DME 9, 15 - 17 June 2022, Zurich & Dübendorf

CO_2 Utilisation via 3D printed reactor and solid oxide cell technologies

Vesna Middelkoop,
Lamiaa Biaz

CO2FOKUS ADVANCING CO_2 CONVERSION

LGi sustainable innovation

vito

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

Overview

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

Overview

CO_2Fokus facts and figures

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

13
PARTNERS

48
MONTHS

01/07/2019
STARTING DATE

8
COUNTRIES

EUContribution:
€3,994,950.00

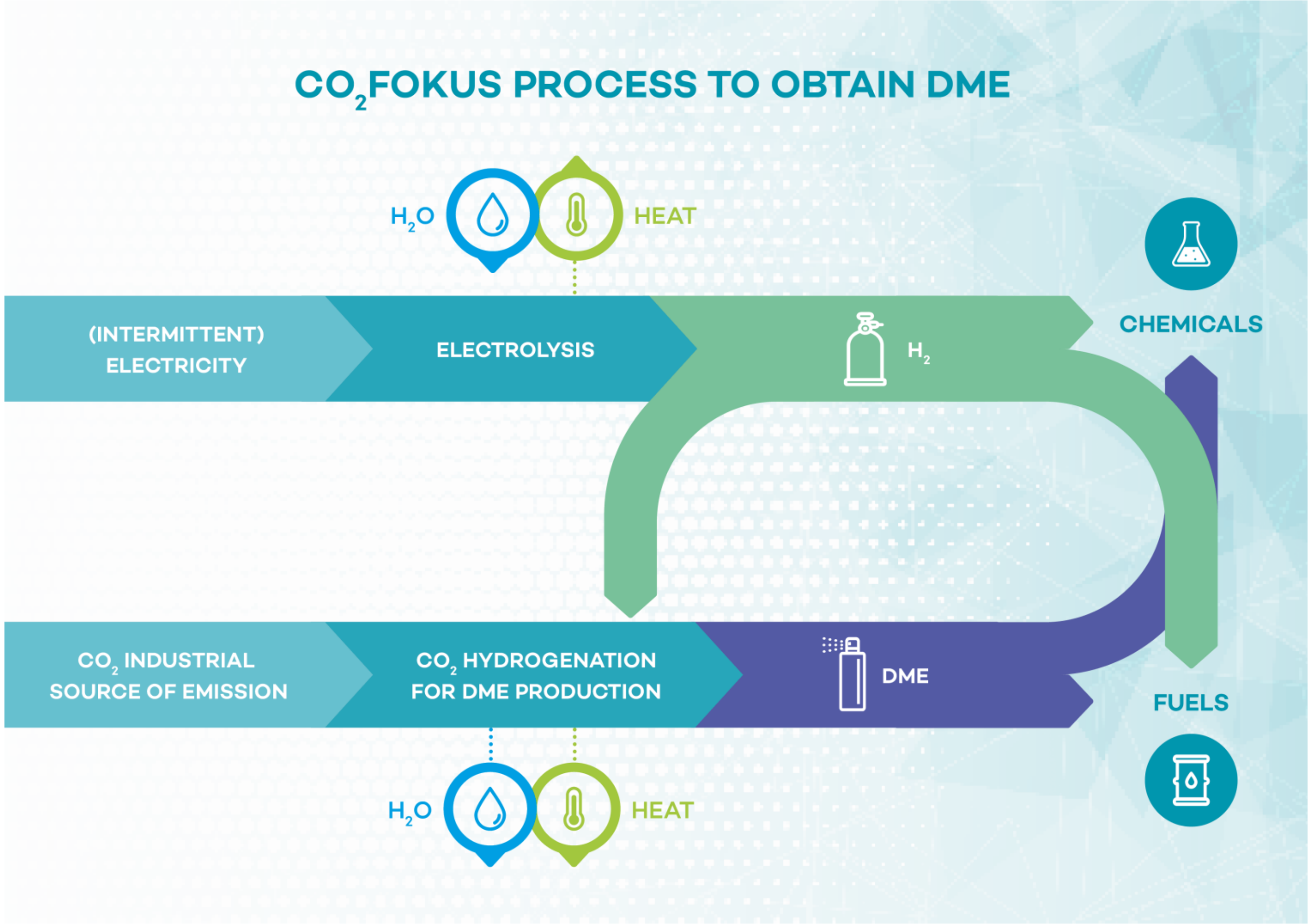
COORDINATED by
vito

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

Agenda

CO_2Fokus concept

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061



CO_2Fokus at a glance

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

A cutting-edge technology to directly convert industrial CO_2 into DME using:

- 3D printed multichannel reactors
- solid oxide electrolyser
- integrating them in industrial environment with CO_2 point source at end-user facilities

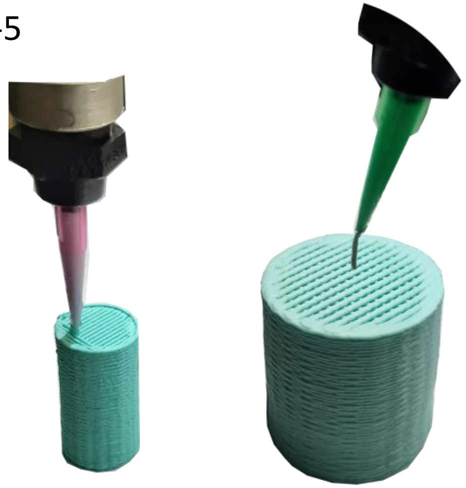
3D printed catalysts for direct CO_2-to-DME

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

Cu-ZnO-Al_2O_3 or ZrO2-based formulations mixed with H-ZSM-5

as-prepared

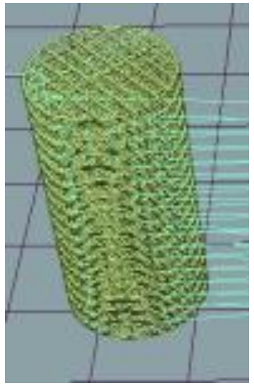
mixing



printing

calcination

calcined



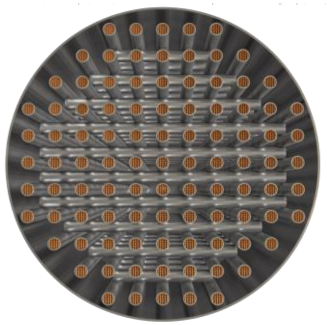
optimising
the printing model

varying design and size

integration
into the reactor

3D printed multi-tubular millireactors

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061



PROCESS INTENSIFICATION
↑↑↑ A/V

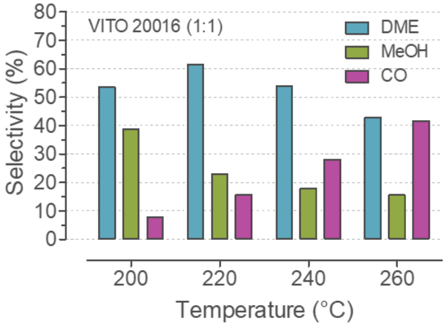
Characteristics required of the reactor:

- Improve the mass transference
- Optimisation of heat dissipation
- Dimensional uniformity of the tubes
- Thermal and mechanical stability
- Ease of handling

while tuning the operating parameters

16 Millichannel Reactor			
Space velocity, NL/kg$_{cat}$/h	T, °C	CO_2 Conversion, %	DME Selectivity, %
8 800	280	12.1	31.0

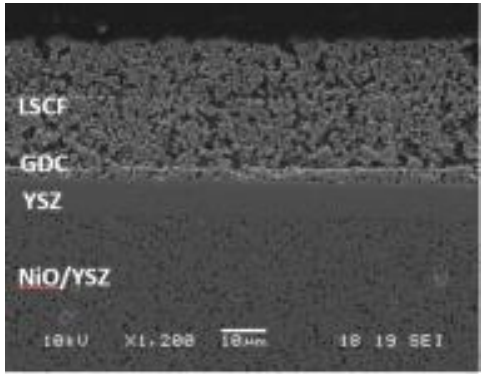
TRL4-TRL6

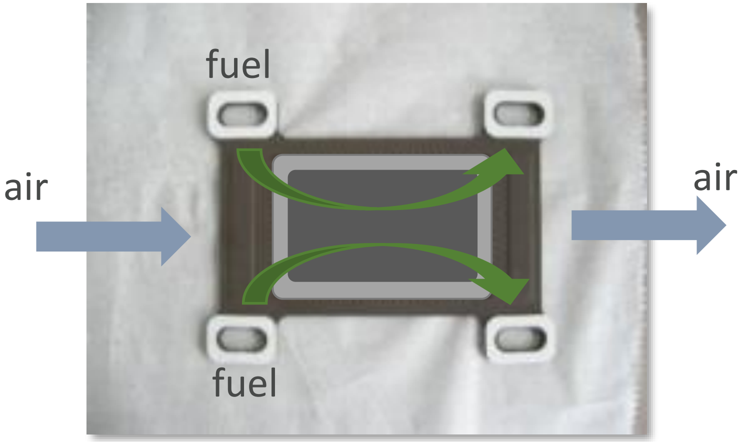


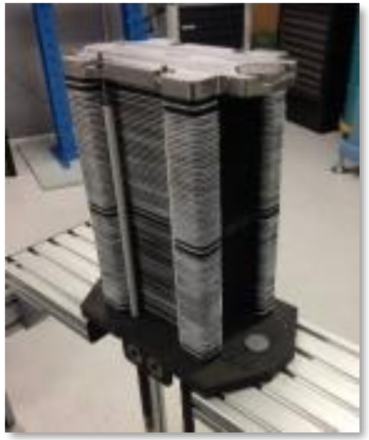
Solid oxide electrolyser cell and design, development for H2 production

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

cell design







- Thin (ca. 250 µm) anode support with GDC/LSCF cathode
- Low cost state-of-the-art materials
- High mechanical strength and reliability

performances	unit	nominal
Conversion	%	60
H_2 Production	Nl	0.30-0.32
Stack power DC	kW	4.5
Thermal cycling	-	100-200

Prototype demonstration and on site integration

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

Key Performance Indicators (KPI)	State-of-the-art	CO2Fokus
Energy efficiency (MJ/ton) DME	2300#	20-30% reduction
Catalyst & reactor design	TRL 3-4	TRL 6
Catalyst durability (hrs)	10^2	10^3
Pressure (bar)	30-70	30
Temperature (°C)	280	250
CO_2/H_2 feed (N L/h)	33/100	500/1500 or larger by numbering tubes
DME yield (%)	20-25	>30 (multichannel reactor)
CO_2 conversion (%)	30	>30
Overall H_2 conversion (%)	50	50

Reactor and SOE units will be integrated into existing carbon-intensive industrial facilities for on-site recycling of CO_2

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

Technology advance beyond the state-of-the-art

- Tuning of catalyst composition and morphology (shape/geometry/porosity)
- Multi-tubular reactors scale-up/increasing throughput: stacking up monoliths and numbering-up tubes
- Reactor design: controlled shape, geometry and macrostructure: large surface to volume ratio, enhanced mass and heat transfer and 10-20% increase in reaction performance
- SOEC Electrolysis for in situ H_2 production
- Integration and operation at industrial CO_2 point source to demonstrate direct conversion of CO_2 and H_2 to DME

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

Agenda

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

PESTEL analysis of the DME market

Political

- **Political changes will be required to extend DME use as an end-product (including as a fuel)**
  - Convincing policymakers and supporting policy changes are the major steps to consider
- **Politicians' consideration set to choose an energy**
  - systemic approach for decarbonization
  - consider a system of solutions for each sector rather than setting for one specific energy (space optimization)
  - geopolitical considerations: shift to renewables, secure energy supply, to preserve economic interests
- **Political steps to use DME as a fuel**
  - After having captured CO2 from industrial emissions, it is reemitted in the atmosphere
  - If decarbonization using such a technology is a debate, the defossilisation of the transportation sector can be achieved with this renewable fuel
  - Decreasing the dependency on fossil fuels is a current debate in Europe and an opportunity for CO2-based fuels
  - The 0 gram CO2 emission target from 2035 is a barrier to use DME as a fuel
  - However, considering that the use of e-fuels does not require to replace combustible engines (while it is the case for the electric vehicles), the inclusion of e-fuels in a mix, could be part of climate mitigation and defossilisation solutions
  - Influencing policy makers to increase the rate of renewable fuels in the transportation mix is the most important political step to introduce DME or more generally renewable fuels in this sector

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

PESTEL analysis of the DME market

Economic

- According to experts the price of DME as a fuel would be higher than current fossil fuels
- The price of rDME produced with a technology such as CO2Fokus might be higher than grey DME:
  - **Energy taxation is an economic leverage** that could influence the price of DME
    - As of 2022, if used as a fuel, DME energy tax is the same as fossil fuels
    - However, to incentivize the use of DME and decrease its price to be competitive with other fuels, the promotion of a lower energy tax rate is needed
  - Besides, **CO2 tax** (EU emission trading system) is beneficial for CO2Fokus technology, as it captures carbone
    - The tax is about 200€ and will make CO2Fokus product much more competitive
    - The competitive advantage depends on the rate of the carbon tax

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

PESTEL analysis of the DME market

Societal

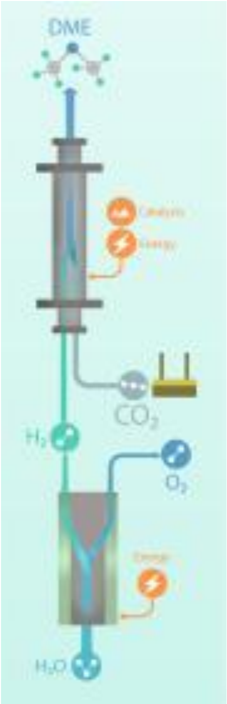
"Even with a great technology, if society does not want or like it, the implementation can be very challenging." (Anonymous expert)

- **Public perceptions about energy:**
  - Citizens tend to be more concerned about affordability of energy rather than its sustainability which is not a priority for them
  - Public perceptions about energy differ across European countries and regions
  - Public perception of energy is often linked with geopolitical factors
- **Steps to influence the use of DME and CCU at a society level**
  - Fact-based information and education on circular economy and CCU topics are important to change the perception and opinion of the public
  - Demonstration that the innovation is tied with people' interests
  - Dialogue with policy makers and CCU and CCS stakeholders would be more determinant than the general public
  - Demonstration of the competitive first-mover advantages for industries for using CO2-based technologies
  - Building business cases with positive outcomes for media -> However, bringing attention to the project at high level may also be risky as it may create some opposition
  - Exchanging with NGOs may be useful in order to understand their views and concerns

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

PESTEL analysis of the DME market

Technological



- Experts highlighted that:
  - Grey DME process is the most widespread
  - Difficulty to scale the current process

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

PESTEL analysis of the DME market

Environmental

- Blue hydrogen recognized in the current legislation as a way to transition to green hydrogen,
  - Renewable hydrogen, including green and blue hydrogen are relevant to decarbonisation.
  - Hydrogen gained much importance in the recent years, which is determining for the CCU market

- CO2Fokus produces DME from industrial emissions that would have gone to the atmosphere, and which will still go to the atmosphere ultimately if used as a fuel
  - However, if it had to replace (at least partly) diesel, it would reduce fossil fuels dependence and if it doesn't avoid CO2 emissions when the fuel is burned, it would avoid emissions from fossil resources that would have been used to produce an equivalent fuel

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

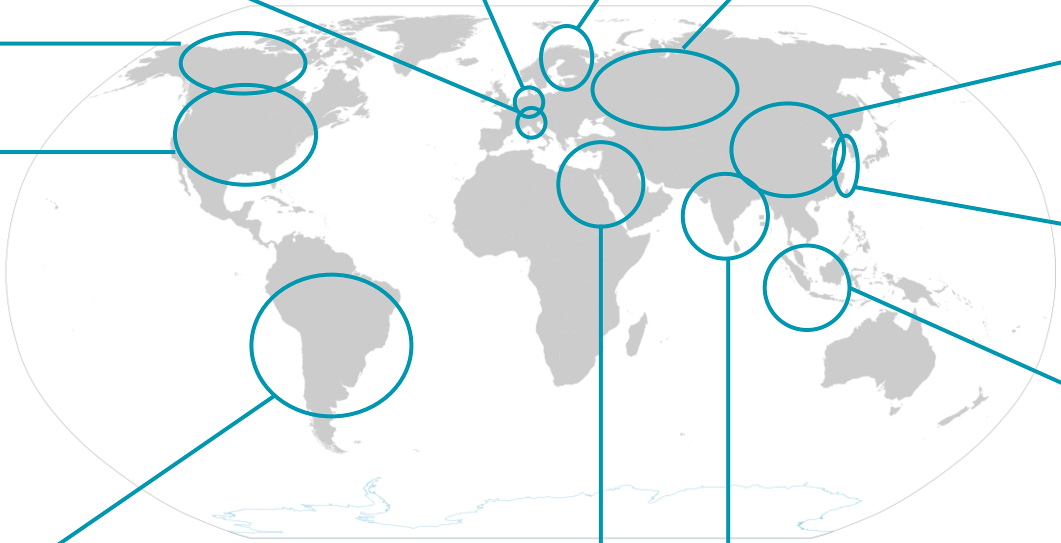
PESTEL analysis of the DME market

Legal

- In the regulatory environment that aims to reduce the amount of CO2 in the atmosphere, classic carbon capture and storage (CCS) is governed by the EU CCS regime.
- **CO2Fokus is excluded from the EU ETS, as CO2 would be emitted**
- As of 2022, several regulations and regulatory incentives for the decarbonisation of energy and industry co-exist, but there is a regulatory gap that needs to be addressed to cover CCU
- Therefore, legislators need to be persuaded that the case of use where carbon is captured, used and reemitted should be included in the EU ETS
- Legal experts highlighted however that there is no legal barrier to use the CCU technology to capture carbone from industrial emissions and use it further in a chemical reaction
- Legal and regulatory incentives are required for using DME as a fuel. According to our legal expert, the regulatory incentives to use a CO2-based fuel is a challenge, and the way captured carbon emissions will be addressed by the regulatory regime will depend on regulatory incentives from the EU
- Beyond the carbon capture incentive for CO2-based fuels, there is a barrier to use DME as a fuel. Indeed, the current CO2 emission standards for new vehicles do not consider renewable fuels
- **According to E-fuel Alliance expert, to increase investments in renewable fuels the current target of 2.6% in 2035 for renewable fuels and non-biological origins, should be raised to 5%**

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

DME geopolitical map



Canada:
Market interested by rDME and by replacing diesel, including for power generation

Zurich/Italy:
Fiat investments in DME

Germany:
Grey DME, interested in rDME

Sweden:
Bio DME leader

Russia:
Producer of Grey DME for aerosol use mainly

China:
Important DME player
Produce DME from coal and might switch to natural gas
Use LPG blending for heating

USA:
Market interested by rDME and by DME as a fuel and LPG blend

Korea:
Important challenger in the region
Produce grey and rDME
Actively developing partnerships aboard

Indonesia:
Interested by DME
Open to DME trucks projects

South America:
There could be a market to replace diesel as a source of power generation

Mena:
Pioneered DME projects with Korea, but project ended because of geopolitical turbulences

India:
Original idea was to use DME for power generation. Million dollars invested but project failed.

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

DME market players

	North America	Europe	Asia
Traditional DME	Chemours	Shell, Linde, Nouryon, AEROSOLEX, PCC Group	中国神华 China Shenhua, TOYO Engineering, CEEC 中国能建 Energy China, Mitsubishi Gas Chemical, JOVO, KOGAS
Renewable DME	oberon FUELS, ChemBioPower, Green Futures Inc (Keep The Engine Change The Fuel), Enerkem	Haldor Topsøe (Catalysing your business), Circular Fuels Ltd, Dimeta	AR Challenges, BIO FRIENDS

recycled for agricultural use for accelerated crop production

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

rDME Segments

CCU market	Example of CCU projects in Europe: • Power to Methanol project in Antwerp • LafargeHolcim recycles CO2 for agricultural use (crop production) • CO2 to methanol by Sweedish CCU plant
Diesel substitute	• Diesel substitute for heavy duty vehicles (HDVs) or shipping • Diesel substitute for agriculture machines
Liquid Petroleum Gas (LPG) blend	• rDME can be blended at 20% into LPG for use in existing LPG vehicles • LPG blend applications for heating
Hydrogen career	• Transportation of hydrogen: a liter of liquid DME contains more hydrogen than a liter of hydrogen
Industrial Use	• Aerosol propellant • Chemical solvent • Refrigerant
Power Generation	• Electricity production

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

Transportation energy mix in Europe

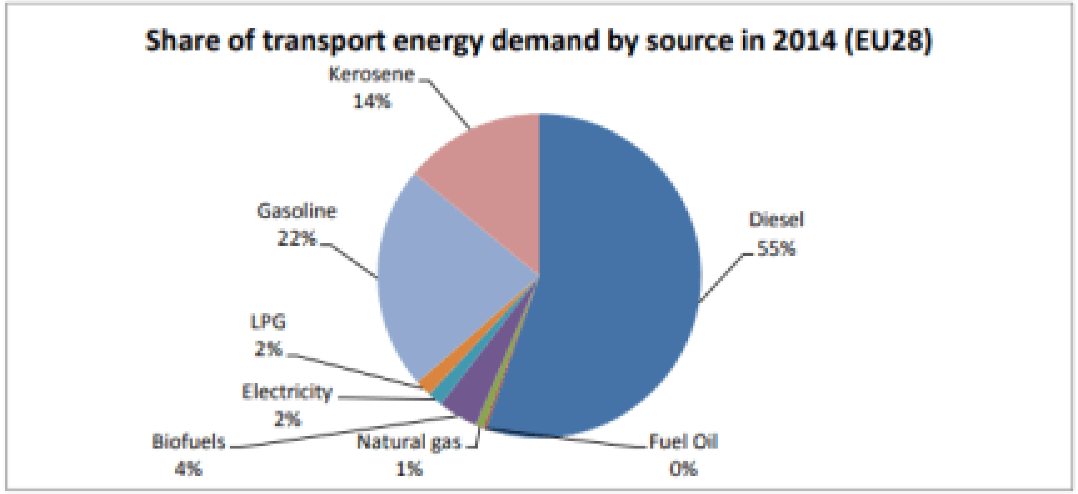


Figure 2 - Share of transport energy demand by source in 2012 (EU28). Source: Eurostat

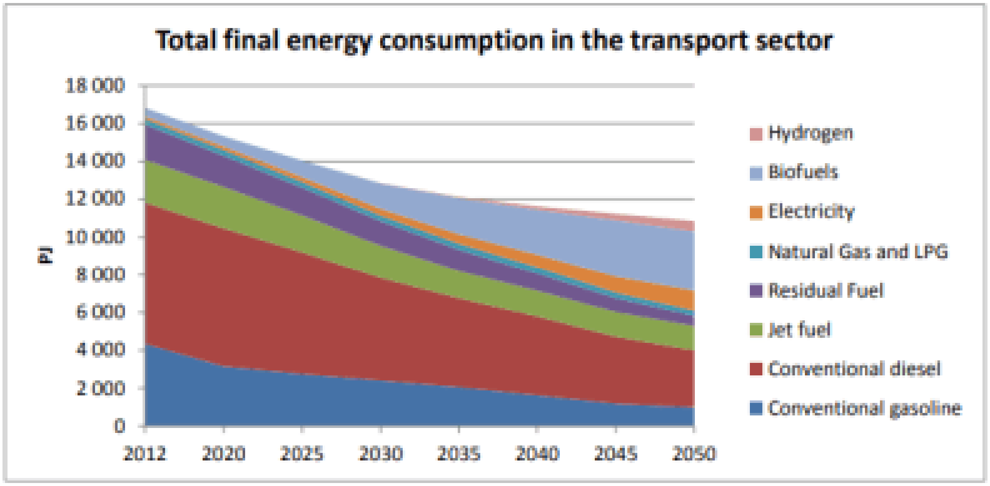
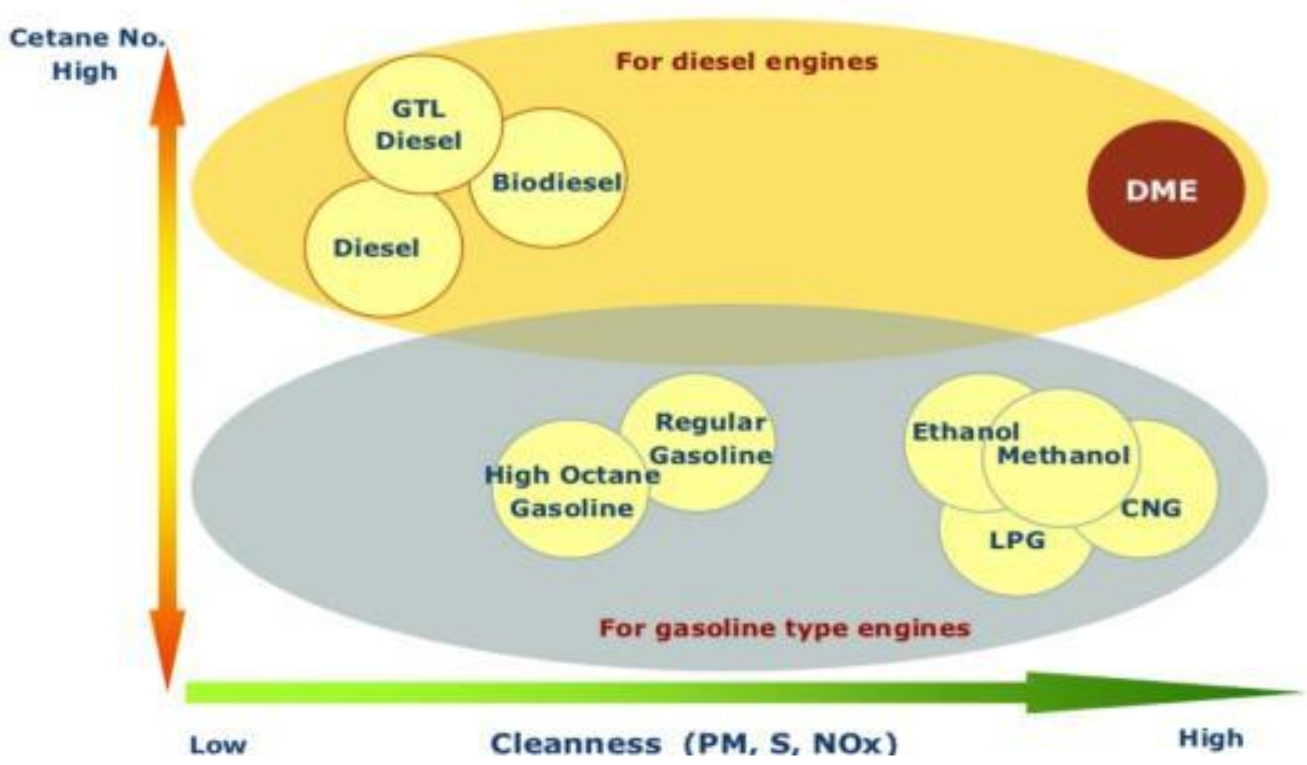


Figure 7 - Total energy consumption in the transport sector in the 2 degree scenario in EU28 (PJ) (Source: IEA ETP (2015))

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

Potential of DME in replacing diesel



As an alternative fuel, DME can address:

- Energy security,
- Energy conservation,
- Environmental concerns,
- The pragmatic realization of depleting petroleum reserves

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

Heavy Duty Truck (HDV) market

- As defossilisation options for the heavy-duty transportation are currently limited, this could represent a market opportunity for DME to replace diesel in HDVs
- Several truck pilots conducted across the world were promising and showcased the great performance of DME within truck engines
- The tests conducted were based on real operations and included filling stations
- As for the DME trucks used, most of the engine remained unchanged, but some component such as the fuel injection system, were tailored to adapt to the DME fuel
- Project pilots:
  - Oberon Fuels
  - Volvo Trucks
  - Mack Trucks
  - Ford Motor Company
  - Bio Friends Inc.

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

Heavy Duty Truck (HDV) market

Climate impact	• Clean fuel that can contribute to defossilisation • Lower GHG emissions, reduces SOx, NOx and soot emissions compared to diesel
Energy efficiency	• Half the energy density of diesel fuel (approximately 55 %) • Requires the installation of fuel tanks twice as large as that needed for diesel
Fuel potential	• According to a 2012 study from Volvo Trucks, by 2030 Bio-DME has the potential for replacing more than 50 % of today's diesel usage in heavy road transport in the EU

Vehicle adaptation	• Injection head and tanks of the vehicle must be modified, since a pressurized tank is required.
	  • Pressurizing DME is however problematic for injection seals in the long term and requires minor modifications to the engines
	  • Apart from the tank and injector changes, no other major changes are required
	• Challenging storage and transportation of DME due to its gaseous nature. DME can use the same infrastructures as LPG

Vehicle adaptation	• Price of DME higher than traditional fuels
Fuel infrastructures	• LPG infrastructure could be used and it would need to be developed extensively

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

Agenda

1. CO2Fokus project
2. CO2Fokus technology overview
3. Overview of the market analysis
4. Open questions

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

Thank you

Q&A

Project to end by mid 2023 → Open to opportunities for project's follow-up

Contact:
vesna.middelkoop@vito.be
lamiaa.biaz@lgi-consulting.com

Contacts

vesna.middelkoop@vito.be
lamiaa.biaz@lgi-consulting.com

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061