METHANOL INSTITUTE

IEA-AMF Technology Collaboration Programme on Advanced Motor Fuels

AMF ANNEX 56:

METHANOL AS MOTOR FUEL

26 OCTOBER 2020 1500 CET | 2200 SGT

Moderator

Tim Chan
Manager, Government Relations & Business Development
METHANOL INSTITUTE

Speakers

Kim Winther
Senior Specialist
DANISH TECHNOLOGICAL INSTITUTE

Nils-Olof Nylund
Senior Advisor
VTT

Franziska Müller-Langer
Head of Biorefineries Department
DBFZ

Martin Tunér
Vice-Dean, Faculty of Engineering
LUND UNIVERSITY

Päivi Aakko-Saksa
Principal Scientist, Research Team Leader
VTT

26 October, 2020

Advanced Motor Fuels TCP and Methanol

Nils-Olof Nylund
Senior Advisor
VTT

On behalf of Jesper Schramm
Professor at DTU
Chairman of IEA AMF

Advanced Motor Fuels TCP

= strong international network

fosters collaborative (RD&D)

provides unbiased information

aims for sustainable mobility

- framework was established by the IEA
- one of IEA's seven transport related TCPs

https://www.iea.org/areas-of-work/technology-collaboration/transport

Character of AMF

- pool and leverage their knowledge and research capabilities from different countries
- exchange of best practices
- take regional and local conditions into consideration when facilitating the deployment of new fuel and vehicle technologies
- AMF does not pursue individual interests
- AMF is the only internationally recognized, technology-neutral clearinghouse for fuels-related information

AMF through the years

Long-standing agreement

- 1984-1989 **Alcohols as Motor Fuels**
- 1990-1998 Alternative Motor Fuels
- 1999-today Advanced Motor Fuels

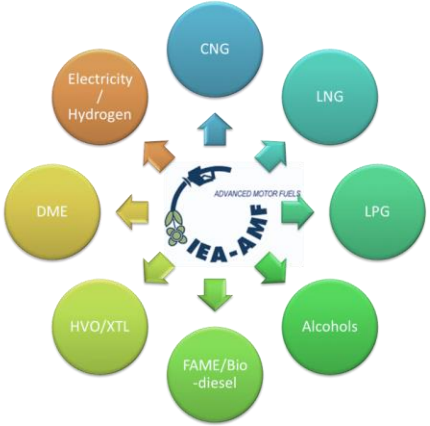
Current term 2020 - 2024

The Advanced Motor Fuels TCP (AMF) is a very active and successful program

- The number of participating countries has grown from
  4 countries in 1984 to 15 countries in 2020
- 61 annexes (projects) have been initiated by the program since its beginning

Scope of the AMF TCP

- AMF works on the entire spectrum of fuels from feedstock, through fuel processing, distribution, and, finally, end use in vehicles.
- AMF works closely with other related Technology Collaboration Programmes either through the End Use Working Party or by way of direct interaction.
- Advanced motor fuels are fuels that fulfill one or more of the following criteria:
  - Reduces GHG emissions
  - Improves life-cycle efficiency
  - Has high energy efficiency
  - Has low toxic emissions
  - Enables fuels for new propulsion systems
  - Contributes to security of supply



AMF Vision

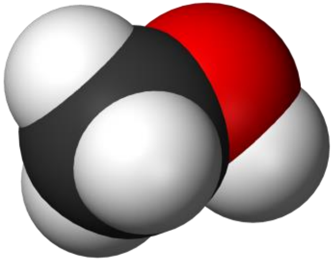
Advanced motor fuels,
applicable to all modes of transport,
significantly contribute to a sustainable society around the globe.

AMF contributes by

- providing a solid basis for decision making (information and recommendations)
- providing a forum for sharing best practices and pooling resources, internationally

Methanol on AMF's radar screen

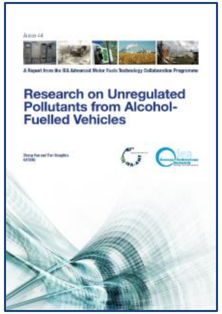
- Methanol is a versatile energy carrier
- Efficient processing
- Multiple feedstock options (fossil & renewable)
- No carbon-to-carbon bonds resulting in soot-free combustion
- Several engine technologies possible (assisted ignition)
  - spark-plug
  - glow-plug
  - dual-fuel
  - ignition improver additives
- Potential for high engine efficiency
- Methanol fulfils most AMF's criteria for advanced fuels!

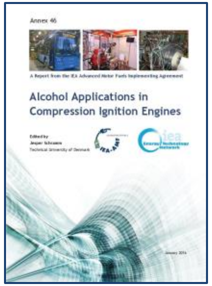


AMF work including alcohol fuels

Bolded items specifically on alcohol fuels

- **Annex 1: Alcohols and Alcohol Blends as Motor Fuels**
- **Annex 3: Diesel Field Trials and Diesel Field Trials Analyses**
- **Annex 4: Production of Alcohols and Other Oxygenates from Fossil Fuels and Renewables**
- Annex 5: Performance evaluation of alternative fuel/engine concepts
- **Annex 26: Alcohols and Ethers as Oxygenates in Diesel Fuel**
- **Annex 35-1: Ethanol as a Fuel for Road Transportation**
- **Annex 35-2: Particle Measurements: Ethanol and Butanol in DISI Engines**
- **Annex 36: Measurement Technologies for Emissions from Ethanol Fuelled Vehicles – METEV**
- Annex 37: Fuel and Technology Alternatives for Buses
- Annex 43: Performance Evaluation of Passenger Car Fuel and Powerplant Options
- **Annex 44: Research on Unregulated Pollutants Emissions of Vehicles Fuelled with Alcohol Alternative Fuels**
- **Annex 46: Alcohol Application in CI Engines**
- Annex 49: COMVEC – Fuel and Technology Alternatives for Commercial Vehicles
- Annex 52: Fuels for Efficiency
- **Annex 54: GDI Engines and Alcohol Fuels**
- **Annex 56: Methanol as Motor Fuel**





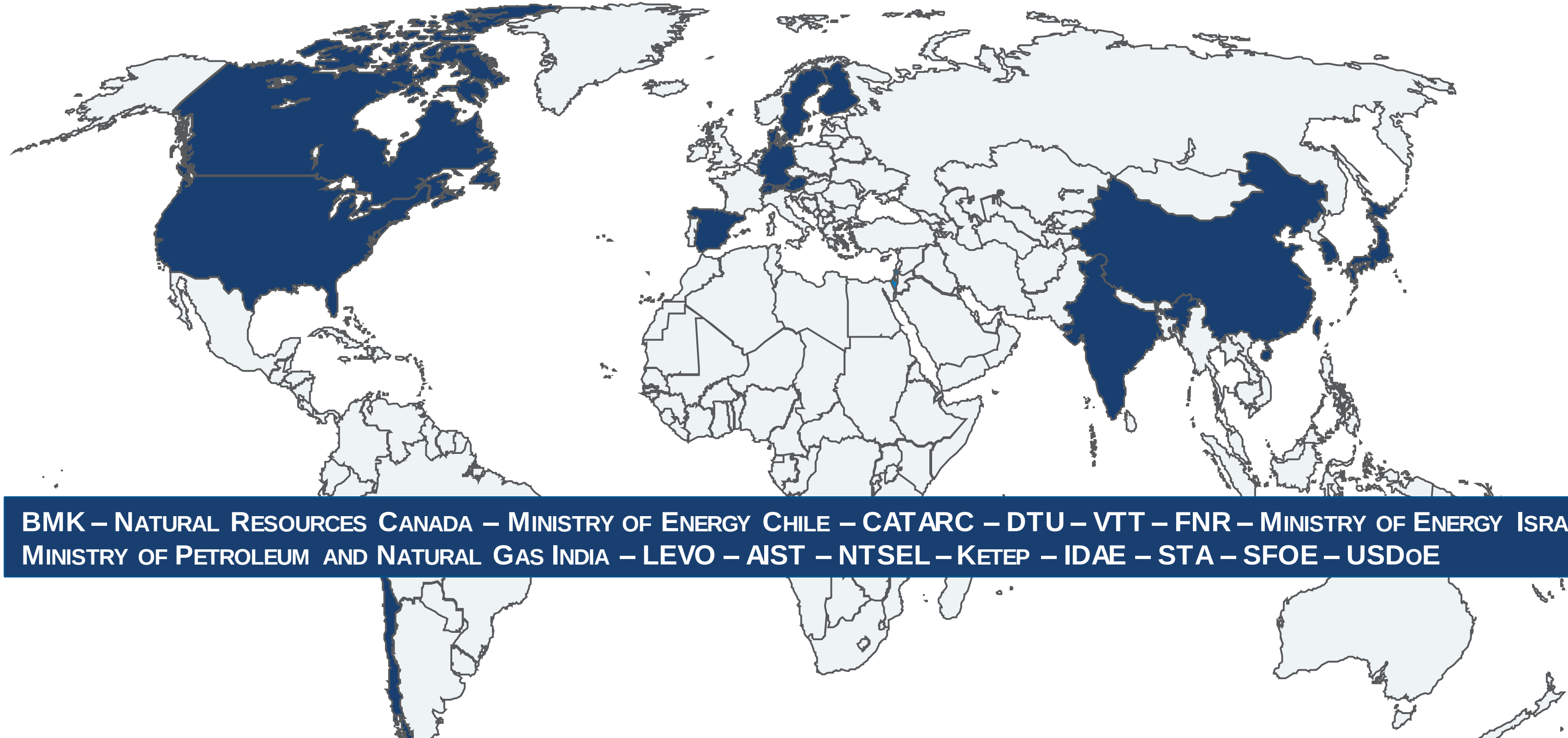
AMF’s current work programme

- Annex 28: Information Service & AMF Website (AMFI)
- **Annex 56: Methanol as Motor Fuel**
- Annex 57: Heavy Duty Vehicle Evaluation (including HD ethanol)
- Annex 58: Transport Decarbonisation
- Annex 59: Lessons Learned from Alternative Fuel Experiences
- Annex 60: The Progress of Advanced Marine Fuels
- Annex 61: Remote Emission Sensing

ADVANCED MOTOR FUELS IEA-AMF Technology Collaboration Programme on Advanced Motor Fuels

METHANOL INSTITUTE

Global Network of Experts



BMK – Natural Resources Canada – Ministry of Energy Chile – CATARC – DTU – VTT – FNR – Ministry of Energy Israel
Ministry of Petroleum and Natural Gas India – LEVO – AIST – NTSEL – Ketep – IDAE – STA – SFOE – USDoE

AMF Contacts

Chair

- Mr. Jesper Schramm, DTU, Denmark

Vice Chairs

- Mr. CB Lee, KATECH, Korea
- Mr. Michael Wang, ANL, USA

Secretary

Ms. Dina Bacovsky,
BEST – Bioenergy and Sustainable Technologies, Austria
dina.bacovsky@best-research.eu

www.iea-amf.org
including AMF newsletter and Fuel Info

Alcohol fuels including methanol are an essential part of AMF's legacy

AMF also foresees a role for methanol as a future energy carrier in the transport sector

26 October 2020

Annex 56
Methanol as Motor Fuel
Prospects for renewable methanol

Franziska Müller-Langer
DBFZ, Germany

Jörg Schröder, Niels Dögnitz, Kathleen Meisel
DBFZ, Germany

Methanol as motor fuel

Agenda

Global transport sector

Overview methanol market

Renewable methanol

Prospects of commercialization as fuel

Global transport sector
Data and statistics 2018

Energy demand

Global: 9,938 Mtoe

Transport: 29%

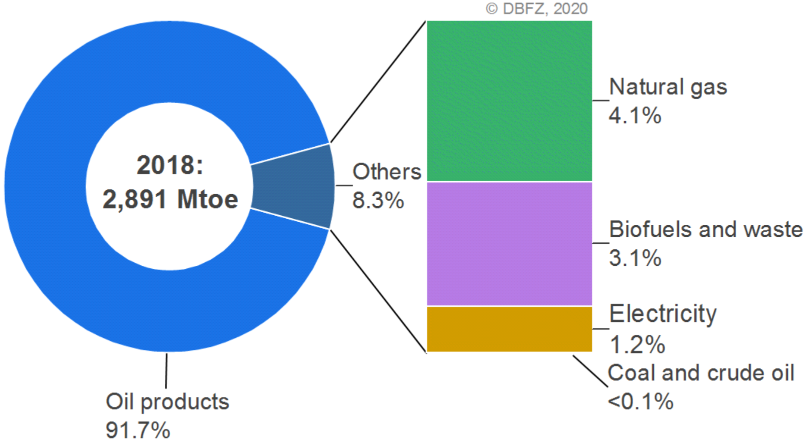
(Increase of 46% compared to 1990)

GHG emissions

Global: 33,514 Mt CO_2-eq

Transport: 25%

(Increase of 44% compared to 1990)



Global energy demand of transport sector

Source: IEA 2020: https://www.iea.org/data-and-statistics/data-tables?country=WORLD

Overview methanol market

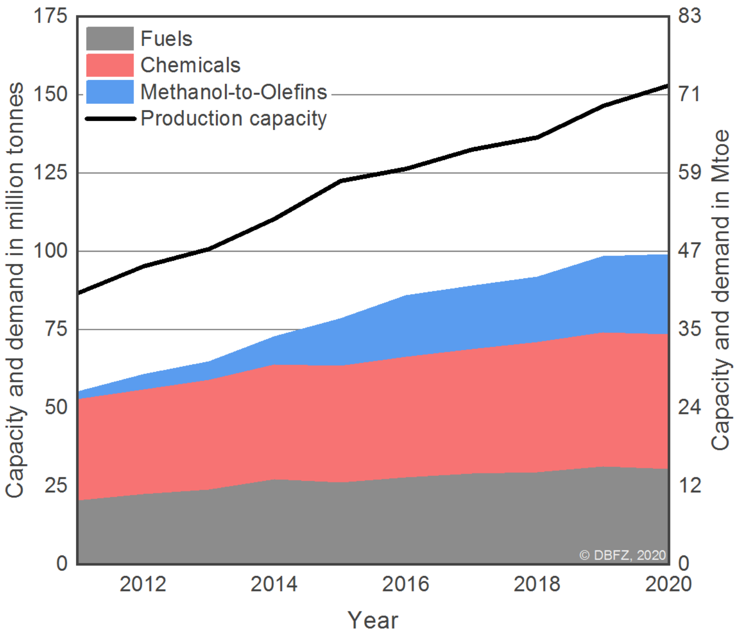
Data and statistics

Methanol as motor fuel

- **Straight** or **blended** in methanol engines
- **Intermediate** for FAME, MTBE, DME, MtG
- **Energy carrier** for fuel cells

Main driver

- **China** with approx. **100 million vehicles** using straight or blended methanol as motor fuel



Methanol is a multipurpose fuel

Renewable methanol

Conversion routes

Global capacity: Less than 1 million tonnes per year

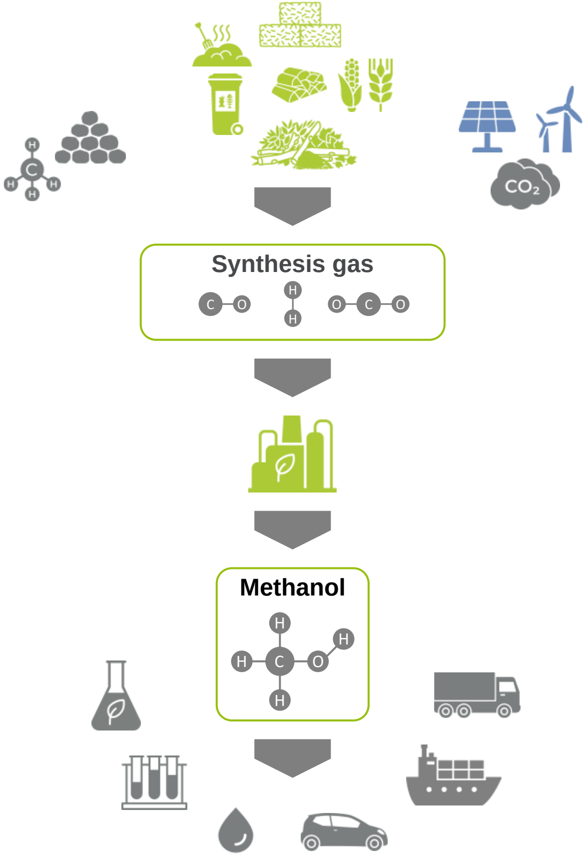
Renewable methanol plants, examples:

- Enerkem, Canada (municipal solid waste)
- CRI, Iceland (hydropower and geothermal energy)
- Södra, Sweden (cultivated wood)

Technology Readiness Level (TRL) of conversion route from

- Biomass: 3 – 7 / Power: 7 – 8

Production capacity of renewable methanol has to be increased



Renewable methanol

GHG emissions (literature based)

Renewable methanol

3 – 69 g CO_2-eq/MJ

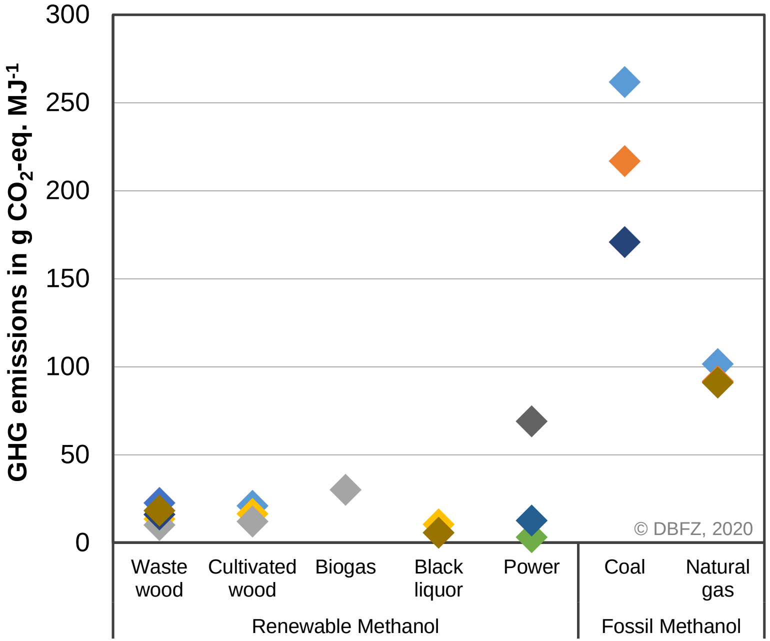
Fossil methanol

91 – 262 g CO_2-eq/MJ

Main drivers

Resources

Conversion technology



GHG reduction potentials of renewable methanol can be competitive to established renewable fuels and are competitive to fossil fuels

Renewable methanol

Production costs (literature based)

Renewable methanol

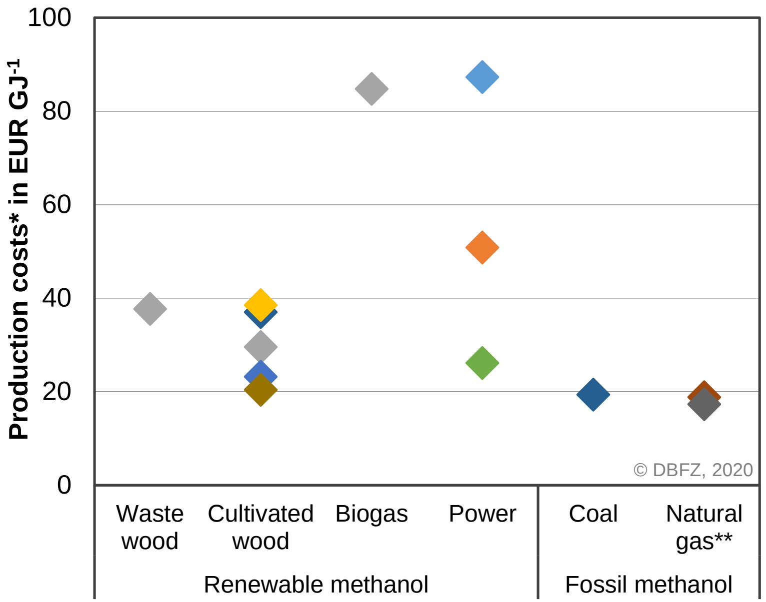
23 – 87 EUR/GJ (costs*)

Fossil methanol

17 – 19 EUR/GJ (price*)

Renewable motor fuels in Europe:

Bioethanol	20 – 35 EUR/GJ	(price*)
FAME	20 – 30 EUR/GJ	(price*)
Biomethane	8 EUR/GJ	(price*)



* normelized to 2018
** price of methanol from natural gas

Production costs of renewable methanol can be competitive to established renewable fuels, if using suitable resources

Prospects of commercialization as fuel

Barriers

Functionality

Scalability

Affordability

Sustainability

Strategy

Roadmap
Stakeholder

Communication

Visibility
Demonstrations

Technology

Availability
Technical instructions

Regulations

Fuel standards
Legislations

Implementing alternative fuels to market needs supporting elements on global, national and local level

Key messages

- Methanol is a multipurpose fuel;
- Production costs and GHG reduction potentials of renewable methanol can be competitive to established renewable fuels;
- In order to support GHG mitigation in transport, production capacity of sustainable renewable methanol has to be increased as soon as possible;
- Supporting elements on strategic, regulatory, technical and communicative level are of overarching importance.

Dr.-Ing. Franziska Müller-Langer

E-Mail: franziska.mueller-langer@dbfz.de
Phone: +49 341 2434-423

DBFZ Deutsches Biomasseforschungszentrum gemeinnützig GmbH
Torgauer Straße 116
04347 Leipzig
Germany

November 26, 2020

M85 for passenger cars

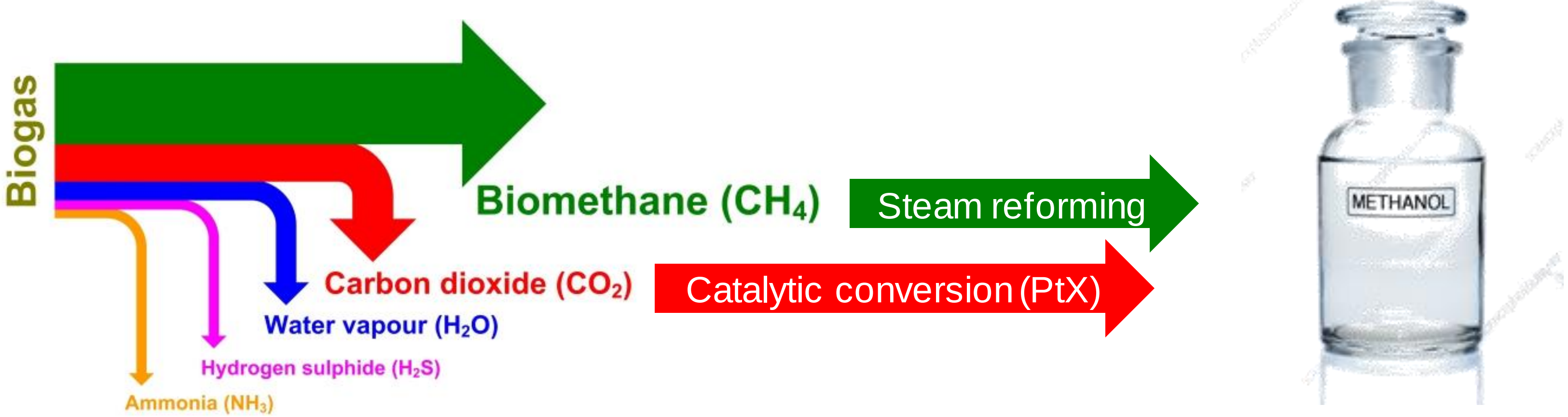
Results and Barriers to Commercialization

Kim Winther
Senior specialist, M.Sc.
Danish Technological Institute
AMF Strategy & Technology Chair

Motivation

From Agricultural Waste to Sustainable Fuel

- Very large biogas potential due to intensive farming
- Biogas from manure greatly reduces CH_4 emissions
  - Net negative CO_2eq can be obtained with closed digesters (RED II)
- CO_2 from biogas is currently wasted (vented to atmosphere)
  - This CO_2 can be captured and converted to methanol



The case for Bio M85

Danish context, RED I Wood Methanol 5 gCO_{2eq}/MJ

	Gasoline E5	Electric DK	Bio M85
Fuel and energy pathway	Corn fermentation and natural gas in CHP	From Danish grid	Wet manure from open digestate with off-gas combustion
Emission in production of vehicle	5.600 kg $CO_{2eq.}$	8.800 kg $CO_{2eq.}$	5.600 kg $CO_{2eq.}$
Emission driving 150.000 km	19.650 kg $CO_{2eq.}$	4.875 kg $CO_{2eq.}$	6.000 kg $CO_{2eq.}$
Life cycle emission	25.250 kg CO_{2eq}	13.675 kg $CO_{2eq.}$	11.600 kg $CO_{2eq.}$

Why methanol?

Why not use methane or hydrogen directly?

- Methanol is more feasible for storage and distribution
- Methane requires new fueling stations and new cars
- Hydrogen requires new grid, new fueling stations and new cars

- On the short-medium term, methanol seems like the fastest option…

- IF we can get existing cars and fueling stations to work!

Our cars

ADVANCED MOTOR FUELS
IEA-AMF
Technology Collaboration Programme on
Advanced Motor Fuels

METHANOL
INSTITUTE

2008 Peugeot 107

Uses Artline SARL E85 Flex-Fuel Kit

- 1-liter n.a. engine
- 68 hp
- EURO 4
- Runs on M100 when warm
- “Check Engine” light turns on
- MOT denied…

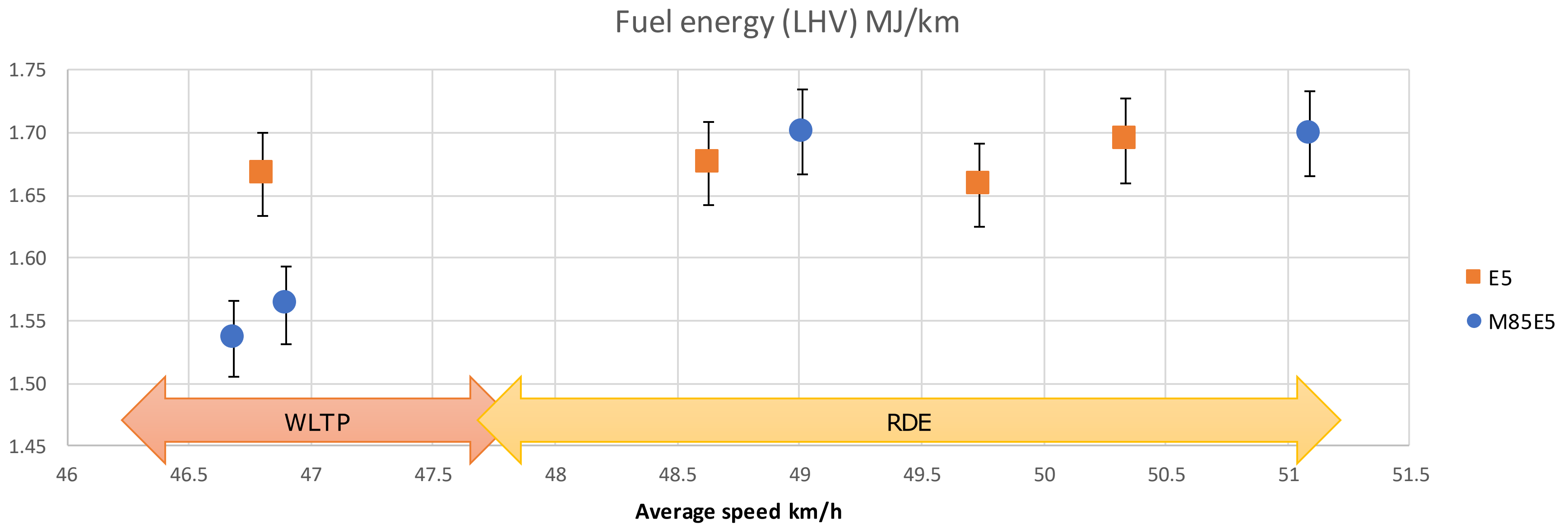
2020 Peugeot 108

Engine calibration by 2M Teknik

- 1-liter n.a. engine
- 72 hp
- EURO 6
- Runs well on M85
- Ny physical changes

2008 Peugeot 107

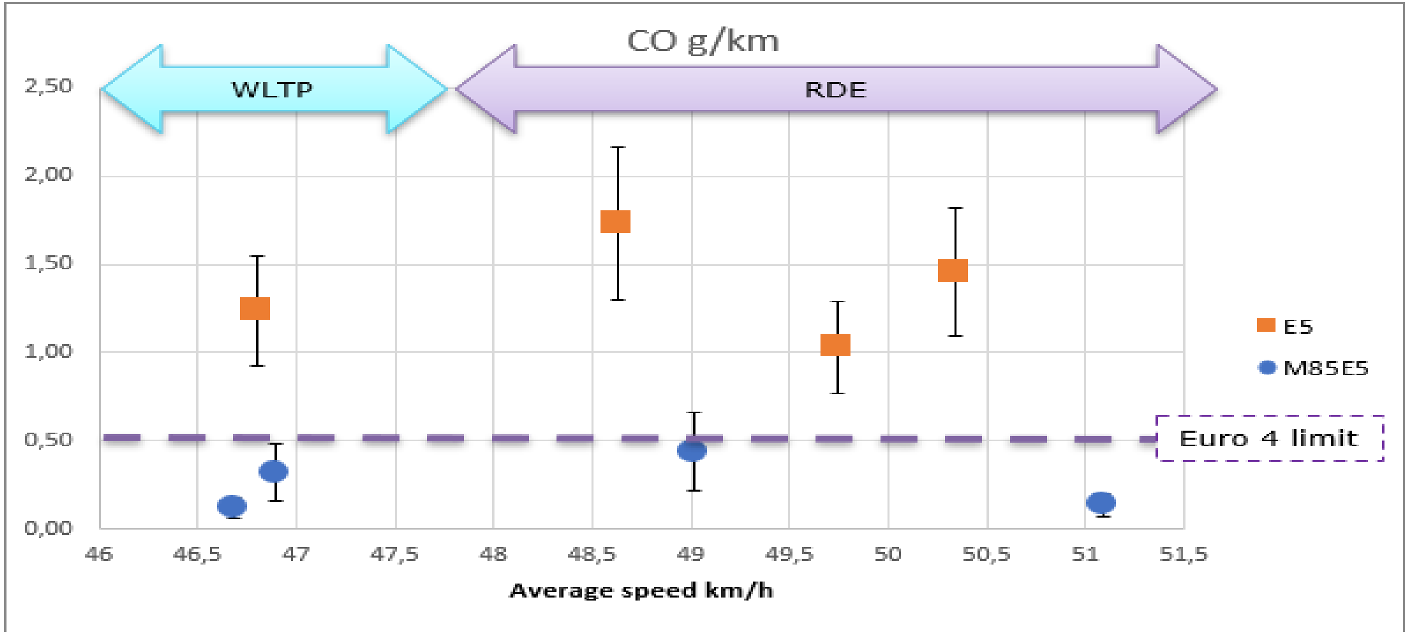
Fuel economy is on par with gasoline



Source: Danish Technological Institute

2008 Peugeot 107

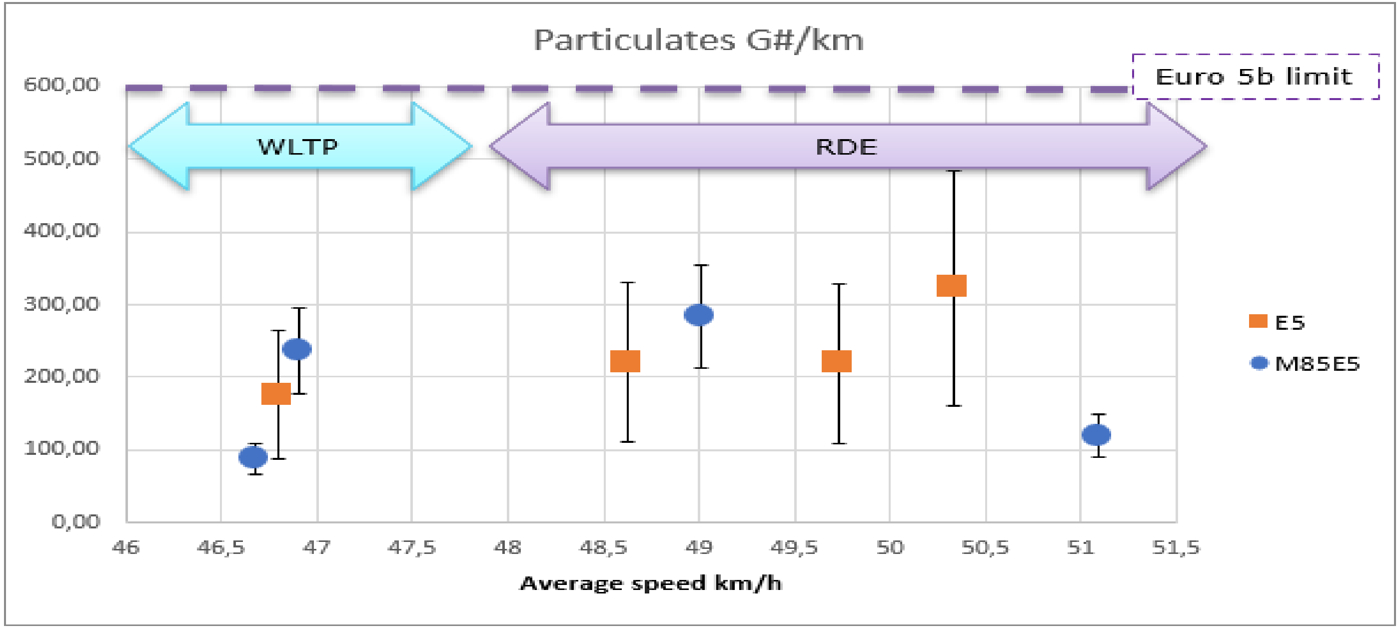
CO is much lower on M85



Source: Danish Technological Institute

2008 Peugeot 107

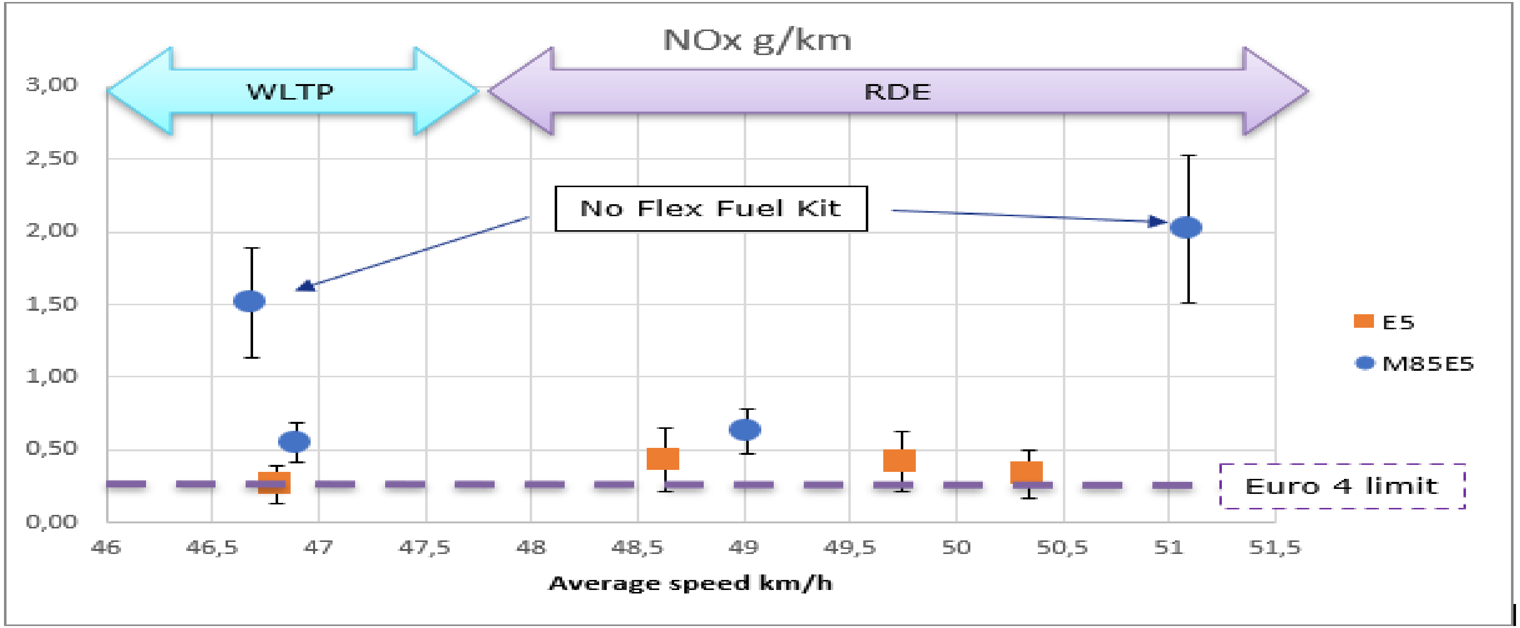
Pn is good in any case



Source: Danish Technological Institute

2008 Peugeot 107

NOx is acceptable for EURO 4



Source: Danish Technological Institute

Summary

2008 Peugeot 107

Fuel type	95 Octane Petrol	105 Octane M85
Air-Fuel Ratio	14,0:1	7,6:1
Fuel energy MJ/l	32,2	18,2
Performance		
Max. power	68 hk	73 hk
Max. torque	97 Nm	102 Nm
MJ/km	1,63	1,62
km/l	19,8	11,8
Car efficiency	15%	15%
Engine efficiency	25%	25%
Emissions		
CO2, g/km	118	118
CO, g/km	1,4	0,4
NOx, g/km	0,4	0,6
Pn, G#/km	234	259

Technology Collaboration Programme on Advanced Motor Fuels

METHANOL INSTITUTE

Latest results

2020 Peugeot 108 (EURO 6) with 2M calibration

ANNEXIIIa Appendix 6
Final RDE emissions results

Conformity of Emissions

AVL

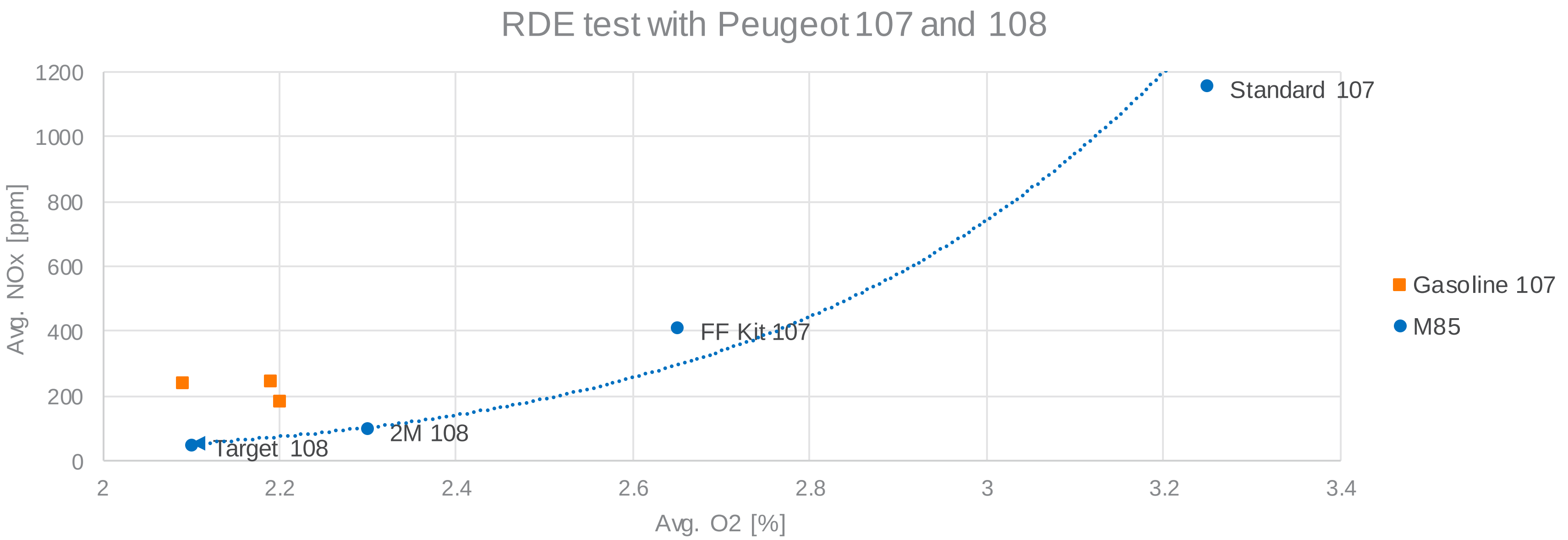
§	criterium	condition	value	unit	pass/fail
ANNEX IIIA 2.1.1	CF max = 1 + margin NOx with margin NOx = 1.1	conformity factor NOx urban <= 2.1	**4.17**		fail
	CF max = 1 + margin NOx with margin NOx = 1.1	conformity factor NOx trip <= 2.1	**1.89**		pass
	CF max = 1 + margin PN with margin PN = 0.5	conformity factor PN urban <= 1.5	**0.61**		pass
	CF max = 1 + margin PN with margin PN = 0.5	conformity factor PN trip <= 1.5	**0.45**		pass

urban		**CO2**	**CO**	**NOx**	**PN**
correction	factor	g/km	mg/km	mg/km	#/km
none		118.81	9.51	250.20	3.671e+11
EXTC	1.60		9.51	250.20	3.671e+11
RF	1.00		9.51	250.20	3.671e+11
ki			9.51	250.20	
final result *			9.51	250.20	3.671e+11
WLTP limit			**1000.00**	**60.00**	**6.000e+11**
conformity factor				**4.17**	**0.61**

trip		**CO2**	**CO**	**NOx**	**PN**
correction	factor	g/km	mg/km	mg/km	#/km
none		106.08	16.06	113.60	2.672e+11
EXTC	1.60		16.06	113.60	2.672e+11
RF	1.00		16.06	113.60	2.672e+11
ki			16.06	113.60	
final result *			16.06	113.60	2.672e+11
WLTP limit			**1000.00**	**60.00**	**6.000e+11**
conformity factor				**1.89**	**0.45**

Towards EURO 6 approval

Only NOx remains to be solved



Source: w ebsite name

Next step…

ADVANCED MOTOR FUELS
IEA-AMF
Technology Collaboration Programme on
Advanced Motor Fuels

METHANOL INSTITUTE

100 cars for trials in 2021

Entire value chain involved

hmk BILCON

West

Danish Methanol Association

OK

Go'on

Skanderborg Kommune

2M Teknik SCANTUNE

TEKNOLOGISK INSTITUT

East

CIRCLE K

DTU

KØBENHAVNS KOMMUNE

EUDP

FDM

Barriers

What stops methanol from being used?

Technical, political, financial

- Exchange agreements
- E10 is cheaper
- Biofuel mandates do not account for actual CO_2
- Bio-CO_2 counts as fossil in the vehicle industry

- => No OEM support

- We need demonstration programs to assure confidence that M85 is safe for vehicles and infrastructure and that any technical difficulties can be solved.

Thanks for watching
Follow us on LinkedIn

October 30, 2020

High Efficiency Methanol Engines

Martin Tunér
Professor
Lund University

Sebastian Verhelst
Professor
Lund University

Methanol properties & methanol engines

Technology Collaboration Programme

by iea

Properties of methanol enables higher efficiencies

Compared to gasoline or diesel

- High RON (knock resistance)
- High burning velocity (increased expansion)
- High heat of vaporization (cooler charge)
- High lean burn limit & higher EGR tolerance
- High hydrogen & oxygen / carbon ratio
- Lack of carbon-carbon bonds

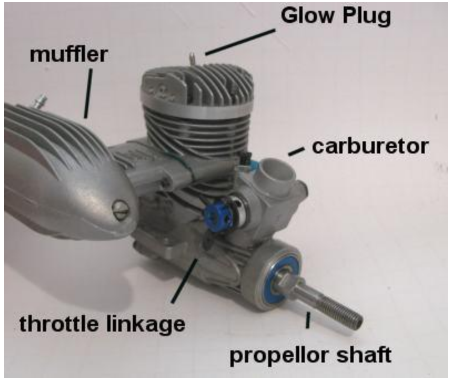
→

- Increased power
- Reduced exhaust heat losses
- Reduced heat transfer losses
- Reduced NOx
- Reduced CO_2
- No soot

Large range of methanol engine applications- versatile, powerful & clean

ADVANCED MOTOR FUELS
IEA-AMF
Technology Collaboration Programme on
Advanced Motor Fuels

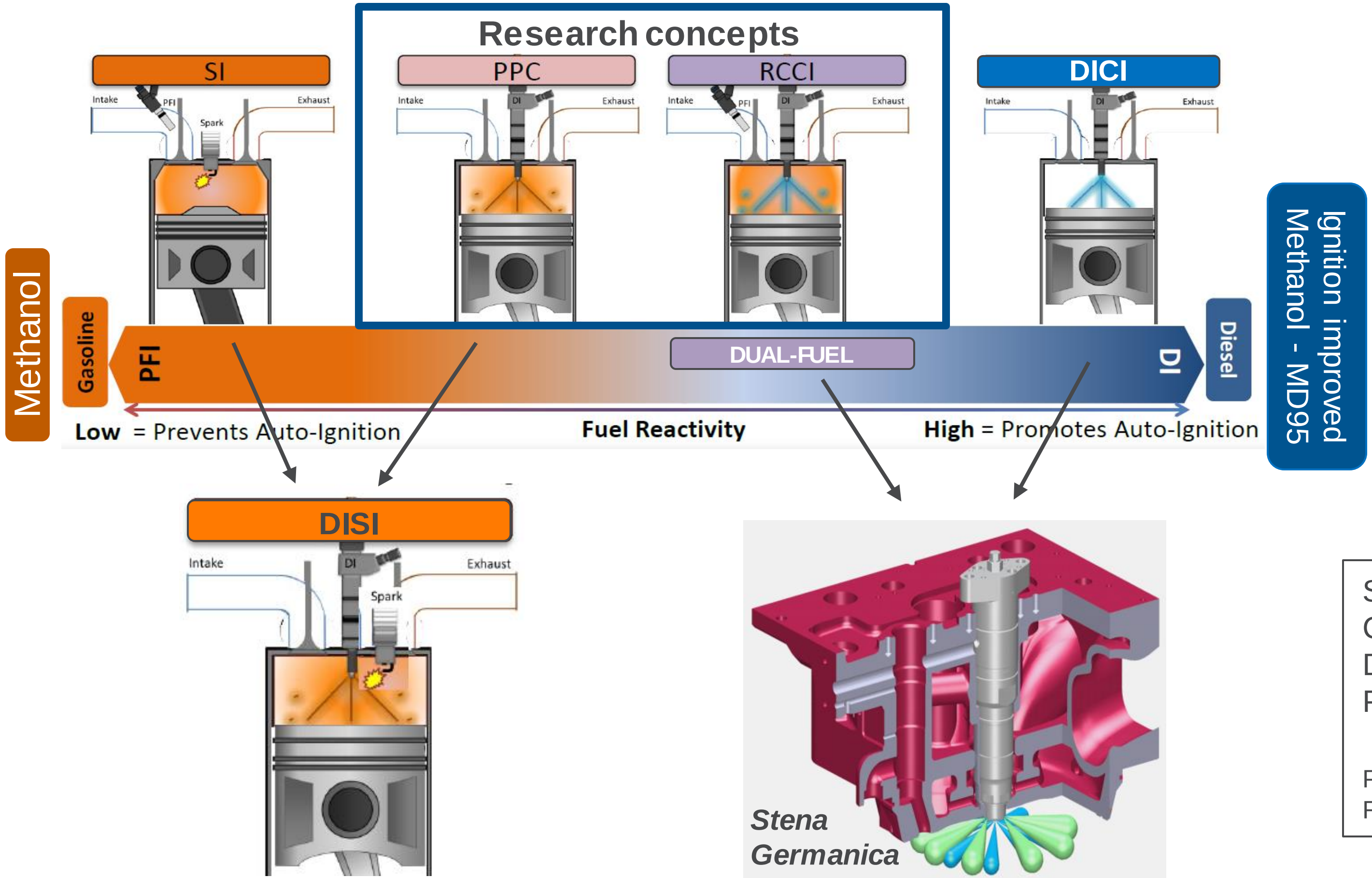
METHANOL
INSTITUTE



Methanol engines – combustion strategies

Technology Collaboration Programme on Advanced Motor Fuels

METHANOL INSTITUTE



SI – Spark Ignited
CI – Compression Ignited
DI – Direct Injected
PFI – Port Fuel Injected

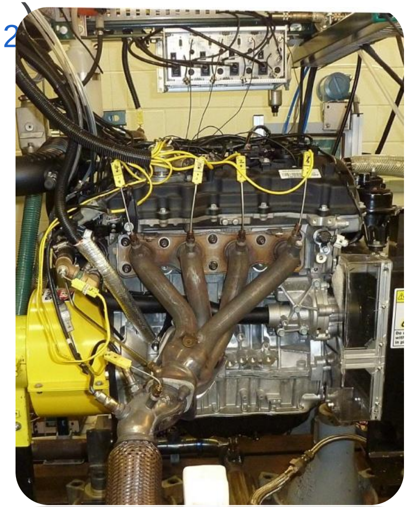
PPC – Partially Premixed Combustion
RCCI – Reactivity Controlled CI

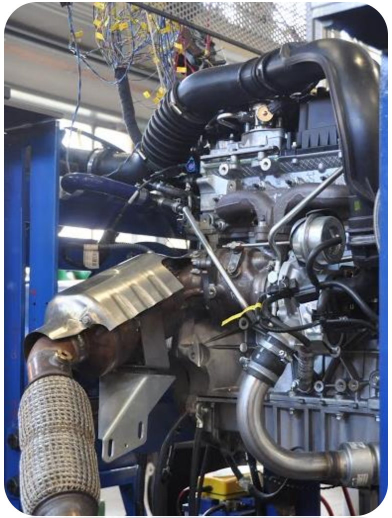
Methanol in gasoline engines - DISI

- Naturally aspirated Direct Injection (DI) engine Hyundai 2.4L at ANL
  - Tested methanol vs. gasoline +ethanol, butanol, E85, M56
  - Stock ECU – load limitations
  - Low-mid load: 2.7 %pt efficiency increase on methanol vs. gasoline
  - High load: 5.6 %pt (eff.=40%, i.e. -20% CO_2)
- Turbocharged DI: Volvo 1.6L “T3”
  - Efficiency +25%
    - MBT instead of KLSA
    - Effect not fully exploited: p_{max} limit
  - NO_x -35%

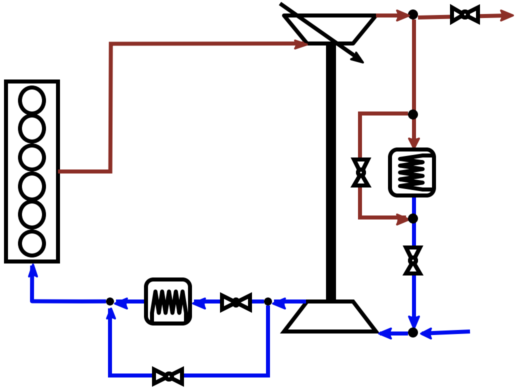
SAE 2015-01-0768

SAE 2018-01-0918

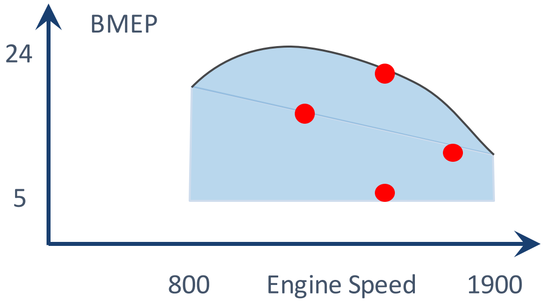


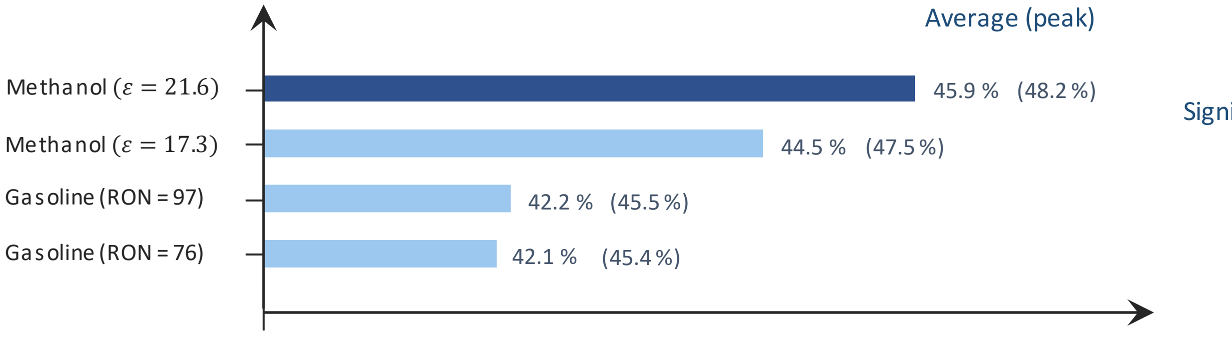


Methanol in diesel engines - PPC



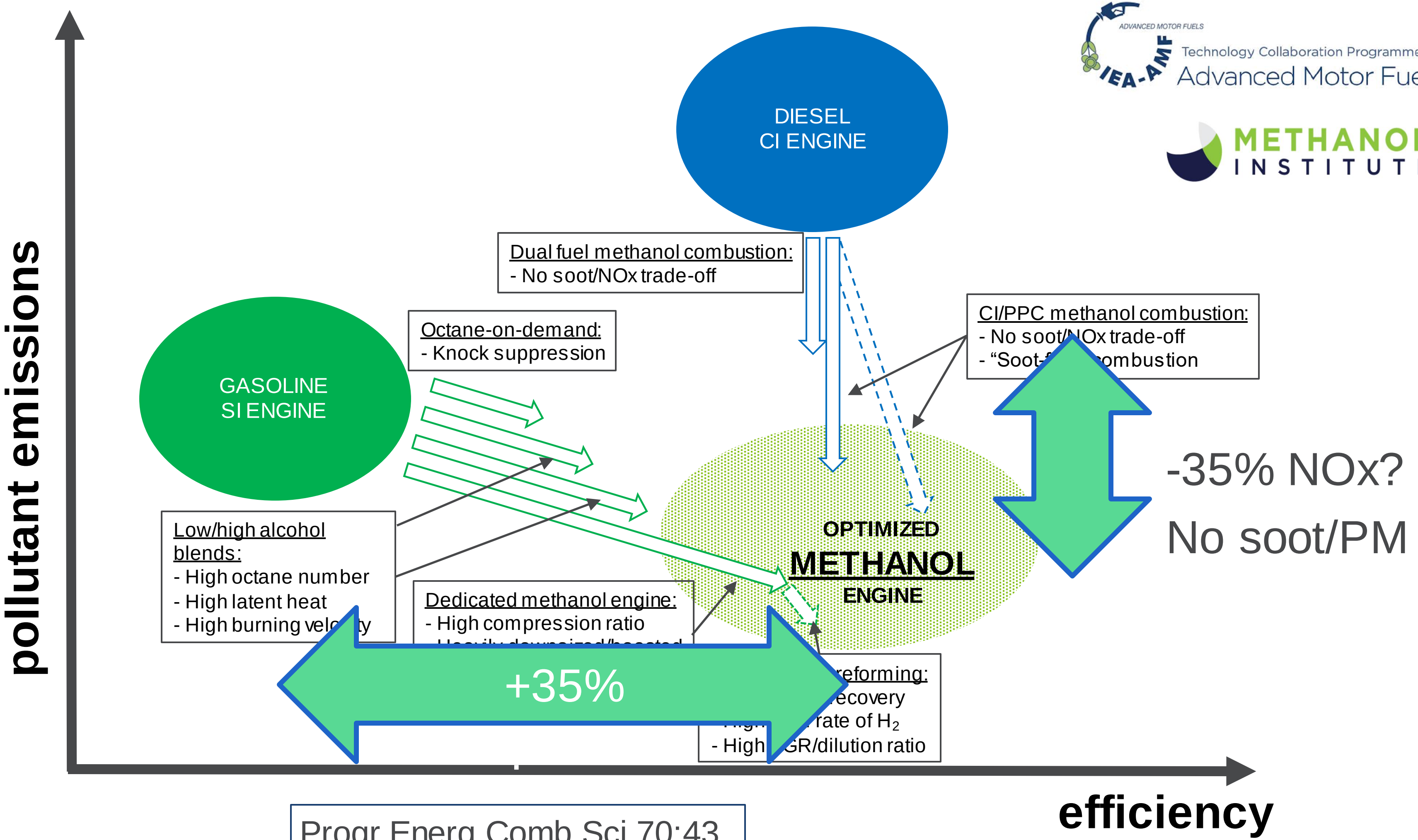
Diesel baseline 45.0% brake efficiency





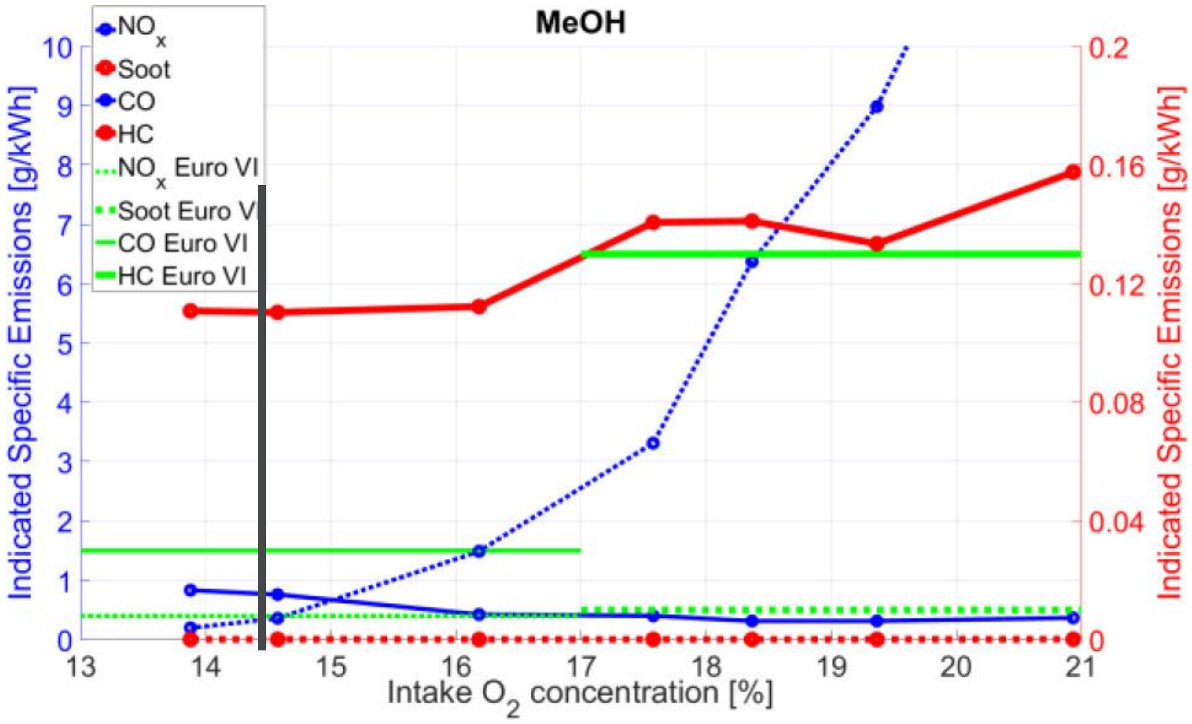
Significantly lower emissions

Erik Svensson, PhD thesis, Lund University



Progr Energ Comb Sci 70:43

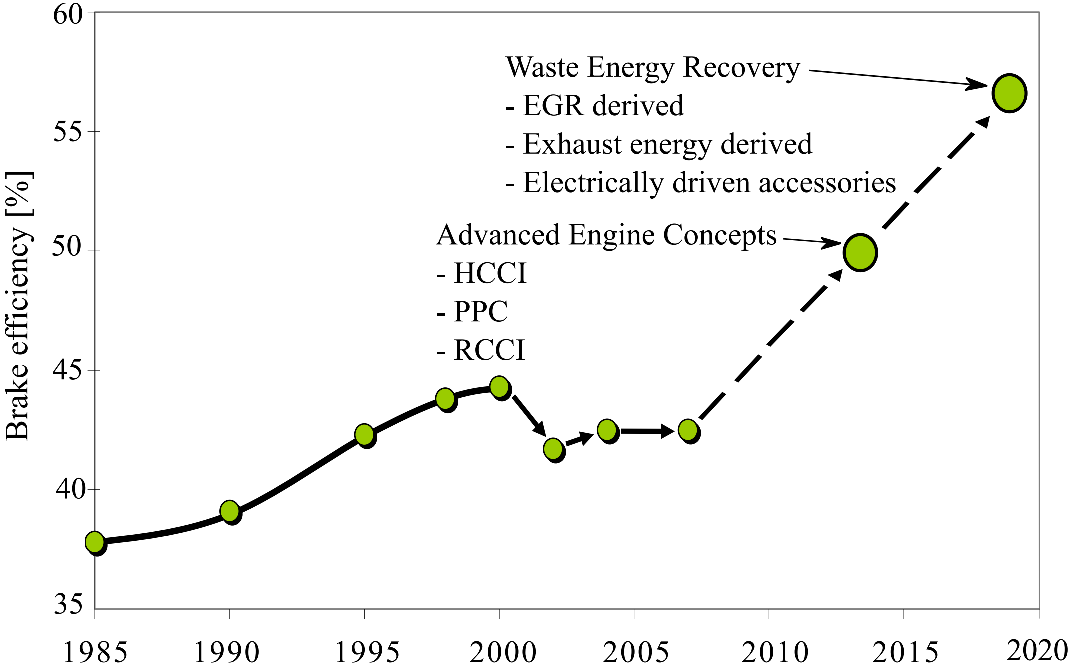
Euro VI compliant w/o aftertreatment



Shamun et al. SAE 2016-01-2288

Fast development of ICE

For gasoline and diesel…



Car engines approaching 50% efficiency

Technology Collaboration Programme on Advanced Motor Fuels

METHANOL INSTITUTE

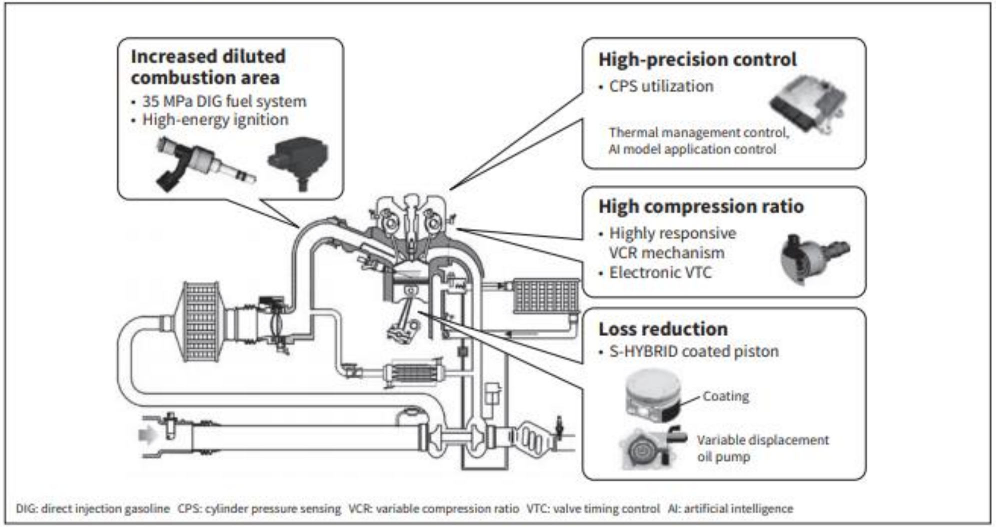
SIP – research program in Japan

High octane (gasoline) engines are surpassing the potential for high cetane (diesel) engines!!!

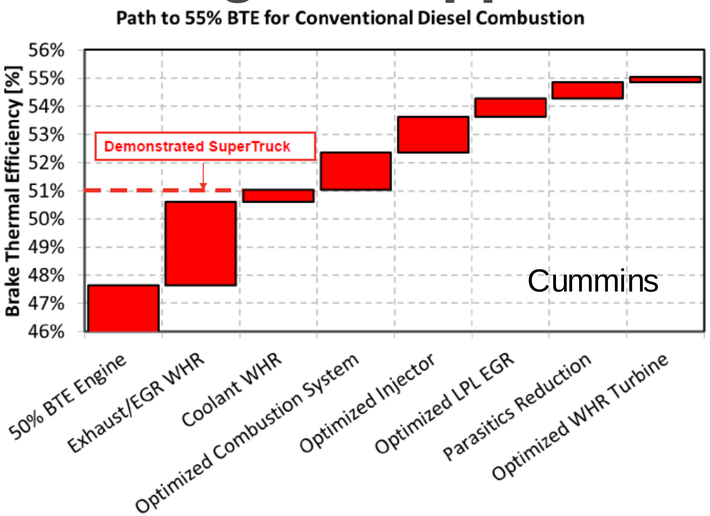
Ultra-lean + assisted compression ignition are critical factors = LTC

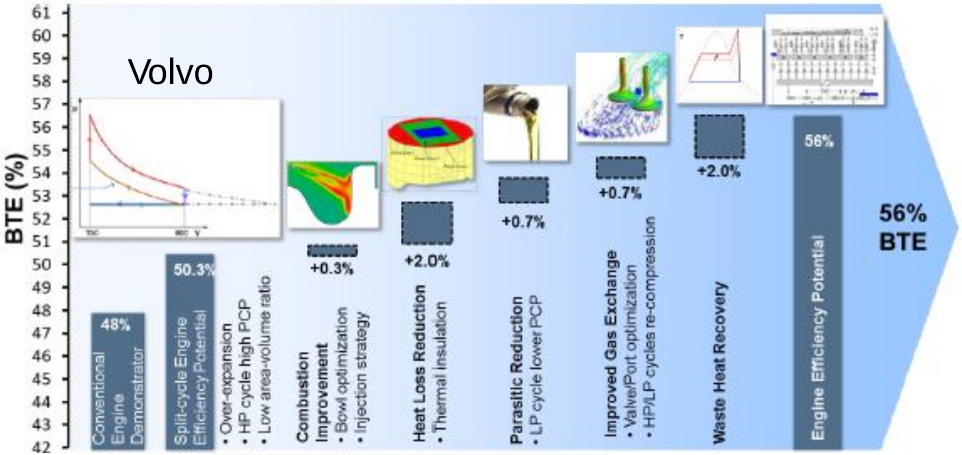
Figure 4 — Lineup of System Products for Achieving 50% Engine Thermal Efficiency

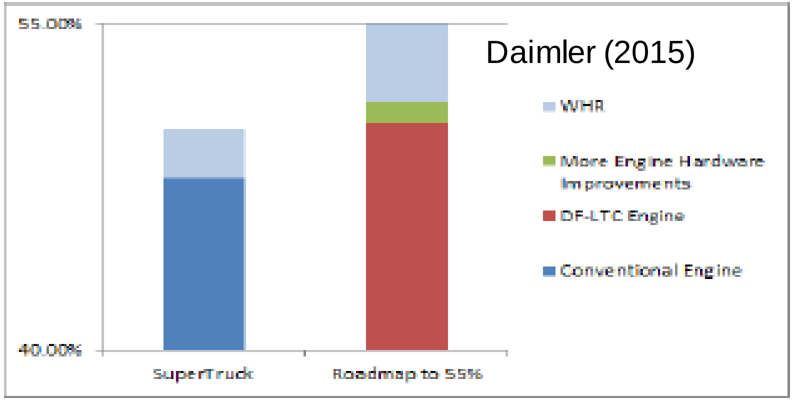
A higher compression ratio, diluted combustion, and reduced loss are important for increasing thermal efficiency. Hitachi Automotive Systems is developing combustion control technologies and system products that achieve this.

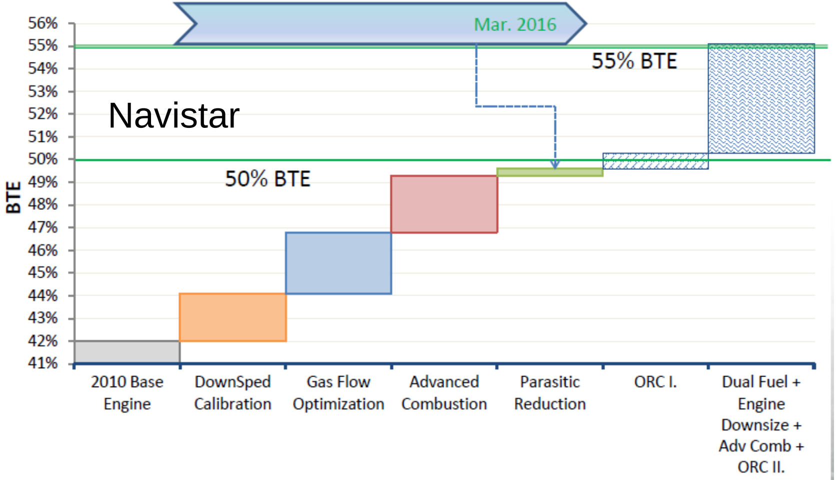


Truck engines approaching 55% efficiency



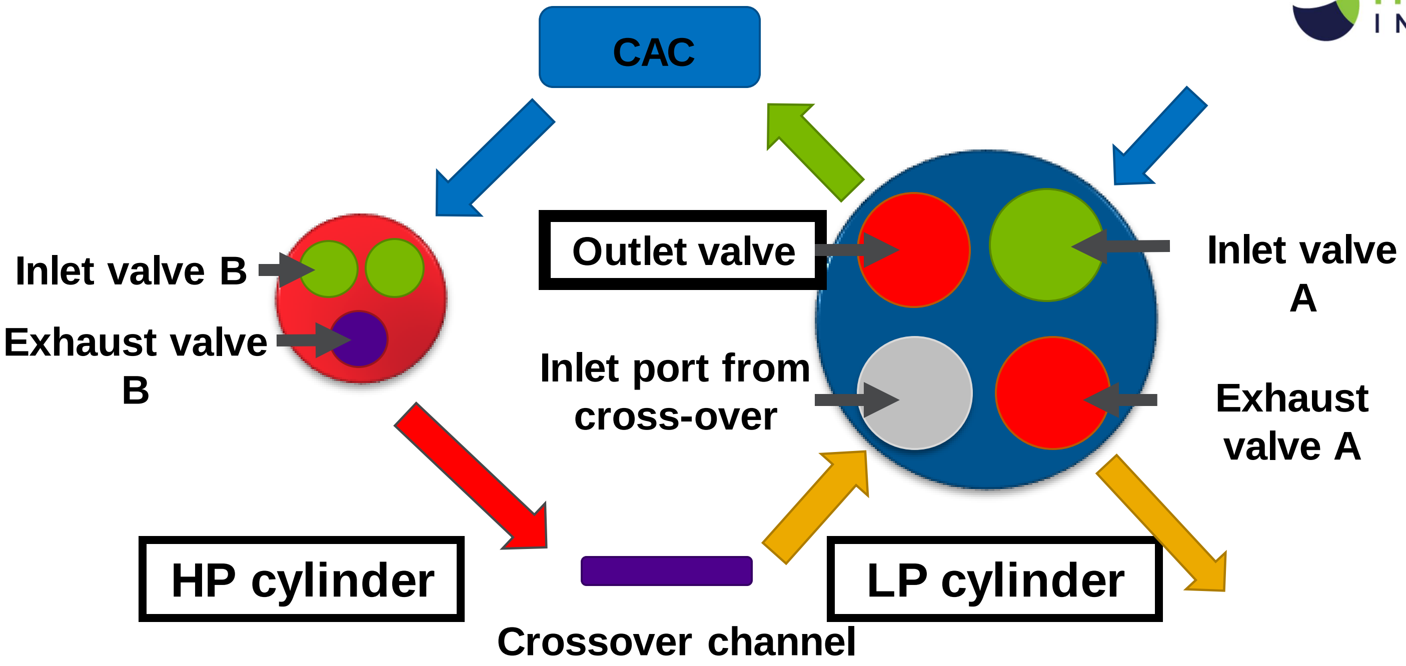






DOE AMR 6/16

New engine concept from Lund: DCEE



56% efficiency (simulations)
Experiments just started on prototype

2015-01-1260

Dedicated methanol engines?

Likely even more efficient!

- Methanol fuel properties are those leading to even higher efficiency
  - Increased autoignition resistance
  - Lean limit extension
  - Low adiabatic flame temperature
  - …
- DCEE on methanol = 60% efficiency?

Potential future applications of high efficiency methanol engines

Technology Collaboration Programme
by iea

IEA-AMF Technology Collaboration Programme on Advanced Motor Fuels

METHANOL INSTITUTE

Potential future applications

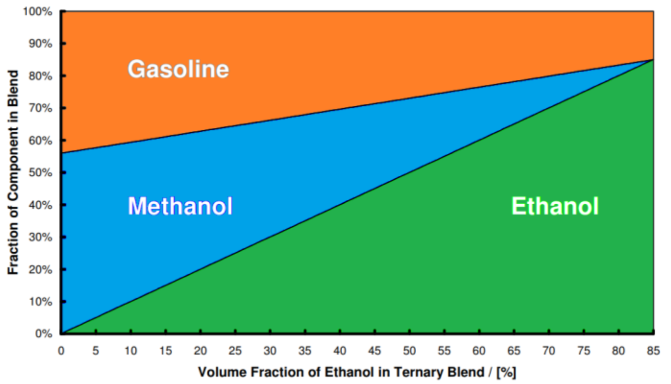
High Efficiency Methanol Engines

- Captive fleets – high energy sectors
- Shipping – ongoing!
- Agricultural-, forestry-, and work machinery
- Long haulage

- Large reduction of CO_2
- Large reduction of soot and NOx
- Large risk reduction from spill

Potential future applications
High Efficiency Methanol Engines

- Drop-in 3% methanol in regular gasoline
  - Ok according to EN228 gasoline standard
- Flex-fuel vehicles (GEM – Gasoline-Ethanol-Methanol)
  - E85 cars originates from M85 cars
- Hybrids – can and should run on renewables
  - Toyota E100 hybrid on Brazilian market
- Low cost sustainable cars on emerging markets



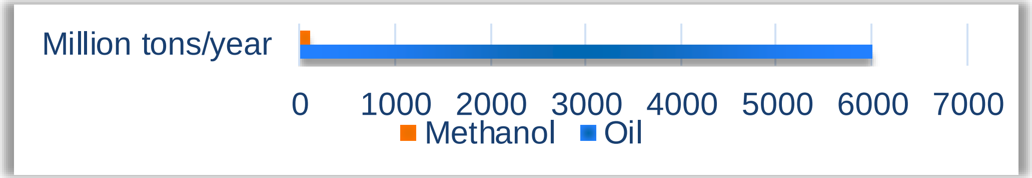
Market penetration considerations

Technology Collaboration Programme
by iea

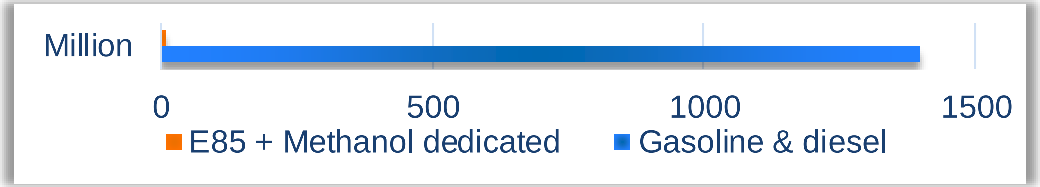
Methanol versus oil

Knowing the challenge

Global production 2019



Number of vehicles 2019



Doubling of transportation by 2050?

How to replace oil?

Technology Collaboration Programme on Advanced Motor Fuels

METHANOL INSTITUTE

Phasing out 6 billion tons of oil annually is not easy

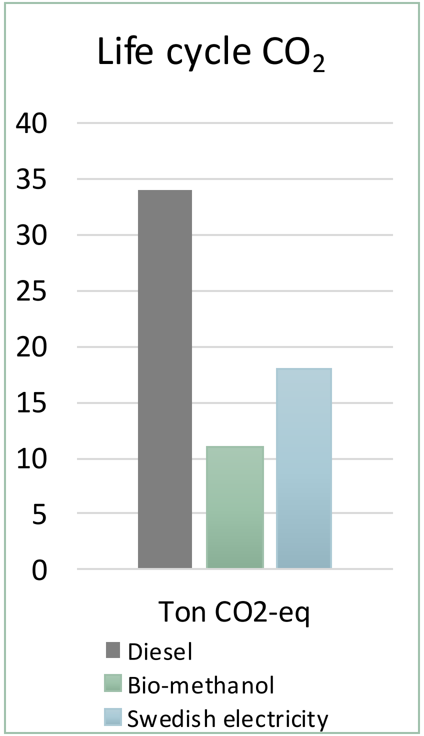
Relevance of various sustainable energy carriers

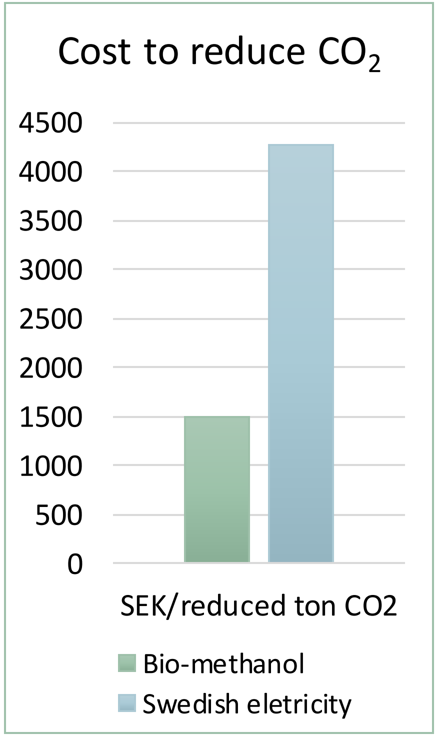
More efficient transportation counters some of the increased energy needs!

- Electric drive on renewable electricity – yes, very important but not enough (IEA 2018 – Future is electric)
- HVO – yes, but probably prioritized for aviation and not enough anyway
- Bio-methane – yes indeed, but too small scale
- Etanol – yes, but not enough – great companion to methanol
- FAME – yes, but not enough
- e-Hydrogen & e-methane – yes, important and great scalability, but practical?
- Bio-methanol & e-methanol – yes, great potential, but not enough on their own

Most based on different and complementery feedstocks! All have their pros, cons, risks and opportunities… another presentation…

Methanol cars versus electric cars





Example:

- Passenger cars
- CO_2-eq from production + use
- 200 000 km WLTP drive cycle
- Brut costs (no tax or subventions)

Quickly changing scenario but shows that bio-methanol is relevant

Barriers?

Few reasons why methanol should not become an important sustainable fuel

- Scalable, affordable and functional
- Engines based on simple and abundant materials

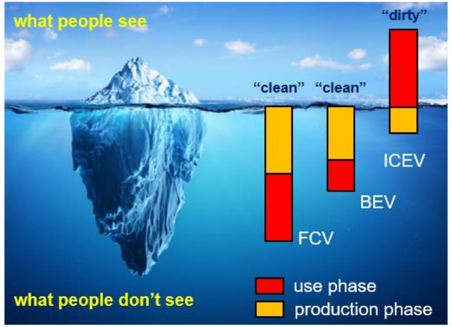
Potential challenges for large scale market penetration of methanol engines:

- Lack of relevant regulations
- Massive break-through on fast charging and new types of batteries for vehicles – depending less on rare materials, allowing increased production of low cost electric vehicles
- Strong cost reduction of fuel cells – making FC vehicles a cost competitive alternative
- Stronger demand for renewable methanol in other sectors

Needs for large scale introduction of high efficiency methanol engines

Legislation

- Holistic lifecycle assessment (LCA) based regulations provide meaning and long term stability markets for sustainable fuels
  - Tail-pipe based regulations "fools the world" and delays important measures against climate change



Bar heights purely for illustrative purposes!

Availability

- Enormous scaling up of methanol production and distribution, relevant engines and vehicles

Technical

- Robust injectors and fueling systems with proof of long term durability
- Fuel standards for neat "fuel" methanol and various blends of methanol.
  - M100, M56 (similar to E85), MD95…
- Certification work for engine and vehicle manufacturers
- R & D into dedicated methanol engines

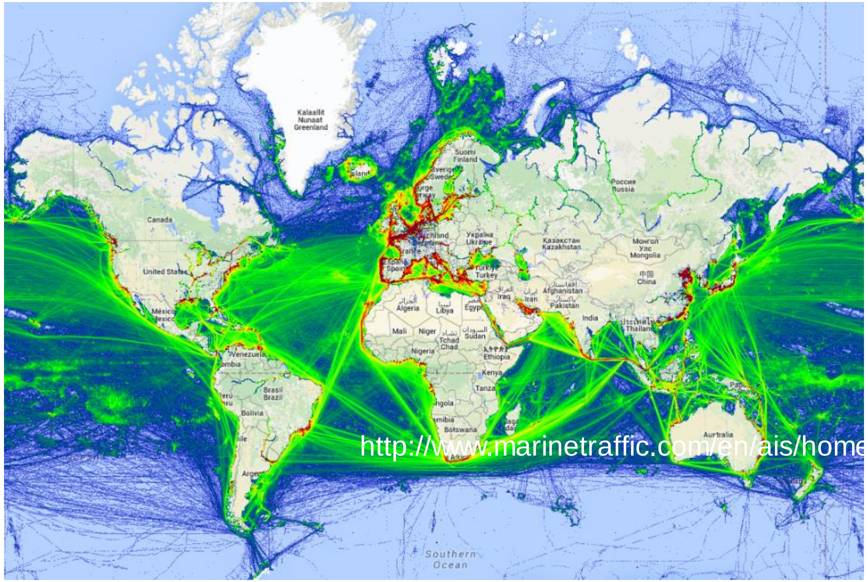
October 26, 2020

AMF TCP Annex 56
Marine Methanol

Päivi Aakko-Saksa
Principal Research Scientist
VTT Technical Research Centre
of Finland

Contents

- Motivation
- Pathways
- Marine engines fot methanol
- Project examples
- Conclusions



Ships travel close to coast where dense population lives

Why clean-burning & climate-neutral marine fuels?

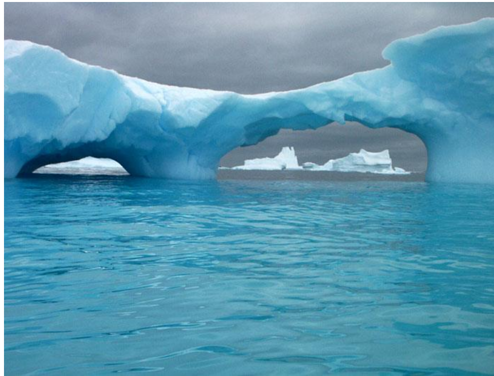
Emission regulations are tightening

Global warming burden of shipping

- GHG strategy of the IMO to cut shipping sector's CO_2 emissions by 50% by 2050 (strategy 2018, rev. in 2023).
- The EU's CO_2 emissions from maritime transport to be cut by min. 40% by 2050 from 2005 levels (EC's White Paper on transport, 2011).

Exhaust emissions harm health and environment

- Fuel sulphur max. 0.1% or scrubbers in SO_x ECAs (2015). 0.5% global limit 2020 (IMO MEPC, 2016)
- NO_x Tier III regulations (2016) for NECA new vessels
- New emissions considered (e.g. black carbon, methane)



Photos: VTT

ADVANCED MOTOR FUELS IEA-AMF Technology Collaboration Programme on Advanced Motor Fuels

METHANOL INSTITUTE

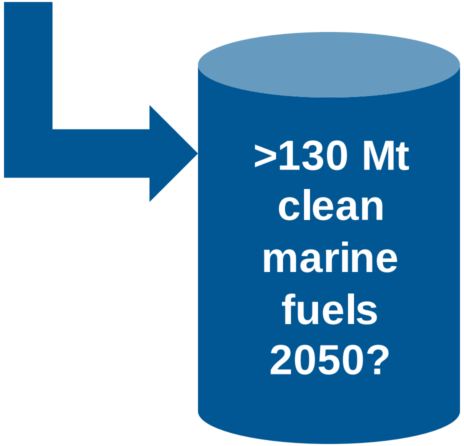
Volume of marine fuels

	SSD e.g. container ships, oil tankers (Mt)	MSD e.g. ferries, cruisers, RoRo, RoPax (Mt)	HSD small, e.g. fishing Vessels (Mt)	**Total** **(Mt)**
Residual	180.5*, 2.3**	26.2**, 0.26*	0.5**, 0.01*	210.3
Distillate	12.2*, 0.4**	20.7**, 0.5*	13.7**, 1*	49.5
LNG	0.03	2.3	0	6.5

SSD = Slow speed diesel MSD = Medium speed diesel HSD = High speed diesel
*2-stroke **4-stroke

Data from Comer et al. (2017) Black Carbon Emissions and Fuel Use in Global Shipping, 2015, ICCT.

GHG strategy of the IMO to cut shipping sector's CO_2 emissions by 50% by 2050



Note: Methanol production capacity is 125 Mt. 40% of demand for fuels (MTBE, FAME, DME, MTG). However, renewable methanol produced only in small scale.

Many fuel options from many sources…

Technology Collaboration Programme on Advanced Motor Fuels

METHANOL INSTITUTE

Sources → **Fuels** → **Engine**

ELECTRICITY
- CO_2&H_2, P2X

BIOMASS
- Lignosellulosic

WASTE
- Manure, plastics

FOSSIL
- Oils, gas, coal

CONVERSION TO

Methane

Methanol

Diesel-type

Petrol-type

LPG-type

Engine + **Emission control**

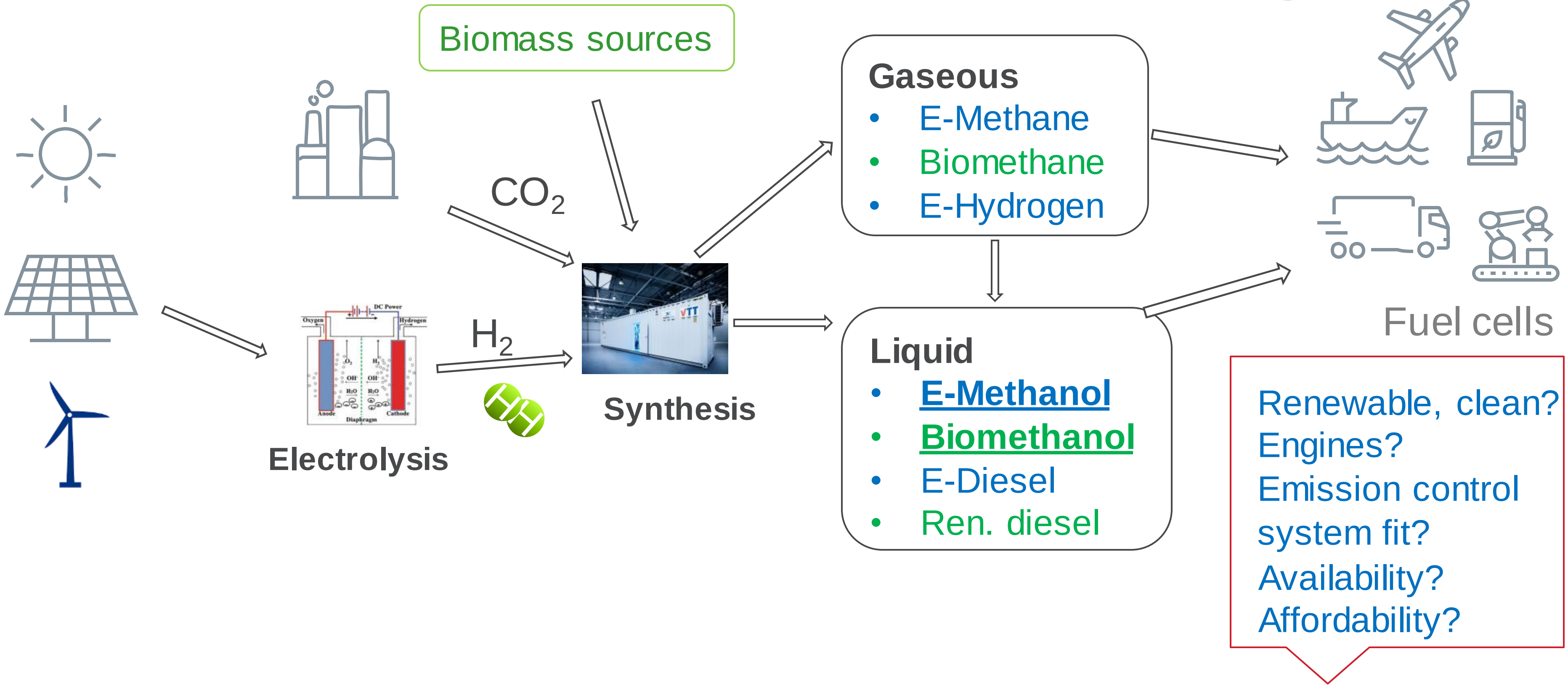
Climate & health benefits

Low GHG

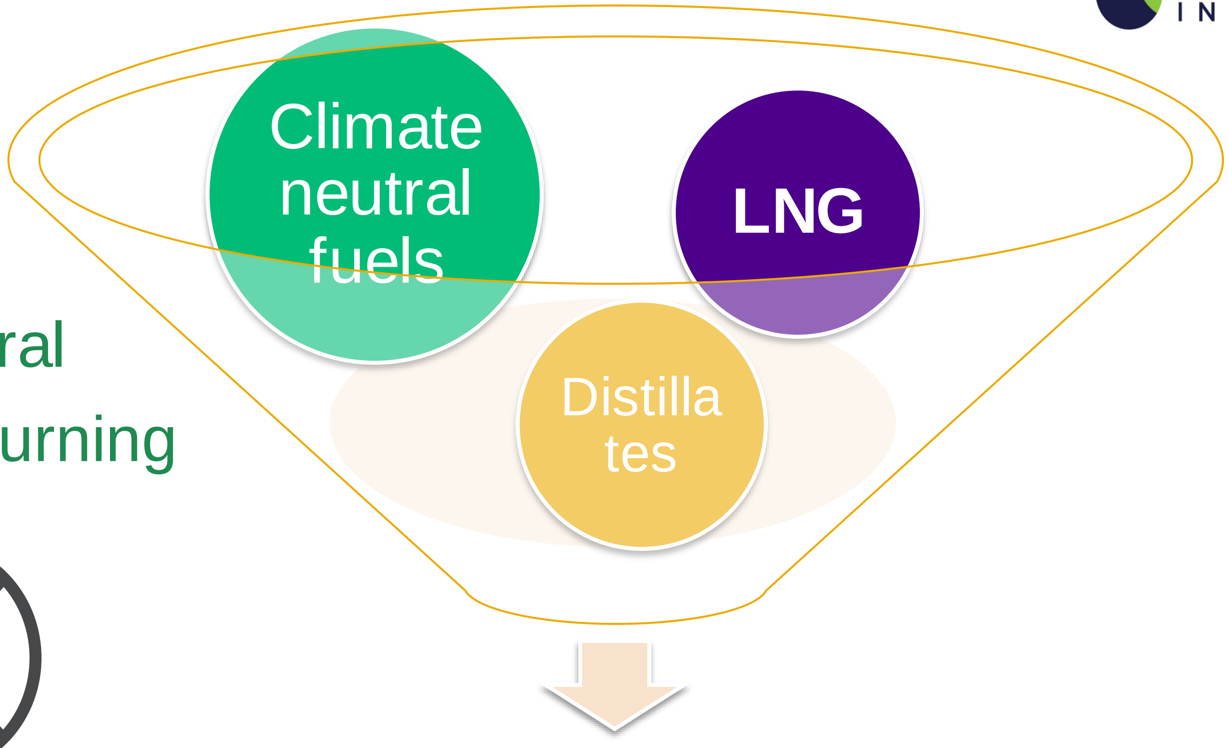
Low SOx, NOx, BC, PM

…can be clean in engines with emissions control

Biofuels and sustainable e-fuels (P2X)



Marine fuels 2050



Climate-neutral

Clean-burning

50% GHG reduction

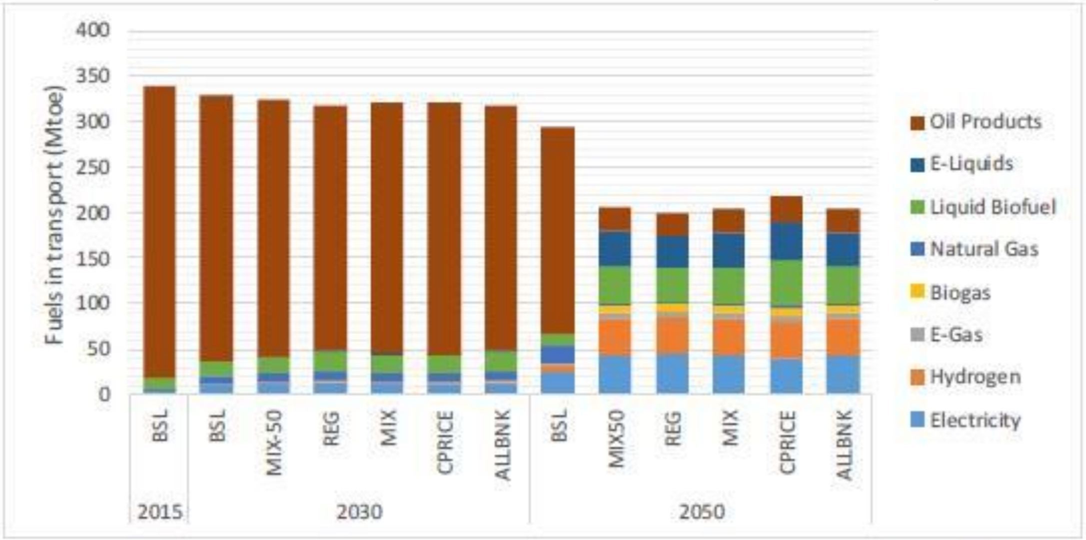
Marine and aviation sectors most dependent on liquid fuels

Technology Collaboration Programme on Advanced Motor Fuels

- Decarbonising electricity is progressing and major steps anticipated by 2050.
- E-liquids and liquid biofuels are foreseen strong contributors e.g. in Europe in 2050 in several scenarios.
- Methanol is liquid and can be produced from biomass or sustainable electricity. Included in definitions of sustainable fuels?

Figure 63: Fuels in transport (including aviation and maritime navigation)

Europe



Source: 17.9.2020 SWD(2020) 176 final Part 2/2
Impact assessment. Stepping up Europe's 2030 climate ambition
Investing in a climate-neutral future for the benefit of our people

Source: PRIMES model

Marine engines for methanol

- Marine diesel engines in ships are mainly **large slow speed diesel engines** and **large medium speed diesel engines**. High speed diesel engines are used in smaller vessels.
- Wärtsilä and MAN methanol duel-fuel engine concepts for large diesel engines.
  - Wärtsilä methanol-diesel retrofit engine concept.
  - MAN dual-fuel methanol engine concept for new-builds.
- Methanol engines designed towards high efficiency (e.g. 42-57%) would compensate low energy content of methanol, and with ultra-low emissions (soot-free combustion).

Methanol use in shipping

- Methanol is one of the marine fuel alternatives having engines available on market.
- **Wärtsilä methanol-diesel retrofit concept**: dual-fuel technology uses diesel as a back-up fuel. Common-rail system for methanol injection, cylinder heads, fuel injectors and changes in fuel pumps. (Haraldson 2013). Used in Stena Germanica in Sweden.
- **MAN has developed dual-fuel methanol engine technology** that is used in more than ten 50,000 dwt tankers.

Picture: Stena Line

Picture: Marine Propulsion News

MAN demonstrated the ME-LGI engine for the shipowners in 2015

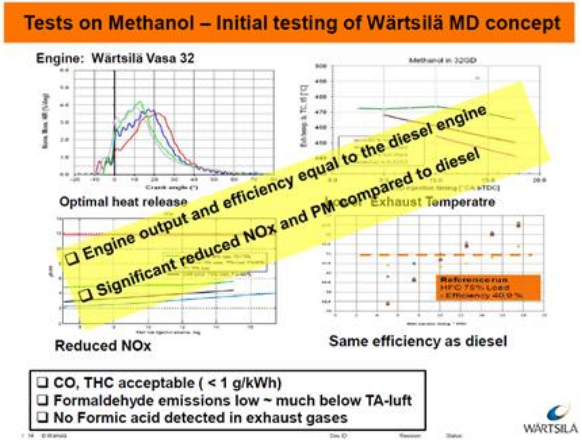
Dual-fuel gas-diesel concept

Preliminary testing example at VTT

At VTT testing with Wärtsilä Vasa 4R32

LN/GD 1.6 MW, CR 13.8:1*:

- NO_x 3-5 g/kWh (Low Tier II)
- Low PM (FSN~0,1 HFO as pilot)
- Low formaldehyde emission.
- Efficiency comparable to running on diesel.



* Haraldson, Lennart. Methanol as marine fuel, 19 March 2015, Helsinki.

Photo: VTT

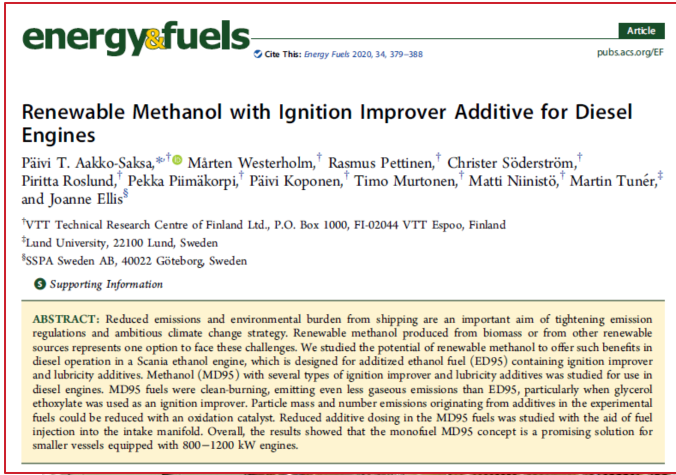
MD95 / Scania engine concept

Potential for smaller vessels

- VTT MD95 study with Scania DC9 E02 270 EEV alcohol engine (market). 8.9 dm^3, CR 28:1, 198 kW.
- MD95 blends were clean burning. Low aldehyde emissions. Particles are "liquid"-type originating from additives and assumedly removable by oxidation catalyst.
- Similar performance for MD95 and ED95 fuels.

MD95 fuels:

- Methanol, dry (80-85 wt%)
- Water (5.5 wt%)
- Ignition improvers
- Lubricity improver
- Stability additive

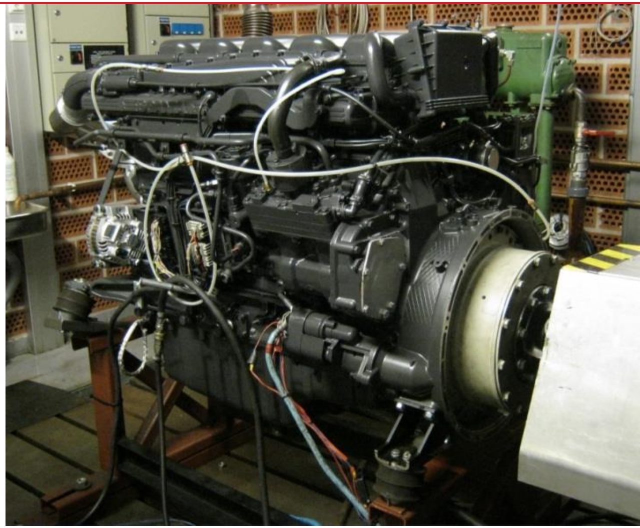

energy&fuels Article
Cite This: Energy Fuels 2020, 34, 379−388 pubs.acs.org/EF

Renewable Methanol with Ignition Improver Additive for Diesel Engines

Päivi T. Aakko-Saksa,[*,†] Mårten Westerholm,[†] Rasmus Pettinen,[†] Christer Söderström,[†] Piritta Roslund,[†] Pekka Piimäkorpi,[†] Päivi Koponen,[†] Timo Murtonen,[†] Matti Niinistö,[†] Martin Tunér,[‡] and Joanne Ellis[§]
[†]VTT Technical Research Centre of Finland Ltd., P.O. Box 1000, FI-02044 VTT Espoo, Finland
[‡]Lund University, 22100 Lund, Sweden
[§]SSPA Sweden AB, 40022 Göteborg, Sweden

Supporting Information

ABSTRACT: Reduced emissions and environmental burden from shipping are an important aim of tightening emission regulations and ambitious climate change strategy. Renewable methanol produced from biomass or from other renewable sources represents one option to face these challenges. We studied the potential of renewable methanol to offer such benefits in diesel operation in a Scania ethanol engine, which is designed for additized ethanol fuel (ED95) containing ignition improver and lubricity additives. Methanol (MD95) with several types of ignition improver and lubricity additives was studied for use in diesel engines. MD95 fuels were clean-burning, emitting even less gaseous emissions than ED95, particularly when glycerol ethoxylate was used as an ignition improver. Particle mass and number emissions originating from additives in the experimental fuels could be reduced with an oxidation catalyst. Reduced additive dosing in the MD95 fuels was studied with the aid of fuel injection into the intake manifold. Overall, the results showed that the monofuel MD95 concept is a promising solution for smaller vessels equipped with 800−1200 kW engines.



*) Murtonen et al., Results with Scania ethanol engine using different fuels. Copenhagen 26.2.2015. (AMF Annex 46. Nylund N-O et al. 21st ISAF Symposium, 2015.

Aakko-Saksa et al. Energy&Fuels. 2020, 34, 379-388. (SUMMETH project).

Emissions from marine engines using methanol are low

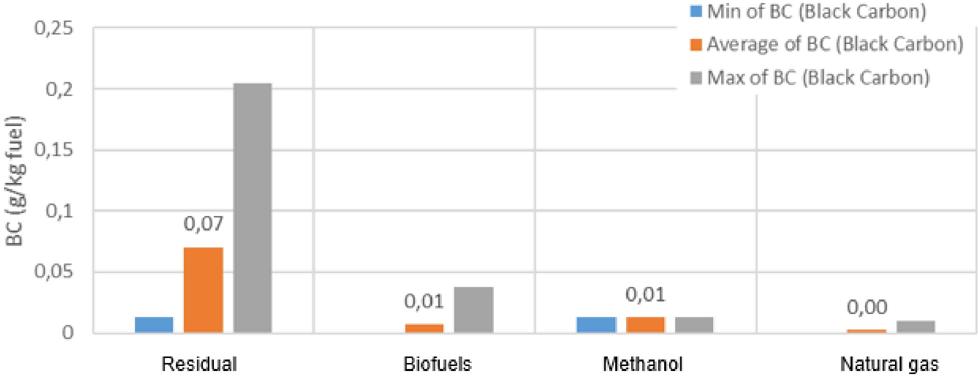
Ship emissions review (INTENS project report)

RESEARCH REPORT VTT-R-00335-19

Ship emissions in the future - review

Authors: Päivi Aakko-Saksa, Kati Lehtoranta

Confidentiality: Public



Black carbon (BC) emissions from marine engines (MSD and SSD). Engine loads >50% MCR. Example from a report of INTENS project.

INTENS project website:
http://intens.vtt.fi/index.htm

The sustainable marine methanol "SUMMETH" project

Focus on smaller vessels with clean methanol

- Market study of smaller vessels in NW Europe
- Development work for smaller methanol marine engines
- Case study design for methanol conversion of a road ferry
- Renewable methanol supply chain investigation

- Website: www.marinemethanol.com

PROJECT PARTNERS

CO-FUNDED BY

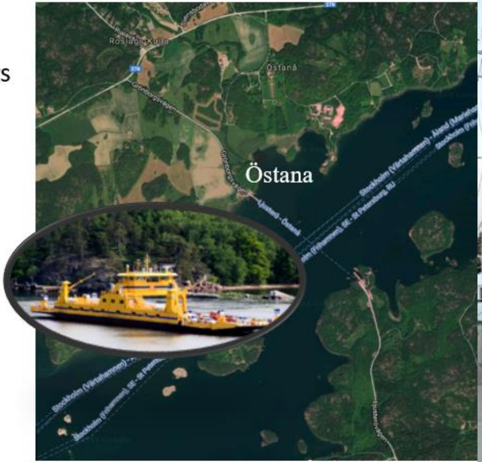
Photo: Kasper Dudzik

The sustainable marine methanol ”SUMMETH” project

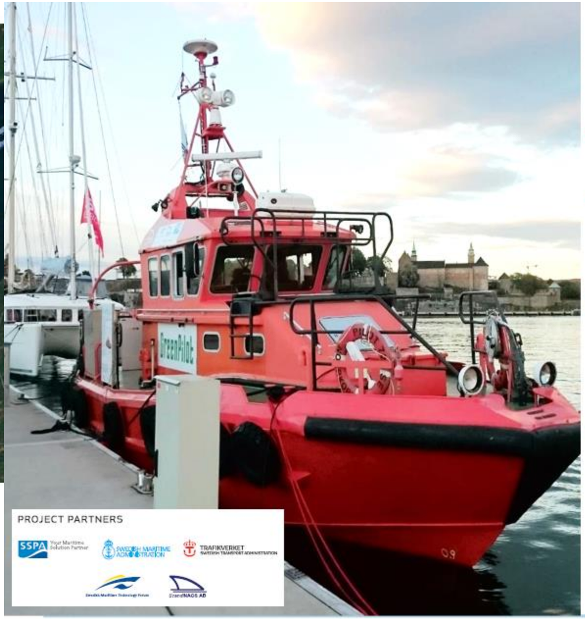
Case study of road ferry conversion

Case study: Conversion of a Swedish Road Ferry to methanol operation

- M/S Jupiter road ferry – 86 metre length, capacity for 397 passengers and 60 cars
- Currently running on diesel fuel, bunkered by truck
- Developed a methanol conversion design with recommendations for fuel storage and supply, safety systems, and bunkering
- Emissions reduction potential compared to operation on diesel fuel



Conversion design developed by project partner ScandiNAOS



GreenPilot

- Conversion of a Swedish pilot boat to run on methanol
- Two engines tested on board with methanol – using spark-ignited port fuel technology
- Fossil-free methanol produced from pulp mill black liquor was used in the tests
- On board emissions measurements verified very low particulate emissions and low NOx

Co-financed by SWEDISH MARITIME ADMINISTRATION TRAFIKVERKET SWEDISH TRANSPORT ADMINISTRATION METHANOL INSTITUTE

New project in Sweden

Harbour tug, pilot boat, coast guard vessel

Lund University | LTH Faculty of Engineering

FASTWATER

Join our Webinar on November 5th, 2020

Methanol: a sustainable, scalable, storable energy carrier

A JOINT INITIATIVE BY LUND UNIVERSITY AND THE FASTWATER CONSORTIUM

FASTWATER consortium fast tracks commercial pathway to climate neutral methanol as marine fuel

A consortium of Europe's maritime research and technology leaders have launched the FASTWATER project to demonstrate the feasibility of retrofit and newbuild vessels to operate on methanol as a pathway to fossil-free shipping.

With funding from the European Commission, FASTWATER will focus on high impact outcomes, designing solutions for existing ships and designs for newbuildings, demonstrating methanol as a future-proof marine fuel to create a fast track to carbon neutral shipping.

Harbour tug, pilot boat, and coast guard vessel

The project aims to commercialise medium and high-speed methanol-fuelled engines for shipping. Consortium members, including original engine manufacturers, shipyards, naval architects, ship owners/operators, port and maritime authorities, classification, fuel producers, and research institutes, will demonstrate feasibility on three vessels running on methanol fuel: a harbour tug, a pilot boat, and a coast guard vessel.

PARTNERS:

Lund University, BALance Technology Consulting, Anglo Belgian Corporation, Heinzmann, Port of Antwerp, Ghent University, ScandiNAOS AB, SSPA, Meyer Werft, Lloyd's Register, National Technical University of Athens, Super Toys, Methanex, Swedish Maritime Administration

Inland waterways – Greenfuel project example

MS innogy fuel cell system

- Demonstration of methanol from CO2 (from air), green electricity and water, for use in the vessel MS innogy and in cars.
- MS innogy fuel cell system (35kW) and battery pack. The FCs are range extenders.
- Waste heat from fuel cells for methanol reformation → high electrical efficiency 40-50%.
- No harmful air emissions, and system is CO2-neutral, low noise and vibrations.
- Knowledge and experience gained from the Pa-X-ell test program (methanol FC on a cruise ship; electricity for the ship's power grid.)

Methanol Fuel Cell Powered Passenger Ferry Sets Sail

BY **THE MARITIME EXECUTIVE** 08-28-2017 07:28:15

The MS innogy, the first vessel in Germany to be powered by methanol fuel cells, was named on Friday. The passenger ferry, which will sail on Lake Baldeneysee, Essen, features a fuel cell system manufactured by the Danish fuel cell manufacture SerEnergy.

https://www.maritime-executive.com/article/methanol-fuel-cell-powered-passenger-ferry-sets-sail

High-Pressure Direct Injection (HP-DI) of Methanol with Diesel Pilot

Yabin Dong, Ossi Kaario, Martti Larmi, Aalto University, Finland

HP-DI methanol, non-premixed dual-fuel (DF)

- DF engine, specially designed cylinder head. Centrally located methanol injector.
- 1500 rpm, CR 16.5. Control of methanol inj. duration.
- IMEP 4.2-13.8bar, methanol substitution (MSR) 45-95%.
- E.g. with MSR 95%, stable combustion due to high IMEP. HC emissions dropped from 26 g/kWh to 0.6 g/kWh.

Conclusions

Early fuel injection has advantages in the DI methanol DF engine. High IMEP (high engine load), high MSR and early fuel injection promising for methanol utilization, combustion stability and emissions.

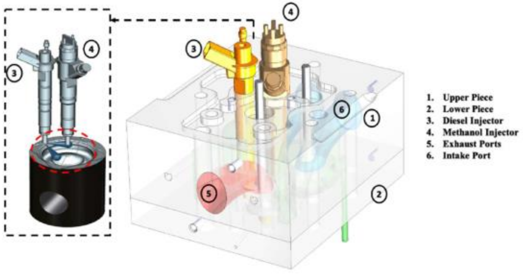
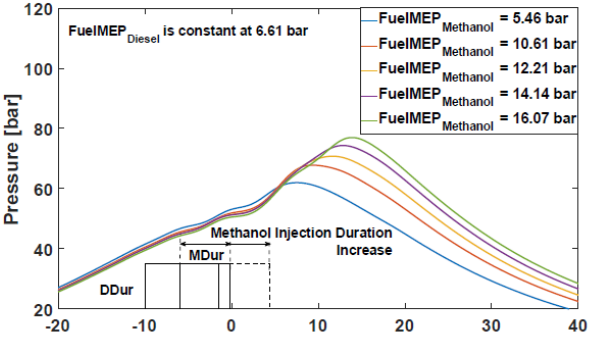
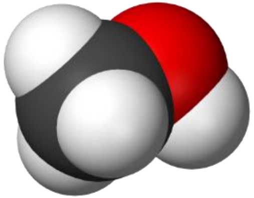


Fig. 1: Two-injector, Three-valve Cylinder Head Design



$FuelMEP_{Diesel}$=6.61bar, $FuelMEP_{Methanol}$=5.46 to 16.07bar

Methanol pros
Methanol cons



Technology Collaboration Programme on Advanced Motor Fuels

METHANOL INSTITUTE

Pros

- Methanol is **liquid fuel**.
- Methanol is already **used for fuels**.
- **Can be of biomass or P2X origin**.
- **Marine methanol engines on market**
- **Low emission** combustion.
- Simple structure **enables design of high efficiency engines.**
- Methanol is **biodegradable.**
- **Tanks can be in the double bottom**.
- Methanol can be **safer than gasoline**.

Cons

- Low heating value.
- Safety issues (toxic like traditional fuels, flammable, burns with invisible flame)
- Possible formaldehyde emission (removed by oxidation catalyst).
- Alcohol compatible materials needed due to corrosion risk.
- Methanol is not soluble in diesel*.

*) Soluble in gasoline with co-solvents.

Renewable methanol offers potential to reduce both climate burden and heath risks of shipping

- Liquid fuel option for marine engines
- Low GHG emissions when of renewable origin.
- Low SOx, NOx, PM and BC emissions.
- Methanol can be used in ICEs and fuel cells.