POWER UPGRADE OF BIOGAS TO BIOMETHANOL OR BIOMETHANE

TOPSOE

Hydrogen & P2X 2022
15-16 June 2022 Copenhagen, Denmark

Joachim Harteg Jacobsen
15 June 2022

TOPSOE AT A GLANCE

Topsoe is a leading developer and provider of solutions and technologies to produce fuels and chemicals essential to the energy transition. For more than 80 years, we have been perfecting chemistry to help industries produce more efficiently. Today, it is our ambition to lead the global transition of heavy industry and transport to a zero-carbon future.

Technology leader in

Hydrogen
Ammonia
Methanol
Renewable diesel

Founded 1940

9%
Of revenue invested in R&D

6,225
In revenue
(DKK million)

903
EBIT before special items
(DKK million)

2,133
employees

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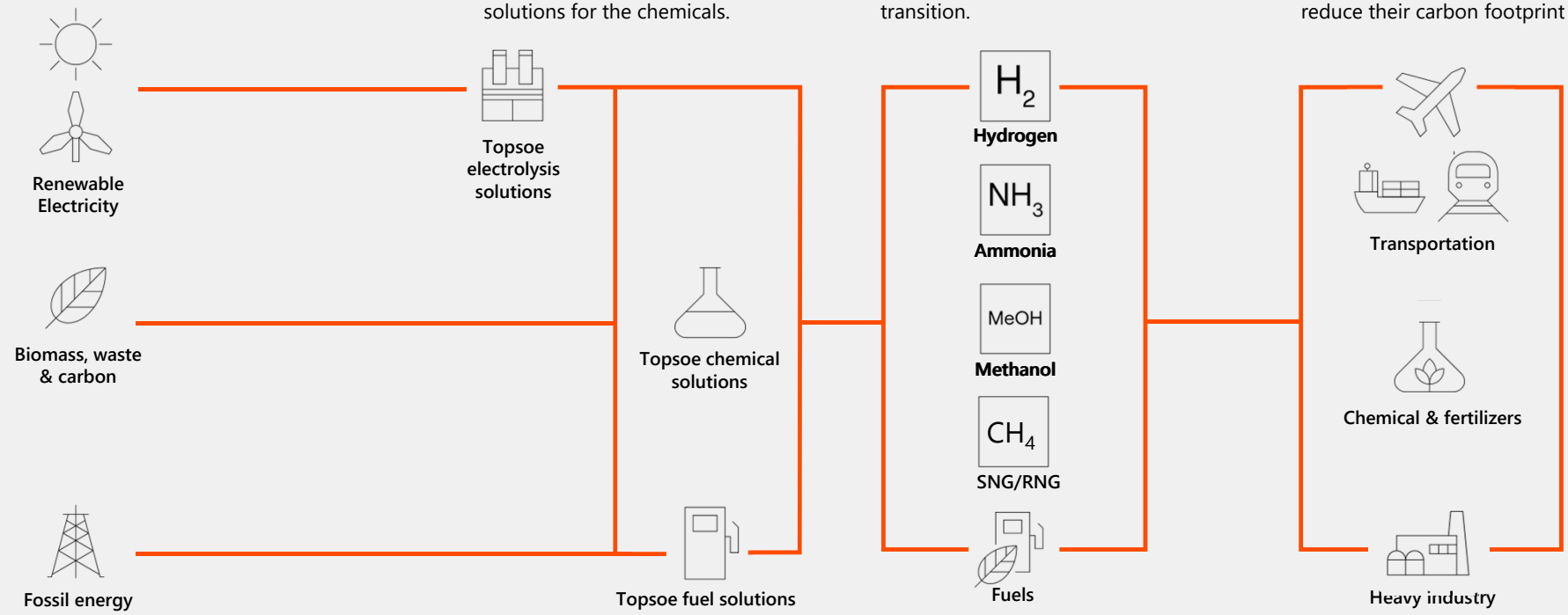
TOPSOE SOLUTIONS ACCELERATE THE ENERGY TRANSITION

ENERGY SOURCES
Fuels and chemicals can be produced from various ways of both renewable and fossil feedstocks.

SOLUTIONS
Topsoe helps customers on their decarbonization journey through advanced energy solutions, such as Power-to-X, renewable fuels and blue solutions for the chemicals.

CHEMICALS AND FUELS
For our customers, the output is more efficient processes or renewable feedstocks, that significantly can lower the carbon footprint, and thereby supporting them in their energy transition.

UTILIZATION
The societal benefits of these end-products come, among other things, in the shape of a cleaner transportation sector and hard-to abate sectors such as steel, cement, and mining, who can reduce their carbon footprint



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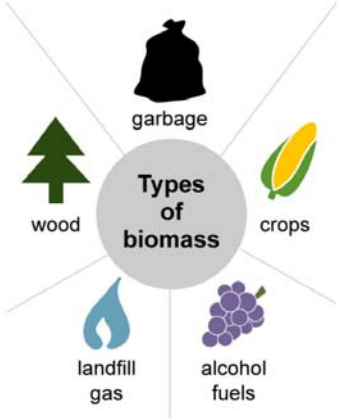
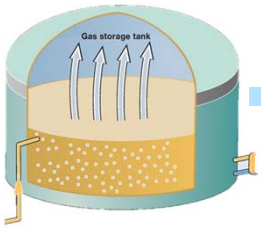
BIOGAS OPTIONS



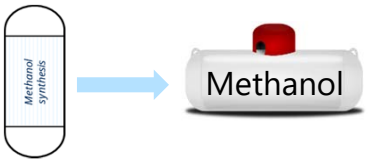
Other biomass applications



~40-45% CO_2

~55-60% CH_4

Biogas to methanol



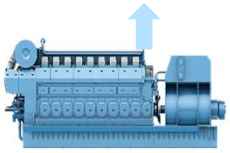
$CO_2 + H_2 \rightarrow CH_4$

CBG / LBG

CO_2 vent

Gas grid

CO_2



Energy grid

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STOICHIOMETRY

HOW MUCH HYDROGEN OR METHANE DO YOU NEED TO UPGRADE THE CO2 ?

UPGRADING THE CO2 TO METHANOL:

EACH CO2 NEEDS 3 × (CH4 OR H2)

METHANE:

EACH CO2 NEEDS 4 × H2

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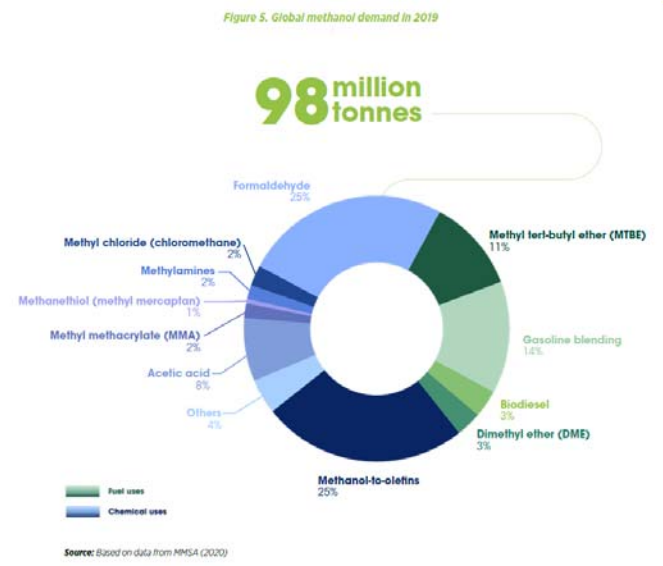
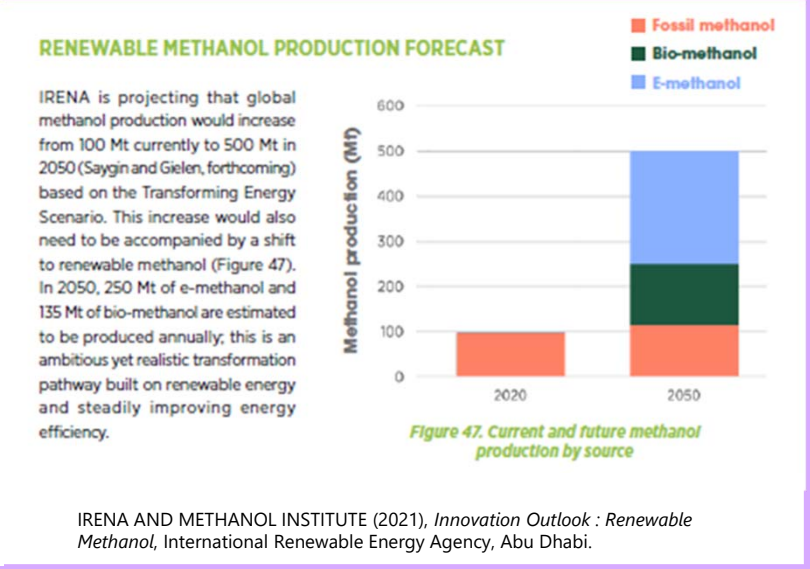
METHANOL A BULK CHEMICAL AND FUEL

Bulk chemical

- Current global market is ~100 million ton/yr and growing at ~3% / yr
- Prices of “grey” methanol varies with gas price in the range 300-800 USD / ton, currently in the high end.





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

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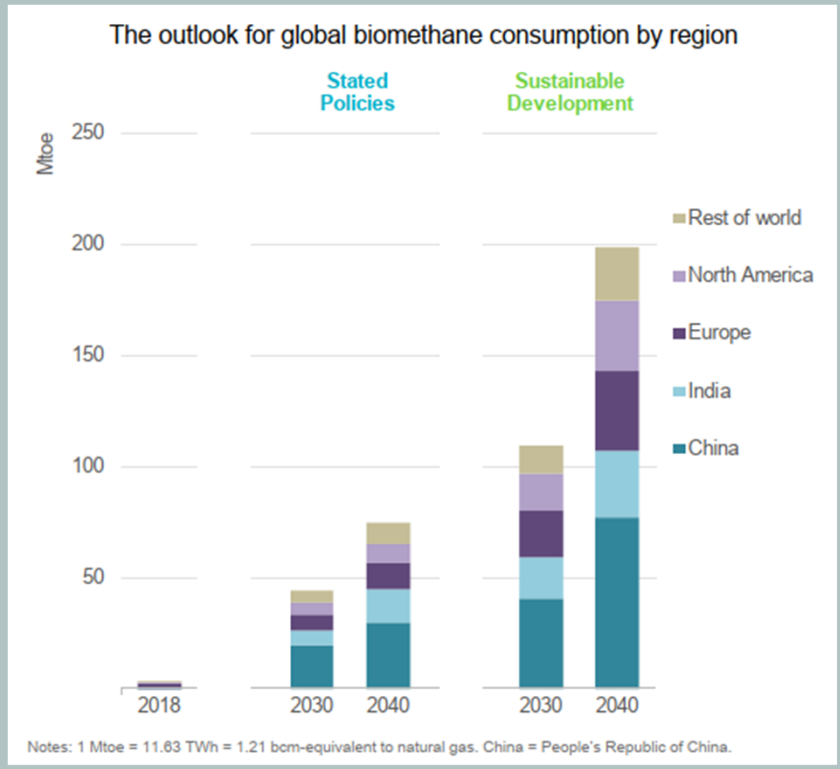
BIOMETHANE: FUEL AND FEED FOR GREEN CHEMICALS

- **Current market and future and applications:**
  - Around 90% of biomethane currently comes from biogas upgrading.
  - Gas injection to remain predominant with possibilities for downstream refining into various chemicals
- **Zooming in:**
  - Europe – REpowerEU aims at 30 billion m^3 biomethane by 2030.



IEA (2020) – Outlook for biogas and Biomethane: Prospects for organic growth. All rights reserved

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Topsoe technology leader in methanol production

Location	Feedstock	Capacity	Start up
Turkmengas, Akhal Velayat, Turkmenistan	Natural gas	5200 MTPD	2019
Shchekino Azot, Shchekino, Tula, Russia	Natural gas	1350 MTPD	2018
Celanese Ltd., Texas, USA	Natural gas	3700 MTPD	2016
Gujarat State Fertilizers and Chemicals, Ltd., Vadodara, India	Natural gas	525 MTPD	2013
Guizhou Tianfu Chemical Co. Ltd., Guizhou, P. R. China	Coal gasification	750 MTPD	2011
Fanavaran Petrochemical Company, Bandar Imam, Iran	Natural gas + CO2	3030 MTPD	2004
Sichuan Lutianhua Stock. Co., Ltd., Sichuan, P. R. China	Synthesis gas	136 MTPD	2003
Petronas Fertiliser (Kedah) Sdn Bhd, Kedah, Malaysia	Synthesis gas	200 MTPD	1998

Selected reference plants by Topsoe design out of 50+ plants by 2021

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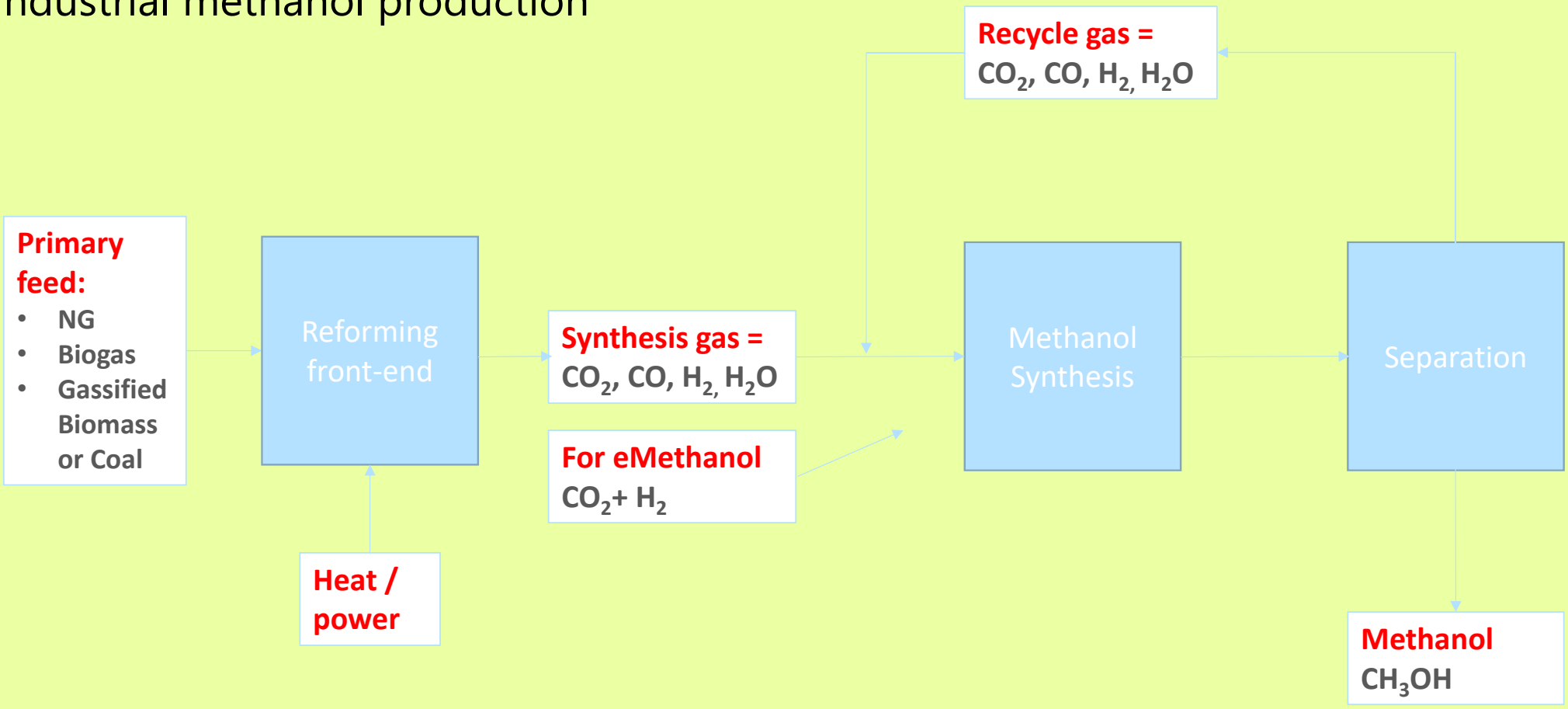
Industrial methanol production



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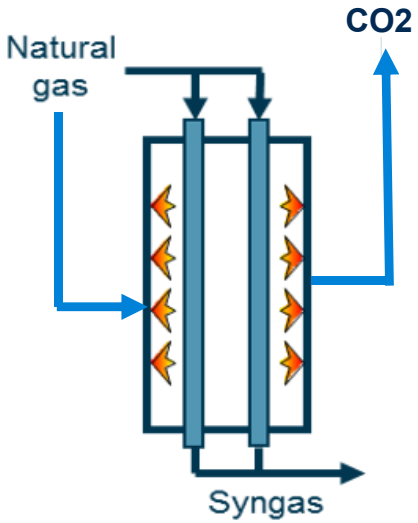
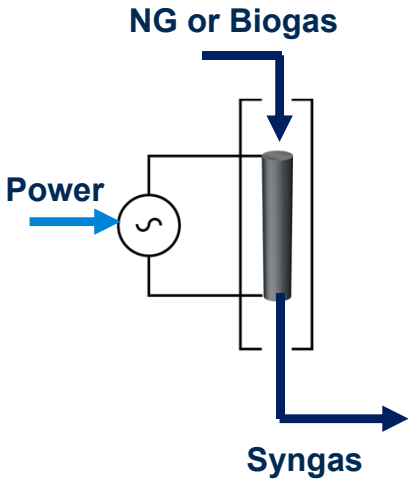
ALTERNATIVES FOR METHANOL SYNTHESIS FRONT-END

Conventional SMR



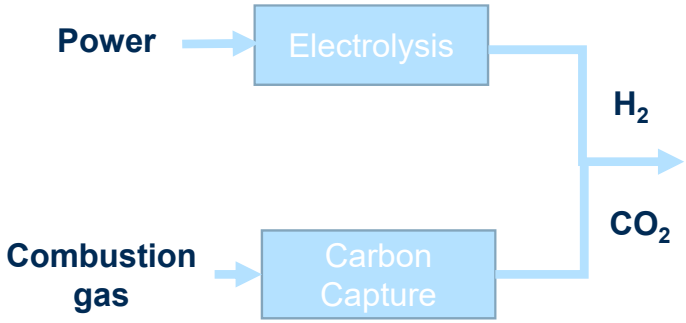
Energy efficiency ≈ 60%
Gas used as source of heat

Topsoe eREACT™



Energy efficiency ≈ 65%
Power used as source of heat

Electrolysis / eMethanol



LT electrolysis:
Energy efficiency ≈ 44%

SOEC
Energy efficiency ≈ 51%

All energy input as power

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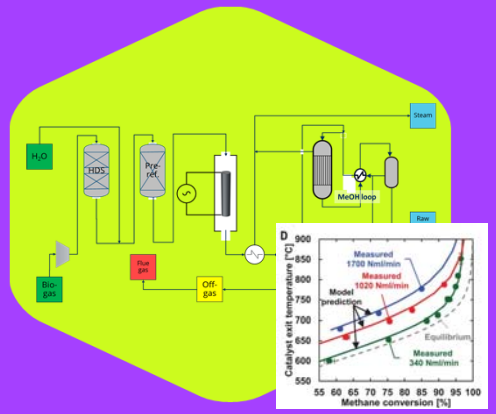
EREACT™ METHANOL ROADMAP
FOR DEMONSTRATION AND TOWARDS COMMERCIALIZATION



120 Nm^3/h syngas

2022:

FID ready for commercial Biogas to methanol plant

2024:

Start of operation

Proof of concept

Demonstration project (Biogas ⇨ MeOH)

Commercialization Biogas ⇨ MeOH

eUDP

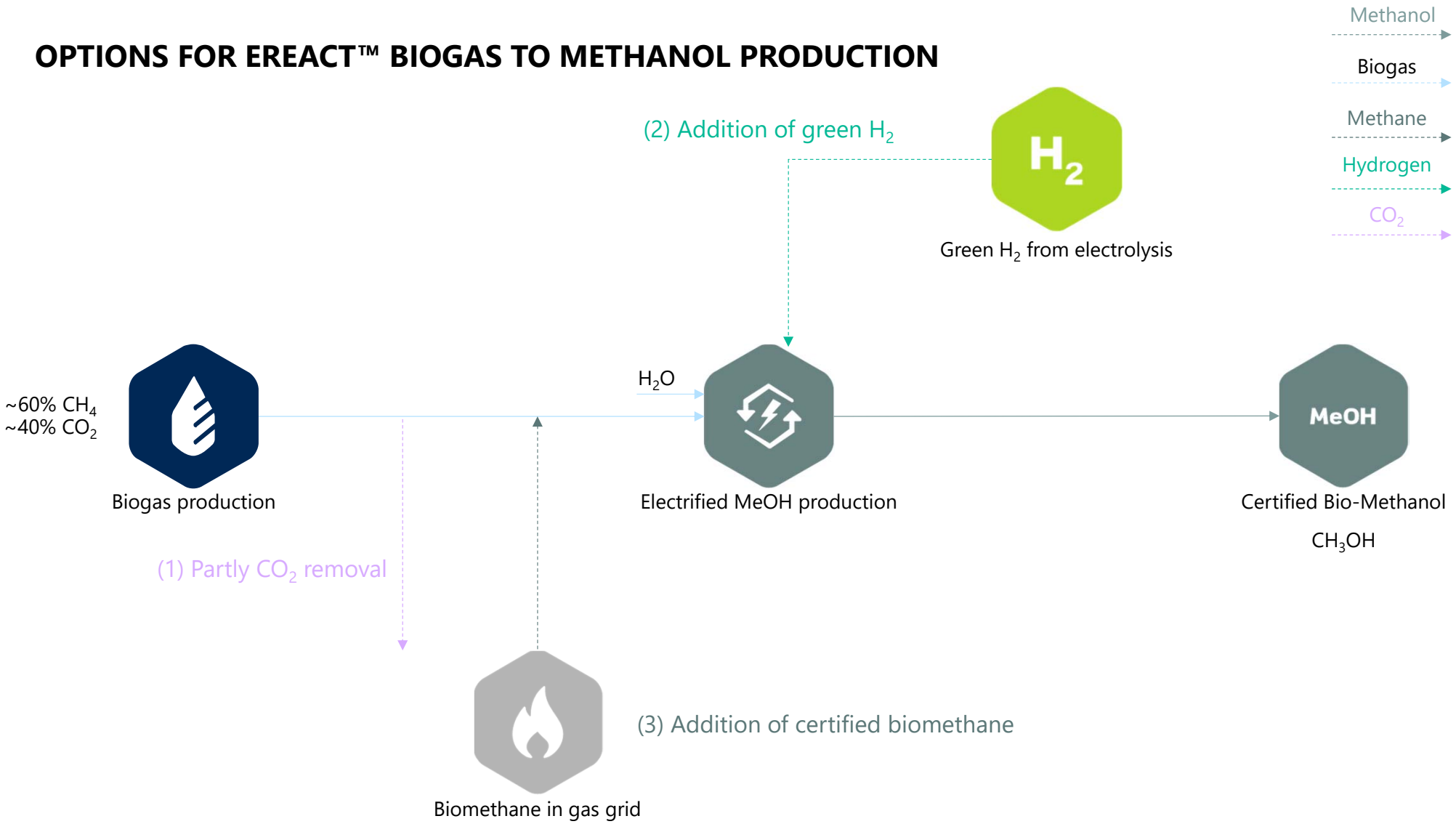
eUDP

2013 - 2018

2019-2021

2022→

OPTIONS FOR EREACT™ BIOGAS TO METHANOL PRODUCTION



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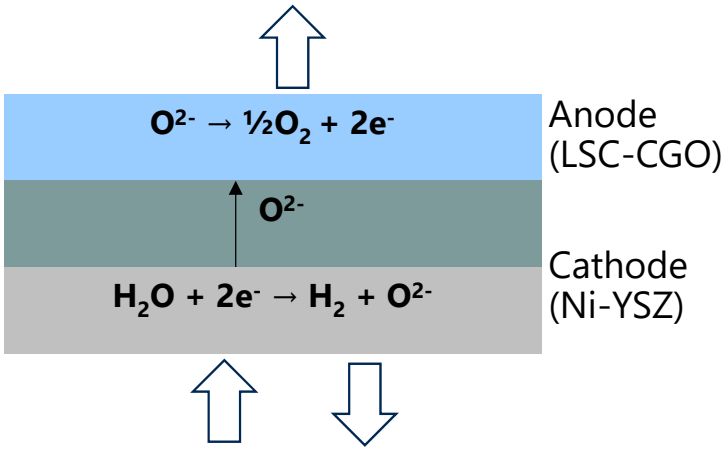
HIGH T SOEC MOST ENERGY EFFICIENT ELECTROLYZER

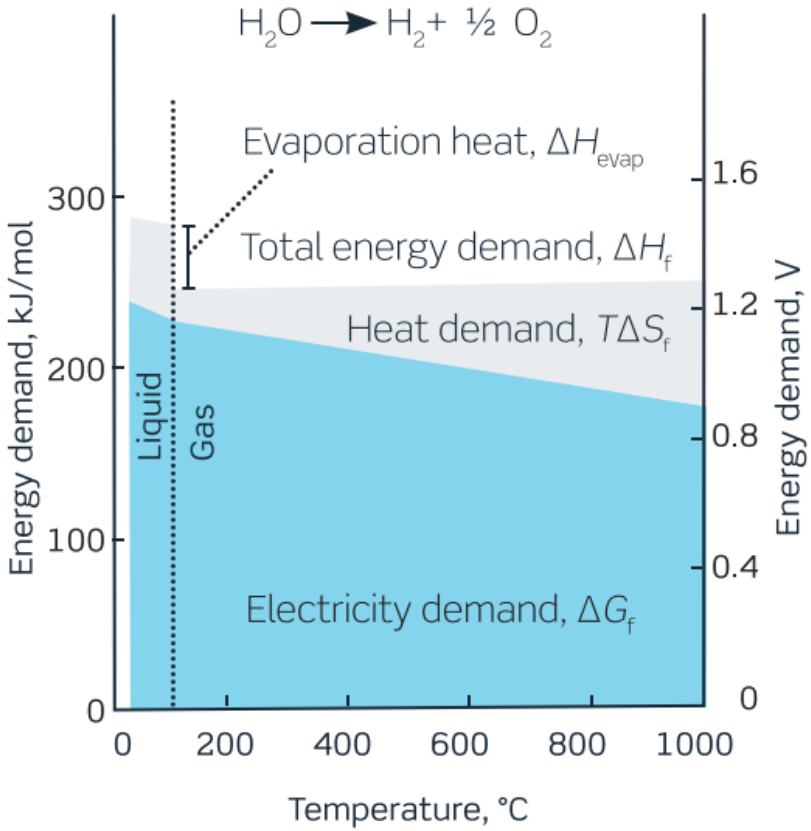
SPECIALLY WELL SUITED FOR INTEGRATION WITH HEAT GENERATING PROCESSES

SOEC electrolysis



Stack power consumption

3.1 kWh/Nm^3 H_2



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ENERGY CONSUMPTIONS AND EFFICIENCIES – INDICATIVE NUMBERS

POWER UPGRADE OF A BIOGAS OF 60% CH4 / 40% CO2 TO CHEMICAL GRADE METHANOL

		Energy input per LHV output		Energy efficiencies	
		BG Gas LHV input	Total Power input	Energy Efficiency to product	District heat output (+/- 50%)
		MW / MW	MW / MW	%	%
Methanol via eREACT™	Partial CO2 vent	0,97	0,52	67%	~10 %
	+ SOEC H2	0,78	0,76	65%	~10 %
	+ LT* H2	0,78	0,83	62%	~10 %
	+ CH4	0,97	0,52	67%	~10 %
eMethanol via BG separation	+ SOEC H2	-	1,97	51% **	~10%
	+ LT* H2	-	2,28	44% **	~10%

* Low temperature electrolysis
** Not including unreacted CH4

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Topsoe's position in methanation

Gobigas, Goteborg Energi

Location	Feedstock	Capacity	Start up
CPI, Xingang, China	Coal gasification	2 x 131,800 Nm^3/h	2024
Huieng, Inner Mongolia, China	Coal gasification	115,600 Nm^3/h	2021
Wulan, Inner Mongolia, China	Coal gasification	78,700 Nm^3/h	2020
Shandong Iron and Steel group Co., Ltd., Rizhao, China	Coke-oven-gas	2 x 55,000 Nm^3/h	2018
Aarhus University/EUDP, Foulum, Denmark	**Biogas + power (SOEC)**	**10 Nm^3/h**	**2016**
Daosheng, Shanxi, China	Coke-oven-gas	27,500 Nm^3/h	2015
Göteborg Energi (GoBiGas), Göteborg, Sweden	**Biomass gasification**	**2,200 Nm^3/h**	**2014**
Petrochina, Inner Mongolia (Wuhai), China	Coke-oven-gas	2 x 56,300 Nm^3/h	2013

Selected reference plants by Topsoe design

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BIOGAS UPGRADE II
A FULL VALUECHAIN FROM BIOGAS TO GAS GRID

- Biogas to SNG (Substitute Natural Gas) via SOEC (Solid Oxide Electrolysis Cell) and methanation of the CO_2 in the biogas
- SOEC is taken to TRL 8
- Methanation taken to TRL8
- Economic analysis has shown that upgrading can compete with traditional upgrade by CO_2 removal
- Carbon utilization is better and CO2 emission avoided

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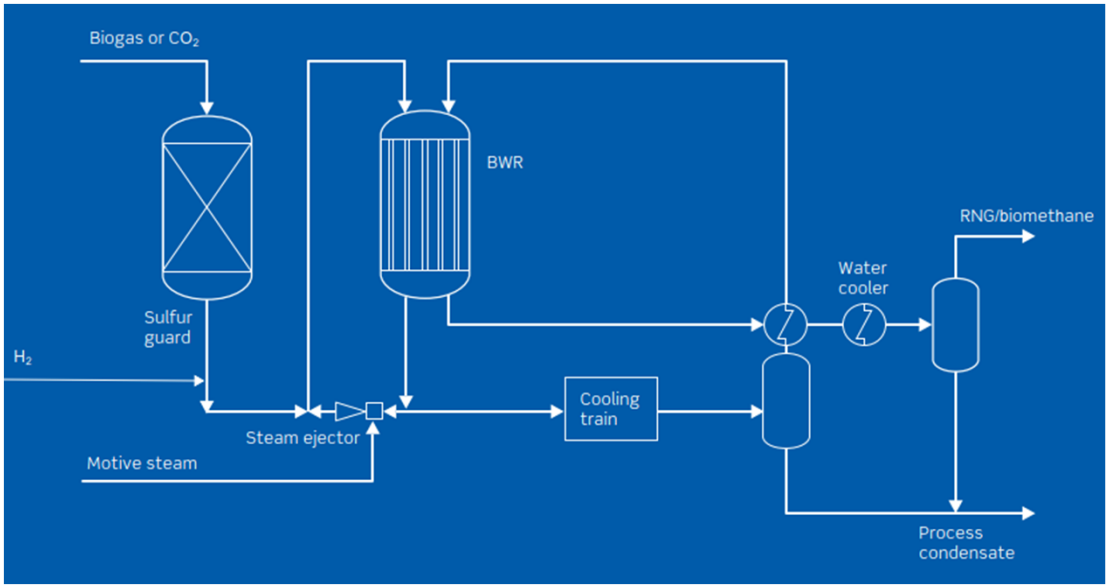
BIOGAS OR BIOCO2 METHANATION
HYDROGEN SUPPLEMENT FROM ELECTROLYSIS

- Carbon source: Biogas mixture or pure CO_2
- Hydrogen addition to achieve: $H_2/CO_2 = 4$
- Isothermal reactor by TREMP™ design
- Integrate with SOEC to achieve an unmatched system efficiency.



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** Not including unreacted CH4

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OUTLOOK AND SUMMARY

- **BIOGENIC CO2 WILL BE A VALUABLE RESOURCE FOR OUR GREEN ENERGY TRANSITION SERVING THE HARD-TO-ABATE SECTORS**
- **UPGRADING BIOGAS BY RENEWABLE POWER TO METHANE OR METHANOL ARE VIABLE ROUTES**
- **TOPSOE HAS ENERGY EFFICIENT TECHNOLOGIES AVAILABLE FOR BOTH ROUTES**
- **THE NOVEL EREACT™ TECHNOLOGY ENABLES FULL BIOGAS CONVERSION TO METHANOL WITH HIGH ENERGY EFFICIENCY AND NO PROCESS CO2 EMISSION**
- **SOEC TECHNOLOGY ENABLES FULL BIOGAS CONVERSION TO METHANE WITH HIGH ENERGY EFFICIENCY BY USING THE HEAT OF METHANATION FOR HYDROGEN PRODUCTION**

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QUESTIONS ?

April 28, 2022

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