ELECTRICITY TO CARBON FUELS

METHANOL | DME | KEROSENE JET FUEL

JAN-WILLEM KÖNEMANN, UTRECHT MAY 18TH 2022

TNO | SYNTHETIC FUELS & CHEMICALS
ADVANCED THERMO CATALYTIC PROCESS TECHNOLOGY

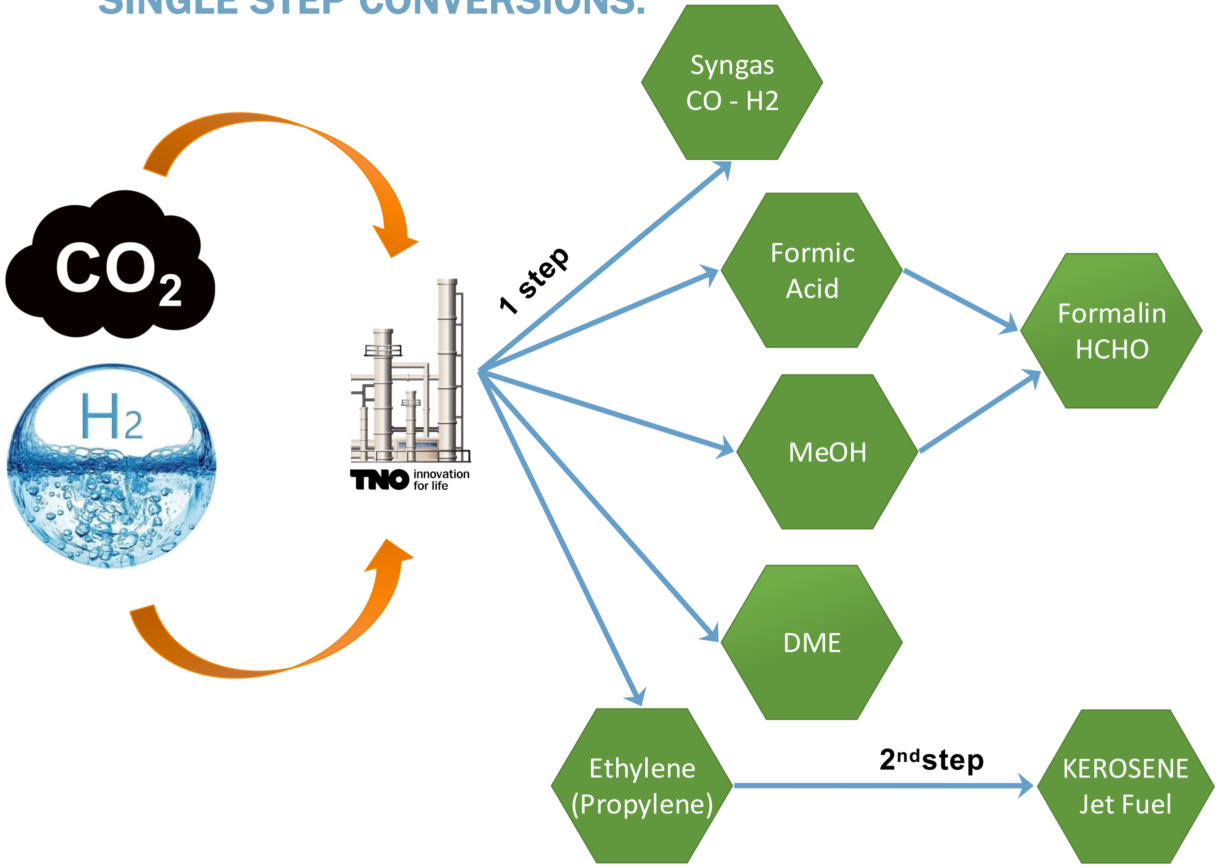
ENERGY TRANSITION IN INDUSTRY:

In a fossil-free future hydrocarbons will remain to be important in the products we use in everyday life.

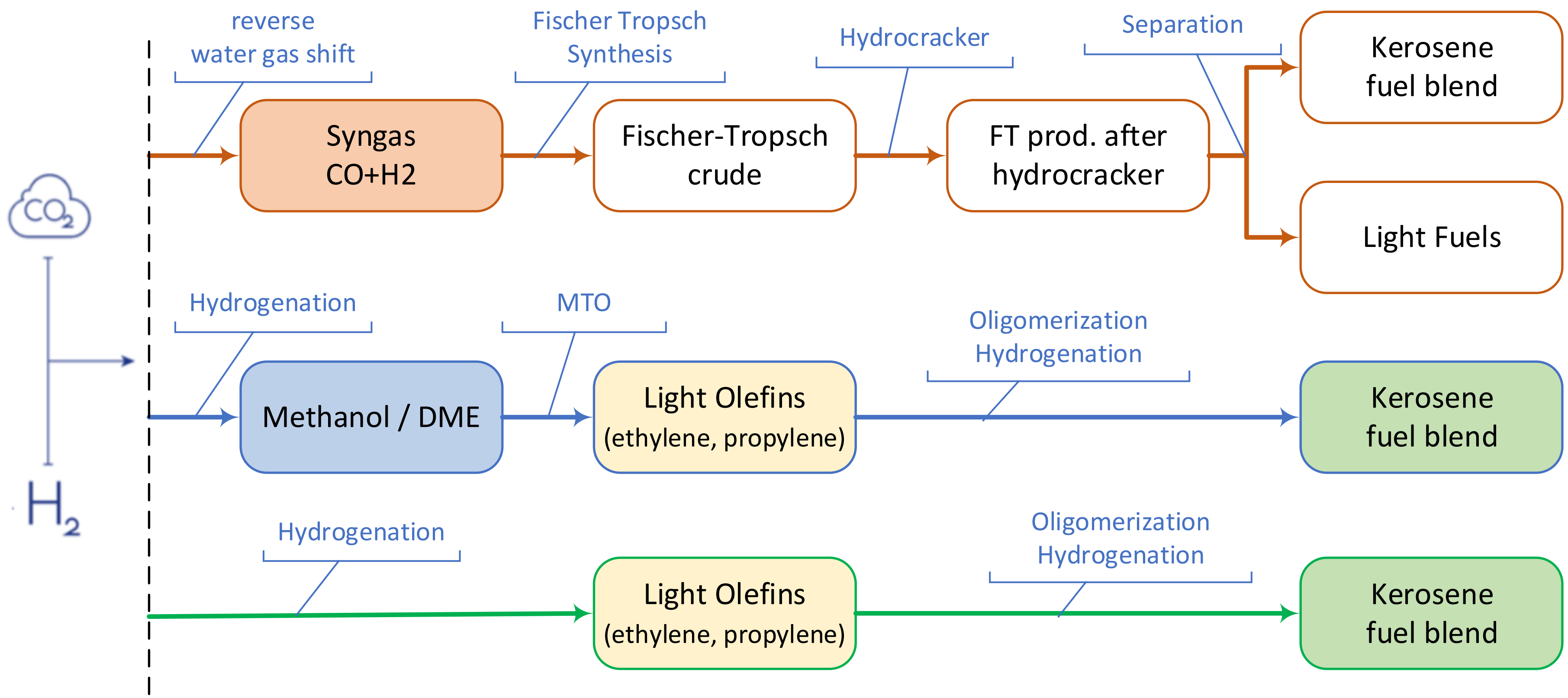
With renewable energy, hydrogen can be produced from water by electrolysis. CO_2 can be captured from biogenic flue gasses or directly from ambient air.

- TNO is recognized as expert on carbon capture processes in industry *and* on clean hydrogen production
- TNO develops technology that converts CO_2 to commodity chemicals for use in industry and the transportation sector.
- These conversion processes are based on process intensification and process integration technology. With smart reactors, products can be made from H_2 and CO_2 in a single step, with high conversion and energy efficiency

SINGLE STEP CONVERSIONS:



E-FUELS OR SYNTHETIC FUELS
PATHWAYS AND TNO FOCUS



E-FUELS OR SYNTHETIC FUELS
DEVELOPMENT TARGETS

Syngas CO+H2	Methanol / DME	Kerosene fuel blend
▪ In one reactor step to the desired composition, P and T, perfect for direct coupling to a downstream FT reactor	▪ One reactor step ▪ High conversion, hence eliminate or minimize recycle streams (10% → 85%) ▪ High selectivity to the product, hence minimal downstream processing	▪ Minimize reactor steps (to 2-3 steps) ▪ High selectivity to the desired kerosene fuel blend, hence minimize by-products, hence use the costly H_2 for kerosene ▪ Optimise the kerosene fuel blend to decrease emissions
Process intensification (less reactors, smaller recycle streams, limited downstream processing) lead to lower costs and a reduced economy of scale		

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SEPARATION ENHANCED PROCESSES

TWO NEW TNO REACTOR CONCEPTS

(PRODUCING SYNGAS, METHANOL, DME AND OLEFINS)

SEPARATION OF WATER PUSHES THE REACTION TO THE DESIRED PRODUCT SIDE:

$CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O$ (hydrogenation)

$CO_2 + H_2 \leftrightarrow CO + H_2O$ (reversed water gas shift)

$CO + 2H_2 \leftrightarrow CH_3OH$ (hydrogenation)

$2\ CH_3OH \leftrightarrow CH_3OCH_3 + H_2O$ (dehydration to DME)

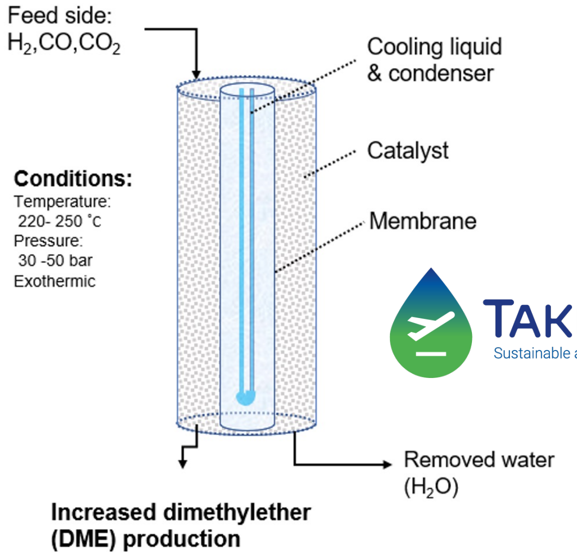
SEDMES (TRL 5 → 6)

- In-situ water separation by adsorption

TRL 5 → TRL 6

SIENNA (TRL 3 →5)

- In-situ water separation by a membrane & condensation



TAKE-OFF
Sustainable aviation fuel from CO_2

TRL 3 → TRL 5

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WHY SUSTAINABLE AVIATION FUELS "SAF" ?
AND WHY E-SAF ??

› **SAF, sustainable kerosene, is the only possibility to make aviation sustainable in the coming decades.**

- The kerosene market is huge, multiple technology routes will have to contribute
- Bio-kerosene is important and cheaper on short term, but is limited in feedstock
- Synthetic kerosene – produced from CO_2, H_2O and electricity - is currently still more expensive but has an unlimited feedstock
- Synthetic kerosene has the potential to reach near 100% green house gas reduction
- The importance of synthetic-SAF is underlined by governmental targets, incentives and market analysis
- Technology development is necessary to reduce costs

	HEFA	Alcohol-to-jet[i]	Gasification/FT	Power-to-liquid
Opportunity description	Safe, proven, and scalable technology		Potential in the mid-term, however significant techno-economical uncertainty	Proof of concept 2025+, primarily where cheap high-volume electricity is available
Technology maturity	Mature		Commercial pilot	In development
Feedstock	Waste and residue lipids, purposely grown oil energy plants[ii] Transportable and with existing supply chains Potential to cover 5%-10% of total jet fuel demand		Agricultural and forestry residues, municipal solid waste[iv], purposely grown cellulosic energy crops[v] High availability of cheap feedstock, but fragmented collection	CO_2 and green electricity Unlimited potential via direct air capture Point source capture as bridging technology
% LCA GHG reduction vs. fossil jet	73%–84%[iii]		85%-94%[vi]	99%[vii]

Clean Skies for Tomorrow Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation, November 2020, World Economic Forum in In Collaboration with McKinsey & Company https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/scaling-sustainable-aviation-fuel-today-for-clean-skies-tomorrow

Total shares in the fuel mix (in %)	2025	2030	2035	2040	2045	2050
SAF ramp up out of which:	**2**	**5**	**20**	**32**	**38**	**63**
Biofuels (including Part A and Part B biofuels)	2	4.3	15	24	27	35
Specific sub-mandate on RFNBOs[129]	**-**	**0.7**	**5**	**8**	**11**	**28**

Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on ensuring a level playing field for sustainable air transport: https://ec.europa.eu/info/sites/default/files/refueleu_aviation_-_sustainable_aviation_fuels.pdf

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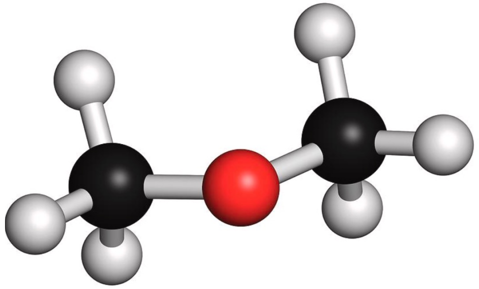
ABOUT DME, THE FRIENDLY CHEMICAL



DME has the potential to become a *huge* commodity chemical

DME: a friendly chemical
e.g. used as propellent in spraying cans (e.g. hair spray)

A modest bulk chemical
~4 Mton annually

DME: an ideal replacement for diesel? in e.g. heavy transport and for electricity generator sets

Soot free, no change to engine, dual fuel option (infrastructure is a hurdle)

Mack Trucks tests alternative fuel DME

2017-01-24

In collaboration with the New York City Department of Sanitation (DSNY) and Oberon Fuels, Mack Trucks has begun a demonstration to test the performance of a Dimethyl Ether (DME)-powered Mack Pinnacle model. DSNY is the first Mack customer to evaluate DME, a non-toxic, clean-burning alternative fuel.

DME: the ideal replacement of LPG (propane, butane) for off-grid applications

Much less H_2 required in production, can use the same infrastructure as LPG and can be blended with LPG

DME: with ethanol an intermediate in the production of sustainable aviation fuel

TNO develops the Take-Off route to produce SAF without by-products MeOH/DME is an intermediate to olefins and SAF

THANK YOU FOR YOUR TIME

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