Circular CO_2 Capture and Utilisation as H_2 Carrier

FORTES European Conference CO_2 Capture, Storage & Reuse,
Christian Schweitzer, bse Methanol, 18-April 2022

bse introduction

Foto: Imago Images / Dirk Sattler

bse History & Milestones

1990 Foundation of the company for client consultant engineeering and EPC with Management buyout and renamed to **bse**$^{\text{enginering}}$ in **1999**

2001 Start implementation of bio-fuel plants in across EU and signing of EPCM contract for a 280,000 m^3 Bioethanol plant

2008 Joining the Methanol industry for a revamping of a existing Methanol plant

2014 Start of the active Business development for the CO_2-to-Methanol technology

2016 R&D project for benchmark of the available catalyst under flexible operation condition

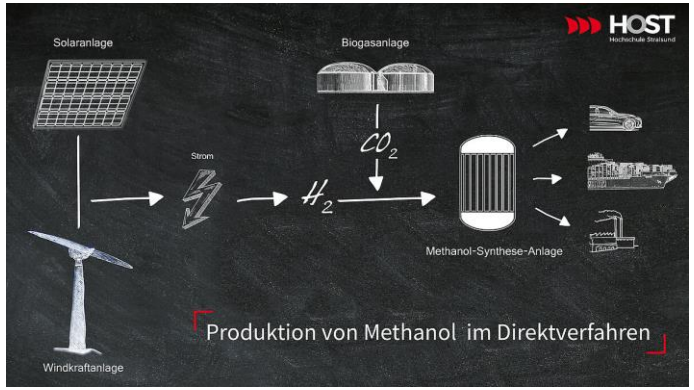
Joint Technical Workshops; Foto from bse Technology Team at 37th Annual World Methanol Conference (BASF, BSE, McPhy, Aker Solutions, Sulzer Chemtech)

2017 Signing the Joint development agreement with BASF for process and catalyst development

2018 Start of the development of skid mounted *Flex*Methanol Units

2020 Start of demonstrator mini methanol plant at IRES with investigation of long-term catalyst behaviour under flexible operation

Up to 240 MW methanol skids business development finished.



IRES BSE Project page: https://www.hochschule-stralsund.de/host/aktuelles/news/detail/n/das-ires-hats-geschafft-endlich-fluessiger-strom-67557/

bse Methanol

2019	Foundation of **bse**methanol as spin of for the Methanol market
2020	Signing of the first EPC-M contract for a *Flex*Methanol 10
2020	Foundation of **bse**group and **bse**construction
2021	Signing of MAN ES (DWE) Cooperation to supply *Flex*Methanol Skids on the global market
2021	Preparation of *Flex*Methanol 10 and *Flex*Methanol 20 supply
2022	Signing JDA with one of the leading elctrolyser companies
2022	1. April Start of Project development in Tunesia
2022	Q/III Start of contruction first of it´s kind plant

Portfolio of 150,000 tpa MeOH in skids by 2025.

Continuation of the project development and target setting for the year 2030 of >1 Million Tons annual production capacity by *Flex*Methanol Skids.

Framework

IRENA Report: Renewable Methanol

Innovation Outlook: Renewable Methanol (irena.org)

- "The production of e-methanol offers a way to increase the value of green power and store electricity in a convenient liquid that can be easily kept for later use."
- In the energy transformation pathway the total demand of renewable methanol will amount 385 Mt per anno in 2050,
- **Modular and standardised** are an advantage to reach the required capacities of e-methanol, p.89
- ***Flex*Methanol bse Methanol/BASF** is Process Provider for complete e-methanol plants,

Power-based production becomes the most prospective and realistic production route of methanol.

Source: IRENA AND METHANOL INSTITUTE (2021), Innovation Outlook : Renewable Methanol, International Renewable Energy Agency

IRENA Outlook Renewable Methanol 2021

Innovation Outlook: Renewable Methanol (irena.org)

- The current methanol demand amounts 98 MT per anno,

- *In the outlook the growth will be estimated according to demand of 120Mt in 2025 and 500Mt in 2050,*
  - "[…] the increase in methanol production is expected to see a progressive **shift to renewable methanol**, with an estimated annual production of 250 Mt of e-methanol and 135 Mt of bio-methanol by 2050 […]"
- Sources of Methanol:
  - **"The largest potential for the production of renewable methanol remains with the hydrogenation of CO_2 to methanol.** Production from CO_2 does not suffer the same feedstock availability limitations as biomass or waste products."

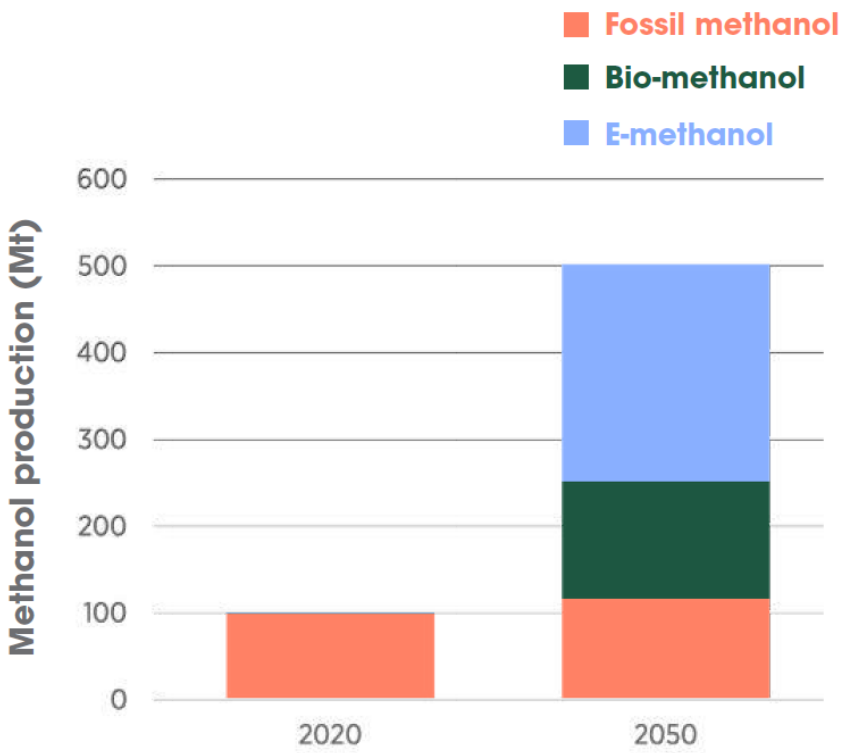


Figure 47. Current and future methanol production by source

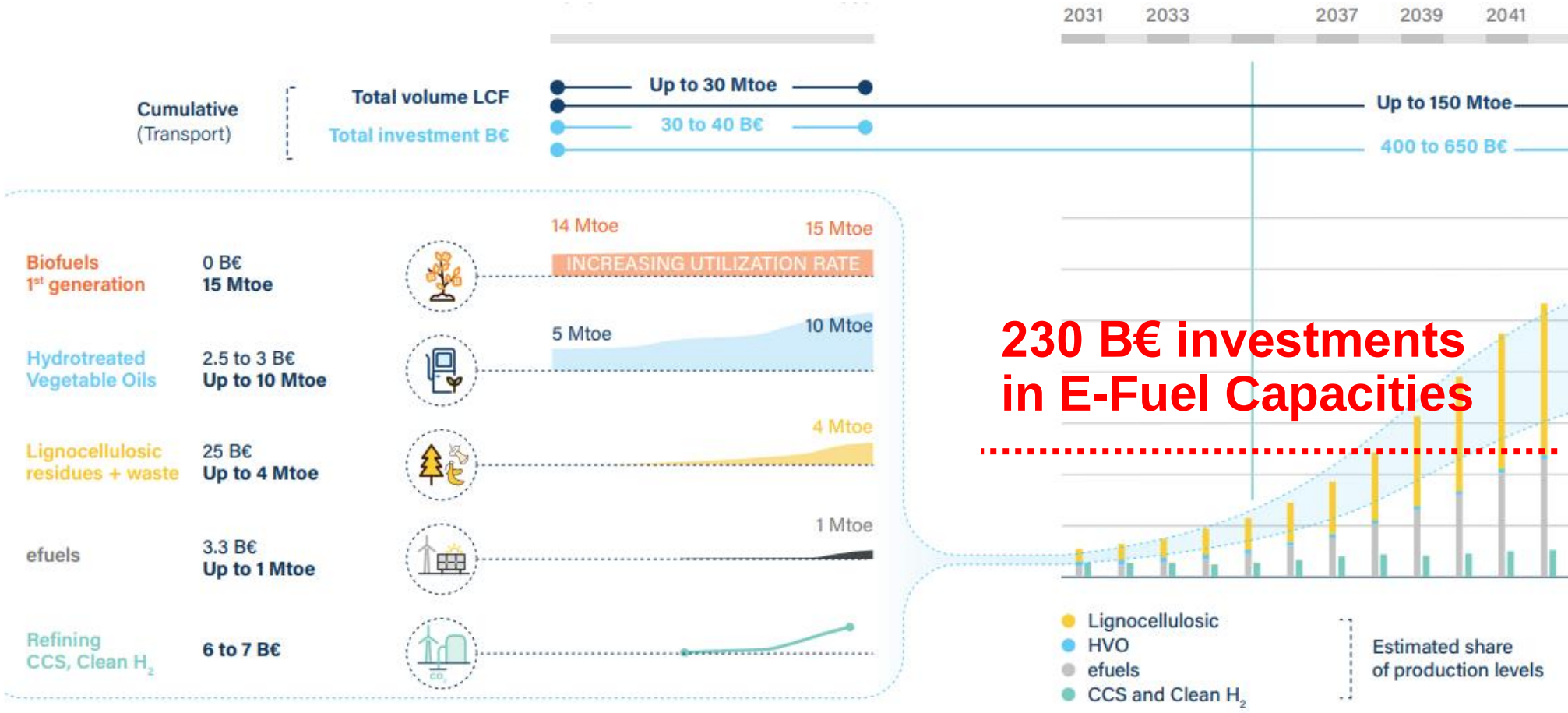
Source: IRENA AND METHANOL INSTITUTE (2021), Innovation Outlook : Renewable Methanol, International Renewable Energy Agency, Abu Dhabi, 89

FuelsEurope Position

FuelsEurope-Clean-Fuels-for-All-Final.pdf

Position Paper „Clean fuels for all“ of the Refiniery Industry (FuelsEurope, 2020).

A potential scenario envisages **investments of 3.3 B€ in the developemnt of E-Fuel capacities by 2030** and a strong growth thereafter.



Source: FuelsEurope

Renewable Energy Directive

EUR-Lex - 32018L2001 - EN - EUR-Lex (europa.eu)

- The RED II is in place since 2018 and has to be implement in Member states by 2021 with following main scope:
- The Member state have to ensure 14% renewable share of the transport energy consumption.
- Biofuels from food are capped at 7%.
- Subtarget of 3.5% for Advanced biofuels applies.
- Power-based fuels (RFNBO) have to be introduced mandatory and Fuels from recycled carbon (RCF) can be introduced obligatory.
- **Biggest Problem: The implementation of rules for RNFBO and RCF are still pending**

Most urgent task of the European Commission is to implement the E-Fuels supply in EU and from outside in flexible production plants!

Xinhua / Imago

Fit for 55 in extension to REDII

https://ec.europa.eu/commission/presscorner/detail/de/ip_21_3541

Instead of 40% GHG reduction target (status 2018) there is the new programm by the European Commision to implement more ambitious measures towards 55% GHG reduction target for 2030.
Impacts: New REDII, rework of ETS and regulation maritime fuels.

Main proposals that relate to Greenhouse gas reduction by:

- Intensification of the Emission Trading
- Reduction of free EUA allocation to carbon leakage industry
- Cancel the free allocation of EUA to the aviation
- Obligation to the Member states to use the EUA auction revenues **fully** for climate and clean energy projects
- „rich“ Member states will have higher GHG emission saving targets (effort sharing)
- Blending targets maritime fuels
- E-Fuels (RNFBO) have to be consumed with at least 2.6% of total energy consumption transport fuels
- Renewable transport energy target increase from 14 % to 20 % due the change to GHG saving quota instead of renewable energy quota

VDI 4635 Power-to-X

VDI 4635 Blatt 2 – Power-to-Liquids

The guideline deals with the conversion of electrical energy into (under ambient conditions) liquid storage media using carbon oxides or nitrogen. Overriding aspects in the construction and operation of PtL plants such as methanol, Fischer-Tropsch and ammonia synthesis are considered. Technical details are dealt with in the respective sheets "Liquid hydrocarbons" and "Ammonia synthesis".

Publication: Power-to-Gas is currently in Green Print. The main sheet is under discussion.
Source: VDI 4635 Blatt 2 - Power-to-Liquids | VDI

“Central requirement to the technology being acknowledged as Power-to-X is the ability of flexible conversion of electricity.” Christian Schweitzer, Deputy Speaker Power-to-Liquids

“The operational flexibility of Power-to-X plants is integral part of the system requirements in the guideline for all technological sheets.” Dr. Johann Kirchner, bse Representative at VDI 4635

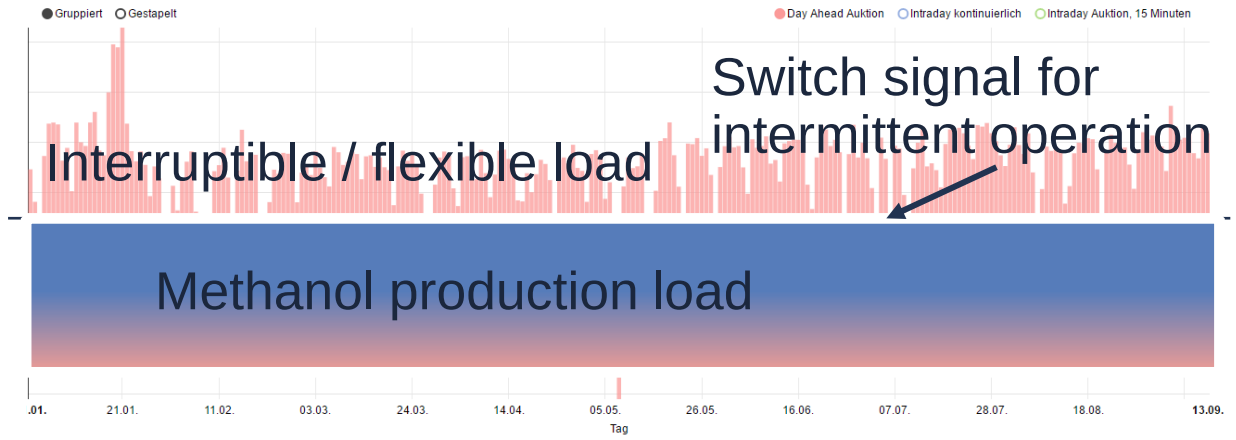
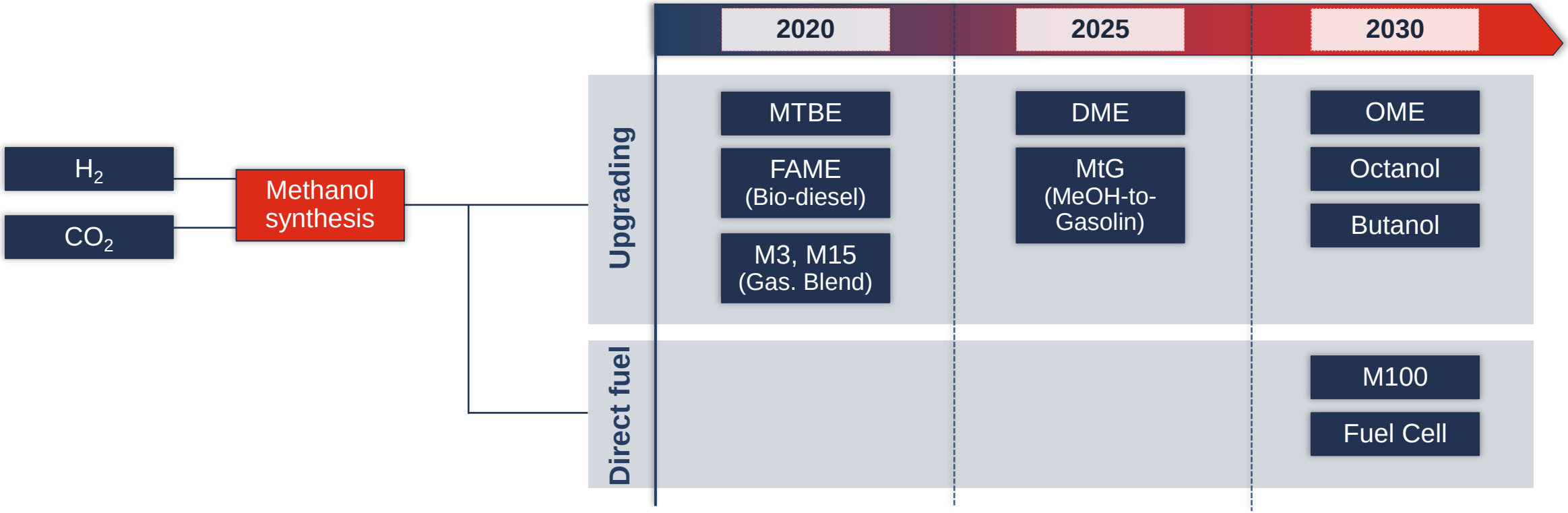


Illustration: Fraunhofer ISE

Markets

E-Methanol as Road Fuel

Development of Fuel Technologies

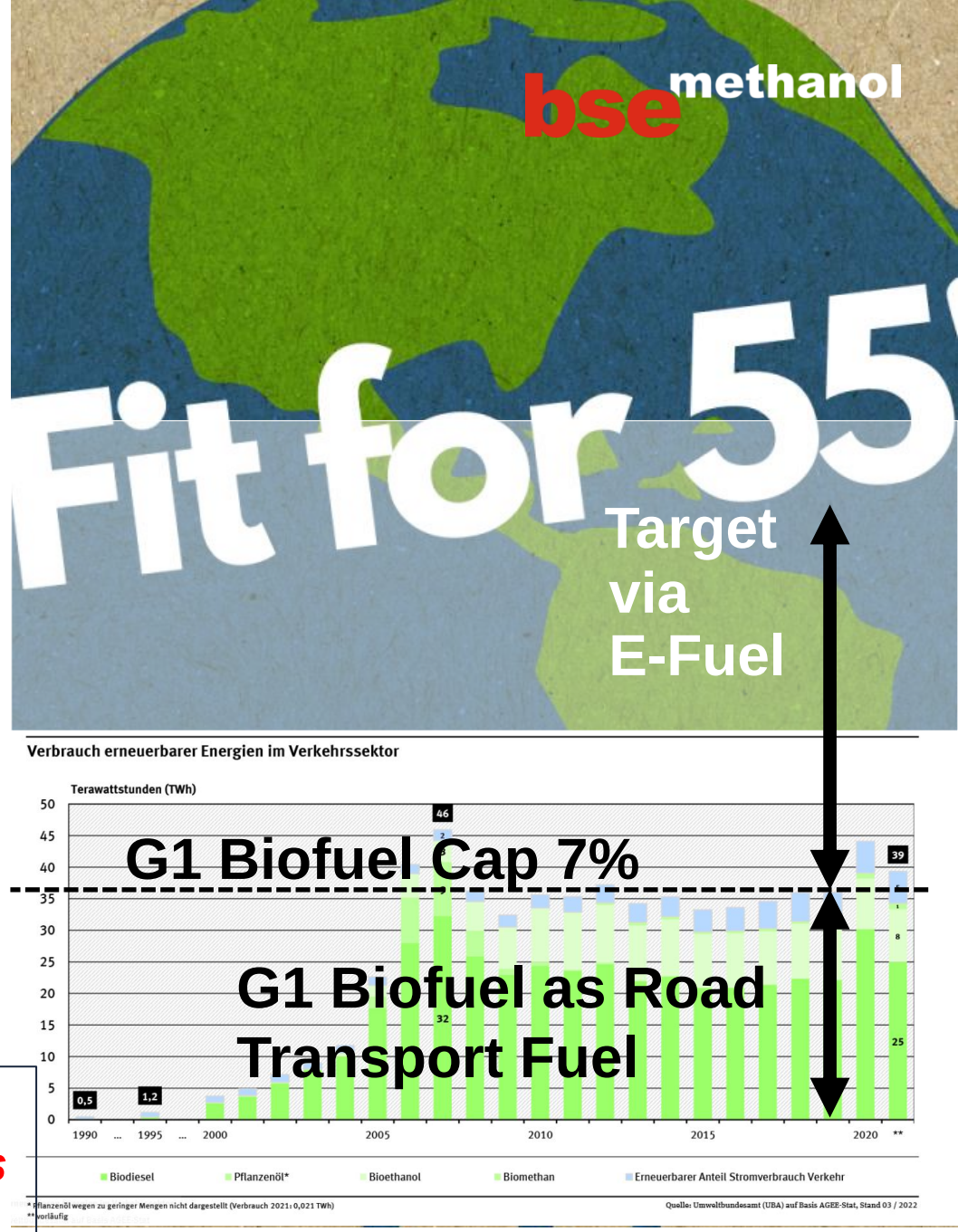


- Contribution to EU blending mandates
- DIN EN 228 conformity with current existing use of Methanol in the gasoline sector:
  - Direct Blending as M3 without any adjustments possible
  - Methyl-tert-butylether (MTBE)

Framework Road Transport Fuel

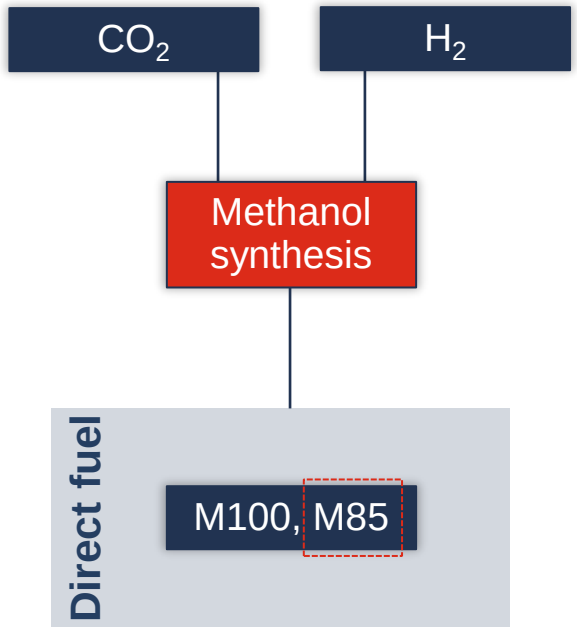
- In place are Blending obligations and ETS like instruments.
- Example Implementation in Germany:
  - The Blending obligation is based on reduction of the GHG intensity. The penalty of non-fulfilment amounts 60 ct/kgCO_{2equ}.
  - In the Fuel Emission Trading (Brennstoff-emissionshandelsgesetz) are obligated the fuel suppliers. The target price of CO_2 is similar to the Emission Trading System (55 Euro per ton of CO_2) and from 2026 free trading of the market in a corridor.

E-Methanol as road transport fuel (component) prevents penalties by blending mandates and prevents CO_2 emission costs.



Source: Das „Fit for 55"-Paket der EU - Europe Direct Magdeburg (ed-md.eu); UBA

E-Methanol as Maritime Fuel



- Promotion of hydrogen-based renewable fuels according to the **National Hydrogen Strategy** (Federal Ministry for Economic Affairs and Energy)
- Methanol is compliant with **emission reduction** regulations (no sulphur, low NO_x)
- Utilisation of **existing infrastructure** for distribution and storage at the harbour
- **Existing safety handle procedures** due to more than 100 years experience in shipping methanol
- Current engines (equipped with spark plugs) perform well with methanol (**retrofit possible**), 2-stroke **dual fuel engines** running on methanol or diesel
- Methanol is **biodegradable** (micro-organism can oxidize methanol)

Methanol is IMO accepted fuel acting as the bridge fuel to the future

Methanol as Global Maritime Fuel

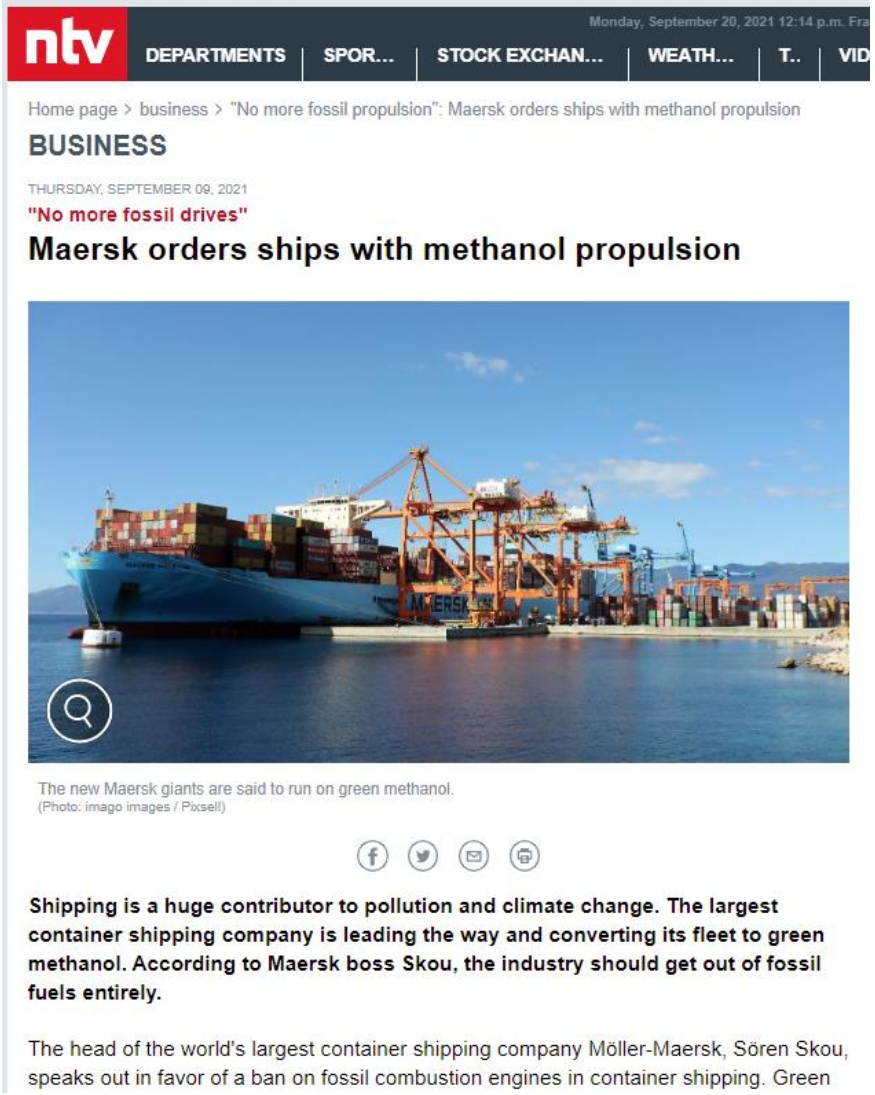
- Methanol IMO conformity and usable to reduce CO_2 obligations.
- No special requirements on methanol as maritime fuel.
- Important aspect ist methanol/water-mixture to improve fuel properties (e.g. lower consumption).
- Methanol engines as dual fuel engines (methanol/diesel) existing.
- Strong growth of global methanol fueled vessels, e.g.:

  Maersk focuses on complete fuel switch to methanol for container ships

Source: https://www.n-tv.de/wirtschaft/Maersk-ordert-Schiffe-mit-Methanolantrieb-article22795069.html

For further Information, e.g. methanol fueled cruisers or Hazid at harbor for methanol bunker fuel please visit:

"MethaShip" - Neuer Brennstoff mit Potenzial | vsm



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Monday, September 20, 2021 12:14 p.m. Fra

Home page > business > "No more fossil propulsion": Maersk orders ships with methanol propulsion

BUSINESS

THURSDAY, SEPTEMBER 09, 2021

"No more fossil drives"

Maersk orders ships with methanol propulsion

The new Maersk giants are said to run on green methanol.
(Photo: imago images / Pixsell)

Shipping is a huge contributor to pollution and climate change. The largest container shipping company is leading the way and converting its fleet to green methanol. According to Maersk boss Skou, the industry should get out of fossil fuels entirely.

The head of the world's largest container shipping company Möller-Maersk, Sören Skou, speaks out in favor of a ban on fossil combustion engines in container shipping. Green

EU Framework Maritime Fuel

[EUR-Lex - 52021PC0562 - EN - EUR-Lex (europa.eu)]

The EU Proposal on the use of renewable and low-carbon fuels in maritime transport limits the greenhouse gas intensity of fuels of vessels as follows:

Max. GHG intensity compared to Reference Maritime Fuel	Year
98%	2025
94%	2030
87%	2035
74%	2040
41%	2045
25%	2050

Eligible fuel to achieve the GHG reduction is e-methanol and the GHG savings shall be determined according to the REDII. With non-fulfilment of reduction of the GHG intensity a penalty has to be paid:

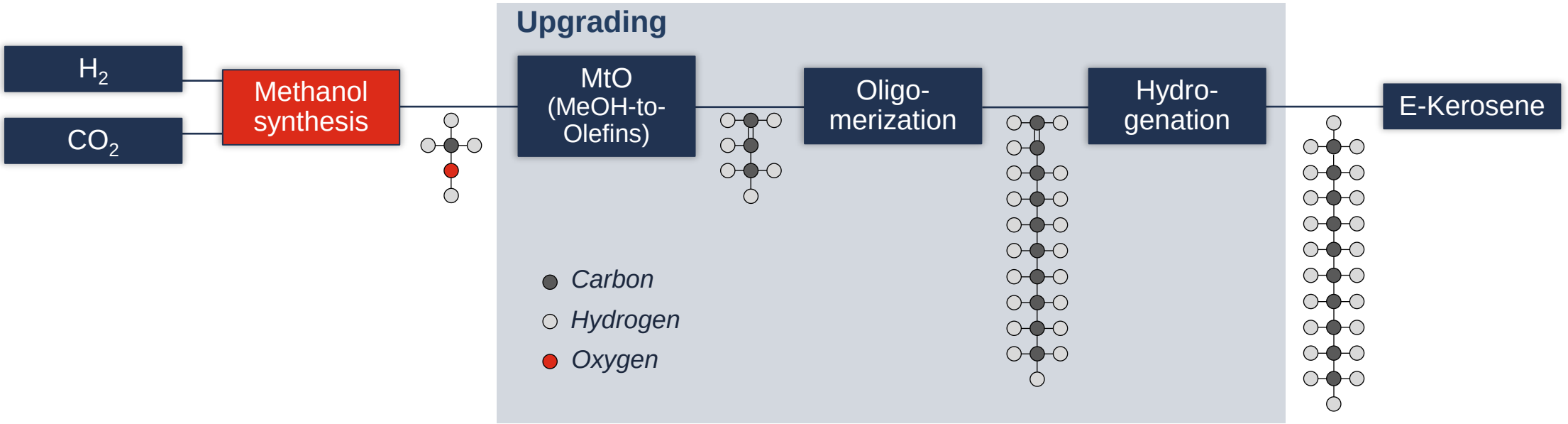
Excerpt from maritime fuel proposal Annex V:

Formula for calculating the penalty laid down in Article 20(1)

The amount of the penalty laid down in Article 20(1) shall be calculated as follows:

Penalty =	(Compliance balance / GHGIEactual) x conversion factor from MJ to tonnes of VLSFO (41.0 MJ / kg) x EUR 2400

E-Methanol as Aviation Fuel

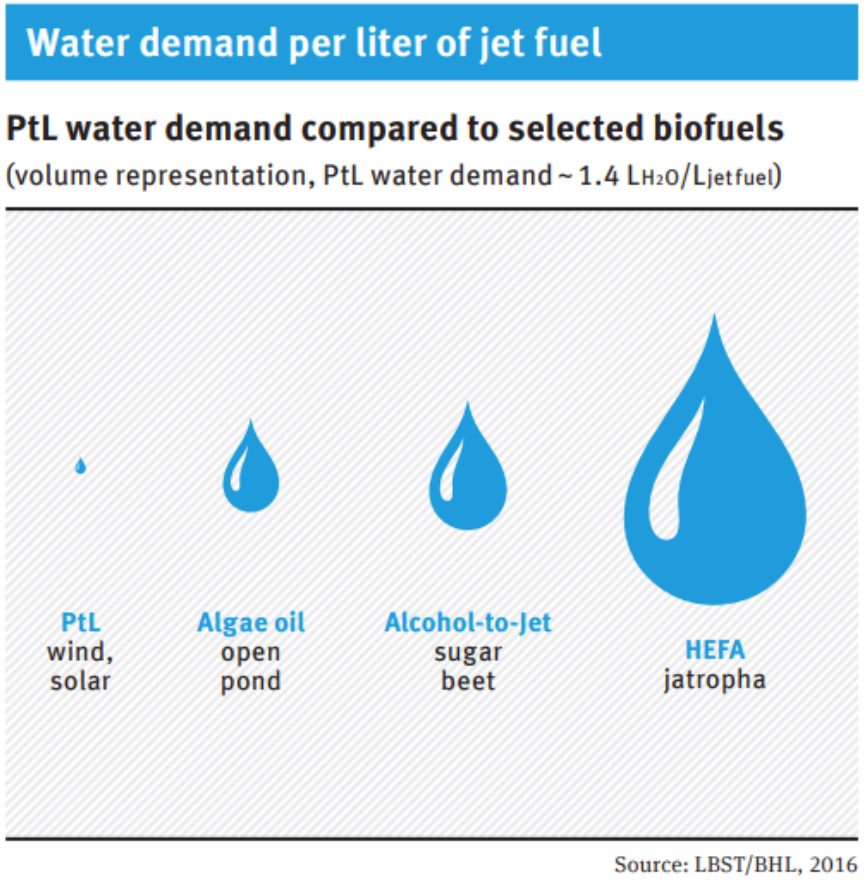


- Guidance for pilot projects concerning Drop-In fuels in aviation (*Federal Mobility and Fuel Strategy*)
- Focus on production of bio-kerosene and e-kerosene by Power-to-Liquids techniques (e. g. **Methanol synthesis** and Fischer-Tropsch synthesis)
- ASTM certification for kerosene from methanol is pending

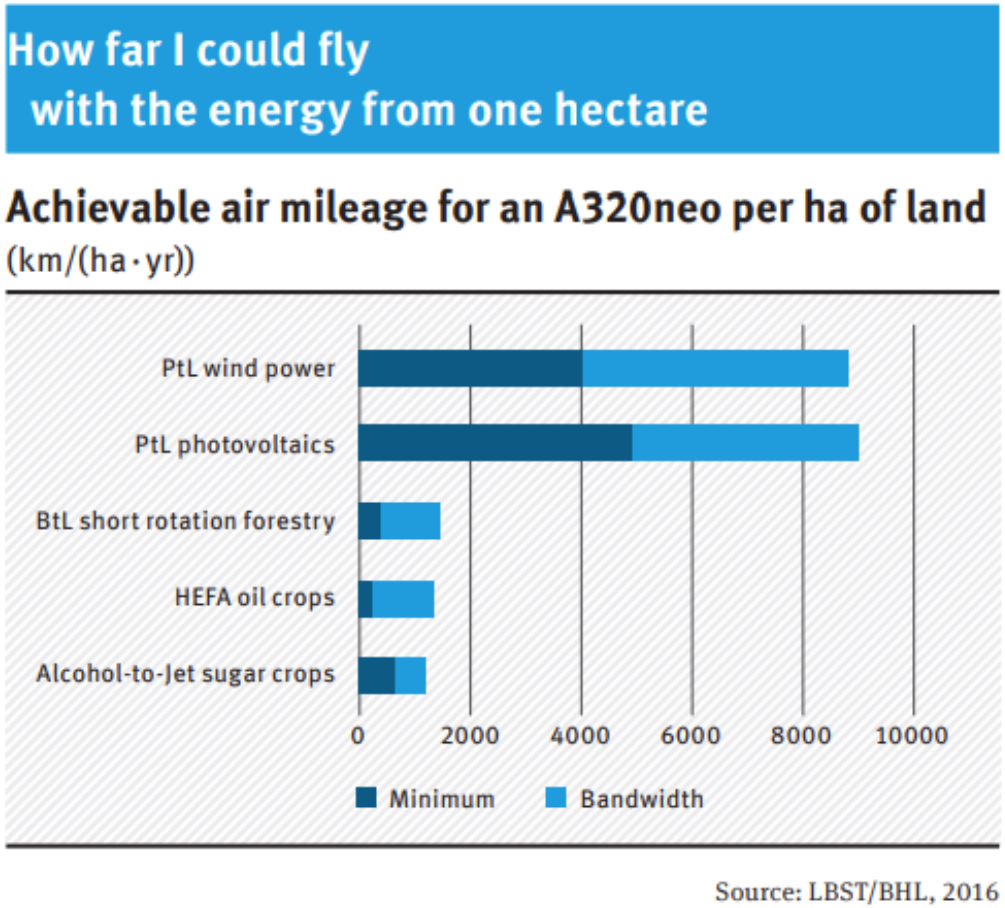
State of the Art of Power-based Kerosene

https://www.umweltbundesamt.de/sites/default/files/medien/377/publikationen/161005_uba_hintergrund_ptl_barrierrefrei.pdf

- The most mature technology of all power based routes is Power-to-Methanol-to-Kerosene (TRL 8).



- Sustainable Aviation Fuels (SAF) from biomass have significant restrictions in regard to land and water consumption



Framework Aviation Fuel

Source: [Fit for 55 and ReFuelEU Aviation | EASA (europa.eu)]

1. **EU**: The free allocation of EUA to the aviation sector in the EU ETS shall be cancelled according to the Fit for 55 initiative:
   - Airlines have to pay for each ton of CO_2 emissions
   - Obligation of fuel suppliers to blend sustainable kerosene incl. Synthetic low carbon / E-Fuels (ReFuel Initiative).

2. **CORSIA** (Carbon Offsetting and Reduction Scheme for International Aviation of currently 88 states).
   - The intention is that airplanes on international flights are obligated to the reporting of their fuel consumption.
   - The CO2 emissions of the total aviation industry gets „frozen“ in the year 2020.

3. **National legislations**, Example Germany **Fuel Blending Law 2021** Power-to-Kerosene:

The mineral oil industry has to secure that Aviation fuels contain a certain amount of e-fuels. All departing flights which are fueled in Germany must contain „power-based aviation fuels“ (e-fuel) according to the binding energetical quota.

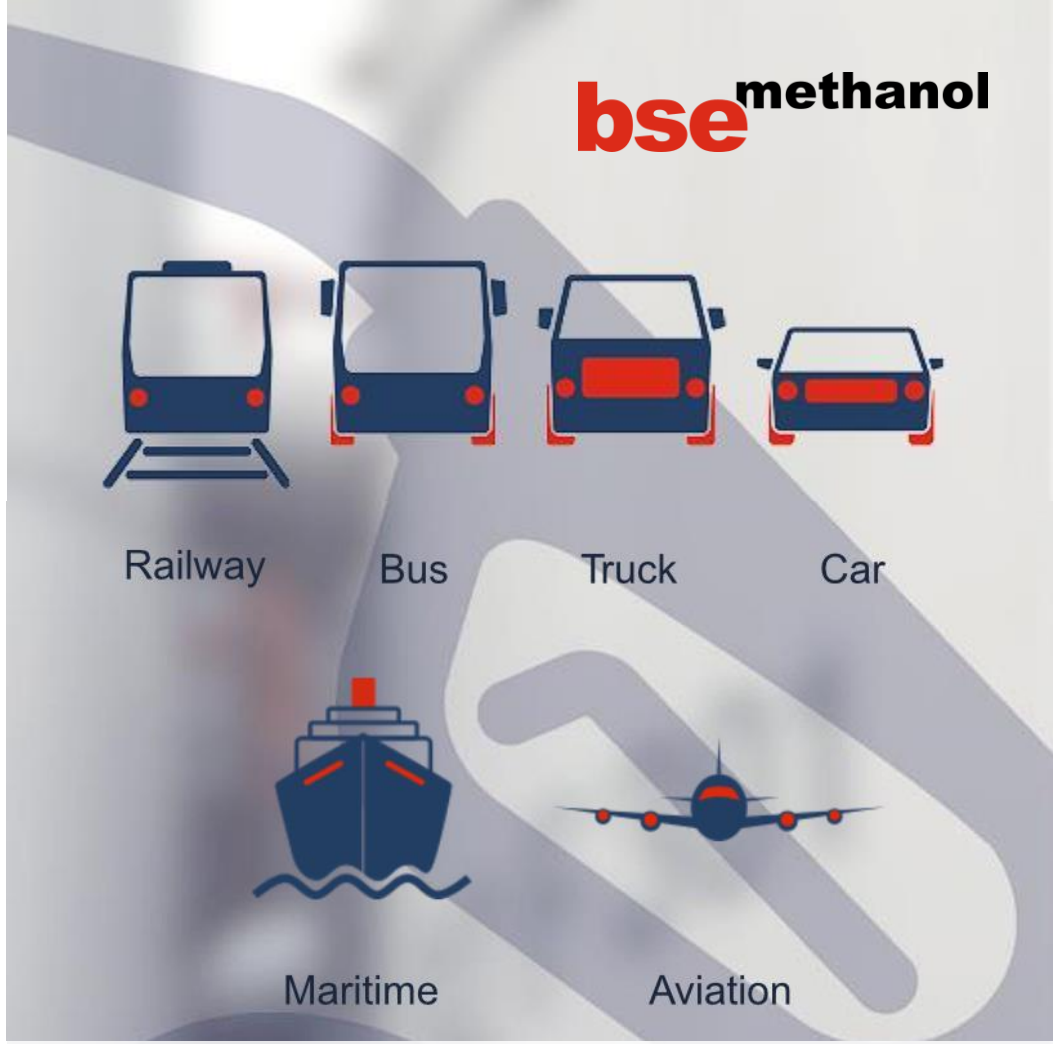
§ 37a (4a) BImSchG Binding Quota:

Year	Energetic Share of E-Kerosene in Aviation Fuel
2026	0.5 %
2028	1.0 %
2030	2.0 %

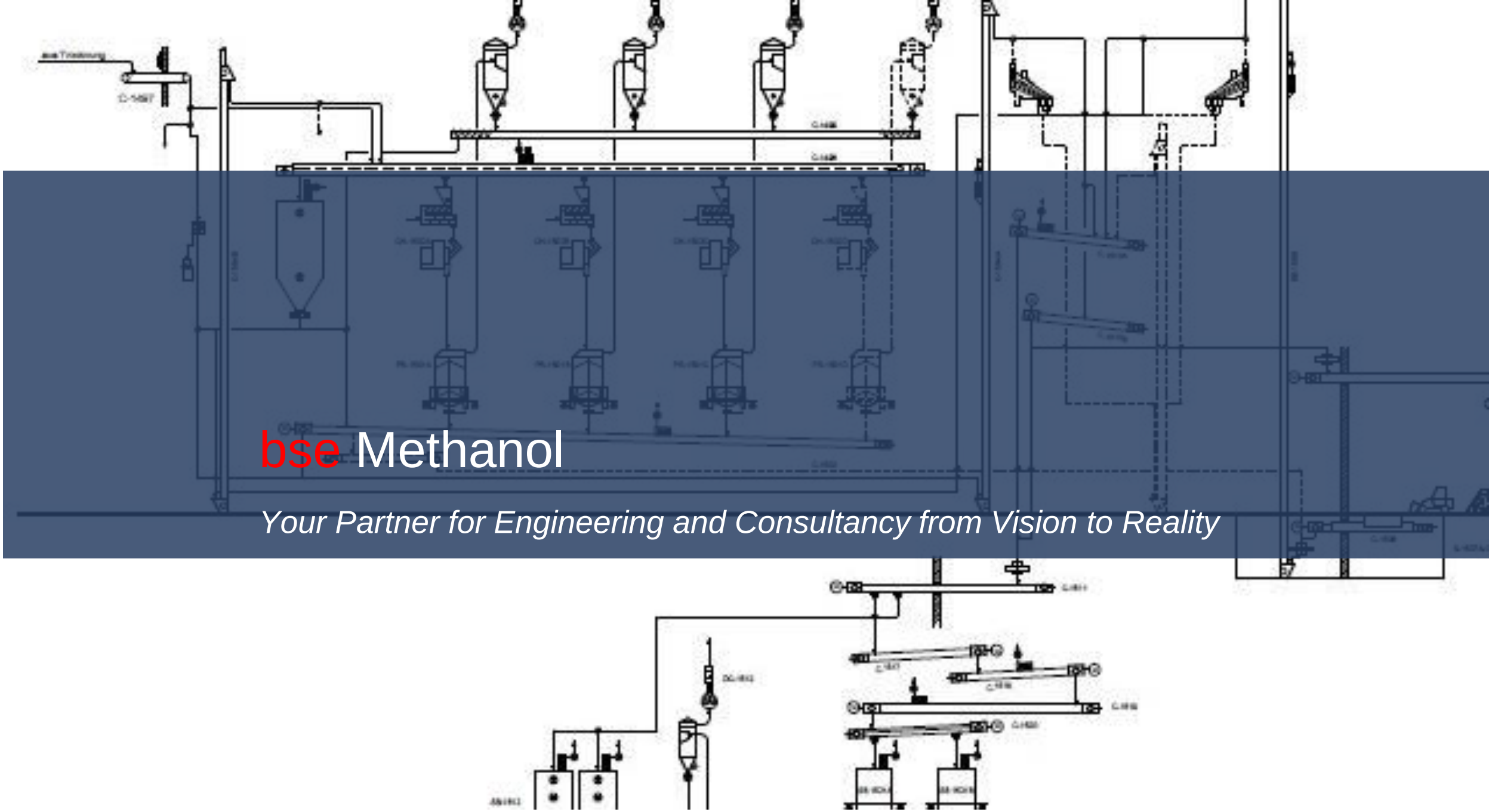
Penalty: 600 €/t for non-reduced CO_{2equ} by aviation fuel

Conclusion E-Methanol

- ✓ Renwable E-Methanol reduce cost impact from Emission Trading Systems.
- ✓ Renewable E-Methanol prevent penalty via blending and GHG saving methodology.
- ✓ Methanol complies in existing road fuel specifications gasoline (MTBE), direct blending and biodiesel.
- ✓ Market of e-methanol as **maritime fuel** is ready, legal implemenation has started.
- ✓ Implementation of **Power-to-methanol as aviation fuel** has to start (jet fuel certification).



Methanol is already applicable as fuel without infrastructre adjustments



bse Methanol

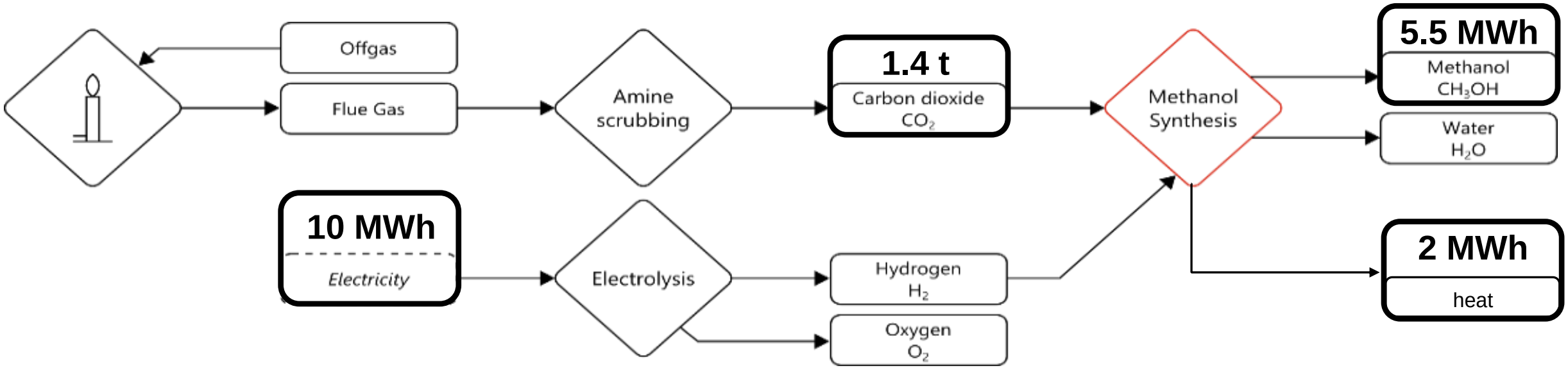
Your Partner for Engineering and Consultancy from Vision to Reality

Power-to-Methanol

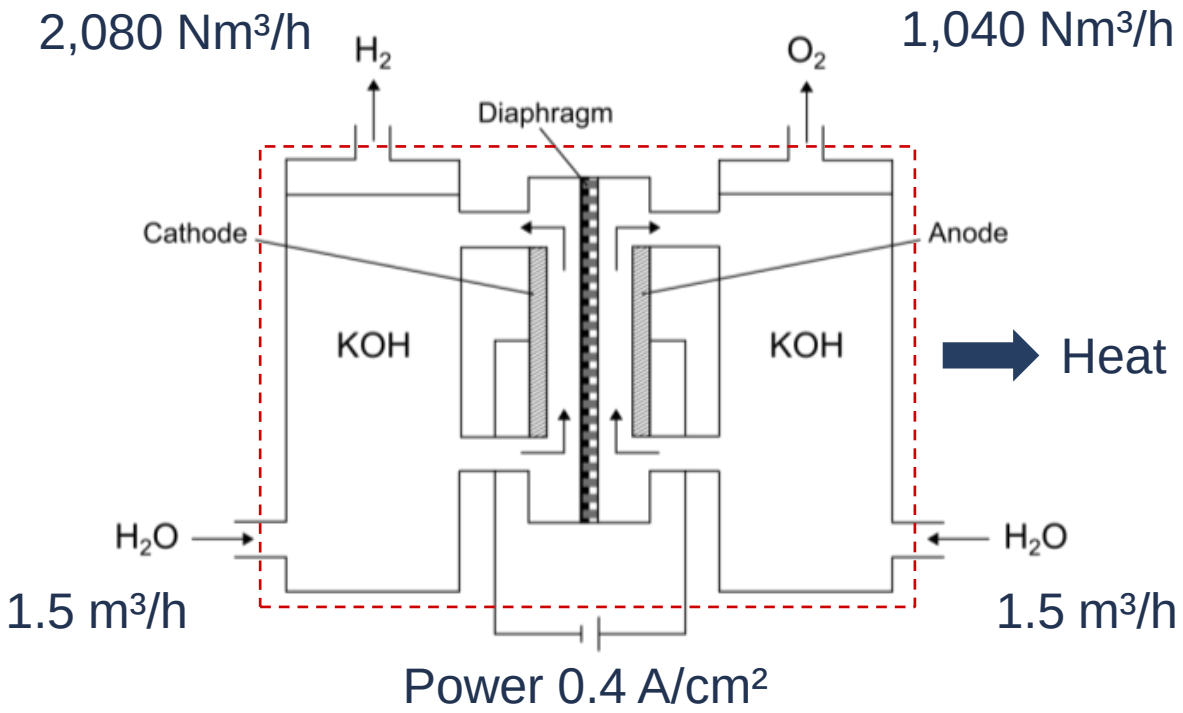
Process Steps

- 200 kg hydrogen and 1.4 t of CO_2 are needed by chemisty to produce 1 t of pure methanol
- 10 MWh power are needed to produce 200 kg of hydrogen by electrochemistry

Economic valuable increase via flexibility of power utilisation



Alkaline Electrolysis



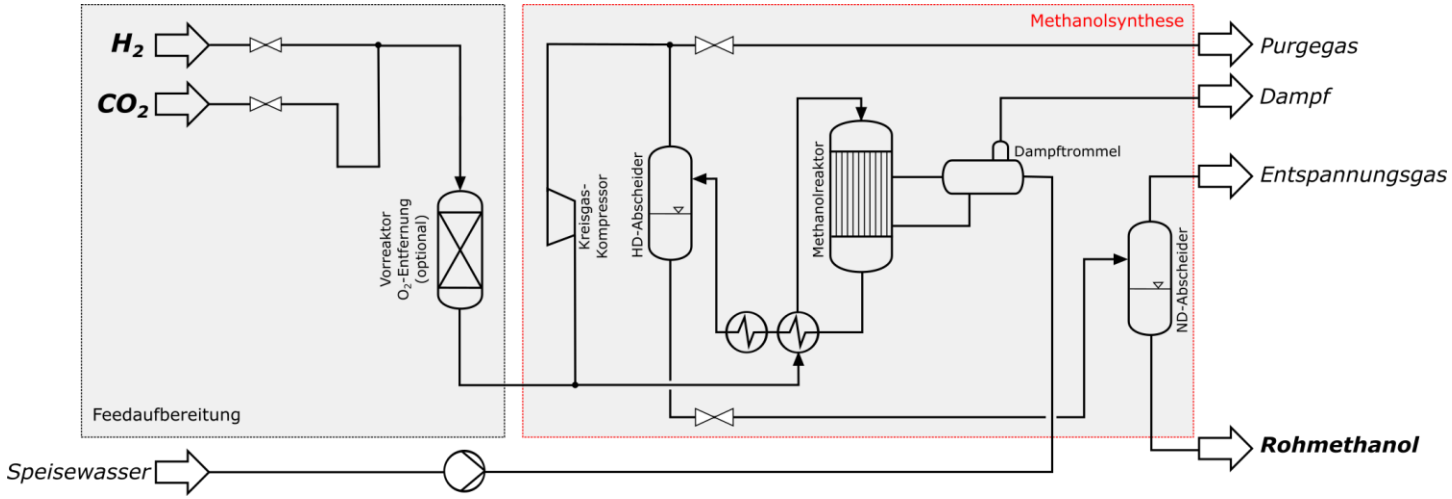
Theoretic energy and mass balance
Heat for further process: 75°C
Energy consumption: 4.95 kWh/Nm^3_{H2} incl. all auxilliaris

Flexibility range: 10 – 100 %

Methanol Synthesis

Process

$$CO_2 + 3\ H_2 \rightleftarrows CH_3OH + H_2O$$
$$CO_2 + H_2 \rightleftarrows CO + H_2O$$
$$CO + 2\ H_2 \rightleftarrows CH_3OH$$



- Reaction heat used for steam production, which is used in subsequent distillation
- Flexibility range: 10-100%
- Process conditions: 240°C, 40 bar
- Cu/ZnO based catalyst (BASF)

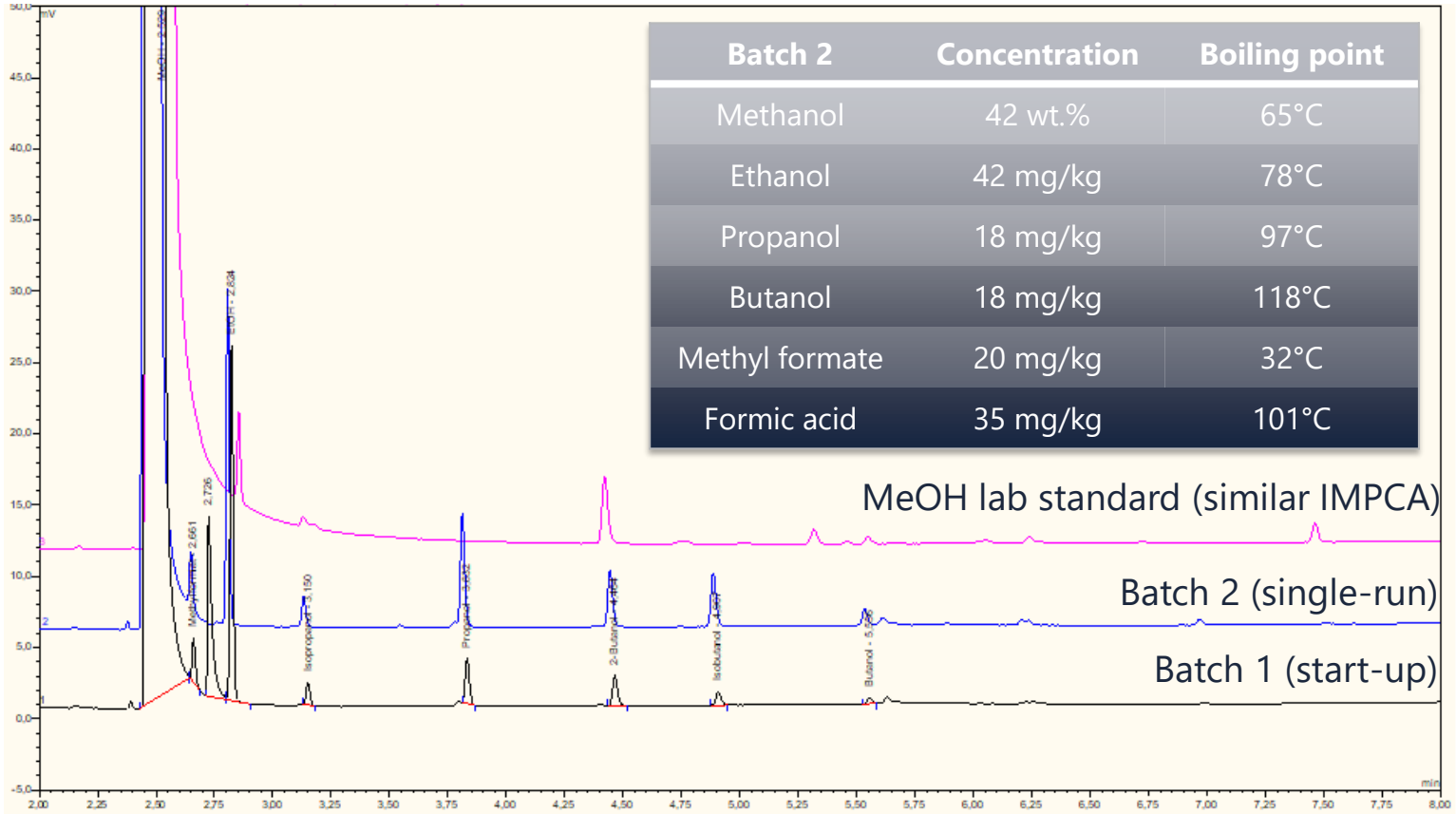
Methanol Plant

State of the Art

Operating result

Analysis of produced bio-methanol

- Crude methanol analysis (GC-FID) in single-run mode



Batch 2	Concentration	Boiling point
Methanol	42 wt.%	65°C
Ethanol	42 mg/kg	78°C
Propanol	18 mg/kg	97°C
Butanol	18 mg/kg	118°C
Methyl formate	20 mg/kg	32°C
Formic acid	35 mg/kg	101°C

bse construction

FlexModules

- The small-scale methanol plant has been designed and developed in modules as

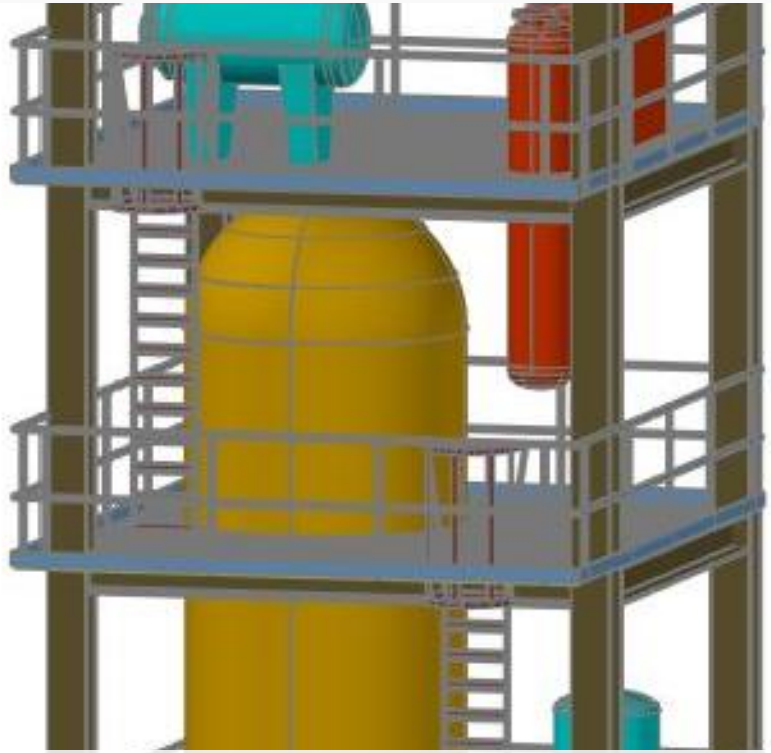
  *Flex*Methanol 10 &

  *Flex*Methanol 20

- Skids with CE-Marking
- Scalable possible together (but not neccessarily) with the electrolyzer als combined modules

  *Flex*Module e-fuel© System

- Skid Technology Synthesis & Distillation:
  - Interface flange 1 m infront of unit
  - Foot print per skid 4.5 m x 4.5 m
- Minimized Risk by
  - clear interfaces with clear responsibilities,
  - simple construction concept on the site and
  - handy access in operation.



Pre-fabricated Skids

- Standardized
- Cost-competitive
- Fast setup
- Broad rollout options

*Flex*Methanol by BSE

Benefits and Added Values

✓ No water-gas shift reaction	➢ There is no need for capital cost intensive Steam Reforming
✓ Mild process conditions	➢ low pressure, 240 °C
✓ No hydrogen compression storage	➢ electrolyzer works on pressure stage of methanol synthesis
✓ Skid-mounted	➢ thus short construction time and short start-up time
✓ Flexible operation of the methanol plant	➢ generator and methanol plant can work together as battery towards the power grid, Methanol plant as flexible load, Flexibility to sell electricity to favourable prices and at favourable times
✓ No tars, no waste	➢ methanol synthesis works on pure gases without any impurities
✓ 4 industrial available process steps	➢ reduction of technical and operational risks

Example of Small-Scale 1st Stage Synthesis

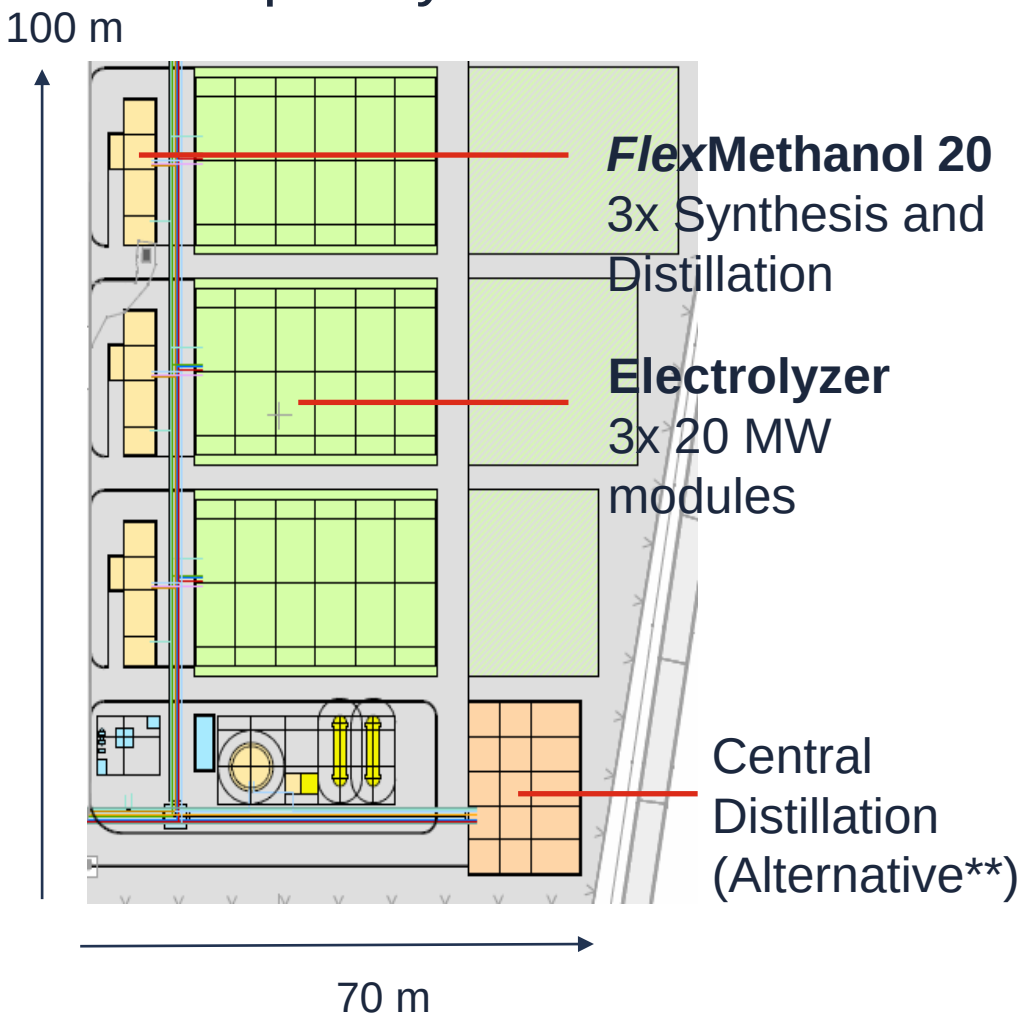
*Flex*Methanol

Categories	Unit	*3x* ***Flex*****Methanol 20***
*Output**		
Methanol	t/y	48,000
Water (Distillation)	t/y	25,440
*Input**		
Power Demand (reference case)	MWh/a	495,120
CO_2 Demand	t/y	66,960
DM Water Demand	t/y	91,200
Required Area	m²	7,000 – 20,000
Technical Depreciation		
Physical lifetime	a	25

*based on 8,000 full load hours
**Skid vs. central distillation

Decentral methanol synthesis and 2nd Stage synthesis at central plant (olefine to kerosene synthesis)

Example layout:



Ongoing Projects

MENA States	TUNol* project **> 7 times *Flex*Methanol 20**	Approx. 1,000 ha area concentrated solar power
Central Europe	In total up to 14 sites (most progressed completion of Basic Engineering) **> 30 times *Flex*Methanol 10 and 20**	Wind, PV solar power and waste incinerators and biomass boiler
South West Europe	In total up to 6 sites (most progressed completion Pre-Basic Engineering) **> 35 times *Flex*Methanol 10 and 20**	Wind and PV solar power
North Europe	2 sites (Feasibility completion, tender phase Basic Engineering) **4 times *Flex*Methanol 20**	Wind and biomass boiler
South America	1st project discussion started ***Flex*Methanol 10**	Wind, PV solar power and biomass boiler
East Africa	1st project in award phase for feasibility study ***Flex*Methanol 10**	Geothermal and PV solar power

*funded by Federal Ministry for Economic Affairs and Climate Action

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