic modeling study of the pyrolysis and oxidation of 3-methyl-2-butenol and 3-methyl-3-butenol. Combustion and Flame 2016;171:237-51.

4. Prospect of internal combustion engine and fuels

"IC engines will obtain new development opportunity by collaborating with electrification and hybridization"

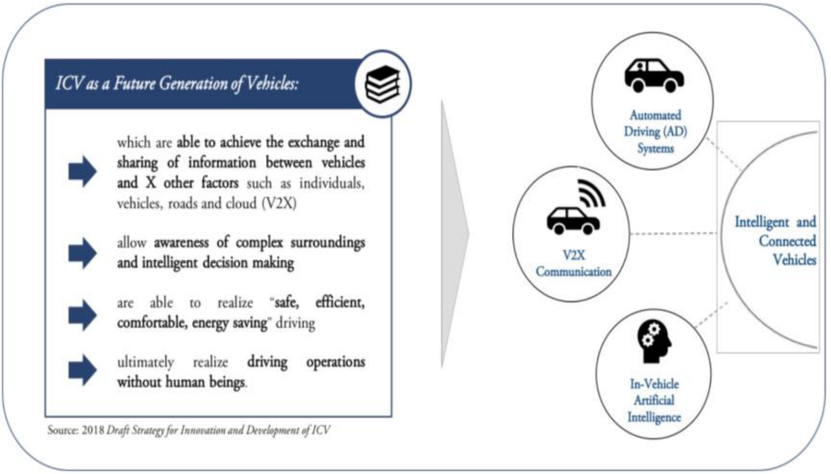
-Prof. Shijin Shuai, Tsinghua University

"~~Fossil~~ fuels will have to underwrite a transition to other sources of energy"

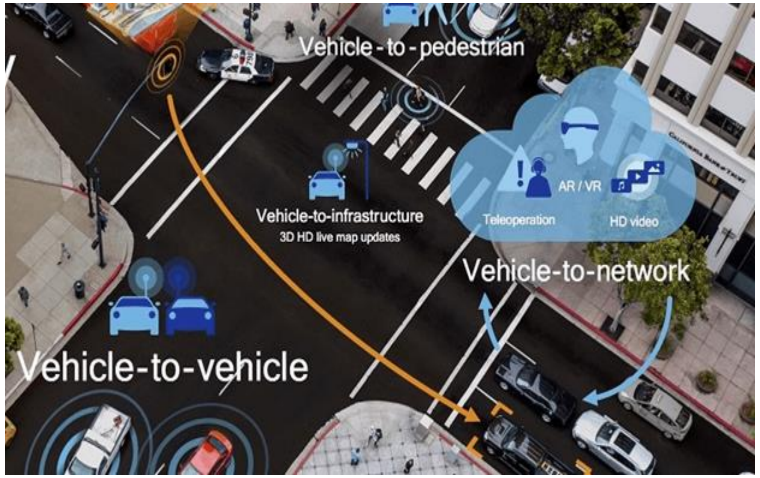
-Prof. Tad Patzek, KAUST

5. Relation between Intelligent connected vehicles (ICV) and automated driving (AD)

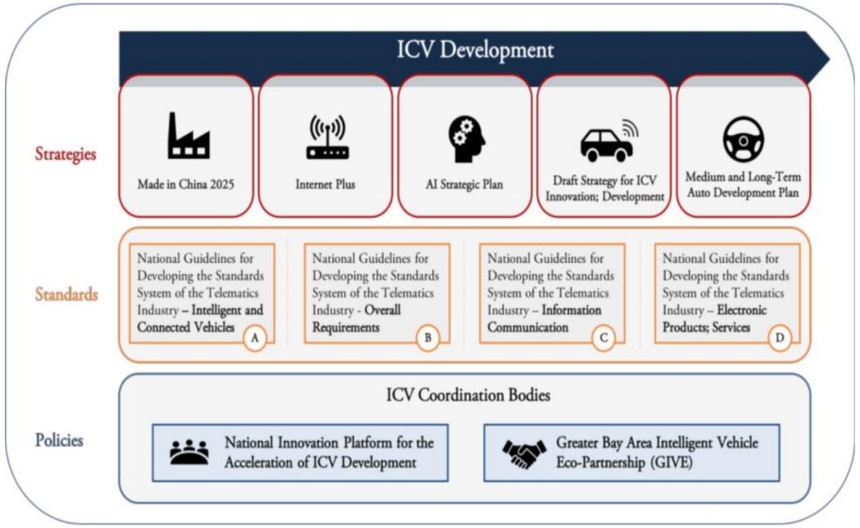
Intelligent connected vehicles



Vehicle to Everything (V to X)

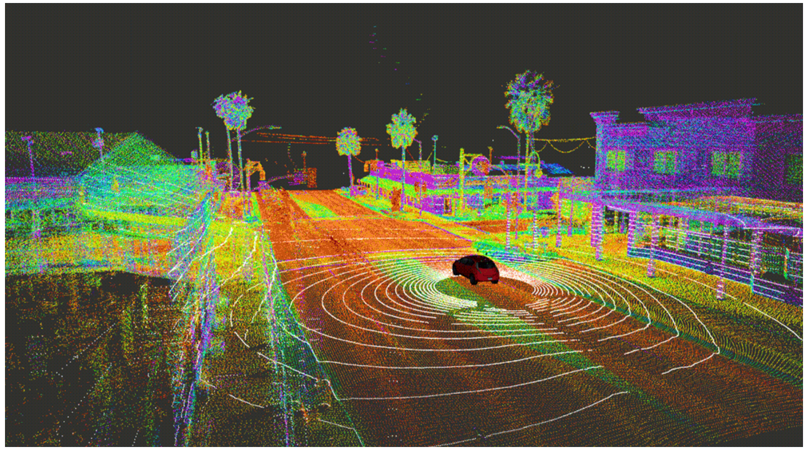


ICV Strategies, Standards and Policies in China

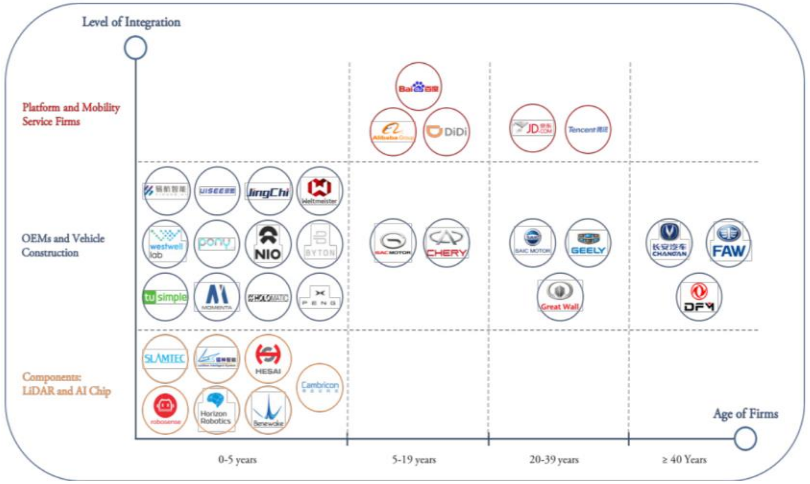


Drivers of ICV Development in China

High-definition (HD) maps



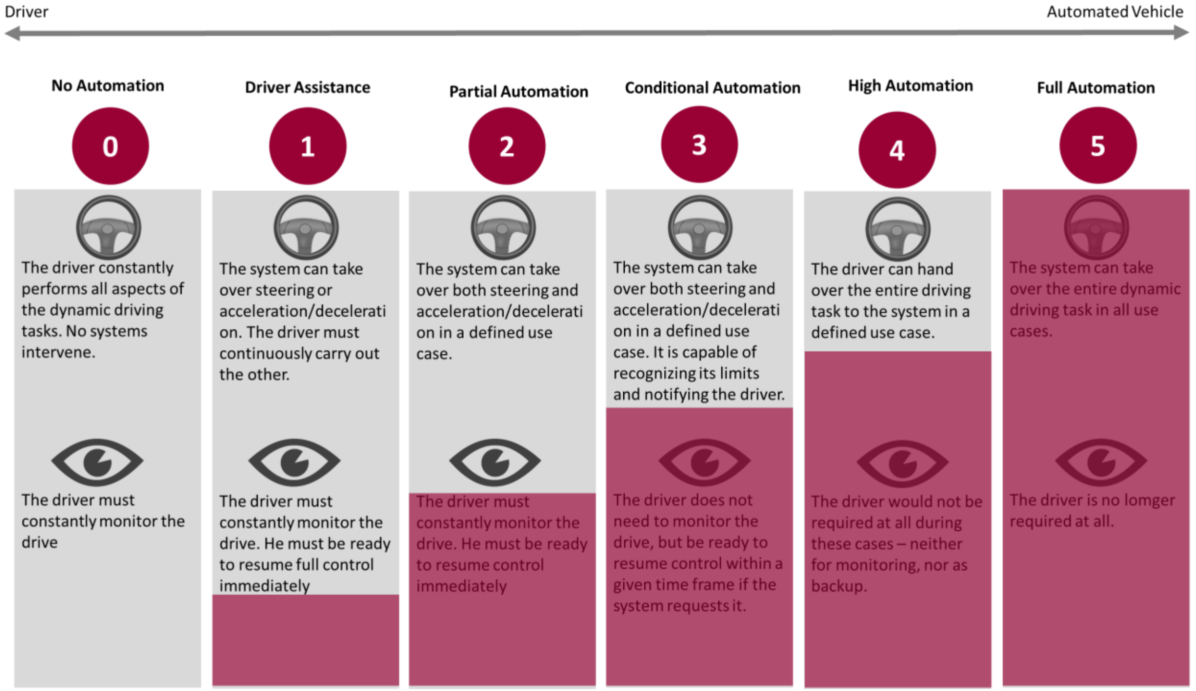
ICV Firms in China



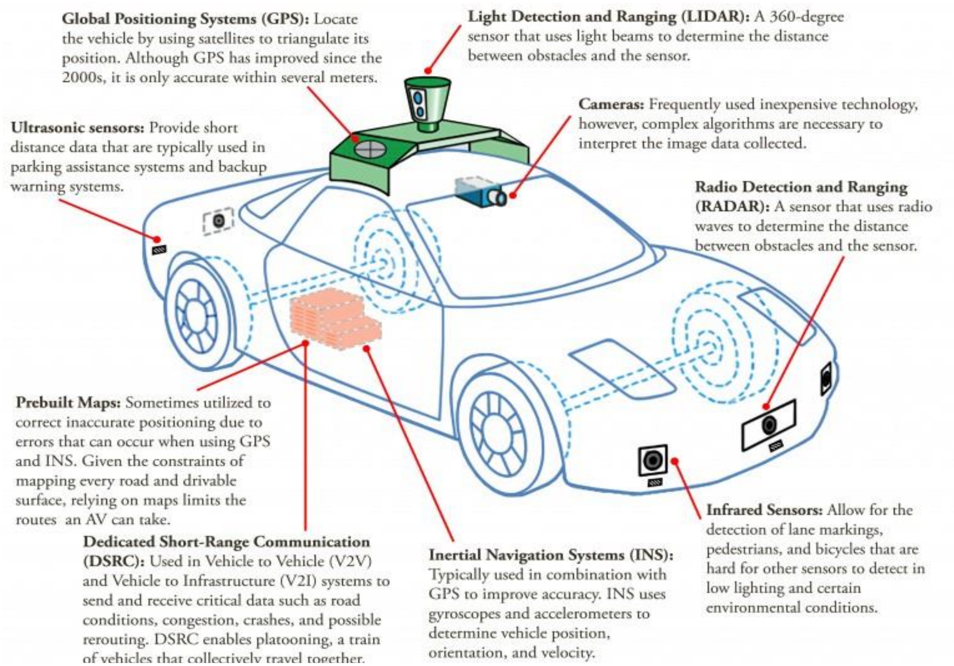
[1] Defining the Future of Mobility: Intelligent and Connected Vehicles (ICVs) in China and Germany
[2] https://www.everythingrf.com/community/what-is-c-v2x
[3] Autonomous Driving in the iCity—HD Maps as a Key Challenge of the Automotive Industry
[4] https://medium.com/cruise/hd-maps-self-driving-cars-b6444720021c

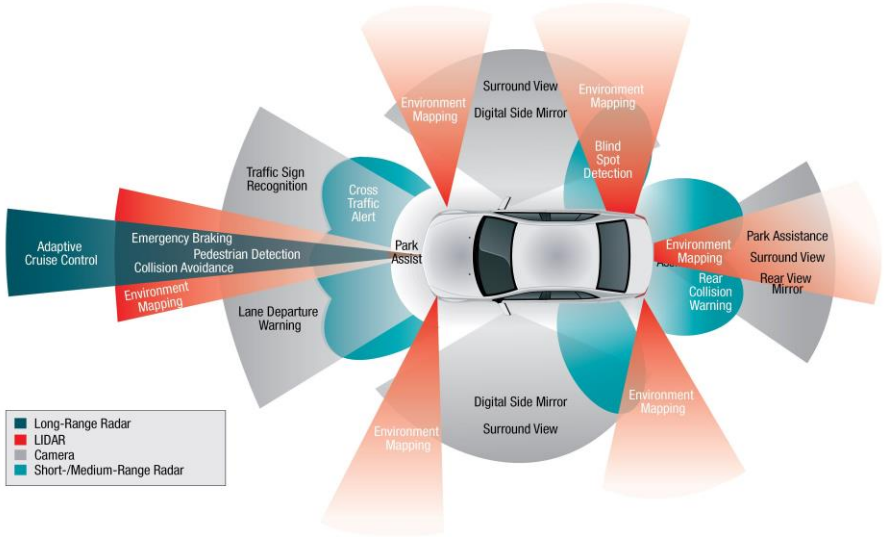
5. Relation between Intelligent connected vehicles (ICV) and automated driving (AD)

Six Levels of Automated Driving (AD)



AUTONOMOUS VEHICLE TECHNOLOGIES





Autonomous will be Connected, automated vehicle may finally stop at Level 4 of particular application scenarios, but the vehicle, road, infrastructure, pedestrian information will benefit the **Intelligent Transport Management System**.

1. https://www.trustvehicle.eu/the-road-to-driverless-vehicles/
2. http://css.umich.edu/factsheets/autonomous-vehicles-factsheet

6. The role of high-definition map for self-driving vehicles

[1]https://www.tomtom.com/products/hd-map/

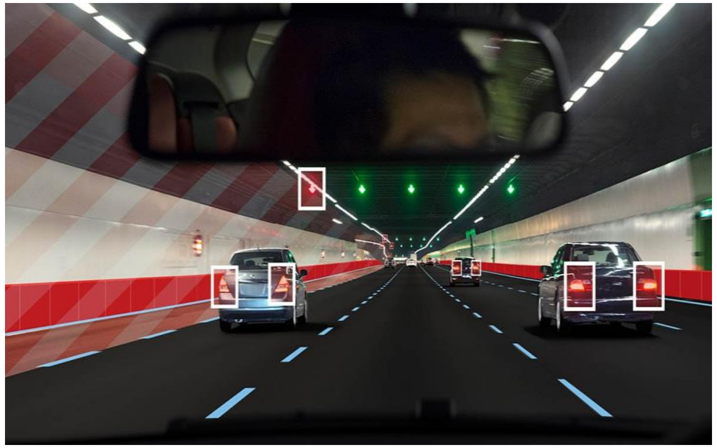
Extended sensor range

Gives context to the vehicle's surroundings, acting as a safety net that sees road signs, lights and around corners.

Sensor-agnostic localization layers

Works with any sensor layout to enhance positioning with localization map layers

Improved sensor perception



Locate and identify signs, lights, poles and other objects to help self-driving vehicles make sense of their surroundings

Safer path planning

Helps vehicles plan a path along any route and execute it safely


THANK YOU :)