Prepared for

International Methanol Vehicle and Fuel Applications Conference and Exposition
国际甲醇车辆和燃料应用会议和博览会

C3 MOBILITY C3行动

CO_2 NEUTRAL FUELS FOR FUTURE TRANSPORTATION 未来交通的CO_2中性燃料

Chongqing, China, 11.10.2019 重庆，中国，11.10.2019

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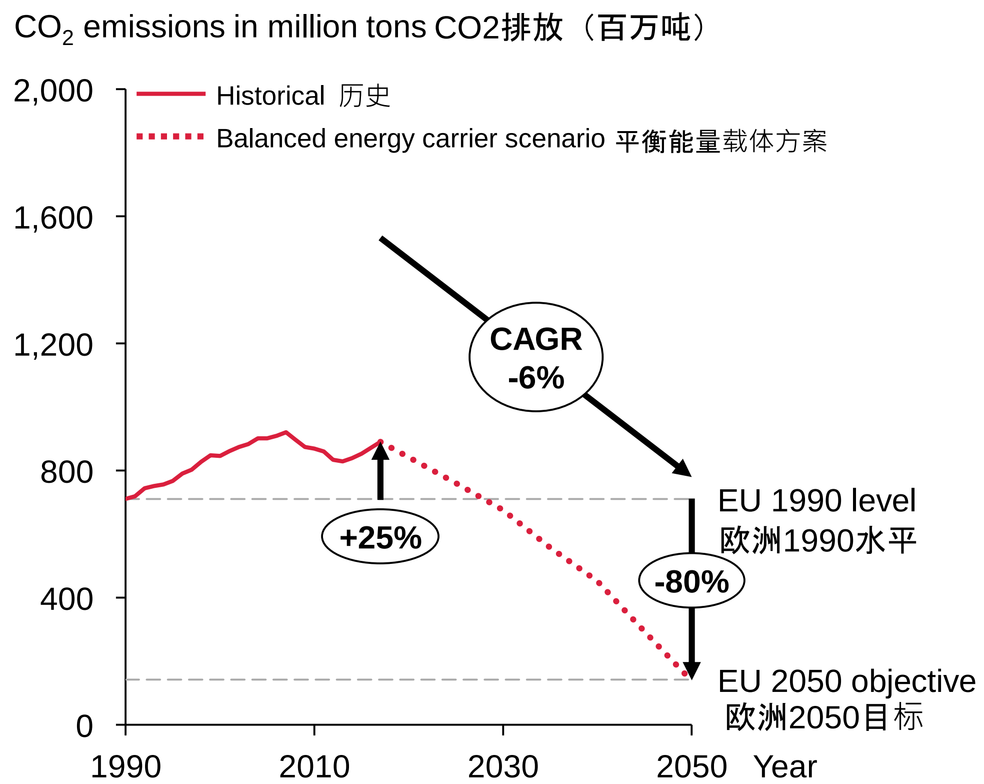
Agenda目录

- Introduction and motivation for e-fuels合成燃料介绍和动机
- What e-fuel to choose?合成燃料选择什么？
- C^3-Mobility C^3行动
- Summary and conclusion总结和结论

To meet the 2050 CO_2 targets, emissions have to be cut each year by 6% – starting today
为满足2050 CO2目标，排放必须每年降低6%-从今天起

HISTORICAL AND MODELED CO_2 EMISSIONS OF ROAD TRANSPORT IN EUROPE

欧洲道路交通历史和模型CO2排放



Source: FEV

- The scenario is designed to fulfill the EU objective of 80% greenhouse gas emission reduction by 2050 compared to 1990 by on-road transport;为满足欧洲道路交通2050年温室气体排放相对于1990年水平减少80%目标设计方案
  - CO_2 emissions are considered since these account for 99% of the greenhouse gas emissions; CO2排放被考虑，是因为其占据温室气体排放99%份额
- Balanced energy carrier scenario平衡能量载体方案
  - Battery and fuel cell electric vehicles, hybrid and electrified powertrains;电池和燃料电池车辆，混动和电气化动力
  - Significant usage of fuels from renewables blended with fossil fuels in all vehicle classes;电池和燃料电池车辆，混动和电气化动力

Within the commercial vehicle category light commercial vehicles account for the majority of sales in major markets
在商用车范畴内轻型商用车为重要市场主要销售对象

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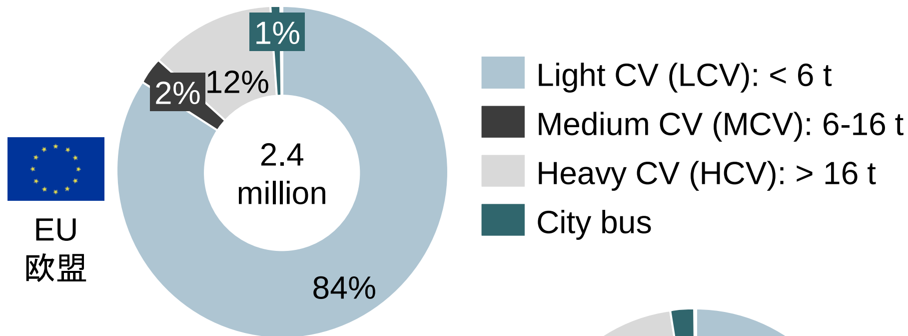
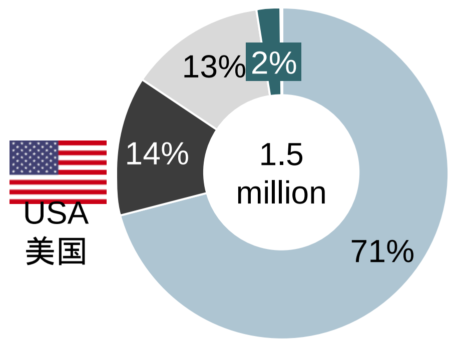
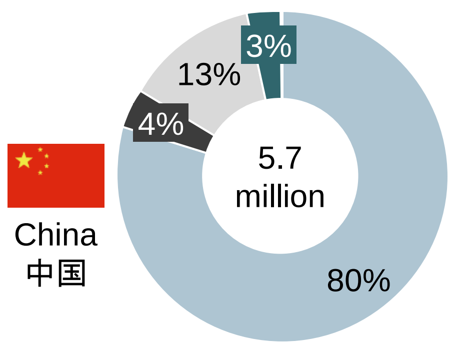
2016 commercial vehicle (CV) sales

2016年商用车（CV）销售







**LCV= Light commercial vehicle轻型商用车
MCV= Medium commercial vehicle中型商用车
HCV= Heavy commercial vehicle重型商用车
City Bus:城市公交

Source: IHS, FEV, fotolia

Key use-cases by CV segment

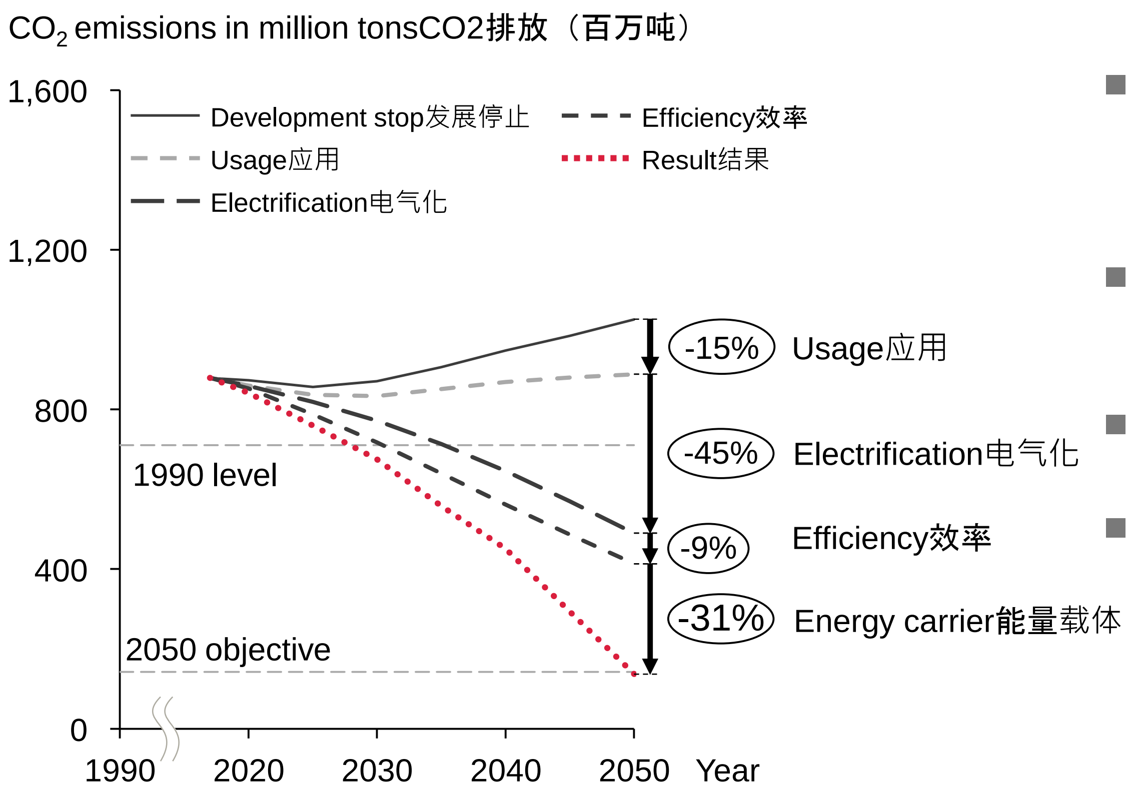
主要商用车类别应用案例

Segment 类别	Typical drive cycle(s) 典型驾驶循环	Vehicle examples 典型车辆
LCV	(Mainly) urban operation （主要）城市工况	
MCV	Urban delivery 城市货运	
MCV	Regional delivery 区域货运	
HCV	Highway operation 高速工况	
HCV	Urban operation 城市工况 (e.g. refuse trucks 垃圾车)	
CITY BUS	Urban 城市	

Electrification and energy carriers from renewables are both required to achieve the reduction goals
电气化和可再生能源能量载体共同进行才能达到降低目标

CO_2 EMISSION REDUCTION PATHWAY FOR ROAD TRANSPORT IN EUROPE

欧洲道路交通CO2排放降低路线



- Development stop considers the increase in person and freight transport；减少停止考虑人均和货运增加
- Usage considers the modal split between road, rail, water and air as well as the utilization of on-road vehicles；应用考虑模式分类，道路，轨道，水运，空运和道路车辆应用
- Electrification includes hybrids, battery and fuel cell electric vehicles电气化包括混动，电池和燃料电池车辆
- Efficiency includes optimizations of vehicles and powertrains；效率包括优化车辆和总成
- Energy carriers consider the mix and source of energy carriers；能量载体包括混合和能量载体来源
  - Energy carriers from renewables have lower CO_2 emissions than such from fossils in this balance相对于化石燃料，可再生能量载体具有低CO2排放

The tank-to-wheel plus carbon sink balance considers the CO_2 emissions created when conversing the energy carrier to kinetic energy and a subtract of carbon sinks that are realized during the production of the energy carrier.

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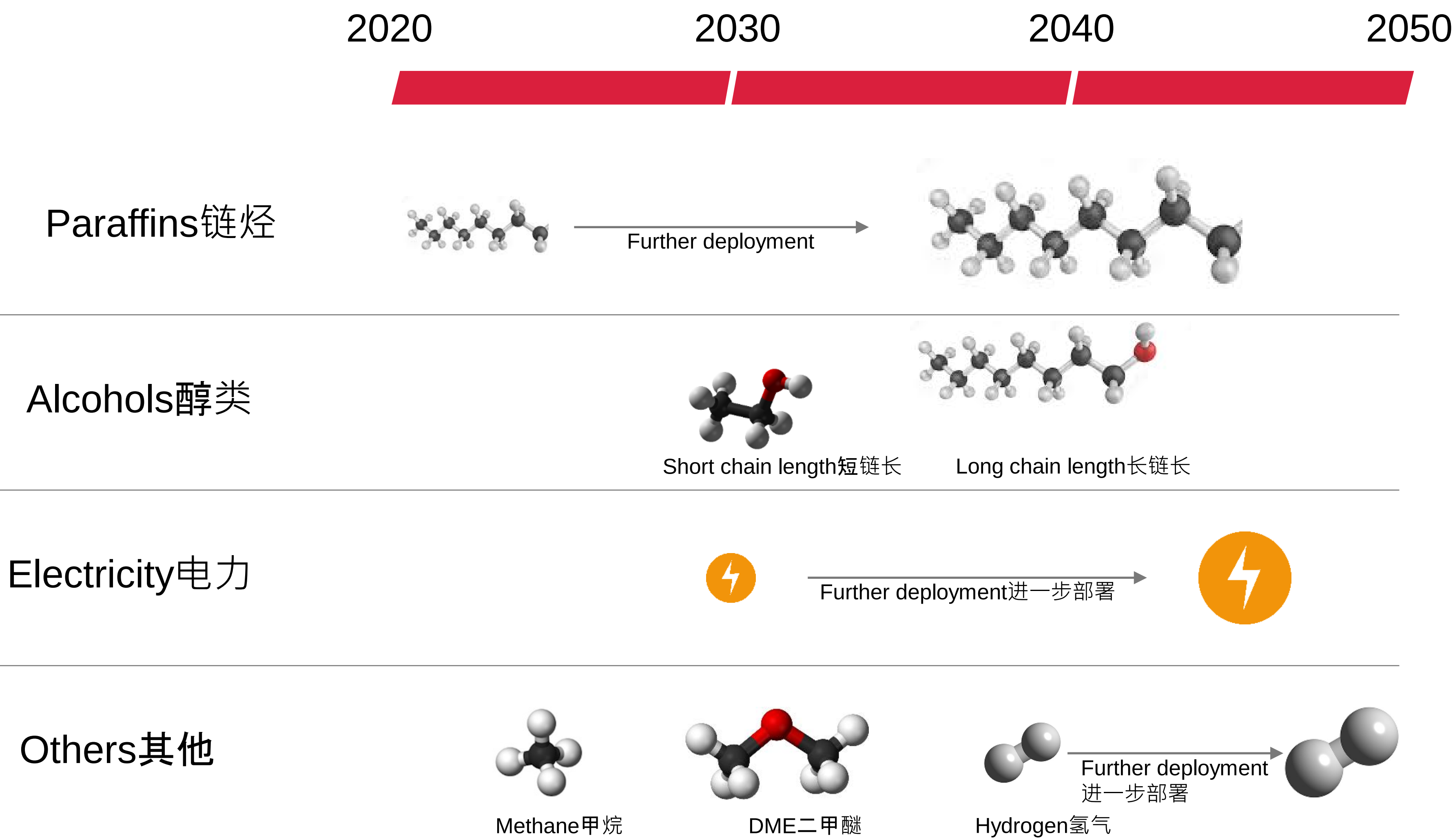
In adaptation of energy carriers we consider many different options
适应能量载体，我们考虑多种不同选项

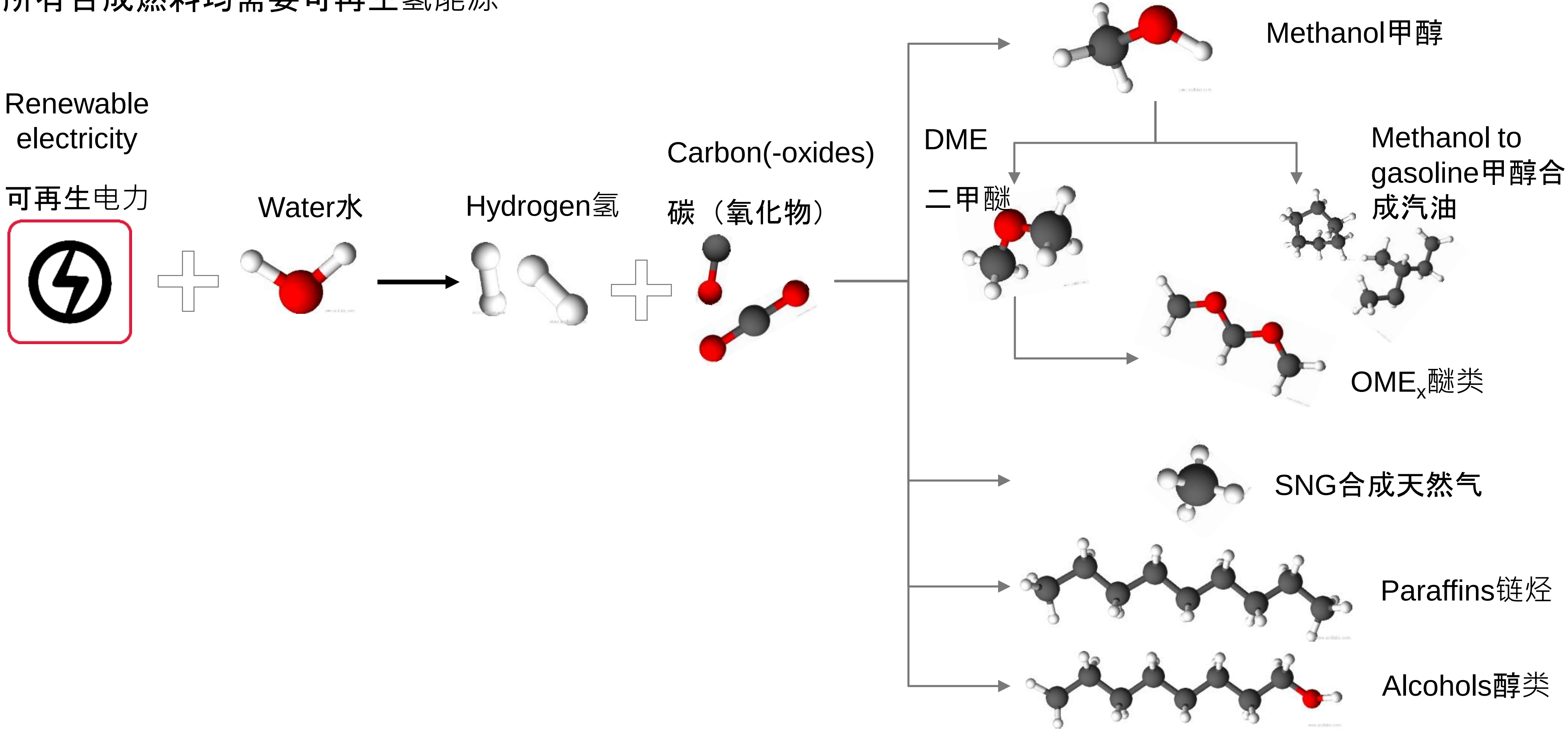


Source: FEV

Electricity based chemical energy carriers show a huge variety
基于电力的化学能量载体呈现巨大多样性

RENEWABLE HYDROGEN IS REQUIRED FOR ALL E-FUELS

所有合成燃料均需要可再生氢能源



Methanol is an already established platform molecule for the chemical industry/ fuel production and an excellent fuel!
甲醇是为化学产业/燃料产品已完善的平台分子和优秀燃料

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METHANOL IS A PROBABLE SOLUTION TO IMPORT RENEWABLE ENERGY TO GERMANY/EUROPE

甲醇是德国/欧洲切入可再生能源的可能解决方案

MeOH is used as fuel already甲醇已作为燃料应用

- First series production M100 truck, claiming 18% costs savings/year第一系列M100卡车产品，宣称年经济性提升18%
- Methanol is used from M5 to M100甲醇应用比例范围从M5到M100
- Applications range from PC to HD应用车型范围从乘用车到重型车

MeOH is promising alternative for SI and commercial engines甲醇是有前景的点火式和商用发动机替代燃料

- Methanol is cheap to produce甲醇生产价格低廉
- Established product and building-block (chemical industry)已建立的产品和产品基础（化学工业）
- Handling and infrastructure is considered to be more complex处理和基础设施比较复杂
- Available applications very limited处理和基础设施比较复杂 (EN228 limits MeOH to 3% v/v, but push from Asia)

	Fuel costs 燃料费用	Availability 实用性	Technology Readiness Level 技术就绪水平	Fuel distribution 燃料分布	Compatibility with existing vehicles现有车辆兼容性
Methanol 甲醇	+/o	o	+/o	o	o/–

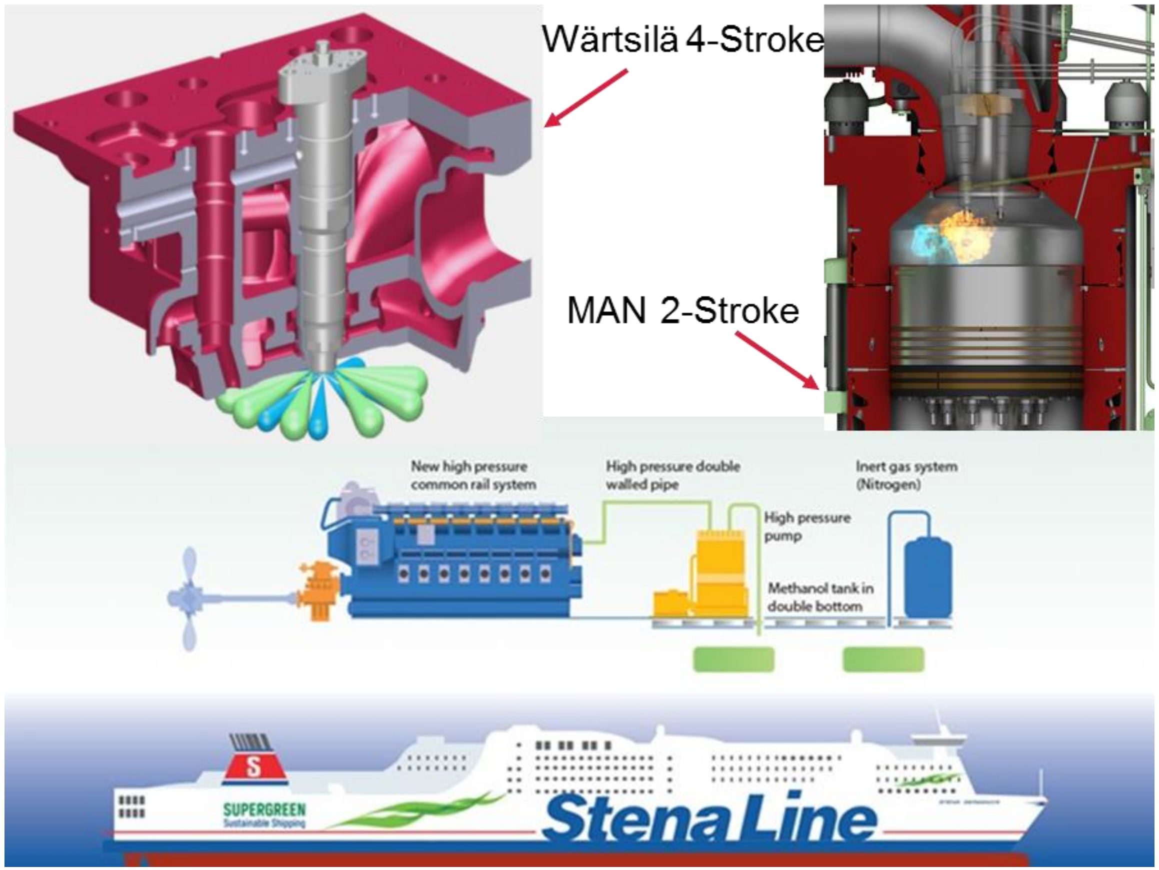
- **Methanol utilization in transport will significantly rise在交通中甲醇应用会极大提升**

Source: bigwheels.my

Diffusive Methanol Combustion II/II甲醇扩散燃烧II/II
Pilot Fuel Assisted Diffusive Methanol Combustion预喷燃料辅助甲醇扩散燃烧

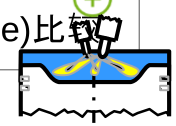
PILOT FUEL ASSISTED DIFFUSIVE COMBUSTION IS BENEFICIAL REGARDING PM AND NOX

预喷燃料辅助扩散燃烧得益于PM和NOX降低



Description介绍

- Methanol combusted according to diesel process with pilot diesel injection按照柴油预喷的柴油过程的甲醇燃烧
- Tests performed by Wärtsilä and MAN Wärtsilä and MAN进行测试：
  - NO_x 3-5 g/kWh (Low Tier II) (+)
  - CO (< 1 g/kWh), THC (< 1 g/kWh) (o)
  - PM only from MGO pilot (FSN ~ 0,1) (+)
  - SO_x only from MGO pilot (99% reduction) (+)
  - Formaldehyde emissions甲醛排放 (~ TA-luft) (+)
  - Same output and load response compared to diesel, full fuel redundancy比较于柴油，相同输出和负荷反应 (+)
  - Same or better efficiency compared to diesel (100% load app. 1% increase)比较于柴油相同或更高效率 (+)



Source: (Haraldson 2015), (Stojcevski 2014), (Stojcevski 2018), (Haraldson 2014), MAN website, MAN publications

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SUMMARY OF THE C³-MOBILITY PROGRAM C³行动项目总结

C³-MOBILITY项目总结

Closed Carbon Cycle
MOBILITY
Klimaneutrale Kraftstoffe für den Verkehr der Zukunft

Bundesministerium für Wirtschaft und Technologie

Description
■ Funding authority资助单位: "Bundesministerium für Wirtschaft und Technologie" (German government德国政府)
■ Duration时限: 3 Years 3年
■ Costs费用: ~24 Mio. € 24百万欧
■ Funding资金: ~16 Mio. € 16百万欧
■ Objective目标: Investigation of climate neutral fuels based on methanol研究基于甲醇的气候中性燃料
■ Partners合作伙伴: Consortium consisting of Universities, Research Institutes and small to large Companies由大学，研究机构和公司组成的联盟

Project Structure项目结构
Project Partners项目合作单位

FEV

AVL
BMW GROUP
Rolls-Royce Motor Cars Limited
C·A·C ALWAYS AN IDEA AHEAD
Continental
DAIMLER
DENSO Crafting the Core
FEV
FH AACHEN UNIVERSITY OF APPLIED SCIENCES
Ford
JÜLICH Forschungszentrum
Fraunhofer ISE
HYUNDAI MOTOR GROUP
LIEBHERR
OWI an der RWTH Aachen
RWTH AACHEN UNIVERSITY
TECHNISCHE UNIVERSITÄT BERGAKADEMIE FREIBERG
Die Ressourcenuniversität. Seit 1765.
TECHNISCHE UNIVERSITÄT DARMSTADT
TECHNISCHE UNIVERSITÄT DRESDEN

Assoziierte Partner und im Unterauftrag

bse engineering
DEUTZ
TEC4 FUELS
GRILLO one
innogy
umicore Automotive Catalysts

Objectives目标

VALUATION OF ELECTRICITY-BASED FUELS BASED ON MULTIPLE QUESTIONS

基于以电力为基础的燃料价值的多种问题：

- Which pathways to which electricity-based fuels (based on Methanol) are possible?**哪种路径**实现哪**种基于**电力的燃料（基于甲醇）是可能的？
- Which optimazations of efficiency do engines enable that are optimized for these fuels?发动机能够做**哪些效率**优化，为这些燃料方面的优化？
  Which technologies or adjustments are required?**需要哪种技**术或调整？
- What overal efficiency does the utilization path have from Well-to-Wheel/ Production-to-Wheel?**从**矿**井到**车轮/产品到车轮应用路线总体效率是多少？
- Which fuels allow a backwards compatibility to existing fleets?**哪种燃料允**许与现有燃料向后兼容性？
- How does a market launch of new or adapted engines or fuels into existing fleets work?**市**场如何操作**新型或者改造后**发动机或燃料融合已存在的发动机和燃料？
- What are the differences compared to a BEV or fuel cell vehicle also regarding costs and infrastructure?**比**较于电池电力车辆活燃料电池车辆关于费用和基础设施有什么不同呢？

Project Structure项目结构
Overall Structure总体结构

Production Pathways of Climate-neutral Fuels Modul I
气候中性燃料产品路线 模块 I

A) Methanol Production甲醇产品

B) Processing & Refinement处理和精炼

Usage of Climate-neutral Fuels Modul II-IV
气候中性燃料应用 模块II-IV

C) Optimal Use of Climate-neutral Fuels in Industry and Transport
工业和交通理想气候中性燃料应用

D) Cross-sectoral Issues
Components and Method Development
部件和方法发展跨行业问题

E) System Evaluation and Market Launch Scenarios Modul I
系统评估和市场应用方案 模块 I

F) Projekt Management and Public Relations
项目管理和公共关系

Project Structure项目结构
Production Pathways to Climate-neutral Fuels气候中性燃料产品路线

FEV

Production Pathways of Climate-neutral Fuels(FZJ, INO) Modul I (A)
气候中性燃料产品路线（FZJ, INO) 模块 I (A)

A) Methanol Production (theoretical / Application) 甲醇产品（理论/应用）

Case 1: Industrial Areas 工业领域

Case 2: Rural Areas 乡郊地区

Case 3: Desert 沙漠

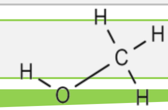
1) CO_2 Washing (theor.) CO2洗涤（理论）

2) Carbon from Biomass(theor.) 碳来自生物质（理论）

3) CO_2/H_2O Capture (theor.) CO2/H2O捕集（理论）

4) Elektrolysis (theor.)电解（理论） H_2

5) Methanol Synthesis (theor.)甲醇合成（理论） CH_3OH



B) Processing & Refinement 处理和精炼

1) OME醚类 (3-5) from Kopernikus (theor. FZJ) — OME

2) 2-Butanol丁醇 Lab (FZJ) — $C_4H_{10}O$

3) MtG 甲醇合成汽 Demonstration Plant (TUF, CAC) — MtG

4) 1-Octanol 辛醇 Lab (FZJ) — $C_8H_{18}O$

5) DME二甲醚 from ALIGN (theor. FZJ, GRIL) — DME

*FZJ: Forschungszentrum Jülich; INO: innogy SE; TUF: Technische Universität Freiberg; CAC: Chemieanlagenbau Chemnitz GmbH; GRIL: Grillo-Werke AG

Project Structure项目结构

Usage of Climate-neutral Fuels中性燃料应用

C) Optimal Usage of Climate-neutral Fuels in Industry and Transport Modul II-IV

工业和交通气候中性燃料理想应用

Research, Development of Combustion Processes and Demonstration

燃烧过程和验证的研究和发展

Cylinder Displacement气缸排量:
≤ 0.5 l … **≥ 2.0 l**

1)	2)	3)	4)	5)	6)	7)	8)
I	I	I	II	II	I, II	II	III, IV (ENGINE)
MtG, $C_4H_{10}O$	CH_3OH, C_2H_5OH, MtG, $C_4H_{10}O$	C_2H_5OH, MtG	DME	$C_8H_{18}O$	OME	CH_3OH, OME, $C_8H_{18}O$	CH_3OH
Drop-In时时混入, Blend, 混合 Monovalent单一 (OPEL, RWTH)	Drop-In时时混入, Blend混合 (BMW, RWTH)	Blend混合 (VW)	Bi-valent双单一 Monovalent单一 (FORD, RWTH, FISE)	Drop-In混入 (FORD, RWTH)	Blend混合 Dual-Fuel双燃料 (HMECT, CPT, TUD)	Blend混合 Dual-Fuel双燃料 (FEV, DAIM, DEUT)	Monovalent单一 Dual-Fuel双燃料 (RWTH, LIEB)
Demo样车: 1 PassCar乘用车	Demo样车: 2 PassCar乘用车	Demo样车: PassCar乘用车	Demo样车: 2 Light CV轻型商用车	Demo样车: 1 Light CV轻型商用车	Demo样车: 1 PassCar乘用车	Demo样车: 1-Zylindermotor 1 Nfz	Demo: 1-Zylindermotor

*OPEL: Opel Automobile GmbH; RWTH:RWTH Aachen University; BMW: Bayerische Motoren Werke AG; VW: Volkswagen AG; FORD: Ford-Werke GmbH; FISE: Fraunhofer ISE; HMECT: Hyundai Motor Europe Technical Center GmbH; CPT: Continental Automotive GmbH; TUD: Technische Universität Darmstadt; FEV: FEV Europe GmbH; DAIM: Daimler AG; DEUT: Deutz AG; LIEB: Liebherr-Components Deggendorf GmbH

Project Structure项目结构
Usage of Climate-neutral Fuels气候中性燃料应用

C) Optimal Usage of Climate-neutral Fuels in Industry and Transport Modul II-IV
工业和交通气候中性燃料理想应用

Research, Development of Combustion Processes and Demonstration
燃烧过程和验证的研究和发展

Cylinder Displacement气缸排量:
≤ 0.5 l … **≥ 2.0 l**

1)	I	MtG, $C_4H_{10}O$	Drop-In, Blend, Monovalent (OPEL, RWTH)
2)	I	CH_3OH, C_2H_5OH, MtG, $C_4H_{10}O$	Drop-In, Blend (BMW, RWTH)
3)	I	C_2H_5OH, MtG	Blend (VW)
4)	II	DME	Bi-valent Monovalent (FORD, RWTH, FISE)
5)	II	$C_8H_{18}O$	Drop-In (FORD, RWTH)
6)	I, II	OME	Blend Dual-Fuel (HMECT, CPT, TUDR)
7)	II	CH_3OH, OME, $C_8H_{18}O$	Blend Dual-Fuel (FEV, DAIM, DEUT)
8)	III, IV	CH_3OH	Monovalent Dual-Fuel (RWTH, LIEB)

1) **Fuels/Material Compatibility** (T4F/Shell) **& Fuel Deterioration/Oil Interaction** (OWI)燃料/材料兼容性(T4F/Shell)和燃料恶化/加油相互作用(OWI)

2) **Method Development 3D-CFDR for Fuel Blends** (AVL, RWTH)混合燃料的方法发展 3D-CFDR(AVL, RWTH)

3) **Thermal Management Optimization** (QP)热管理优化(QP)

4a) **Exhaust Gas Aftertreatment** (Components) (TUD, UMI, AVL)废气后处理（零部件）(TUD, UMI, AVL)

4b) **ANB** (Strategy) (FEV, FISE)ANB(策略)

5) **Injection Systems喷射系统:** **5c) PassCar DME乘用车二甲醚**(DENSO) **5a) PassCar OME乘用车二甲醚** (CPT) **5b) CV + Large Engine商用车+大发动机** (LIEB)

6) **Fuel Sensors燃料传感器** (CPT)

7) **Model-based Torque Path and Ignition 基于模型扭矩路线和点火**(FEV, WEG, FHAC)

D) Cross-sectoral Issues module-spanning Components and Method Development

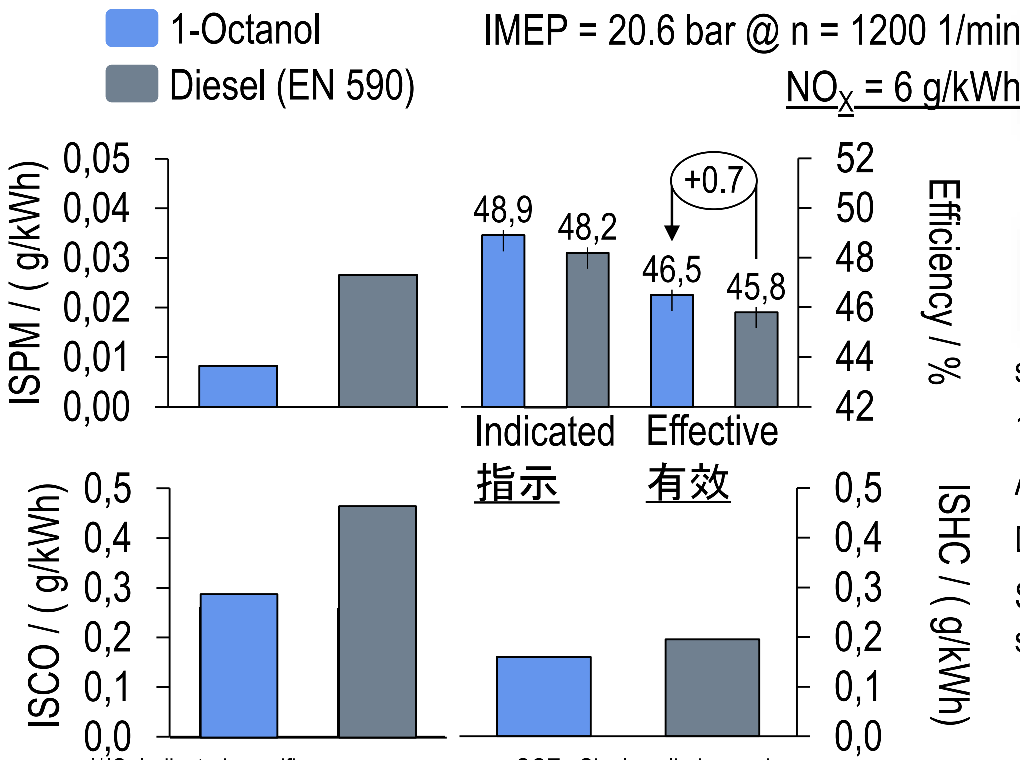
*T4F: TEC4FUELS GmbH;
OWI: Oel-Waerme-Institut gGmbH;
AVL: AVL Deutschland GmbH; QP: AVL qpunkt GmbH;

*UMI: Umicore AG & Co. KG;
DENSO: Denso Automotive Deutschland GmbH;
WEG: Weissgerber Engineering; FHAC: FH Aachen

Heavy Duty combustion concept with CO_2 neutral fuel for post-EU VI
应对欧VI后CO_2中性燃料应用于重型车的燃烧概念

MORE DEGREE OF FREEDOM IN CALIBRATION TO INCREASE EFFICIENCY AND LOWER EMISSIONS

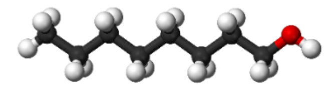
在提升效率和降低排放方面更多标定自由度



**IS: Indicated specific…
IMEP : Indicated mean effective press.
Comparison at cruise point operation = engine calibration parameters and combustion center kept constant

SCE: Single cylinder engine
DOHC: Dual overhead camshaft

Power to fuel liquid energy carrier
能量到液态燃料能源载体



SCE based on series vehicle class

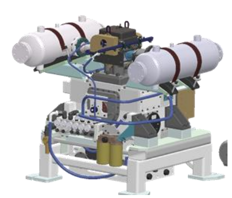
12.8 L (2.13 L / Cyl.)

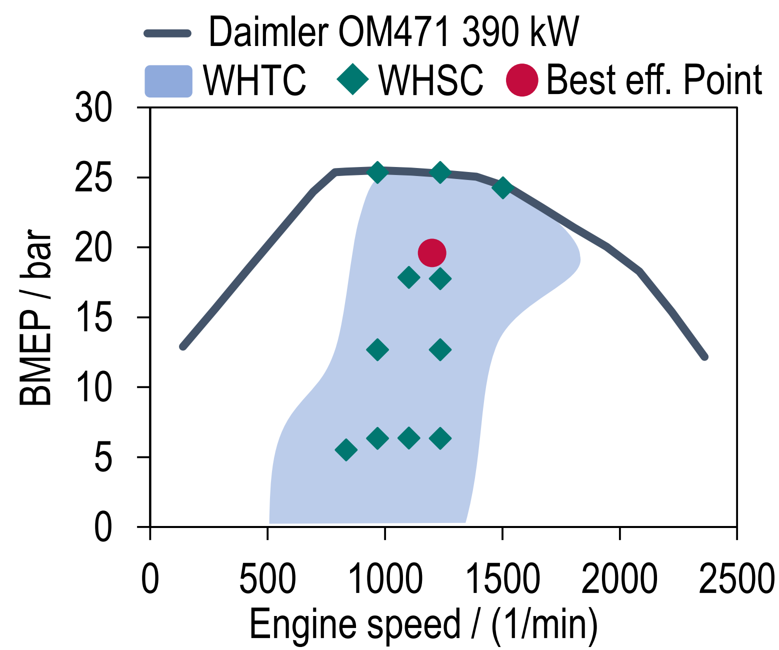
Amplified common rail

DOHC cylinder head

Steel piston with flat step bowl

HD SCE



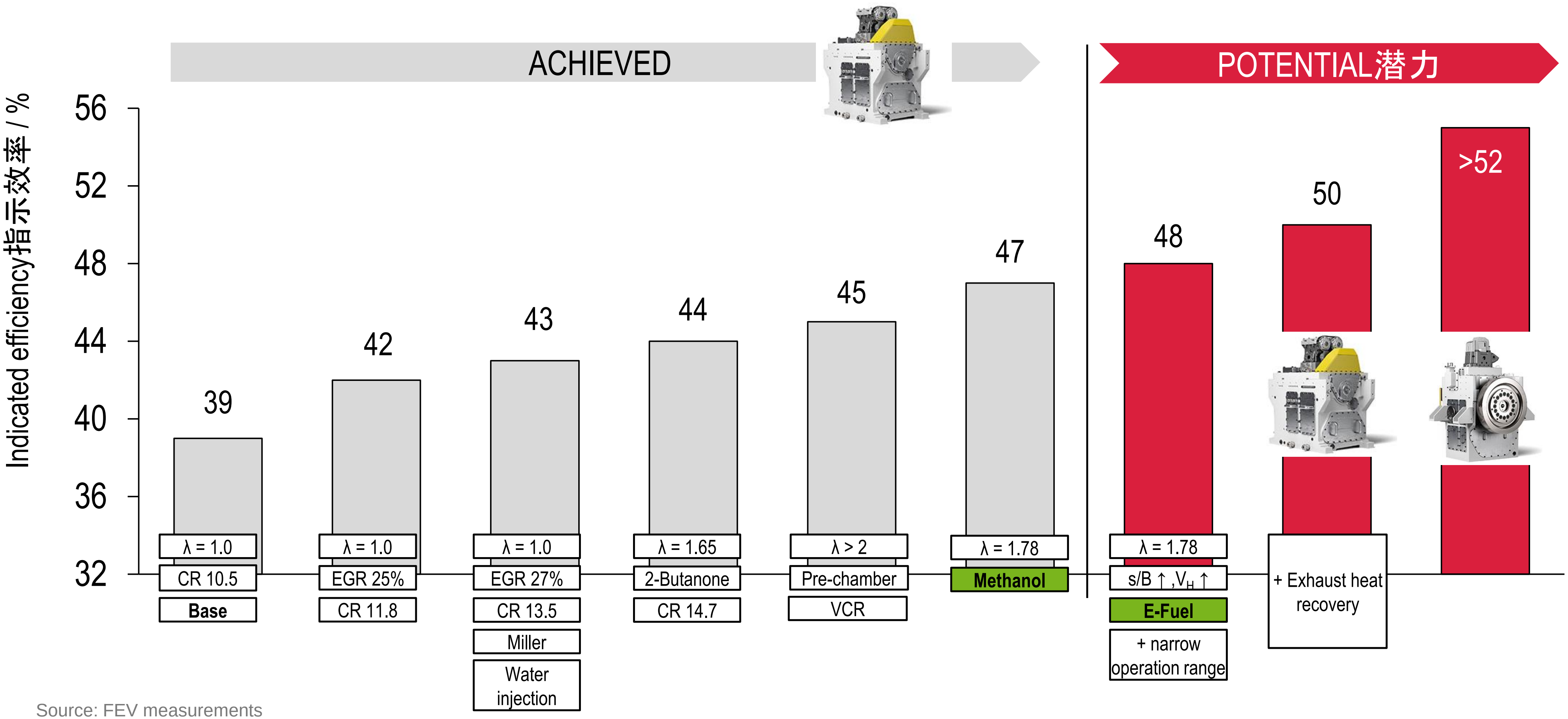


*Example of multi-cylinder engine map

Source: FEV

Methanol Spark Ignition – E-fuels are not only CO_2 neutral but also have better combustion performance than fossil fuels
甲醇火花点火-合成燃料相对于化石燃料不仅CO2中性而且具有更高燃烧特性

47 % ACHIEVED ALREADY – 50 % IN SIGHT 47%已经实现-50% 在望



Source: FEV measurements

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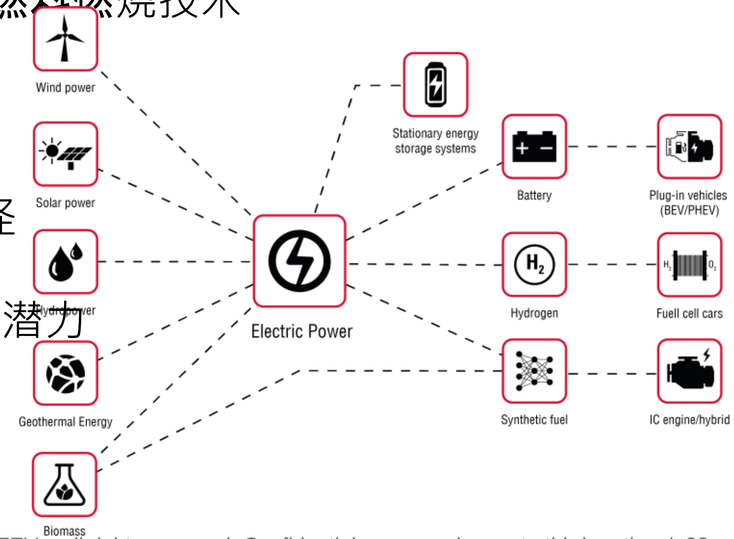
The future drives electric – battery electric, fuel cell vehicles and e-fuels!
未来驱动电力-电池，燃烧电池车辆和合成燃料！

CONCLUSIONS结论

- Complementary to electrification, e-fuels are key for achieving the CO_2 emission reduction goals of the road transport sector in 2050; 作为电气化补充，合成燃料为实现2050道路交通CO2排放降低目标是关键手段
- Green hydrogen and methanol are the most common educts for all other e-fuels and could serve as chemical energy carrier for a carbon-neutral economy; 绿色氢气和甲醇是所有其他合成燃料最通用的物质，并且其可以作为碳中性经济的化学能源载体
- Within the C³-Mobility project, FEV investigates combustion of methanol and e-fuels synthesized from methanol; 在C³-Mobility项目中，FEV研究甲醇和甲醇合成的燃料燃烧技术
- Methanol has been and already is in use as a fuel for internal combustion engines; 甲醇作为内燃机的燃烧正在或已经被应用
- There are multiple ways to combust methanol:燃烧甲醇有多种途径 Both CI and SI offer potential for emission reduction combined with increased efficiencies; CI和SI均呈现出排放降低和效率提升的潜力



Source: FEV

