Bio-fuels, e-fuels and their role in the future energy mix

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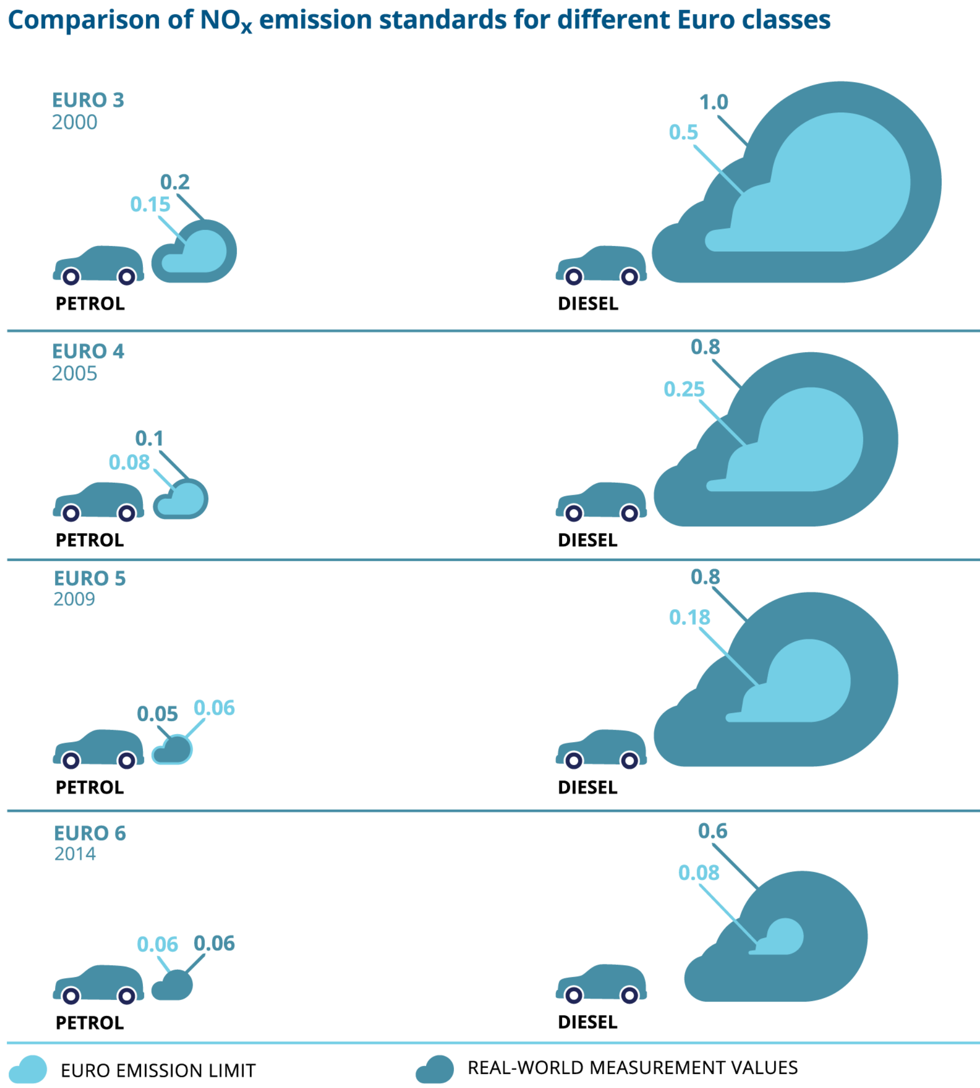
What we see in the press

- “The EU plans to ban sales of new ICE powered vehicles in 2035”
- “Britain, Israel and Singapore plan to ban the sales of new vehicles with IC engines in 2030”
- “Internal combustion engines are hindering the clean energy future”

It’s not the engine, it’s the fuel

- Harmful ICE emissions have been considerably reduced
  - Vast improvements in after treatment technologies
  - Global regulation became stricter and will continue to
- CO2 emissions are a result of the fuel used and not a inherent to engine technology
  - $C_8H_{18} + 12.5\ O_2 \rightarrow 8\ CO_2 + 9H_2O$
  - $CH_3OH + 1.5\ O_2 \rightarrow CO_2 + 2H_2O$
  - $H_2 + 0.5\ O_2 \rightarrow H_2O$
- Carbon emissions can be reduced by:
  - using fuels with less carbon or no carbon
  - Producing synthetic fules with use of carbon originating from waste or the atmosphere



Alternative fuels driving decarbonization

- Reduction in carbon emissions can begin **right now**
  - Effective for the existing ICE based transportation fleet
  - Using the existing distribution, re-fueling and storage infrastructure
  - Effective for sectors where an ICE will continue to be dominant (shipping, aircraft, off-grid power generation etc.
  - Effective for other types of fuel burning machines (industrial steam boilers etc.)
- “Drop in” capability with existing engines
  - little to no changes required (depending on fuel)
  - Possibility for blending with existing fuels(E5, E10 etc.)
  - Flexible fueling for the same machine (eg. E85/gasoline flex fuel system)
- Energy storage for the future distributed renewable energy system
  - Power to Gas/ Power to Liquid
  - Better than other storage methods in energy densty and storage capaciy

Combustion of hydrogen in ICE

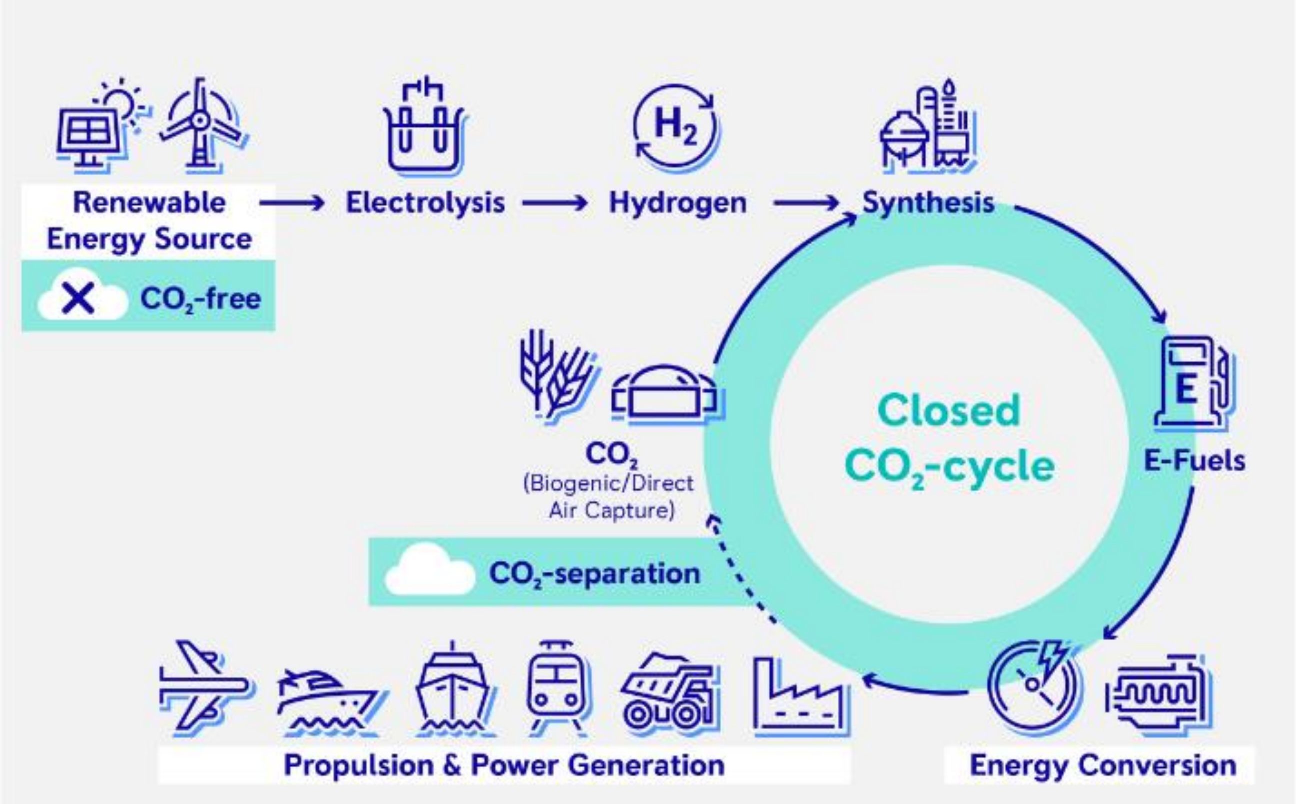
- Hydrogen has many advantages as a fuel for ICE
  - Very wide flammability limits
    - The engine is able to operate at ultra-lean conditions
  - No carbon emissions directly from fuel
  - The most common element in nature
    - Has a well established production method
    - Renewable energy can be used to produce it
- This however, comes with several challenges:
  - Low energy density as a gas (at room temperature)
  - High pressure compression and liquification possible but complex
    - 700 BAR tanks have been developed for various applications
    - liquid hydrogen tanks (at -253ºC) have also been developed and are under testing
    - Both methods suffer from leakage issues and are energy intensive
  - Increase in NOx emissions
  - Effect of hydrogen embrittlement on engine materials lifetime
  - Re-fueling infrastructure is currently not wide spread
  - Saftey considerations
    - Very easily ignitable during unplanned leakage
    - Failiure of High pressure or very low temperature storage devices

Combustion of hydrogen in ICE

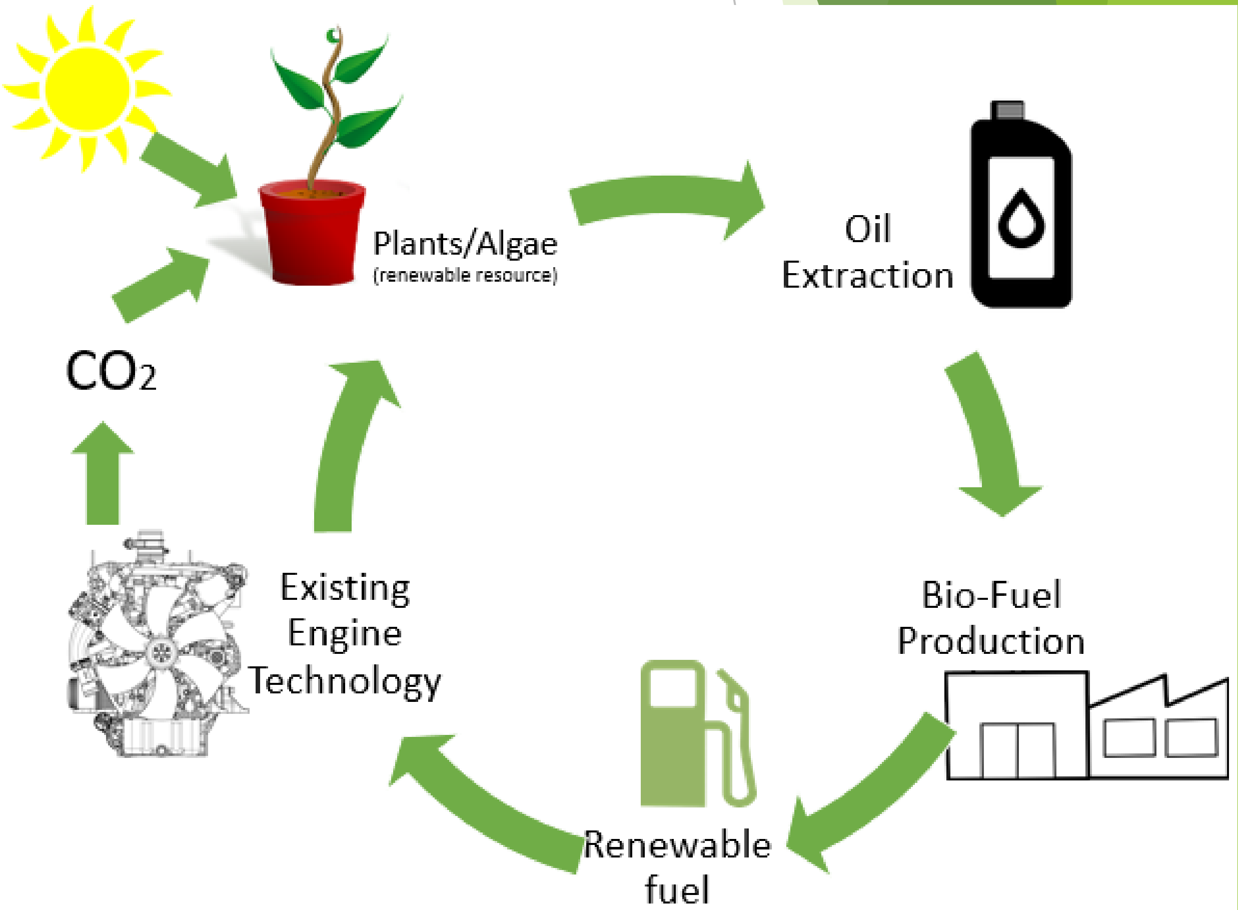
Currently in the R&D phase, with Toyota leading the effort for ICE and fuel cell vehicles

The Closed CO2 cycle of the two liquid fuel alternatives

e-fules



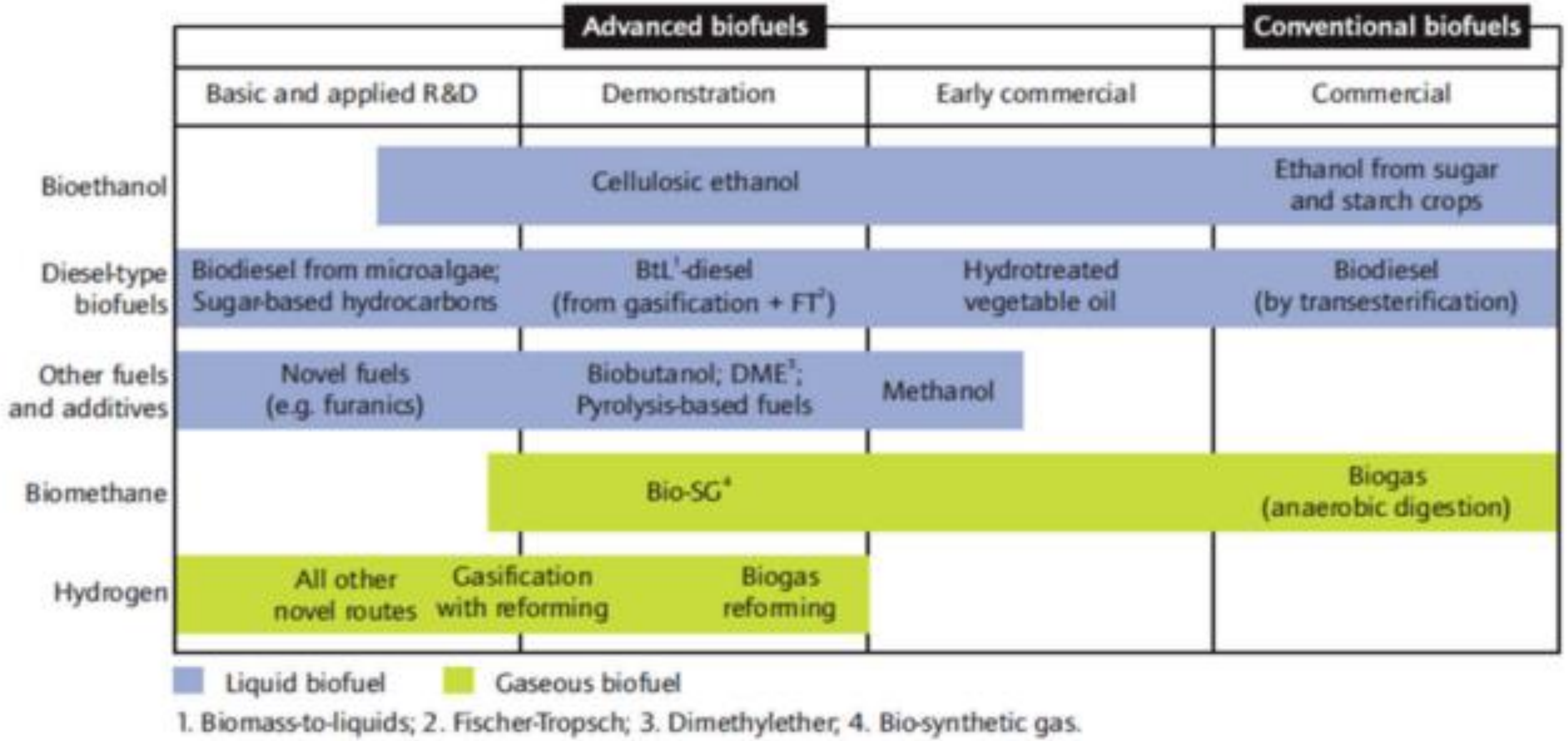
bio-fules



Bio fuels

- Bio fuels can be made from various plant-based materials
  - Straw, manure, wood waste, sugarcane, waste vegetable oils etc.
- production methods are divided to generations:
  - First generation Bio-fules
    - Firmentation of simple sugars (e.g. ethanol sugar cane)
    - transesterification of vegetable oils and animal fats (e.g. alkyl ester “biodiesel” from vegetable oil)
  - second generation Bio-fules
    - Thermochemical conversion of carbon based materials (e.g. organic waste gasification to produce syngas. The syngas can be turned into various fuels via a fischer-Tropsch process)
    - Biochemical conversion through enzymatic-hydrolysis of cellulose resulting in sugars fermrnted into alcohol (using plant based waste)
  - Third generation bio-fuels
    - Derived from algae that produce an oil that can be easily refined into diesel
    - The algae can also be genetically manipulated to produce other types of fuels

Bio fuels, continued



Bio fuels, continued

- The most common bio fuels in use are ethanol (for SI engines) and biodiesel (for CI engines)
- These fuels are suitable for use in current engines with little modification
  - Changes to the fuel supply system for correct flow and resistance to corrosion
  - In cold climates cold start aids need to be installed (glow plugs etc.)
- Blends are being used with no modification to hardware
  - E5 and E10
  - B20
- The trend is to move away from bio fuels made from growing crops on land and focus on more renewable and energy efficient sources (waste, algae).

e-fuels

- e-fuels (power-to-liquid) are considered the “fourth generation” bio-fuel
- Production:
  - Electrolysis of water to produce Hydrogen
  - Seperation of CO2 from the atmosphere or other sources (water, biomass, flue gas)
  - Chemical synthesis of the desired fuel
  - the process can be carbon-free if renewable or excess energy is used
- Many types of fuels can be synthesized:
  - e-methanol, e-methane, dimethyl ether (E-DME), e-ammonia,e-diesel...
- The ones considered most energy efficient
  - e-Methanol (typically for SI engines)
  - e-DME (typically for CI engines)
- P-to-L can also be used to store off-peak excess energy with high density

e-fuels

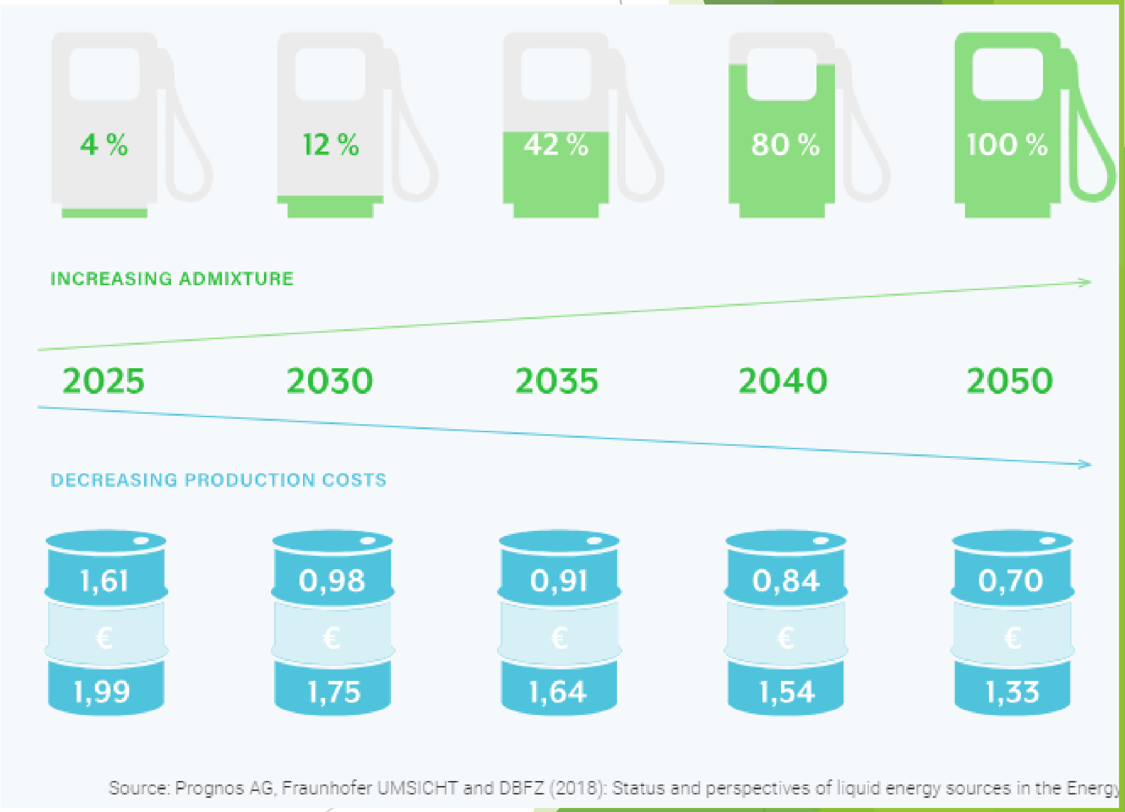
	Theoretical Conversion Efficiency from Hydrogen	Typical Plant Conversion Efficiency from Hydrogen	Thermophysical Conversion for Storage [kWh/kg]	Typical Overall PtX Efficiency	E-Fuel Transportation to Final User [kWh/kWh_{fuel}]	WTT Efficiency
E-Hydrogen (700 bar)	-	-	5.5	0.60	0.09	0.55
E-Hydrogen (liquid)	-	-	11	0.54	0.1	0.49
E-Methanol	0.886	0.797	-	0.53	0.07	0.49
E-Diesel	0.834	0.693	-	0.46	0.05	0.44
E-Ammonia	0.870	0.783	-	0.52	0.07	0.48
E-DME	0.915	0.824	-	0.55	0.07	0.51
E-Methane (220 bar)	0.825	0.743	0.15	0.50	0.07	0.47
E-Methane (liquid)	0.825	0.743	0.5	0.49	0.07	0.46

e-fuels, continued

- e-Methanol $CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$
  - Can be easily used in SI engines
    - High RON, high HOV, high flame speed, high energy per unit of fuel-air mixture
  - Energy density ~1/2 of gasoline
  - To produce 1 kg of methanol, 1.37 kg of CO2 and 0.19 kg of H2 are required.
  - Other possibilities in ICE
    - On-board reforming to hydrogen using exhaust gas heat
    - Dual-fuel operation of CI engines with variable energy substitution rates
- e-DME $2CO + 4H_2 \rightarrow CH_3OCH_3 + H_2O$
  - The carbon source for production is CO, converted from CO2. can also be produced from methanol
  - A suitable fuel for CI engines
    - high cetane number, low ignition temperature, and high speed of vaporisation
  - Energy density ~60% of diesel
  - No C-to-C bonds- large reduction in particulate emissions (negating DPF)
  - Currently in the research stage

Challenges to e-fuel adoption

- Energy requirements of current technology
  - Electricity consumption, only for the reactants needed to synthesize 1 kg of e-methanol, is about 10 kWh for H2 and up to 2 kWh for CO2
  - Hurts WTT efficiency
- Avaliability of “green energy”
  - Relying only on excess energy will limit production capability
- The price
  - Current offerings (Porsche) cost 10 euro/liter- X5 of gasoline
  - Price is expected to decrease with larger scale production
- The regulatory environment
  - EU delayed LDV ICE ban, but the politics are still in favor
  - Government incentives could speed up adoption



Dor Group Methanol initiatives

- During the last decade, DOR Group (Via its innovation arm Dor-Motors) has put forward an intensive R&D effort to expand the use methanol as a clean, competitive alternative fuel. Among the developments:
  - Internal Combustion Engine conversions to operate with Methanol
    - (M100 engine technology)
  - Development and Production of Low-Carbon Methanol based fuel (“DOR-Mix”)
    - reducing up to 15% CO2 emissions compared to diesel.
  - Launched the first in the world Medium Duty Vehicle operated with Methanol
  - Design of a conversion KIT – upgrading existing diesel gensets for hybrid methanol – diesel use.
- Replacing diesel fuel with alcohols in relevant applications has both environmental and economical benefit:
  - Reduction (dual fuel) or elimination of particle emissions (soot)
  - Reduction in NOx emissions
  - e-fuels
  - Diesel fuel is subject to high tax policies that are expected to continue increasing



Dor Motors

- Dor-Motors current initiatives are:
  - Diesel genset dual-fuel conversion kits:
    - Self-tuning ability for various fuels (Methanol, Ethanol, Hydrogen etc.)
    - Implementation at customer sites (Ashdod port, etc.)
  - M100 genset conversions offered to customers via “energy as a service”
  - Conversions of oil burners for direct combustion of alternative fuels and fuel blends
  - Hydrogen energy initiatives
    - Production and storage methods
    - Fueling infrastructure and usage in HFC industrial vehicles (forklifts, trucks etc)
- **Looking for collaboration with interested parties**

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Questions?