Alternative Kraftstoffe auf Basis regenerativer Energie

Alternative Fuels Based on Renewable Energy

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Technologiezentrum Jülich

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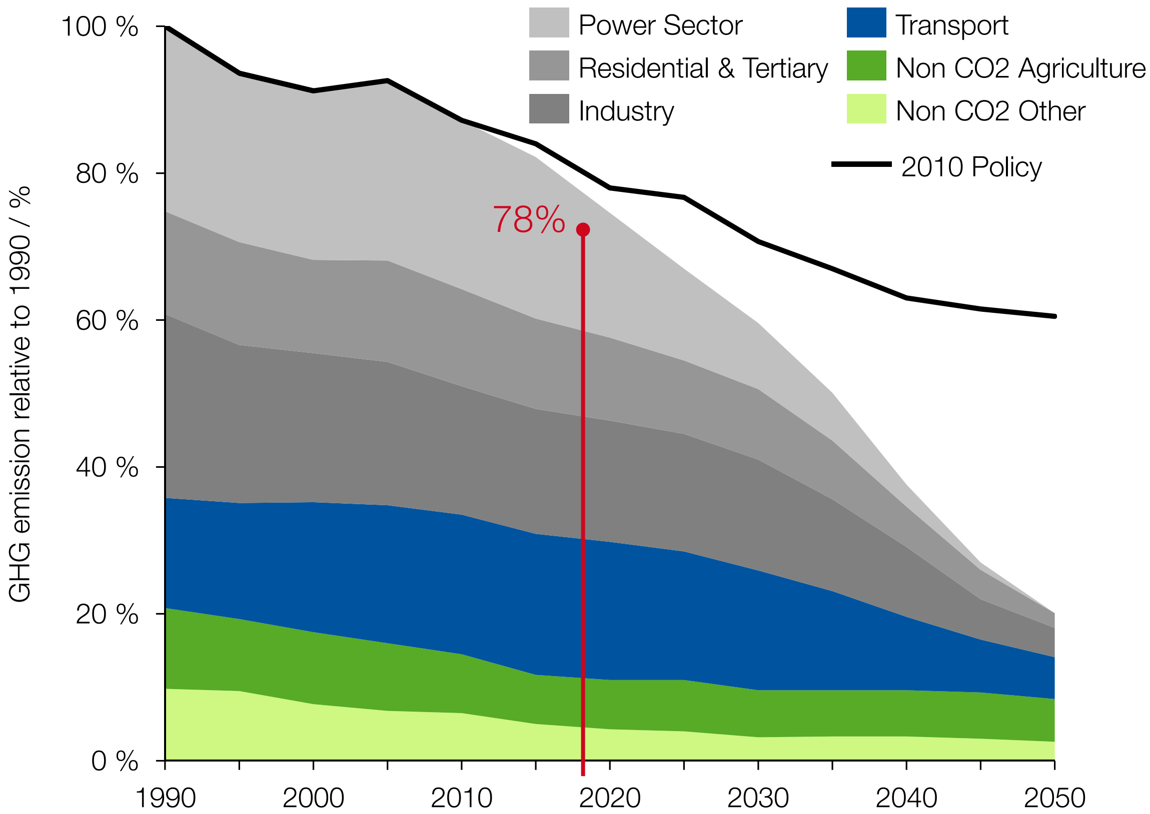
FSC The Fuel Science Center | RWTH AACHEN UNIVERSITY

Preventing rapid climate change requires dramatic reduction of GHG emissions in all sectors: transport, power, industry, household, farming

GHG REDUCTION ROADMAP OF THE EUROPEAN COMMISSION

- Total GHG emission reduction
  - 80% until 2050
  - 40% until 2030
  - 20% until 2020
- Additional Targets 2020
  - Ratio of renewable energy 20%
  - Increase of energy efficiency 20%
- Sector Targets 2050
  - Almost all electric power from regenerative sources (97%)
  - Transport: GHG -60%

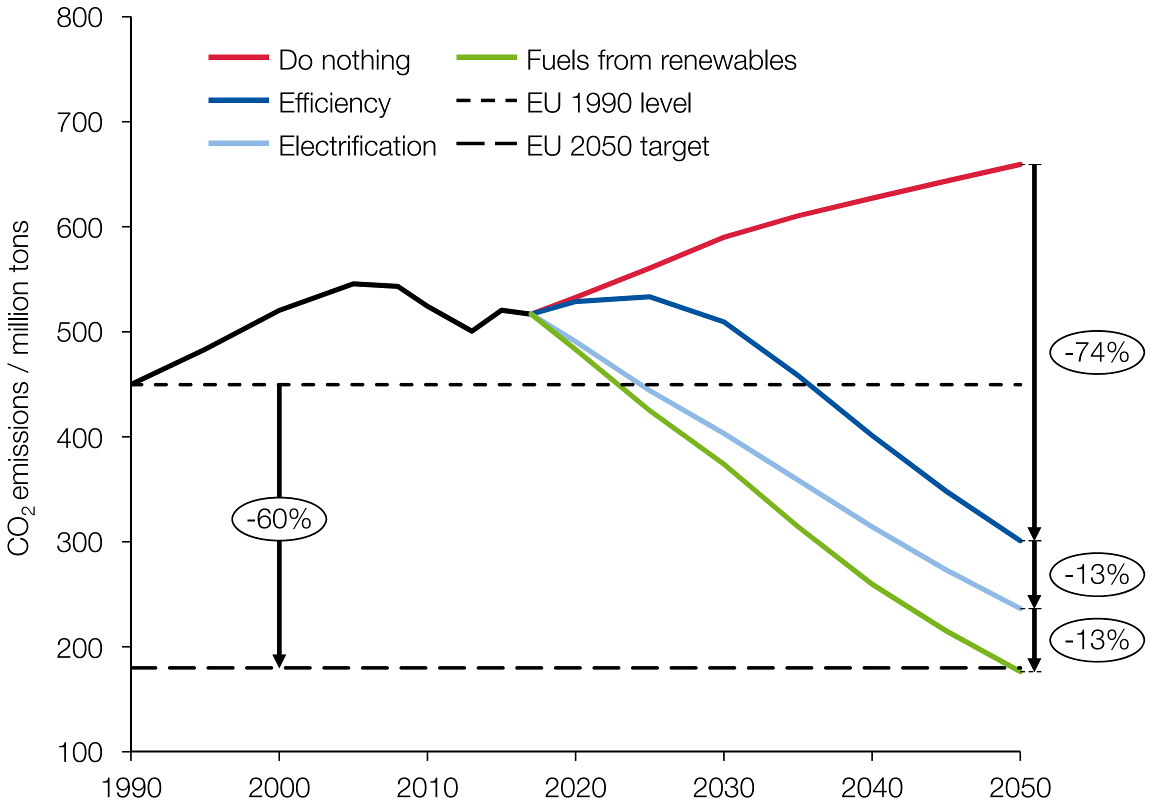


Source: European Commission, 2050 low-carbon economy, Climate Action

In Order to Achieve the Sectoral Targets, Synthetic Fuels Must Make a Significant Contribution

SCENARIO TARGET FOR 2050: 60 % CO_2 REDUCTION COMPARED TO 1990

- Electrification considers
  - HEV and PHEV
  - BEV and FCEV
- Vehicle efficiency increase
  - Vehicle and powertrain measures
  - MHEV
  - Shift to gasoline powered cars
- Fuels from renewables blended to gasoline and diesel
  - 30 vol-% of the liquid fuels in 2050



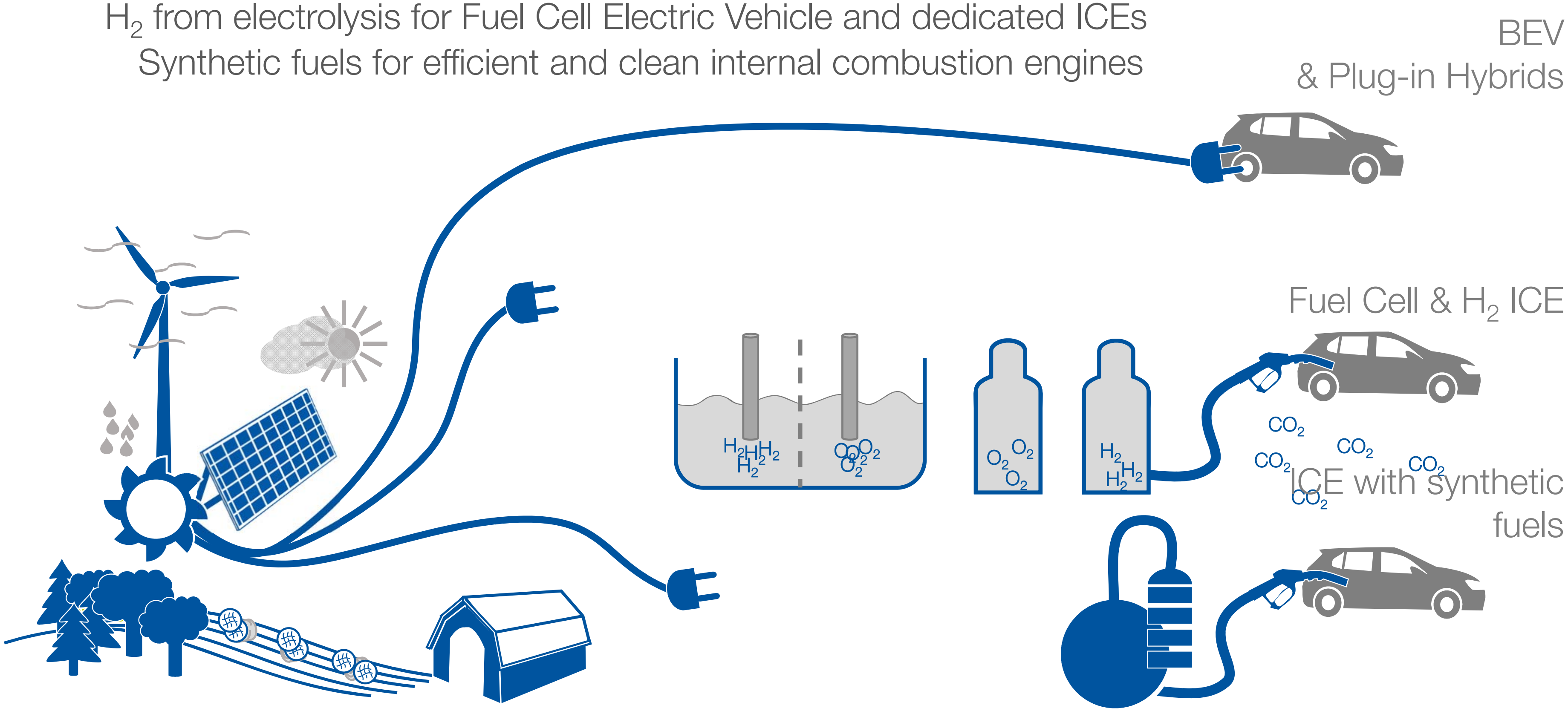
Source: Lüdiger, T.; Wittler, M.; Nase, A VDMA study: Transformation of Powertrain – the electrification and its impact on the value added of vehicle powertrains by 2030, Frankfurt, 2018

Sustainable Propulsion Systems
Based on Renewable Energy Sources

Battery Electric Vehicle (BEV) and Plug-In Hybrids

H_2 from electrolysis for Fuel Cell Electric Vehicle and dedicated ICEs

Synthetic fuels for efficient and clean internal combustion engines

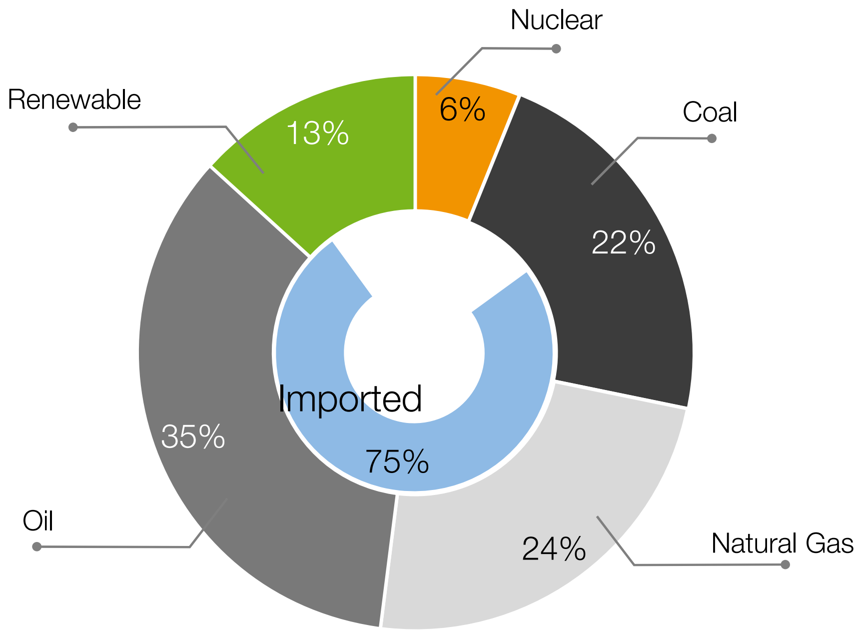


Primary Energy Supply Germany: Energy Will Continue to be Imported

90 % OF IMPORTED PRIMARY ENERGY HAS TO BE RENEWABLE

Today

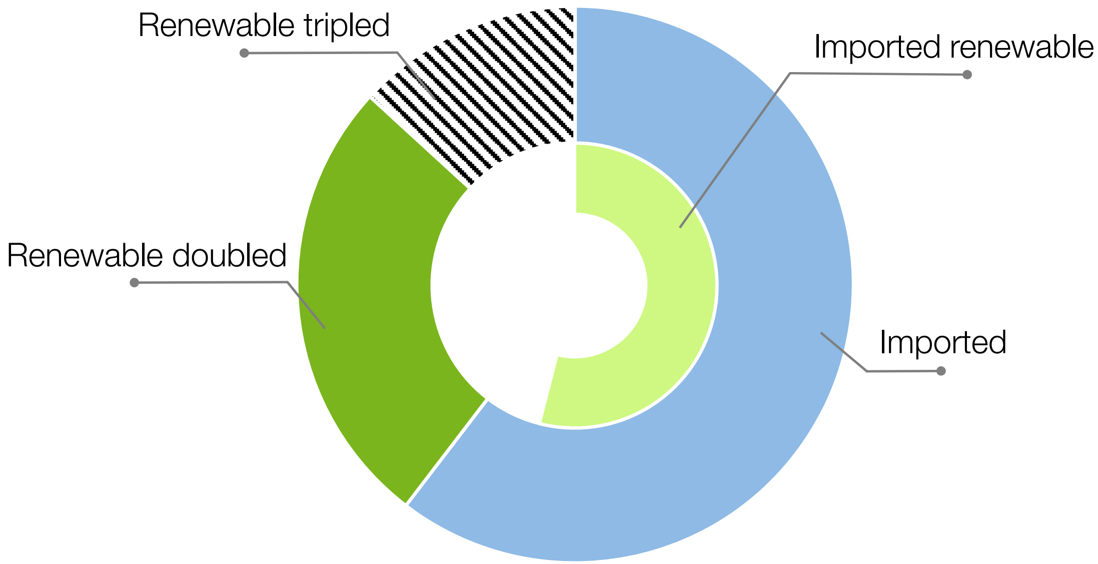
- ~13.500 PJ total energy consumption
- 75% imported



Source: BMWi 30.07.2018 Energiedaten

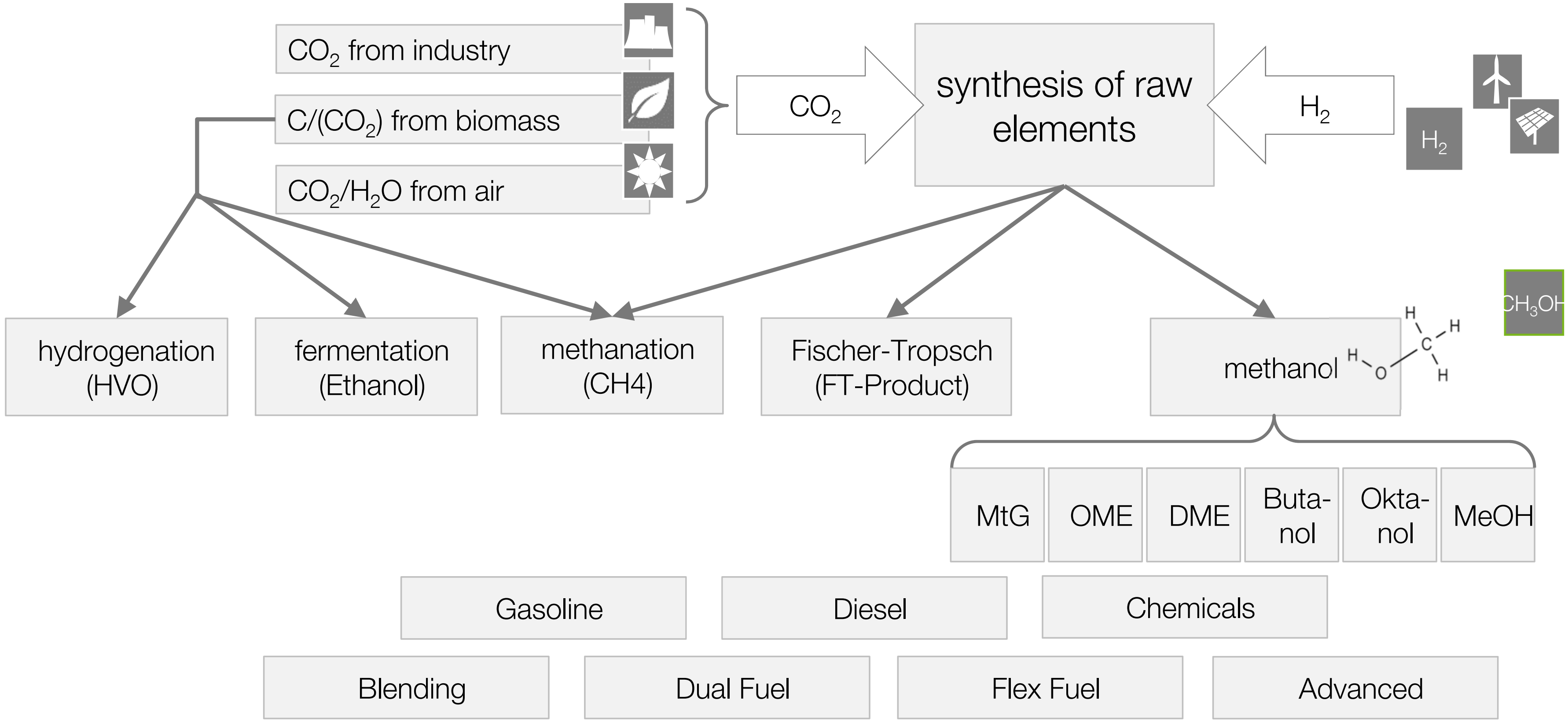
Scenario for 2050

- Target: 90% CO_2 reduction → 0 % lignite (or CCU)
- Compensated by doubling/tripling renewable in Germany
  → Expand wind and solar power, biomass etc.



Fluctuating Renewable Energie Ressources and Necessary Imports Require Chemical Storage (Power to X)

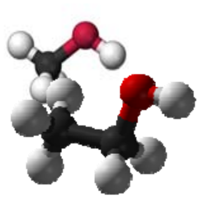
METHANOL AS BASE ELEMENT FOR MULTIPLE FUELS



High Variety of Synthetic Fuels from Renewable Resources for Gasoline and Diesel Engines

EXEMPLARY OVERVIEW OF SYNTHETIC FUELS

Short Chain Alcohols



Short chain alcohols like methanol and ethanol are highly knock resistant liquid fuels

FT-Fuel

The gasoline fraction of FT-fuel is LPG-like

Methane

Methane is a gaseous, highly knock resistant fuel

Gasoline type fuels

HVO

Hydrotreated vegetable oils (HVO) can be synthesized from vegetable and animal fats

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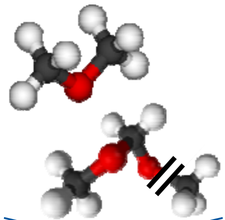
The Diesel-fraction of FT-fuel is very similar to HVO

Higher alcohols

Medium-chain length alcohols like 1-Octanol, can be blended in high amounts to FT-fuel and fossil Diesel

DME/OME



DME is a gaseous diesel type fuel, OME are liquid diesel type fuels with very high oxygen content

Diesel type fuels

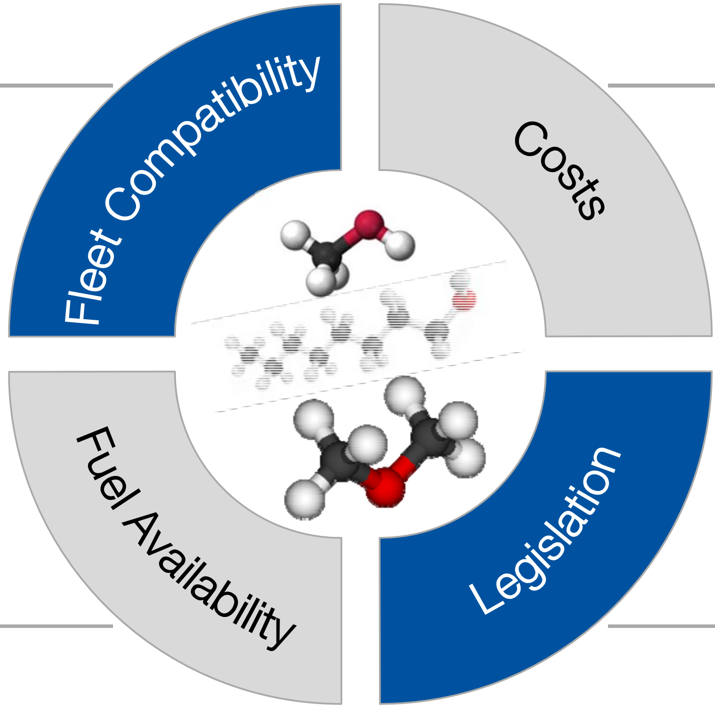
Low required hardware changes High

The Biggest Challenges to Achieve a High Share of Renewable Fuels on the Market are Fleet Compatibility, Costs, Fuel Availability and Legislation

PARTICULARLY IN SHORT TO MEDIUM TERM PERSPECTIVE

Solution for usability in most vehicles to achieve well-to-wheel CO_2 reduction quickly

Decreasing production costs to become an attractive option for CO_2 reduction



Scale-up of well known production processes for renewable fuels

Adaption of fuel norm and consideration of CO_2 incentive for industry and / or consumer

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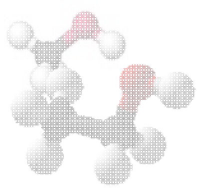

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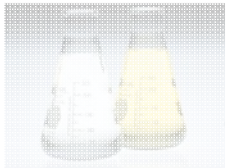

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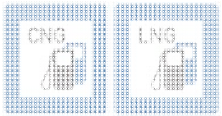

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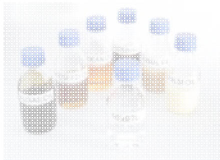

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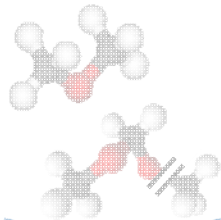

DME is a gaseous diesel type fuel, OME are liquid diesel type fuels with very high oxygen content

Gasoline type fuels | Diesel type fuels

Low — required hardware changes — High

Introducing Synthetic Diesel Fuel Could Lower the Well-to-Wheel CO_2 Emissions Drastically on Current Vehicle Fleet

	Unit	EN590 Diesel	80% Diesel 20% 1-Octanol	50% Diesel 50% 1-Octanol*	1-Octanol	EN590 Limits
Boiling Range	°C	180-350	180-350	180-350	195	
Amount Evaporated 250°C	% v/v	19.1	39.9	60.1	~100	< 65
Amount Evaporated 350°C	% v/v	94.7	95.8	97.35	~100	> 85
Calorific Value	MJ/kg	42.9	41.8	40.5	38.2	
Density (15°C)	kg/m^3	834	835	836	837	820 - 845
CN / DCN*	-	52.3	49.1	42.6	33.8	> 51
Oxygen Content	% m/m	0.14	2.9	6.22	12.3	
Vapor Pressure	mbar	<1	<1	<1		
Kinematic Viscosity	mm^2/s	3	3.6	4.5	5.7	2 – 4.5
Enthalpy of Vaporization	kJ/kg	358	412	460	562	
Flame Point	°C	78	79	80	81	> 55

* interpolated (mass/volume or molar quantities)

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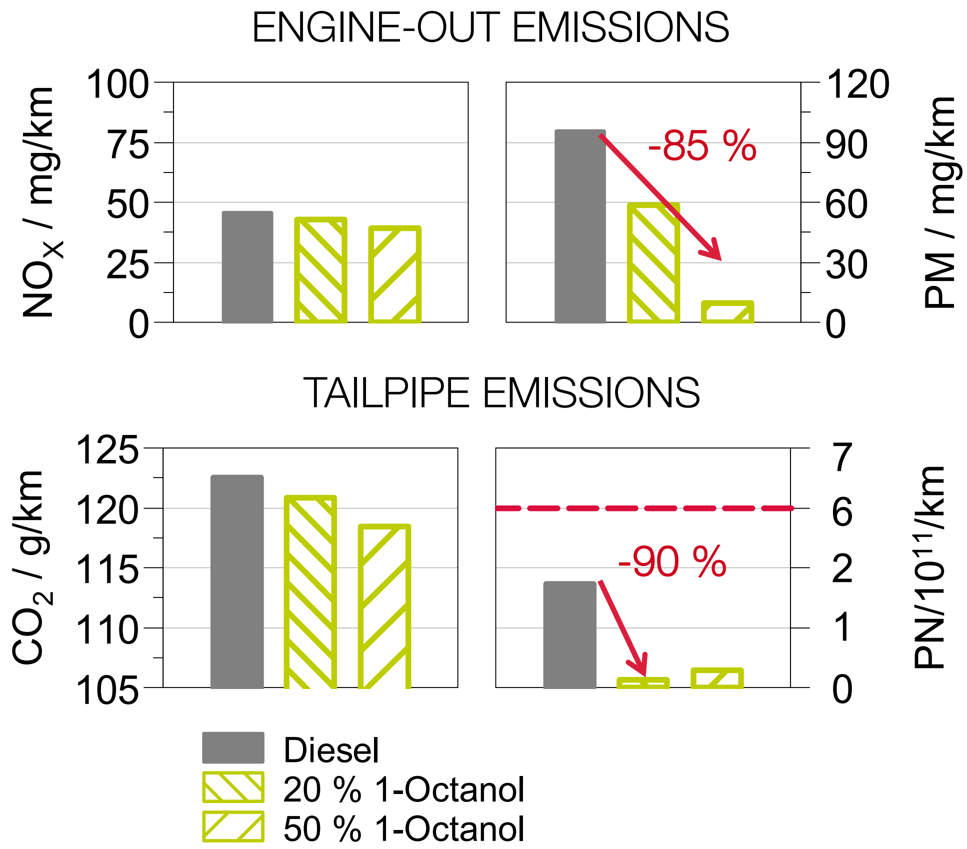
Additional to the CO_2 Reduction Pollutant Emissions are Reduced Significantly

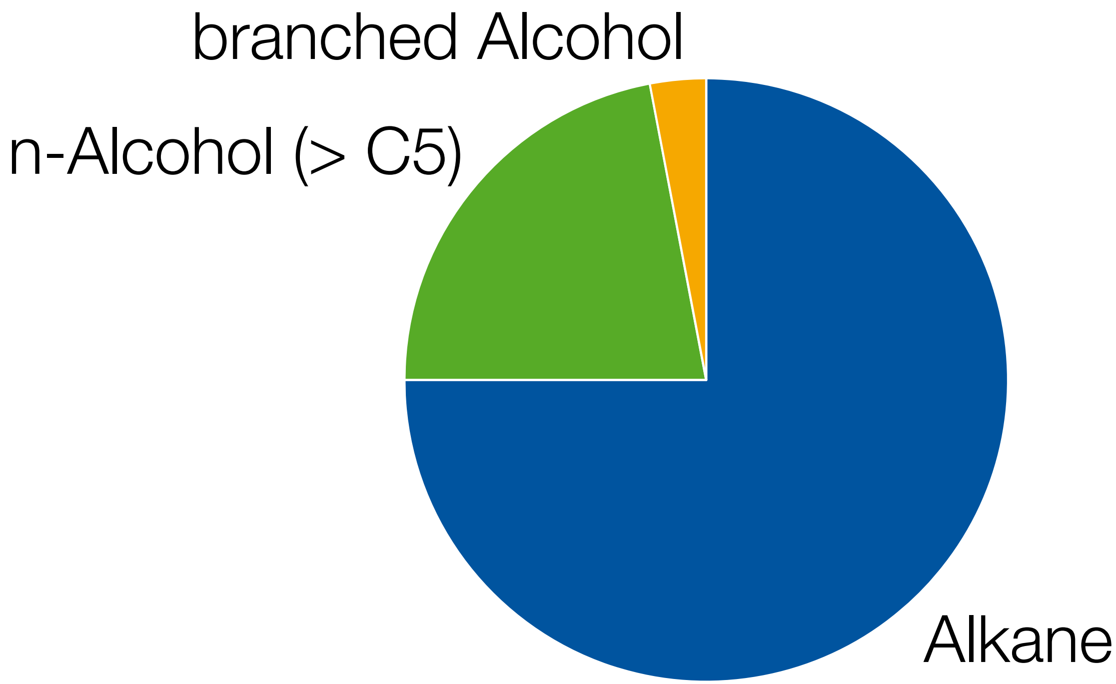
UP TO 90 % REDUCTION OF PARTICULATE EMISSIONS



- 4-cylinder Diesel engine (OM651)
- 2143 cm³ Displacement
- EURO VI Legislation
- DOC and DPF Exhaust after treatment
- High- and low pressure EGR
- NEDC

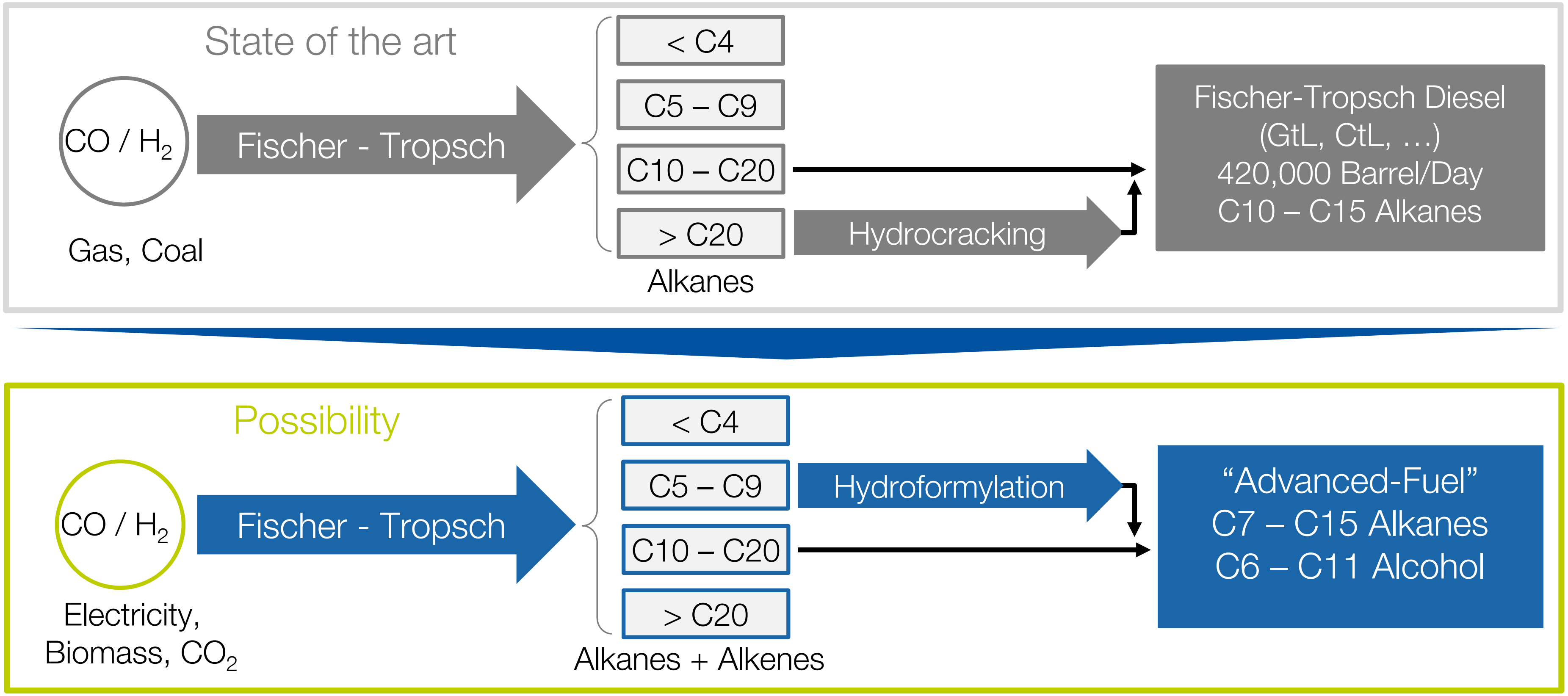
Conclusion from This Results: Alkane-Alcohol Blends Show High Emission Reduction Potential with Very Good Drop-In Capability

FULL CO_2 REDUCTION POTENTIAL IF FOSSIL DIESEL IS SUBSTITUTED ENTIRELY



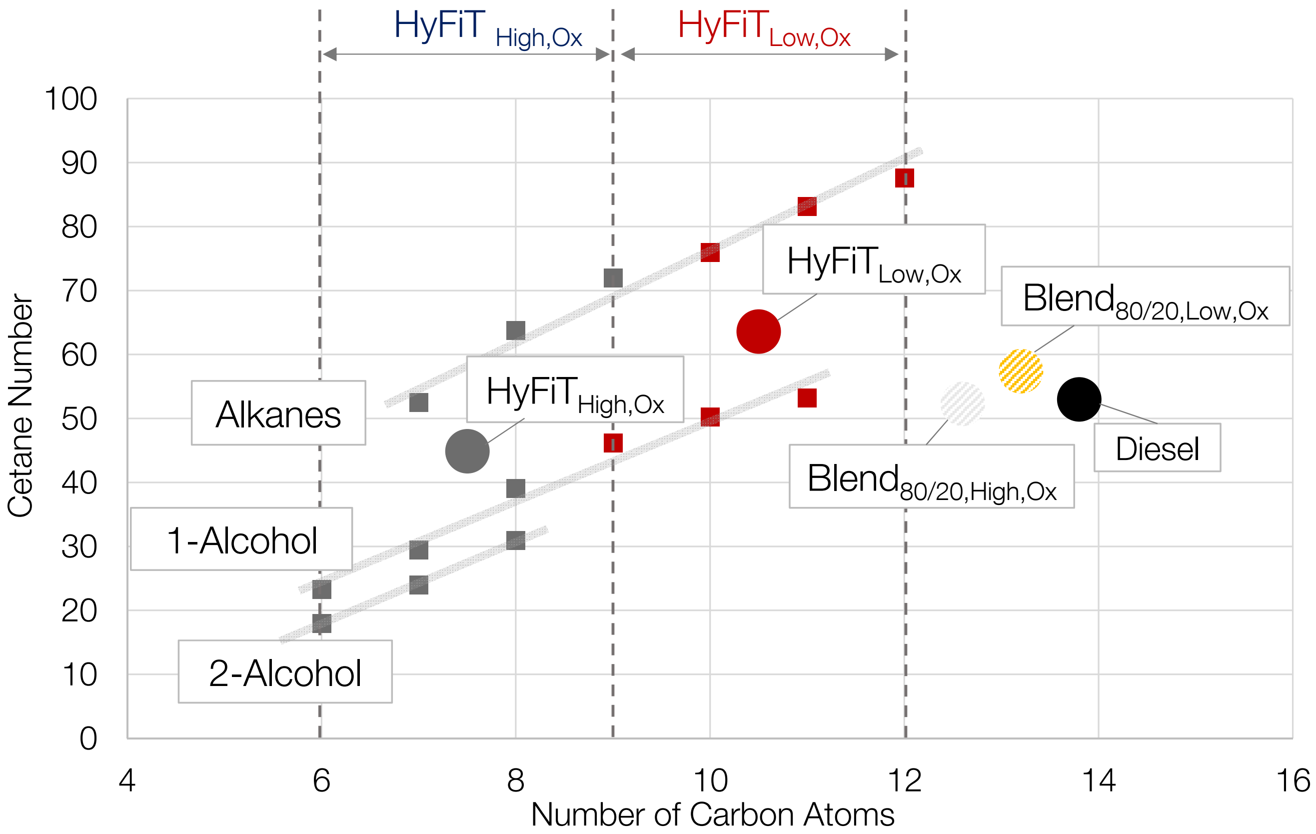
Fischer Tropsch Synthesis Coupled with Hydroformylation is a Technically Controllable and Scalable Process

COMBINING WELL KNOWN PROCESSES



Fischer Tropsch Synthesis in Combination with Hydroformylation Allows a High Variability in Fuel Compositions

"HyFiT"- FUELS FOR ENGINE TESTING



HyFiT $_{High,Ox}$

- Alcohol share = 40% m/m
- Alkane share = 60% m/m

→ max. alcohol share

- Oxygen share = 6% m/m

Blend $_{High,Ox}$

- Oxygen share = 1.3% m/m

HyFiT $_{Low,Ox}$

- Alkane share = 90% m/m

→ max. alkane share

- Oxygen share = 1.1% m/m

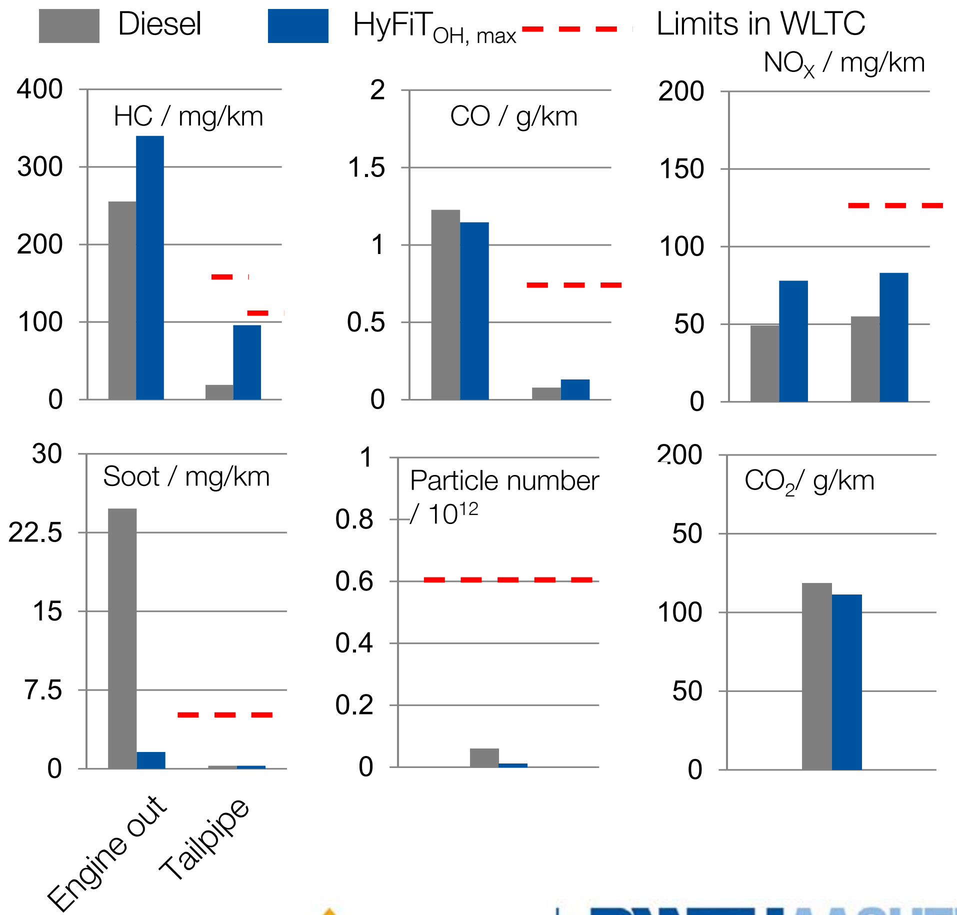
Blend $_{Low,Ox}$

- Oxygen share = 0.7% m/m

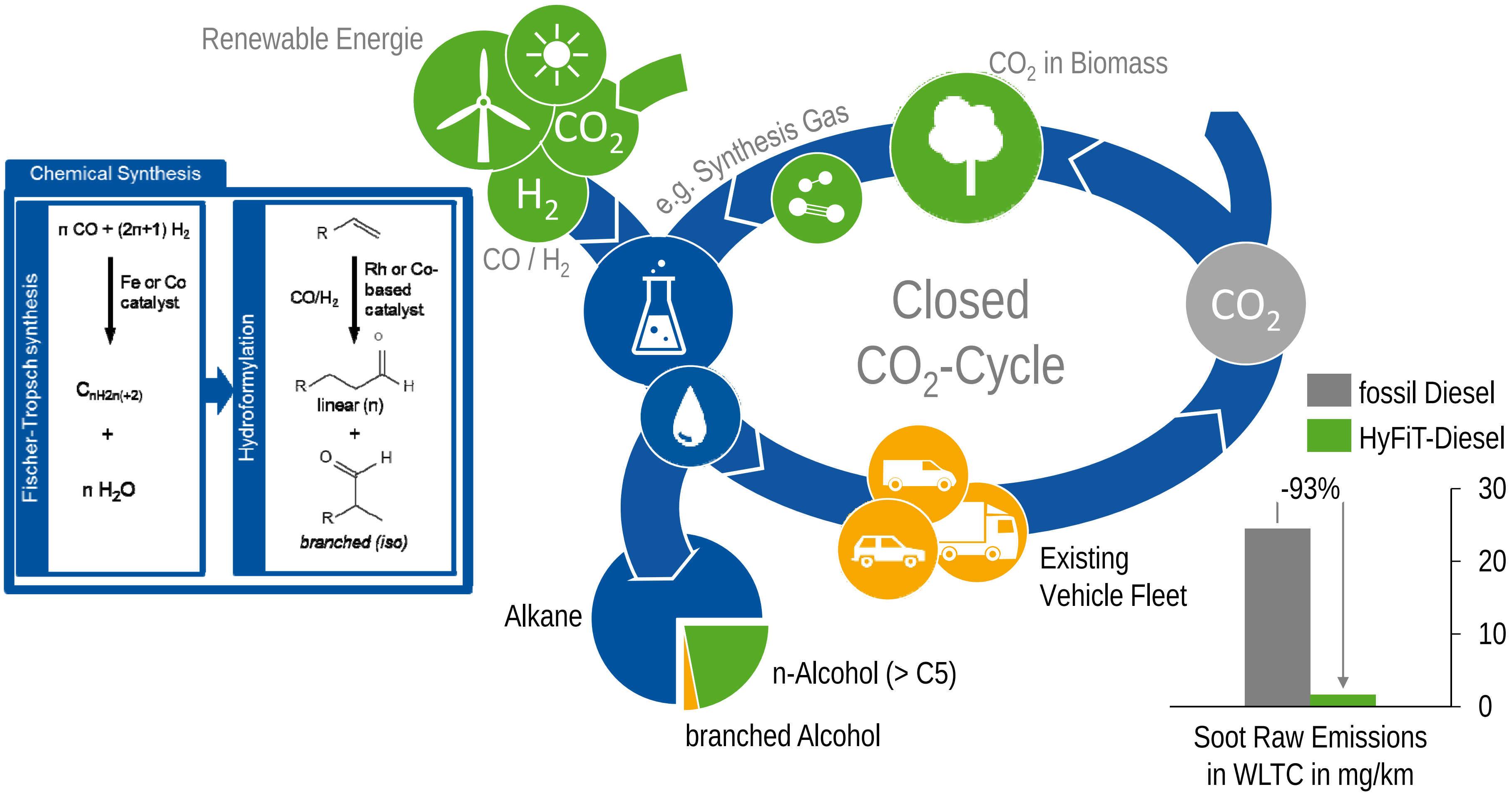
Vehicle Tests Confirm
the High Emission Reduction Potential of the New “HyFiT”-Fuels

FURTHER POTENTIAL BY OPTIMIZED ENGINE CALIBRATION

- 4-cylinder Diesel engine (OM651)
- 2143 cm³ Displacement
- EURO VI Legislation (NEDC Calibration)
- DOC and DPF Exhaust after treatment
- High- and low pressure EGR
- **WLTC**



HyFiT Fuels:
High Emission Reduction Potential, Closed Carbon Cycle and Drop-In Capability



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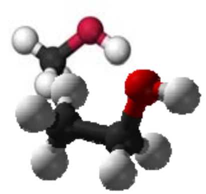

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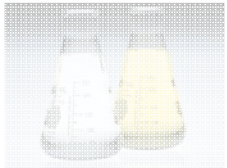

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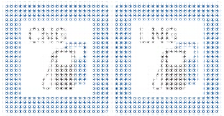

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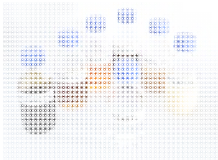

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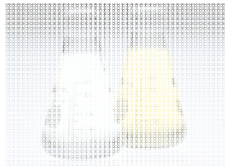

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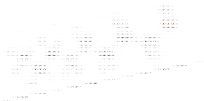

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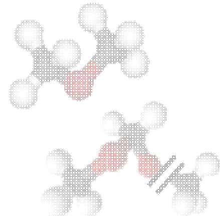

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Gasoline type fuels

Diesel type fuels

Low required hardware changes High

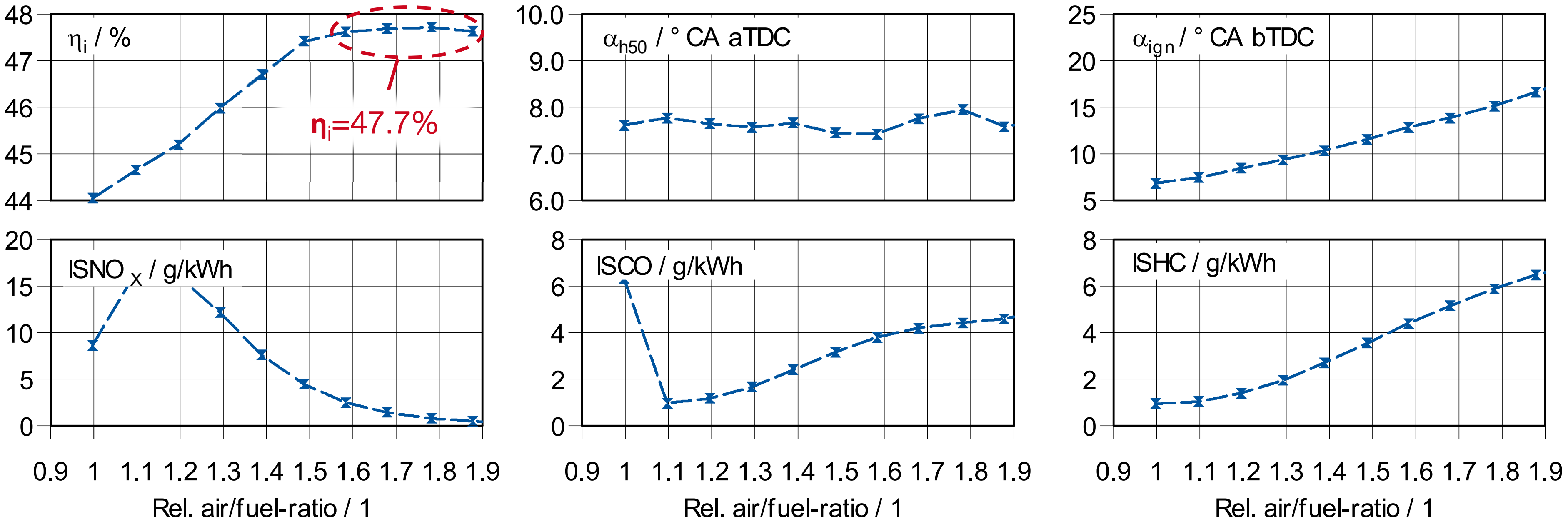
High Efficiency Improvement Using Methanol in a Lean Burn Gasoline Engine

Current Status: Maximum Indicated Efficiency of 47.7% with Methanol

VARIATION OF REL. AIR/FUEL-RATIO USING METHANOL

n = 2000 min $^{-1}$; IMEP = 18 bar
CR = 14.7; S/B = 1.2; p_{rail} = 200 bar; SOI = 320° CA bTDC
Methanol

- $BSFC_{optimum}$ for Methanol at 2000 min^{-1} and 18 bar IMEP
- Maximum indicated efficiency achieved at λ = 1.78



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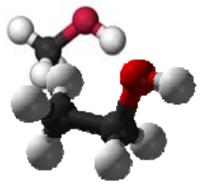

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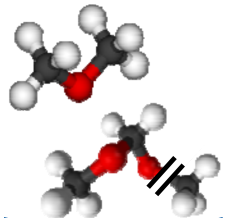

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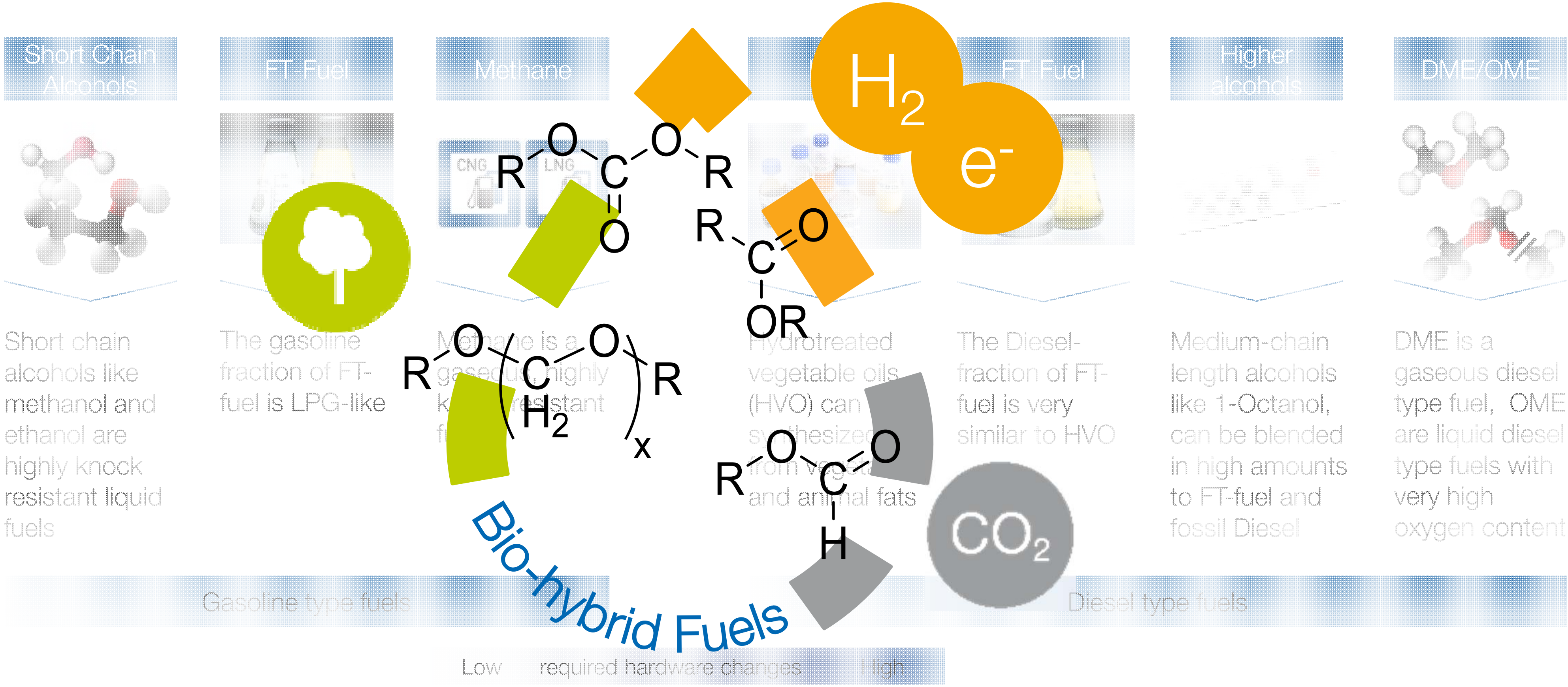
Gasoline type fuels | Diesel type fuels

Low — required hardware changes — High

Long Term Solutions:
Bio-hybrid Fuels as Integration of Biomass, CO_2 and H_2 / e^-

FUNDAMENTAL RESEARCH ON NEW RENEWABLE FUELS



The “Fuel Design Process” as an Integrated Approach between Propulsion and Production Technology

DEVELOPED AND ESTABLISHED IN EXC “TAILOR-MADE FUELS FROM BIOMASS”

The Fuel Design Process

Propulsion

Combustion and emissions
- Mixture formation
- Ignition behavior
- Emission formation
- Lubrication
- …

Thermo-physical properties
- Density
- Viscosity
- Surface tension
- Vapor pressure
- …

Sustainability analysis
- Energy balance
- (Eco-)Toxicity
- Economics
- Societal needs and acceptance
- …

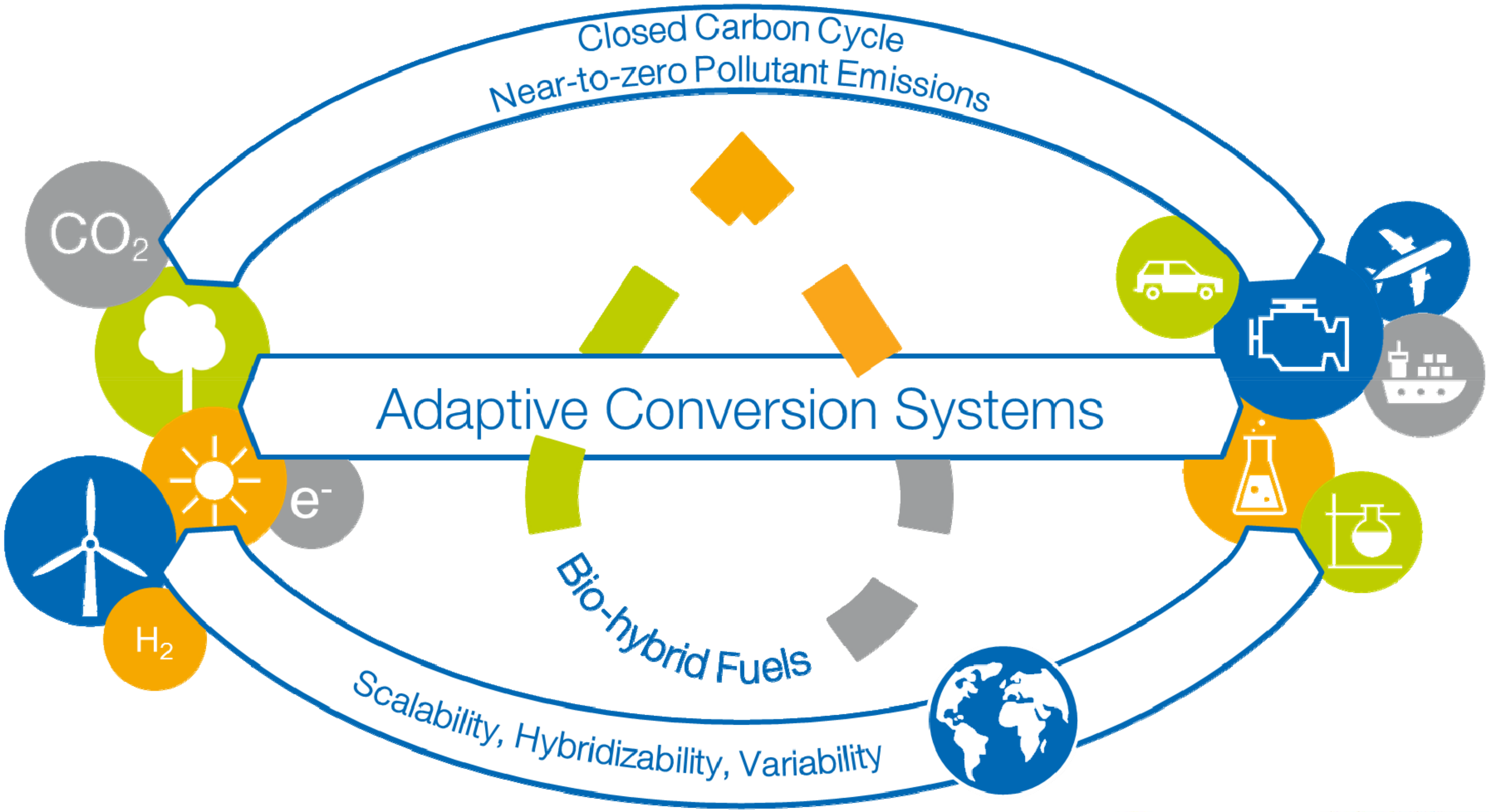
Production

Molecular structures
- Combustion mechanism
- C/H/O content
- Functional groups
- Detailed connectivity
- …

Synthetic processes Pathway design
- (Bio-)catalysis
- Reaction engineering
- Systems process engineering
- …

W. Leitner, J. Klankermayer, S. Pischinger, H. Pitsch, K. Kohse-Höinghaus, Angew. Chem. Int. Ed. 56 (2017) 5412–5452.

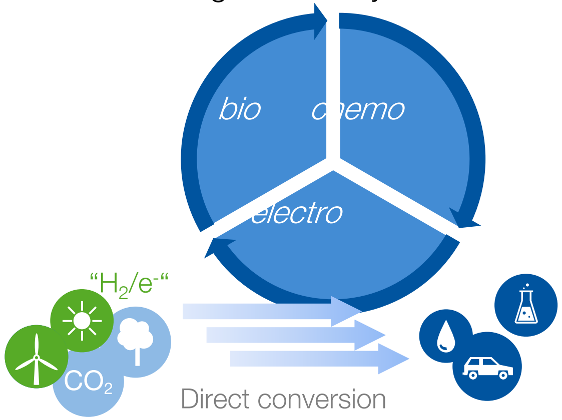
Vision of The New Cluster of Excellence "The Fuel Science Center" - FSC



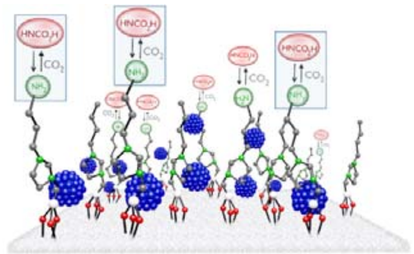
Fuel Production: Adaptive Refinery Concepts

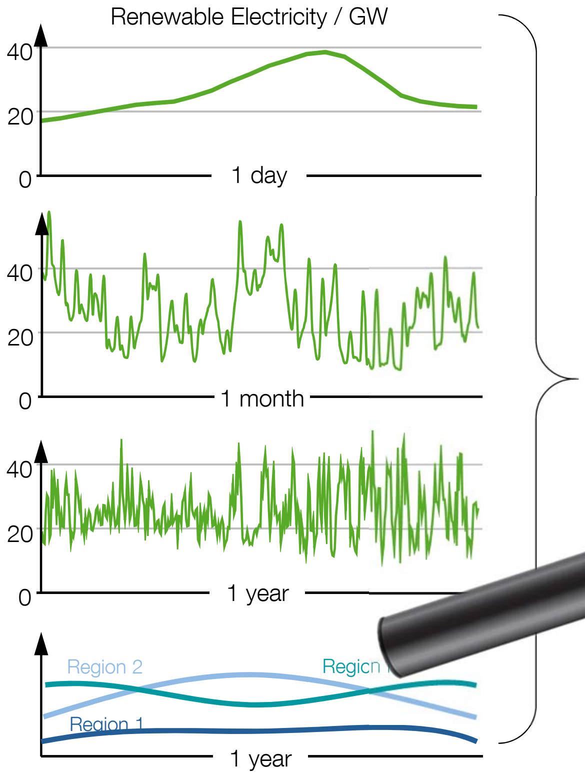
FUNDAMENTAL RESEARCH

Integrated catalysis

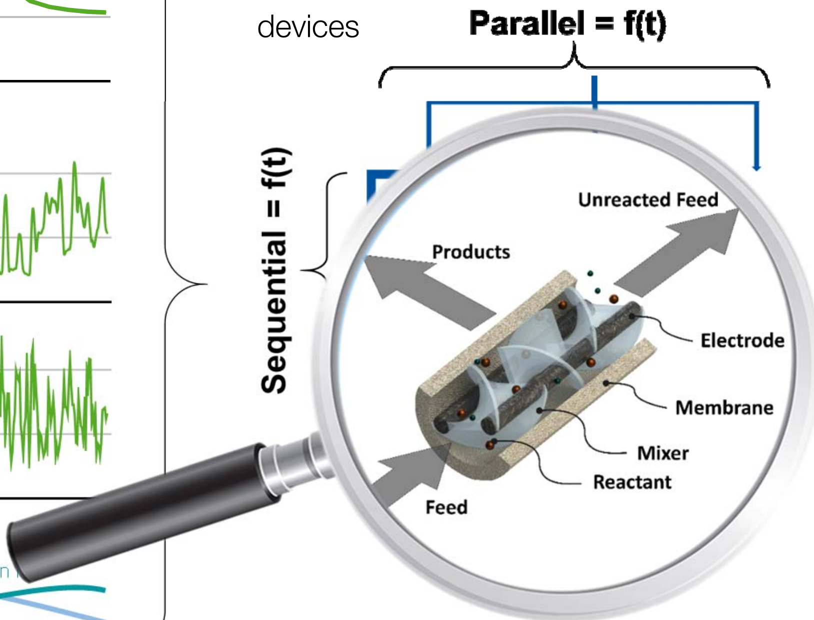


Switchable catalyst systems





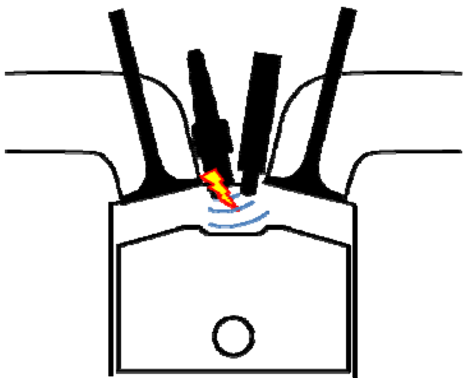
Modular devices

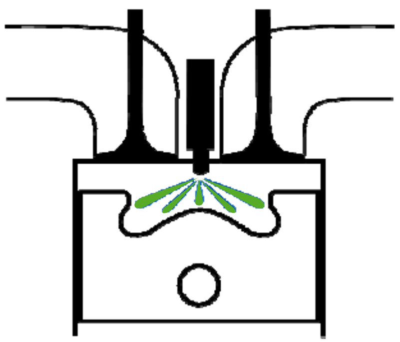


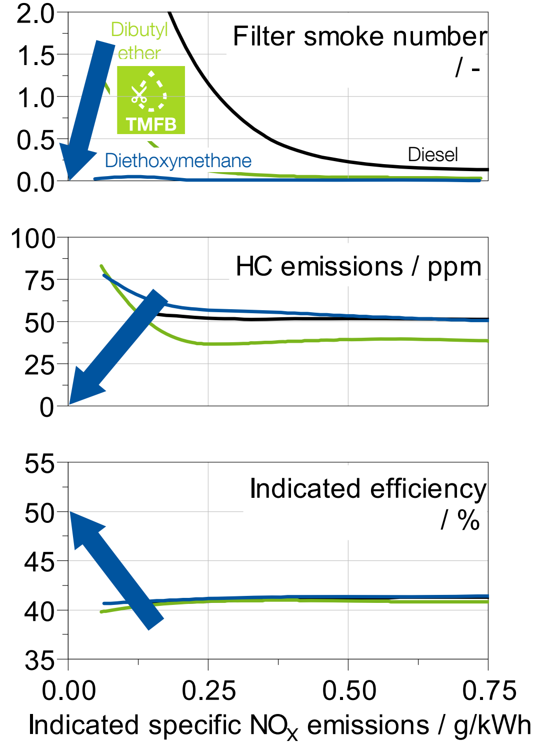
Integrated electrochemical reaction and separation

Propulsion System:
Highest Efficiency and Near-to-zero Pollutant Emissions

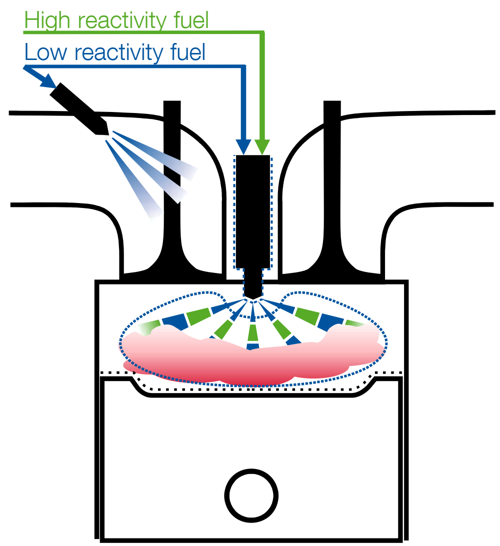
FUNDAMENTAL RESEARCH







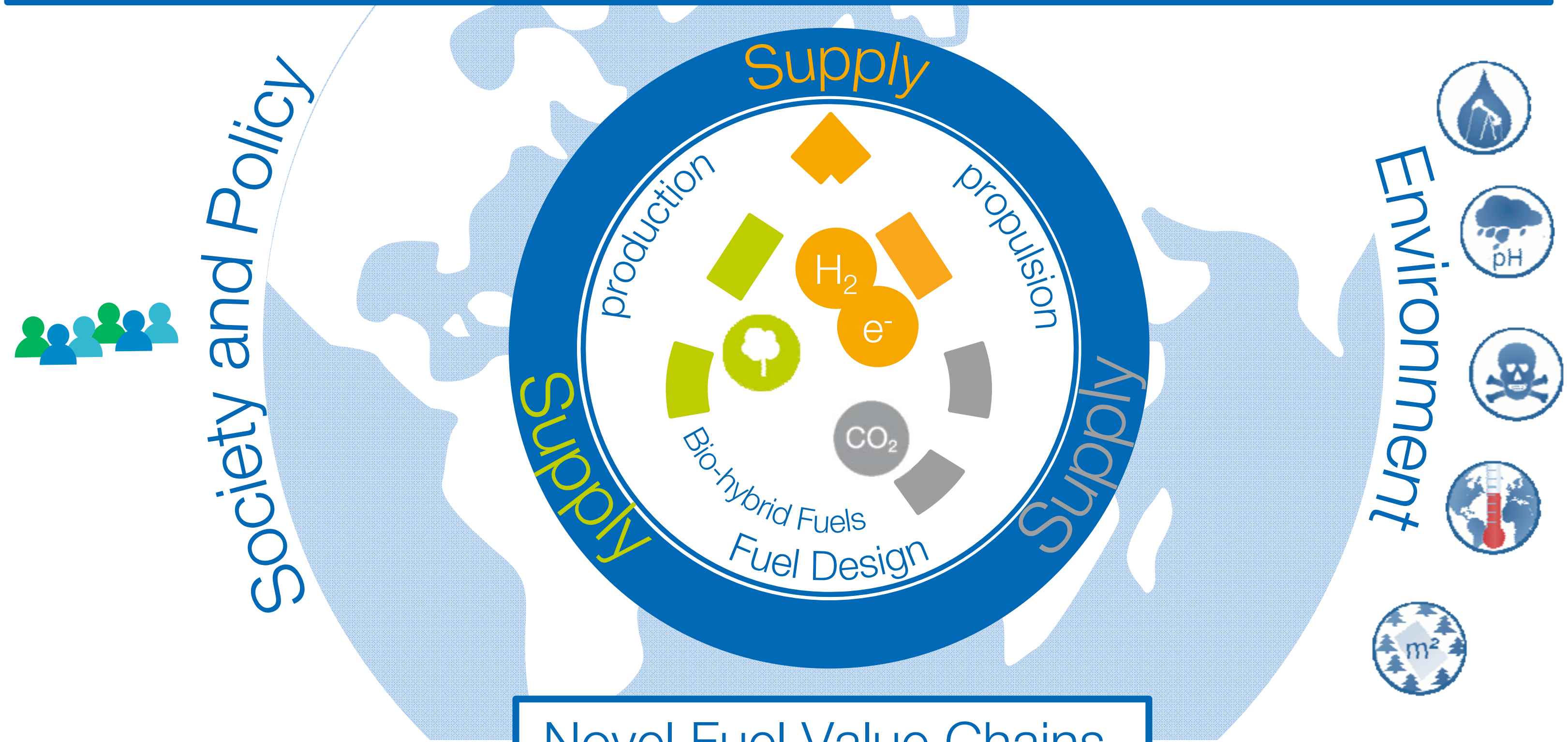
Adaptive
Molecularly Controlled Combustion
System



Fuel Design and
Sustainable Cross-sectorial Value Chains

FUNDAMENTAL RESEARCH

Integrated Design Method for Sustainable Fuel-Based Mobility



Novel Fuel Value Chains

Alternative Fuels Based on Renewable Energy Are Essential to Achieve Sectoral GHG Reduction Targets and Minimum Pollutant Emissions

CONCLUSIONS

Short to Medium Term Perspective

- Fleet compatibility, costs, fuel availability and legislation are biggest challenges
- Energy import has to be taken into account → sector coupling has to be part of the solution
- Based on a few raw products multiple fuel options are possible
- Combination of well-known fuel production pathways can already lead to significant improvement

Long Term Perspective

- Fuel design helps to further improve efficiency and reduce pollutant emissions
- Adaptive synthesis processes and combustion systems can cope with fluctuating renewable feedstocks
- Bio-hybrid fuels combine advantages of bio-fuels and e-fuels

Thank you for your attention!

Bastian Lehrheuer
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