Efficient use of Low-Carbon Fuels in Internal Combustion Engines

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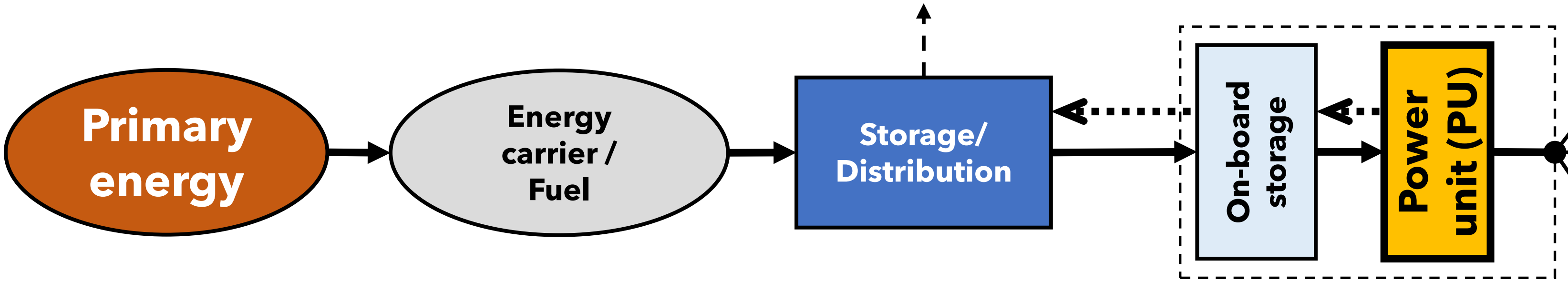
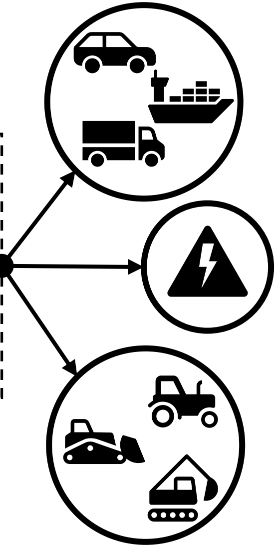
The propulsion *ecosystem*





How to select a Power Unit (thermal, hybrid, electric) for a certain application:

- Cost
- Performance, consumption
- On-board and global conversion efficiency
- Rules:
  - Pollutants
  - CO_2 and other greenhouse gases
- Range
- Recharging/refuelling infrastructure

Defossilizing propulsion:

- Fossil fuels ⇨ energy carriers/vectors

Requirements:

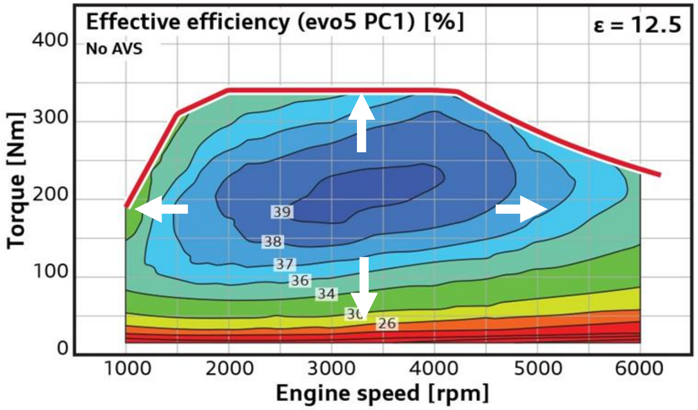
- Availability of wind, solar and biomass energy
- Installed capacity
- Distribution and storage infrastructure

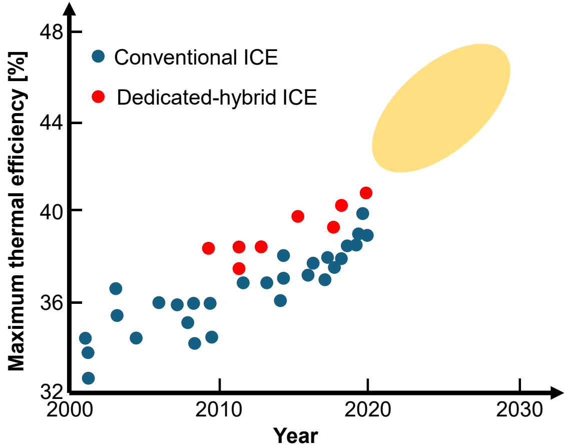
The IC engine evolution

1992 → today…

- High efficiency operation range continuosly extended

- Maximum engine efficiency increasing with electrification:
    - ~40% mild-hybrid
    - >40% full-hybrid
    - ~ 50% series-hybrid

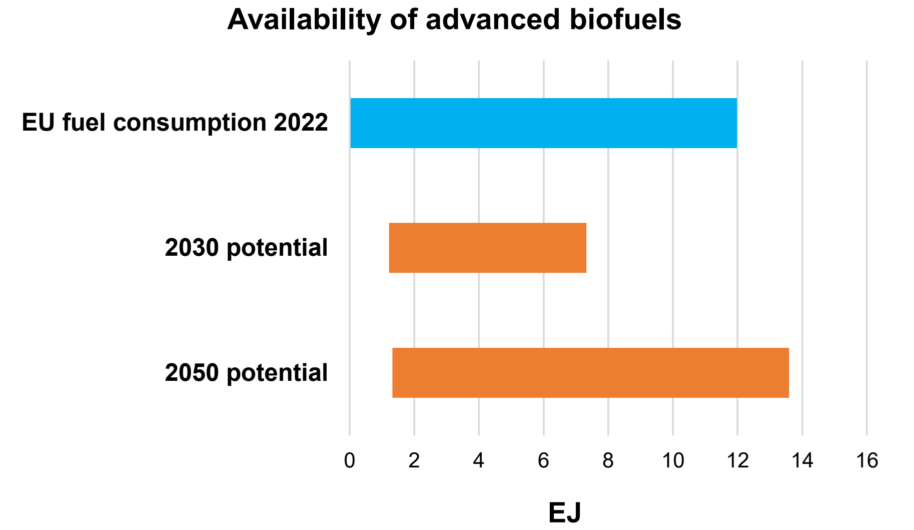




Defossilization of IC engines

Advanced bio-fuels

- Expected important contribution from Biomethane, bio-ethanol, bio-methanol, bio-gasoline, biodiesel and HVO.



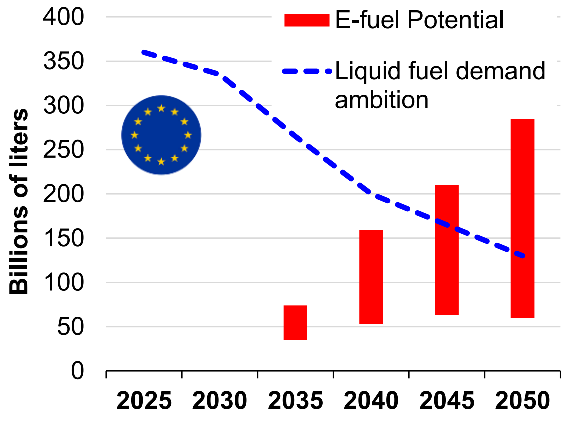
Source: Imperial College/Concawe

Synthetic fuels (e-fuels)

- Decarbonization of aviation and maritime transport
- Road transport? Efficiency vs convenience:
  - Local production: avoiding *curtailment*
  - Complementing *pure* electrification
  - Possibility to import

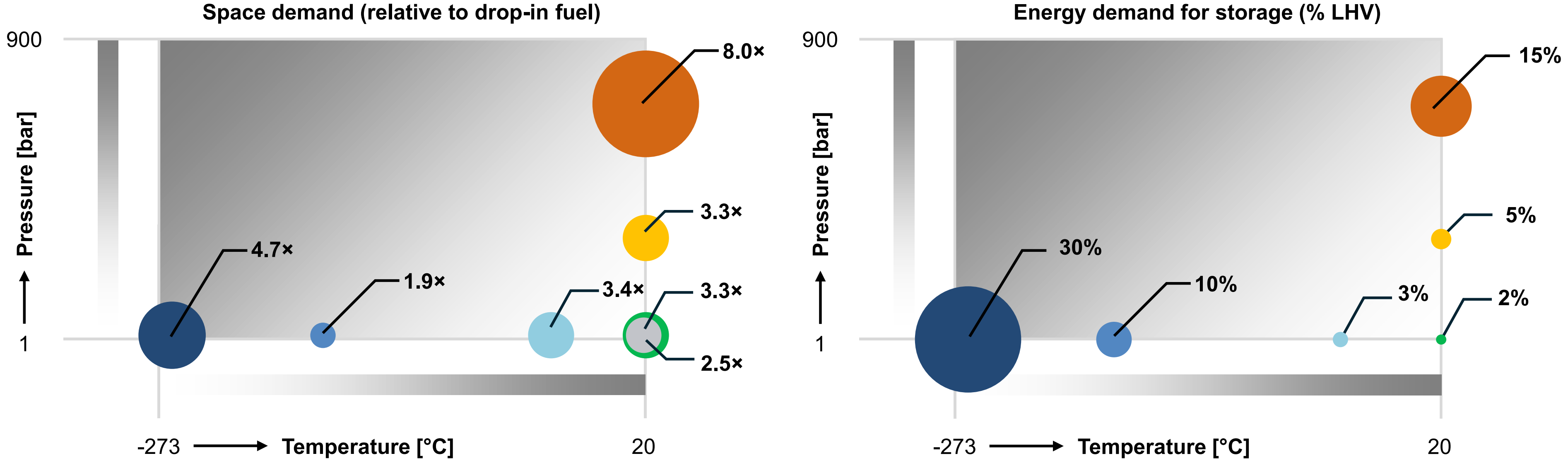
2023: 10.8 TWh of electricity cut, enough to generate **hydrogen** to power up to **20,000 city buses** throughout the year.

Source: W. Tillmetz (Uni-Ulm)



Source: Porsche Consulting GmbH

E-fuels for IC engines



Liquid storage

- Liquid hydrogen (**-253°C**)
- Liquid methane (**-165°C**)
- Cooled ammonia (**-33°C**)
- Pressurized ammonia (**10 bar**)
- Methanol (**ambient**)

Gaseous storage

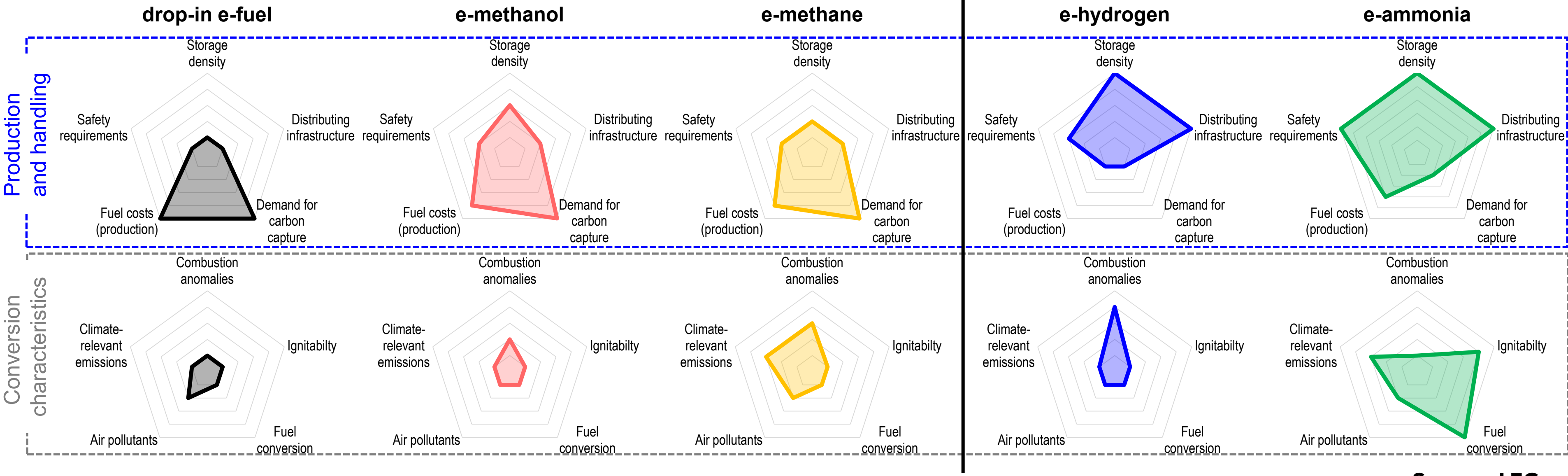
- Compressed hydrogen (**700 bar**)
- Compressed natural gas (**300 bar**)

Source: LEC

E-fuels for IC engines

Availability → **Properties** → **Use**

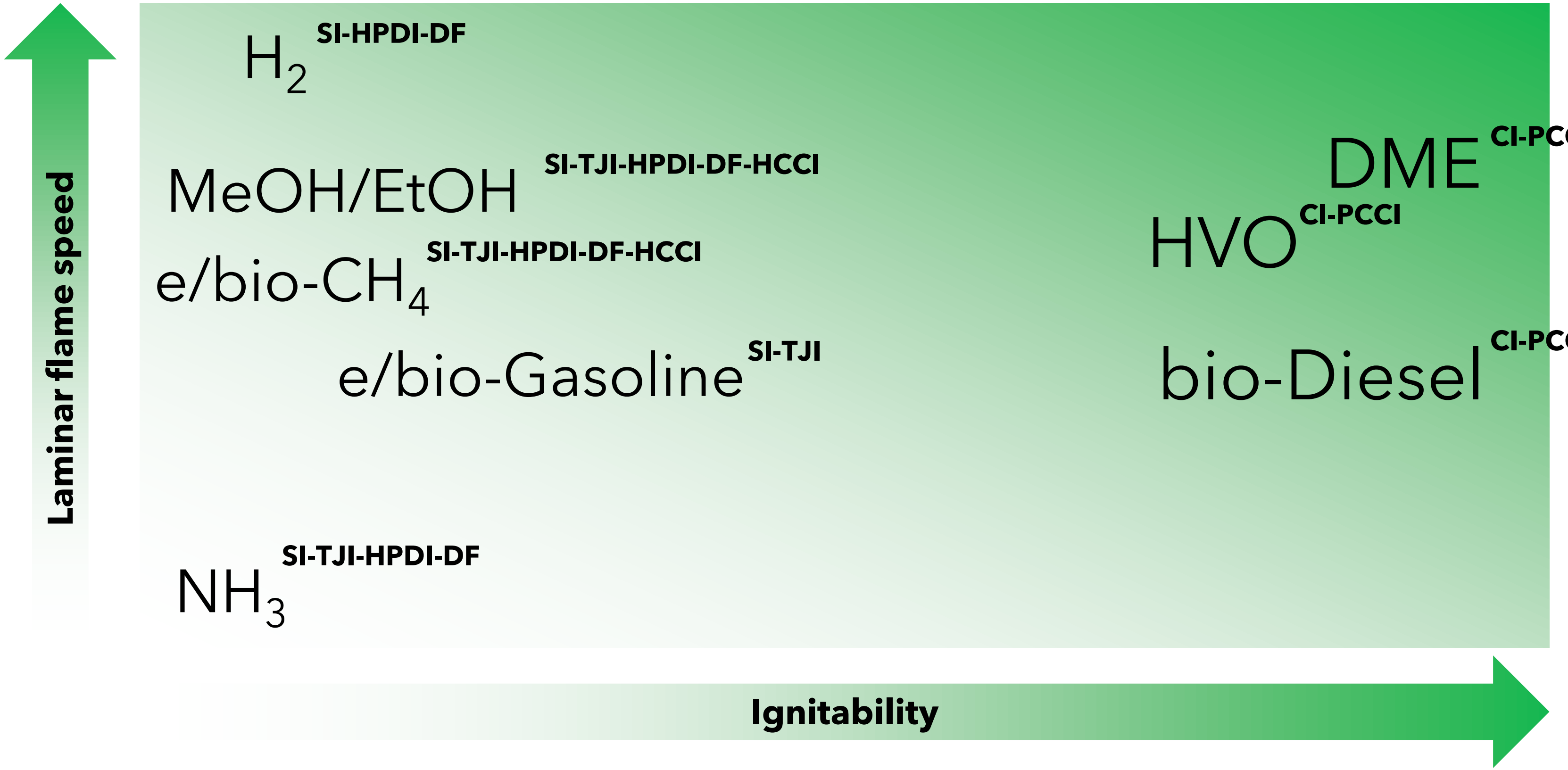
***Carbon-based* e-fuels**	***Carbon-free* e-fuels**



Source: LEC

E-fuels for IC engines

SI: spark-ignition
TJI: turbulent jet ignition
HPDI: high-pressure direct-injection
DF: dual-fuel
CI: compression-ignition
HCCI: homogeneous charge compression ignition
PCCI: premixed charge compression-ignition



H_2 fueled IC engines (H2ICE)

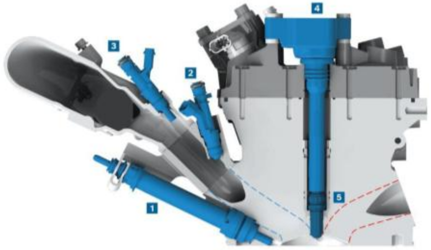
High-performance cars

Light and heavy duty transport

Power generation and off-road

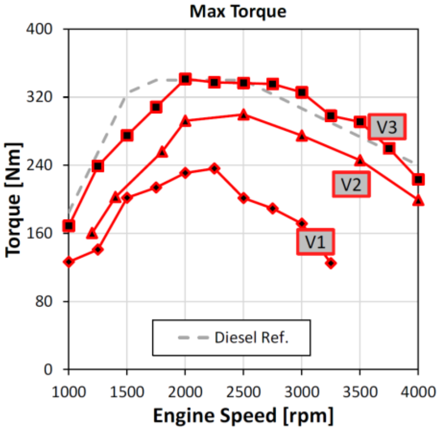
H_2 fueled IC engines (H2ICE) - today

Spark-ignition



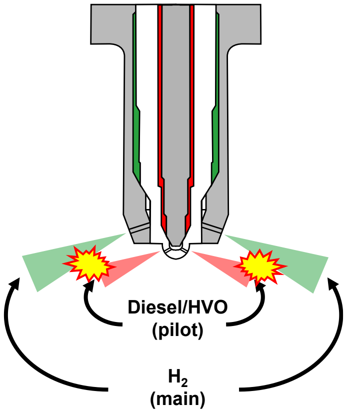
- Lean combustiojn ($\lambda > 2.5$)
- Direct-injection (low or high pressure)
- Turbocharging

⇨ Max efficiency ~45%
⇨ *zero-impact* (ATS)



Sources: BOSCH, PHINIA

Compression-ignition



- Diffusion combustion: high compression ratio, no abnormal combustion

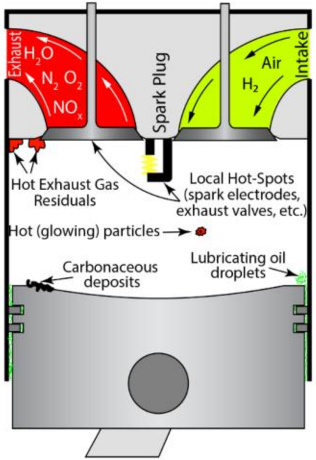
⇨ Max efficiency >50%
⇨ CO_2 emissions lower than 3 g/t km *zero-emission* limit

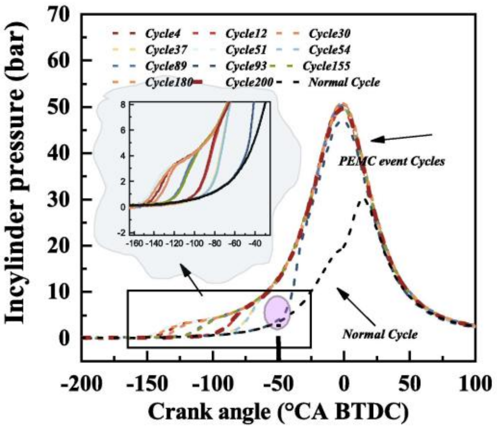
Sources: Westport, Volvo

H_2 fueled IC engines (H2ICE) - challenges

Spark-ignition

Avoid pre-ignition



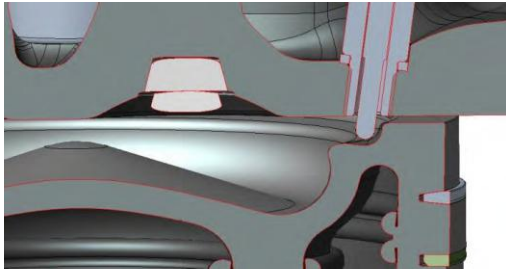


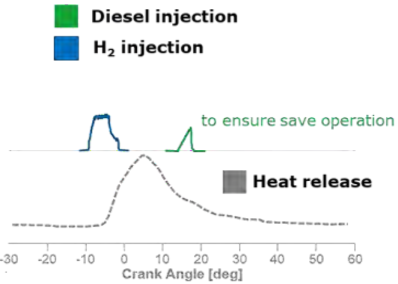
Non-controlled combustion caused by hot spots and deposits.
- Limitation of efficiency
- Detailed study of the causes
- Use of *flexible* spark plugs

Compression-ignition

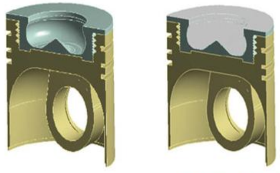
- Minimizing the pilot fuel

Glow plug





Catalyst coating

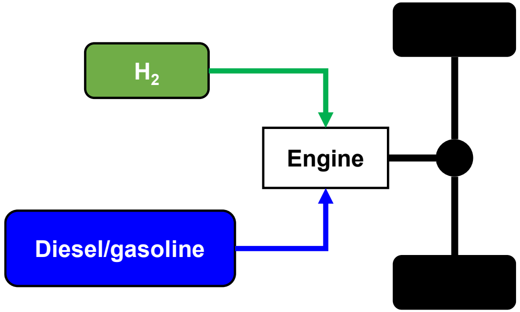


Modified piston without coating

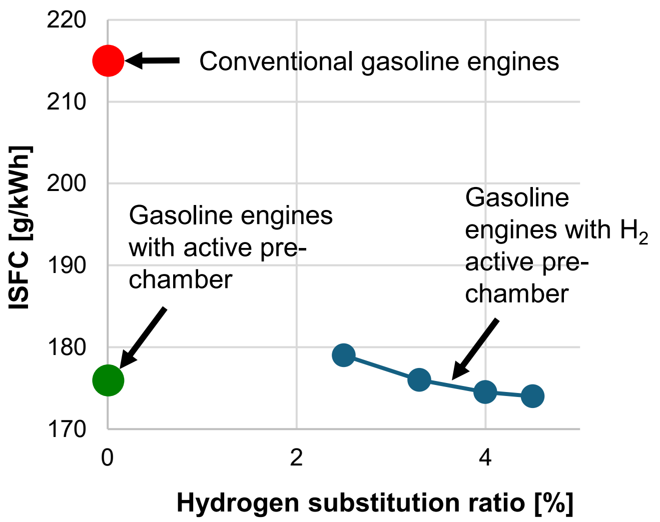
Modified piston with coating-Platinum-300microns

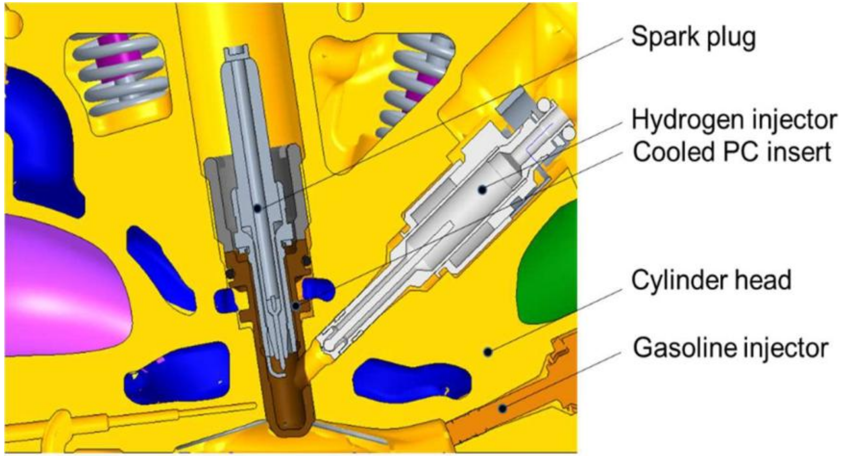
Reducing H_2 ignition delay

H_2 fueled IC engines (H2ICE) – dual-fuel



Ultra lean operation ($\lambda > 2$)
-15% fuel consumption reduction

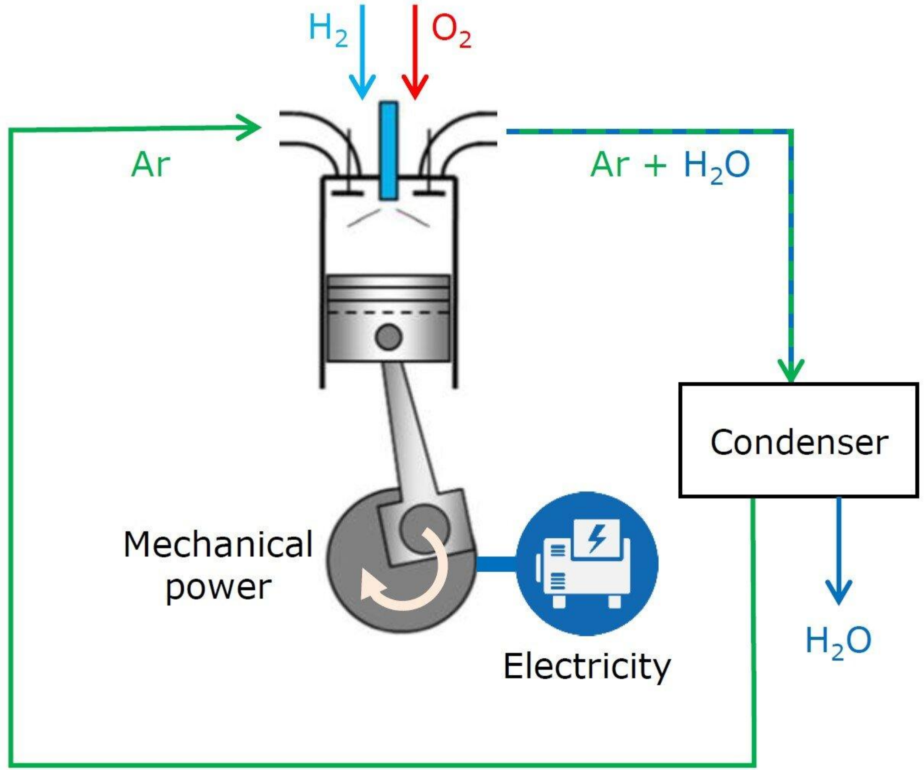




- H_2 tank of modest size
- System easy to build

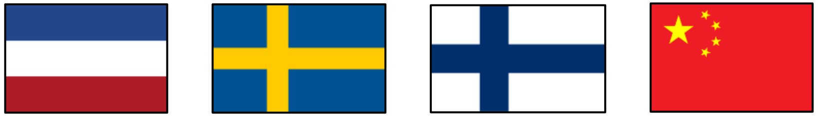
Sources: China FAW Group, Jilin University

H_2 fueled IC engines (H2ICE) – future?

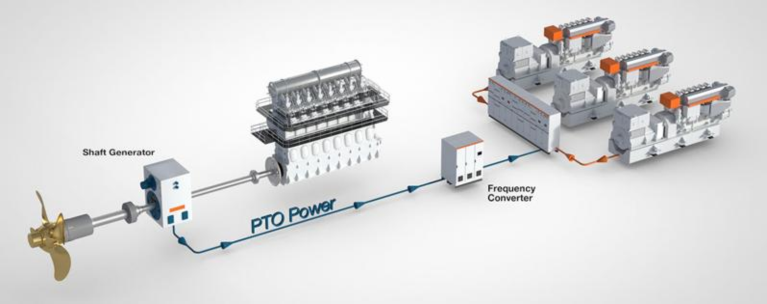


Argon power cycle *zero pollutants engine*

- Closed-cycle engine (condensation of exhaust H_2O)
- H_2 ed O_2 from electrolysis
- 65% potential efficiency (high Ar c_p/c_v ratio)
- Suitable for distributed power generation (*grid balancing*)
- APC academic and industrial research active in different countries

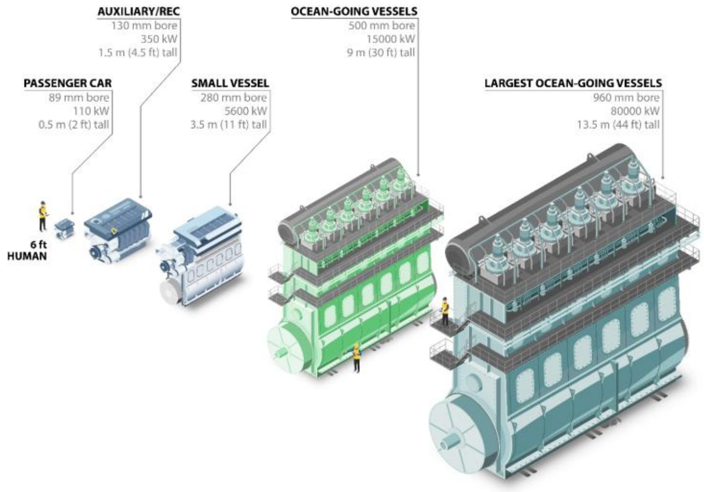


Defossilization of maritime transport

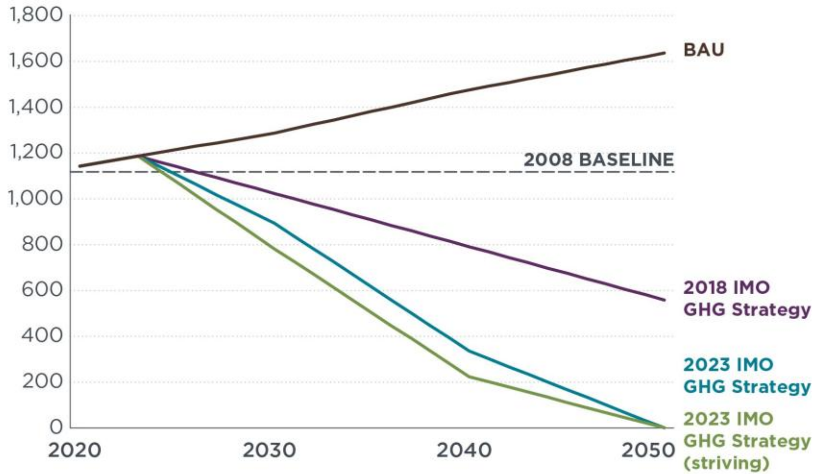


Different IC engines onboard:

- Propulsion (low-speed – 2-stroke, medium–high speed - 4 stroke)
- Gensets (4 stroke)



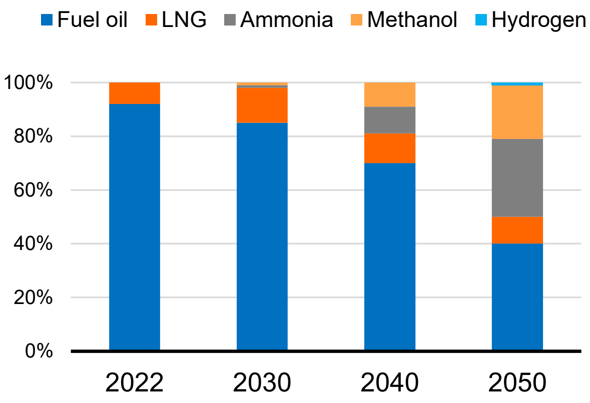
$CO_{2,eq}$ WTW reduction target for maritime transport



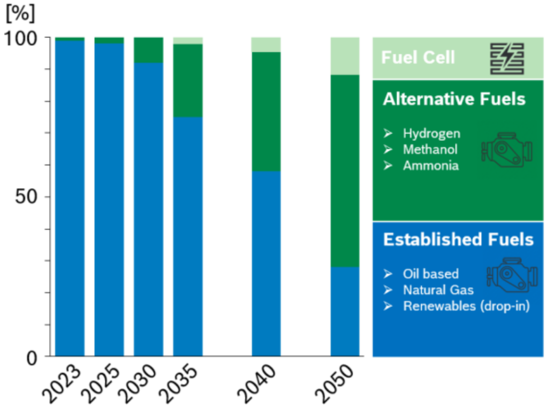
Sources: IMO, ICCT

Defossilization of maritime transport

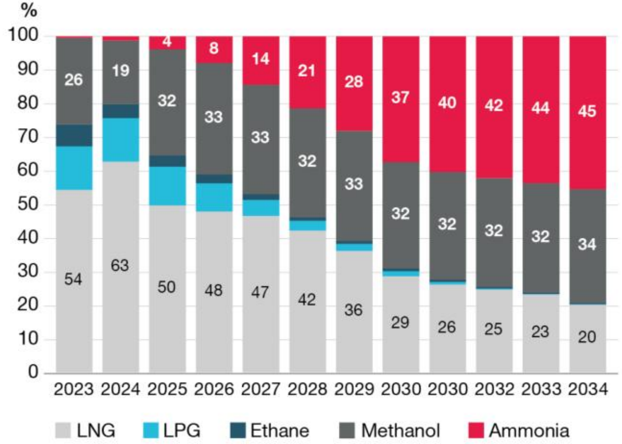
MPAT & Dahiatsu Diesel



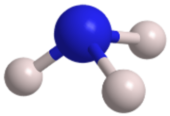
Bosch



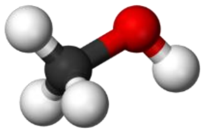
Everllence (dual-fuel 2T orders)



Ammonia



Methanol



$$\eta_{WTT,NH_3} = 47\%$$

$$\eta_{WTT,MeOH} = 43\%$$

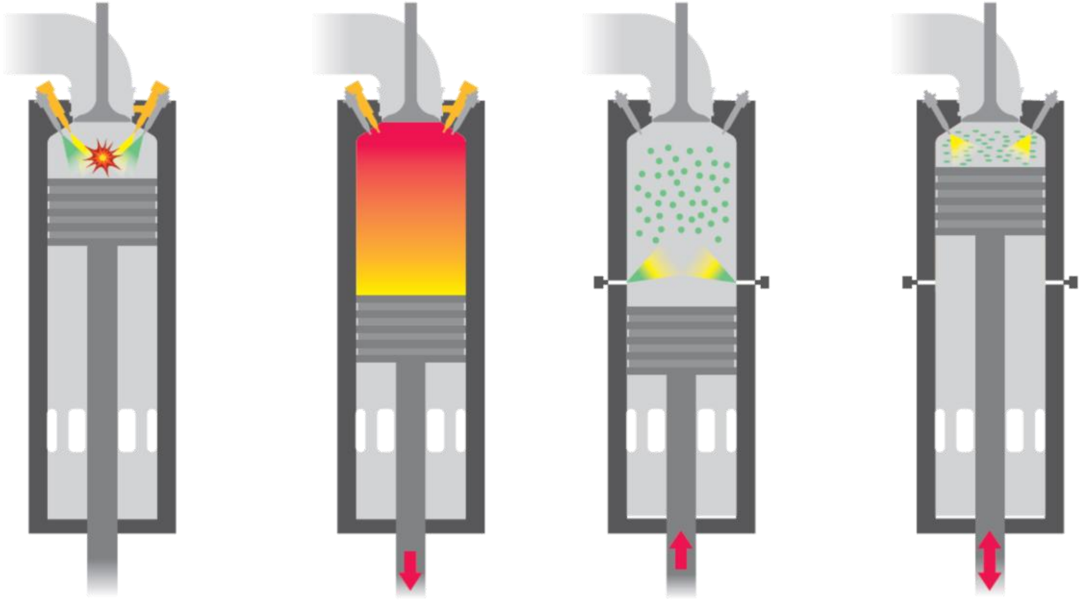
- Different technologies
  - Retrofit
  - Dedicated engine

⇨ Maximizing TTW efficiency e emissions reduction

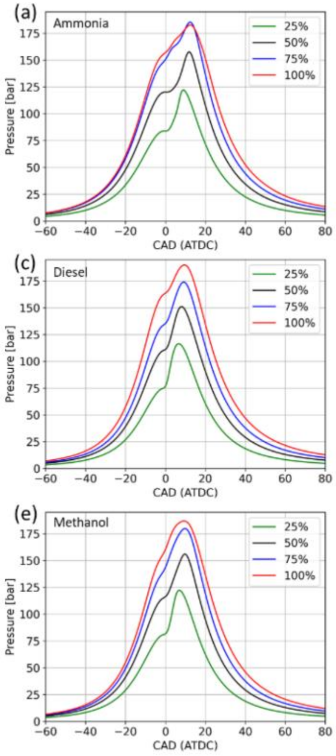
Source: IAV

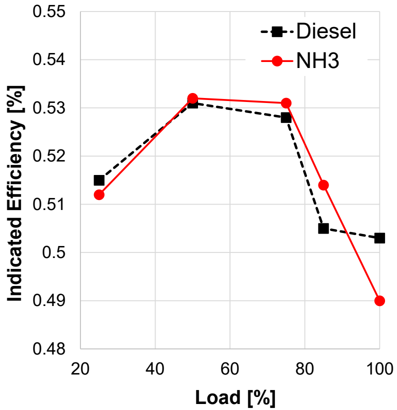
Defossilization of maritime transport – 2S / dual-fuel

Diffusive		Premixed	



Pilot & HP Injection	Expansion	Compression & LP Injection	Pilot injection, ignition

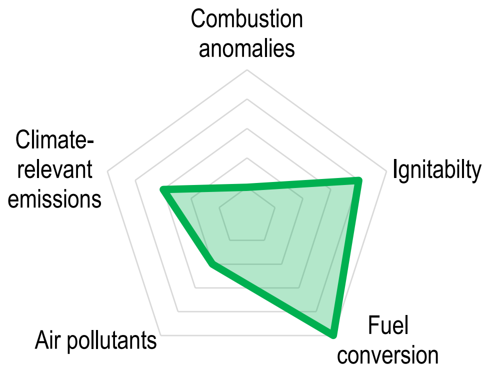


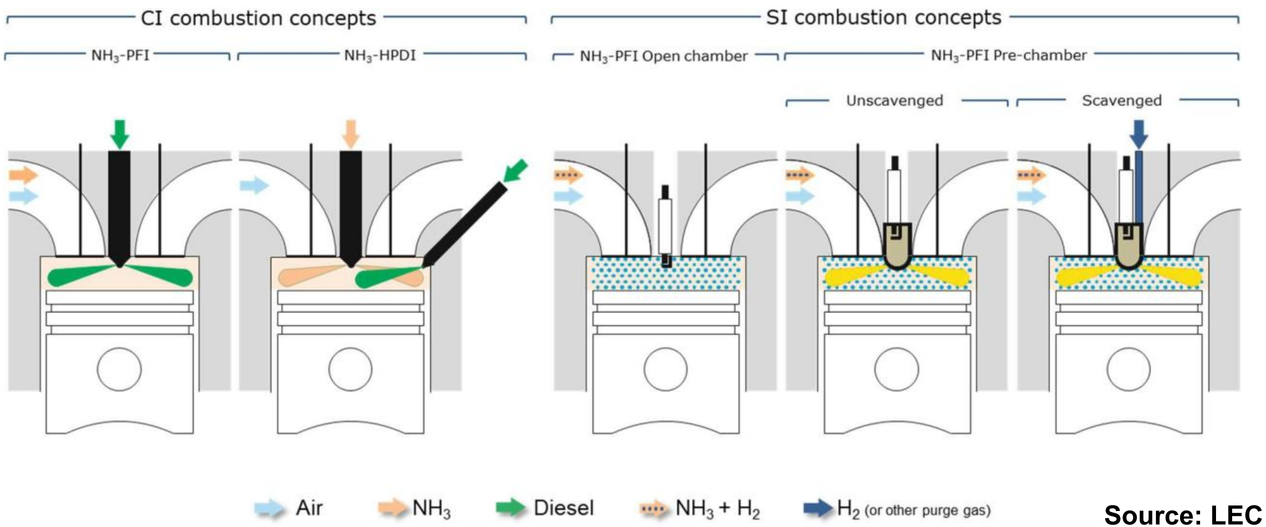


- 95% GHG reduction
- Ammonia combustion efficiency >99.5%

Source: Everllence

Defossilization of maritime transport – 4S / NH_3



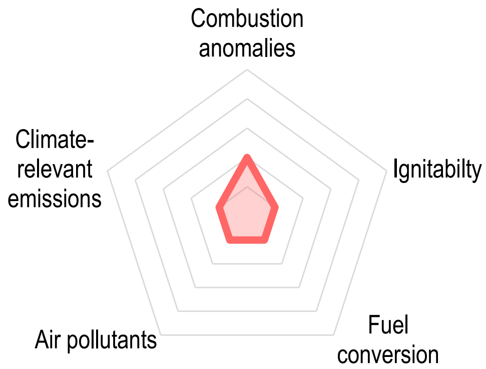


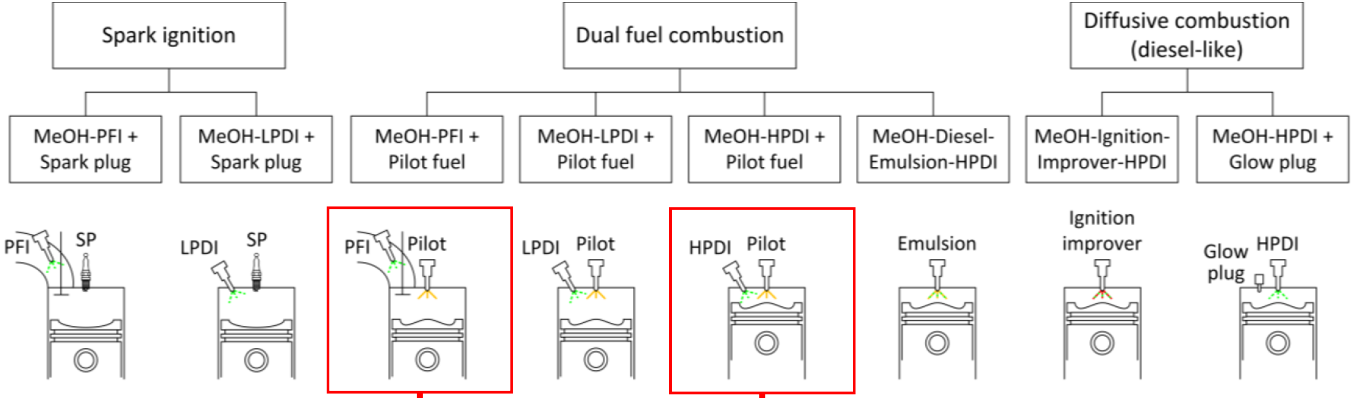
Source: LEC

- High RON and low flame speed
- GHG emissions: N_2O (GWP = 300)
- Pollutants: NO_x ed NH_3
- Compatibility with lubricants

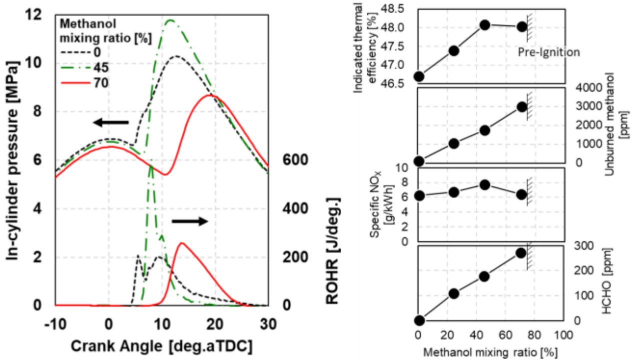
- Diesel pilot injection or prechamber (passive or H_2-active)
- Combustion chamber design: turbulence generation
- SCR for exhaust gas after-treatment
- Maximum efficiency: ~45%

Defossilization of maritime transport – 4S / MeOH

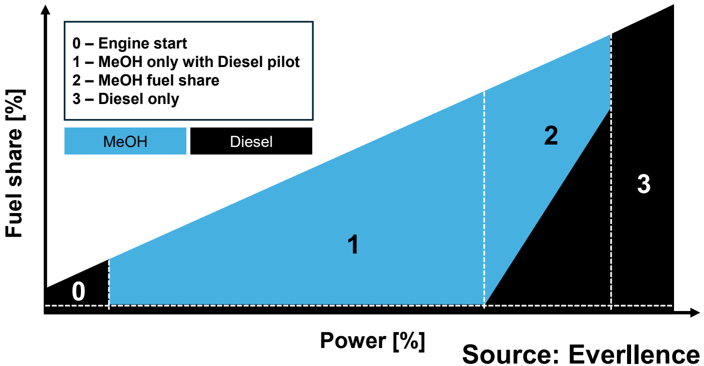




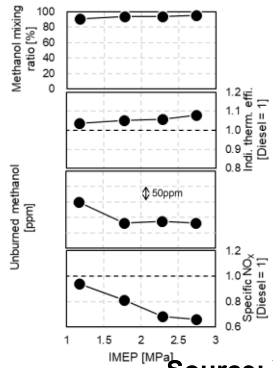
Fonte: LEC



Source: YANMAR



Source: Everllence

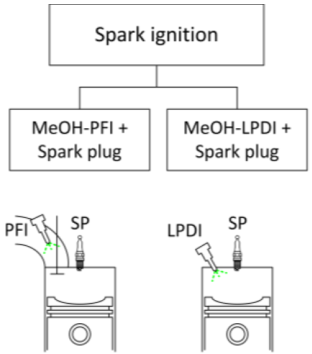


Source: YANMAR

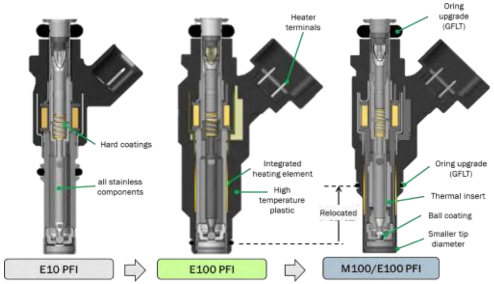
MeOH for cars/trucks/buses

Advantages:
- High heat of evaporation
- High octane number
- High flame speed
- Large flammability range

Drawbacks:
- Cold start
- Material compatibility
- Injector cavitation



Dedicated PFI and GDI injectors



Heater OFF

Heater ON

Vehicle applications

26000 public transport vehicles (Taxi, bus)

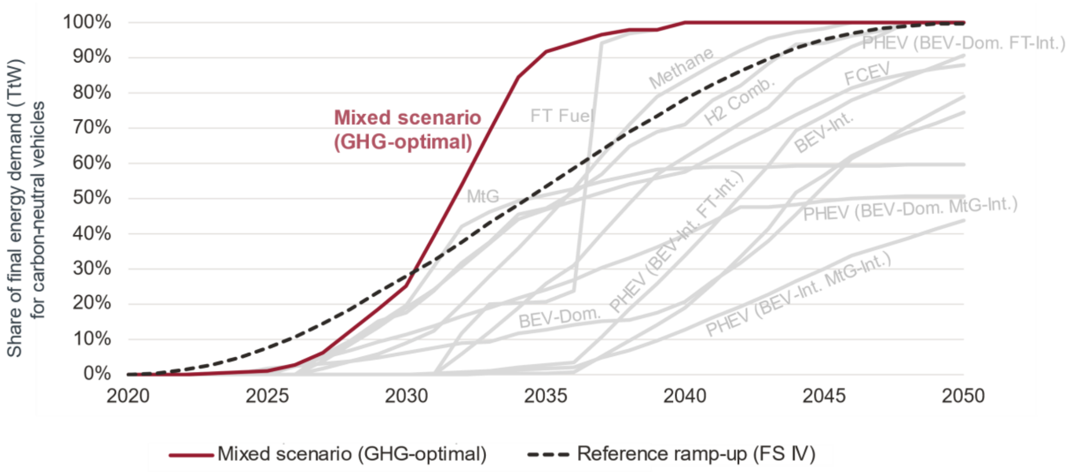
Electrified powertrain (CR = 15, max efficiency: 45%)

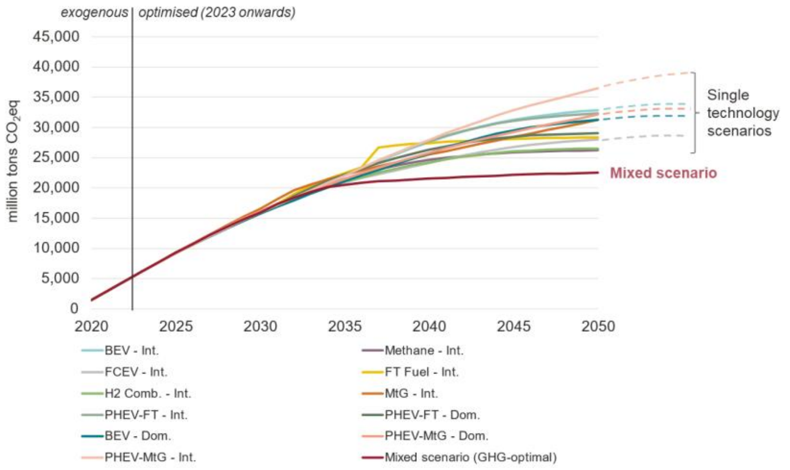
Heavy duty truckwith dedicated engine

Fonti: Geely, Phinia

Road transport defossilization – *drop-in* e-fuels

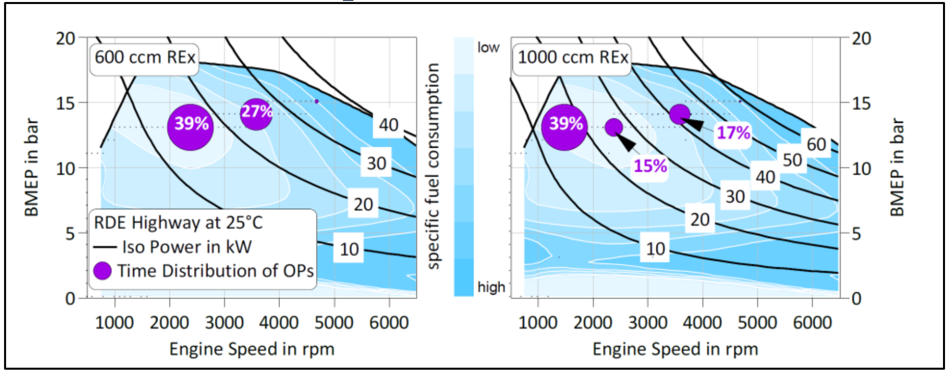
- A combined use of different propulsion systems can accelerate the decarbonisation of road transport compared to the use of a single technology, with a significant contribution from electrified vehicles powered by e-fuels.



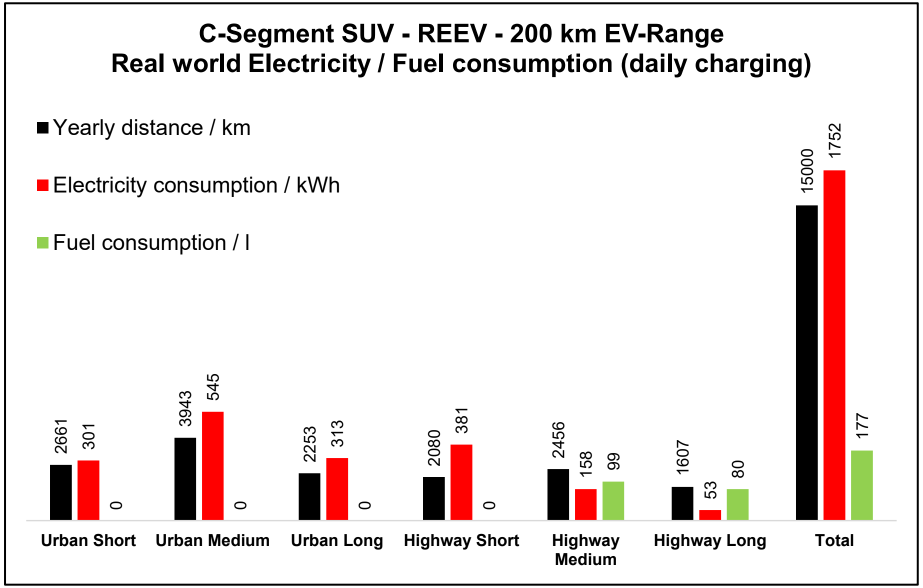


Sources: FVV, Frontiers Economics

Road transport defossilization – REEV

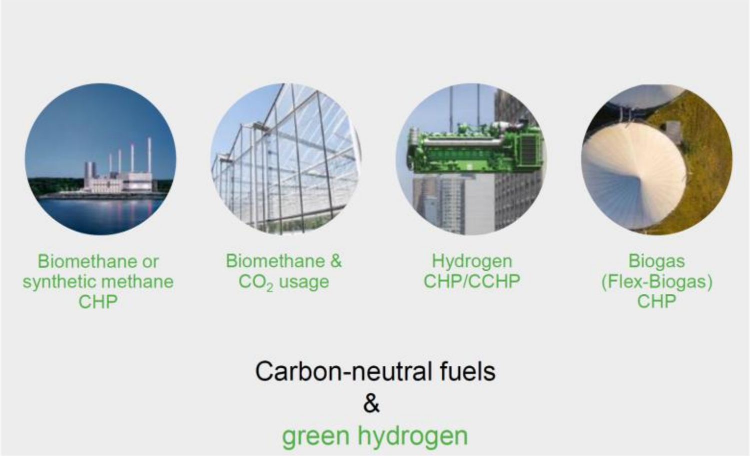


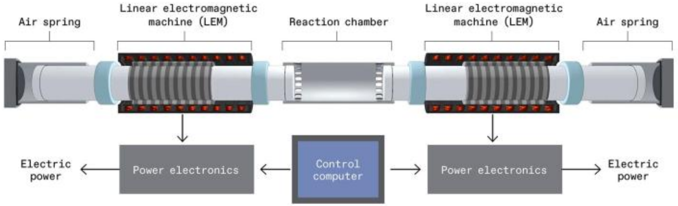
- BEV platform *hybridized*
- Series-hybrid propulsion
- Reduced battery capacity that still guarantees most (short) journeys in electric mode

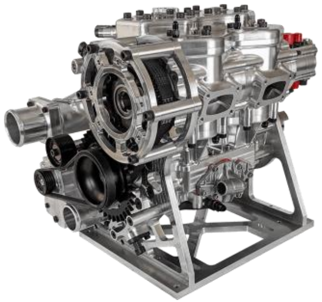


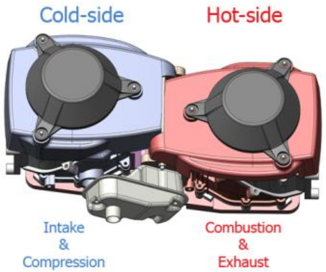
Source: IAV, FEV

Biofuels and power generation







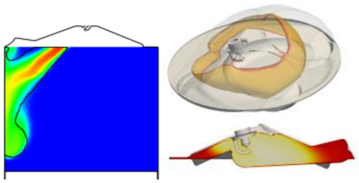


The ICE Group

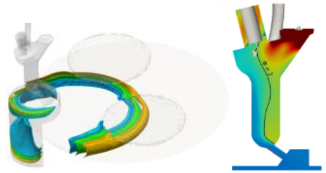
- In-house 1D (Gasdyn) and CFD (Lib-ICE) software development for performance and emissions prediction in high efficiency and low emission internal combustion engines.

- Research and industrial collaborations

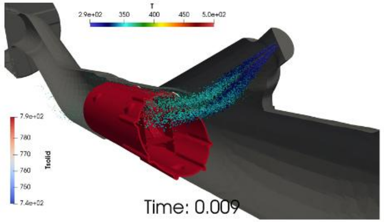
H2-ICE



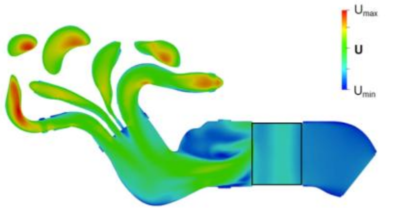
Ammonia-ICE



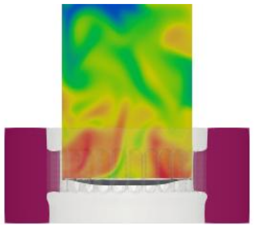
SCR



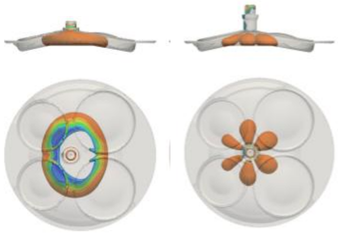
TWC



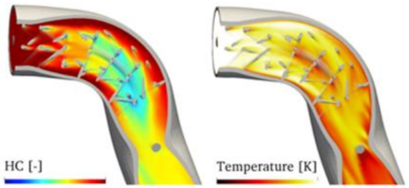
Marine engines



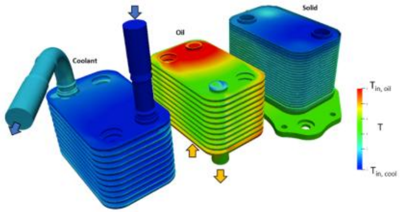
Ignition systems



Innovative substrates



Thermal management



Conclusions

- Biofuels and e-fuels can contribute to the defossilization of transport, power generation and off-road sectors;

- The IC engine can efficiently operate today with sustainable fuels with an effective contribution to the reduction of GHG emissions;

- Integrated research:
  - Fuel production from renewable sources
  - Conversion in engine
  - End-use

  to support the development of new technology and sustable value chains.

Thanks!

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