Status of bio-Methanol Production*

Greening of Inland Navigation, Short Sea Shipping and River-Sea Shipping

Workshop March 24, 2021

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Fuels & Energy Consulting

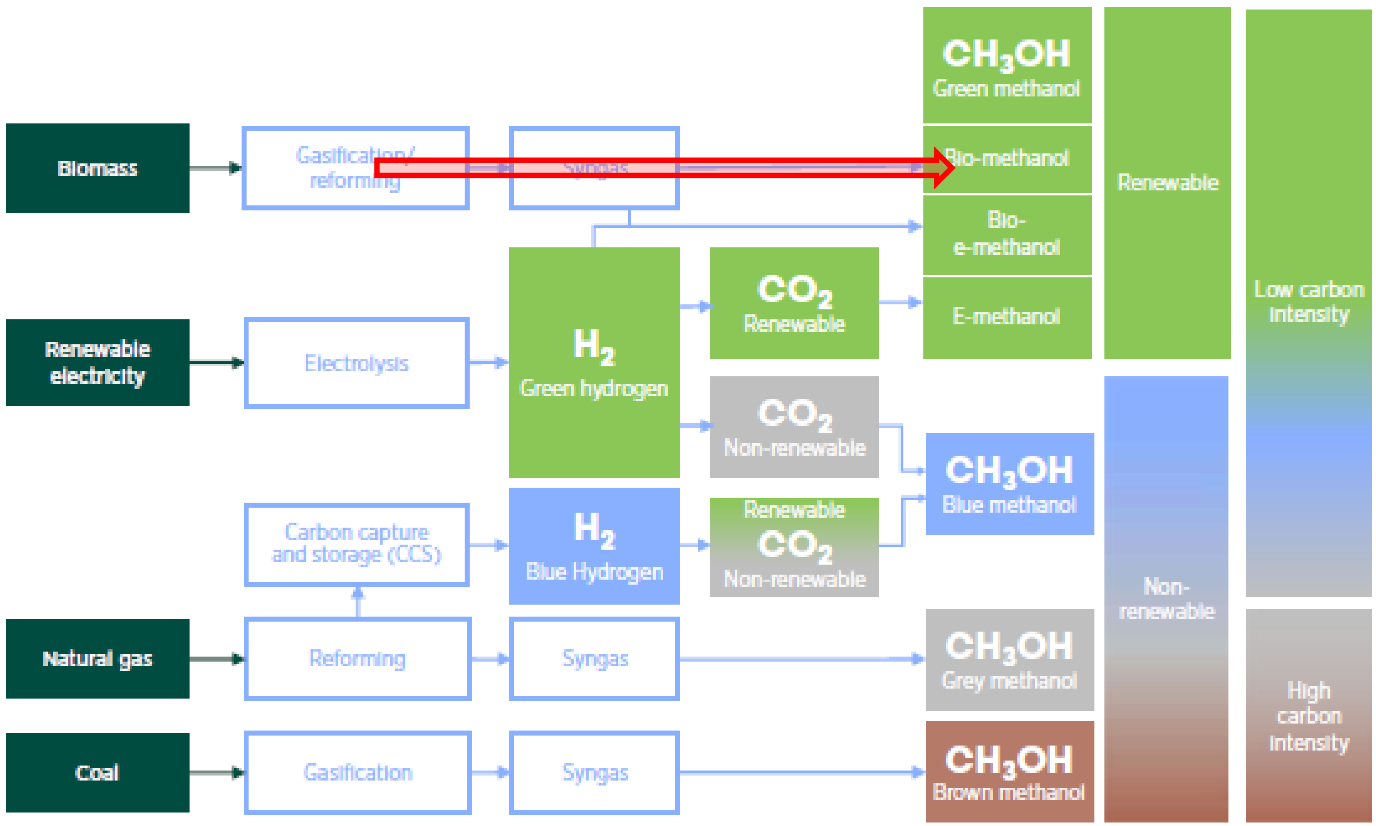
* Based on IRENA / Methanol Institute report
Innovation Outlook: Renewable Methanol

Content

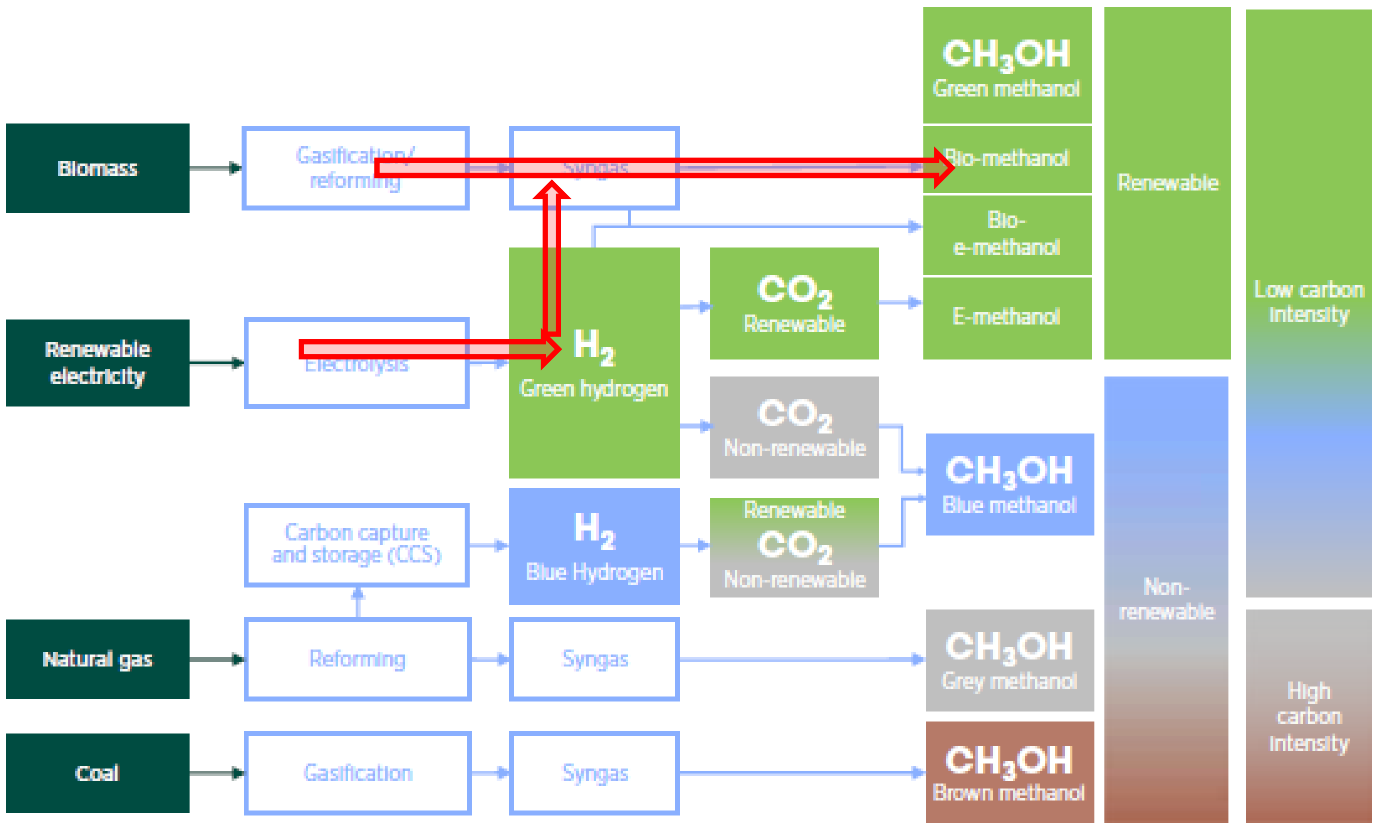
- **Overall system**
- **Some technology**
- **Plants and projects**
- **Elaboration of Production Cost**
- **Summary: Overall production cost**
- **Reports in the presented field of knowledge**

Bio-methanol production pathway

Green Methanol via Biomass gasification

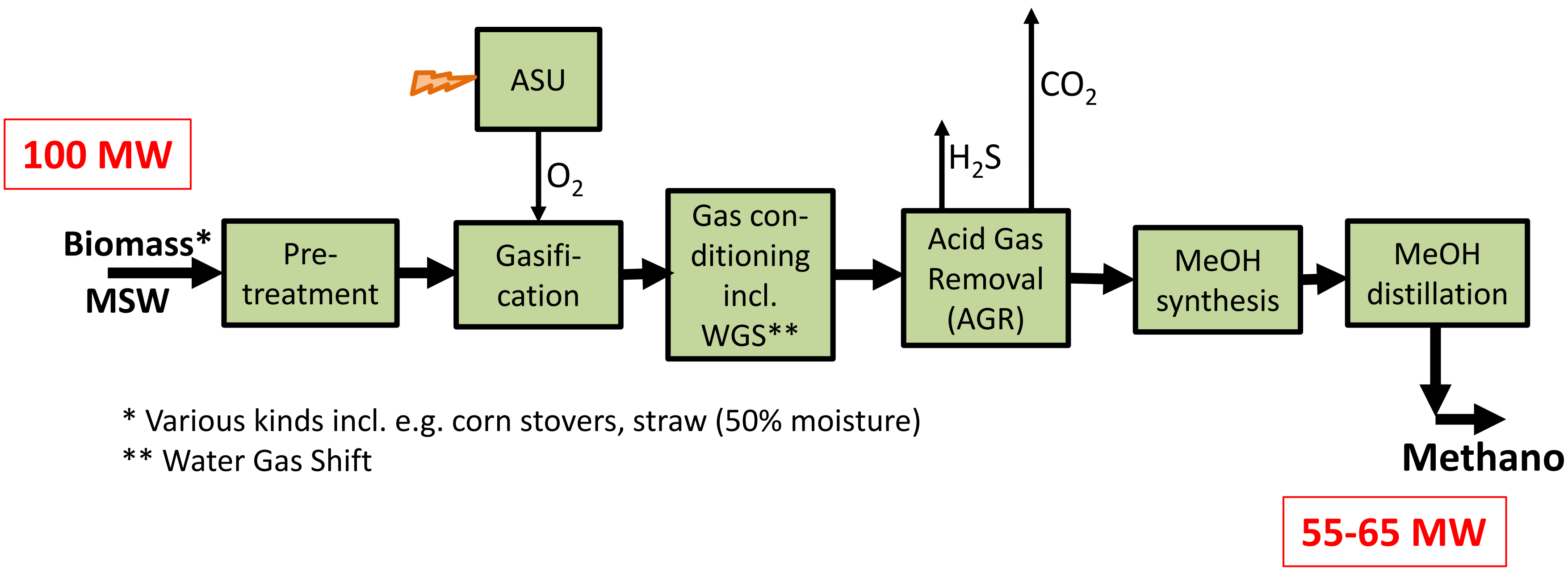


Combined Bio- and e-Methanol



Gasification-based Methanol Plant

Bio-Methanol via Biomass and MSW gasification

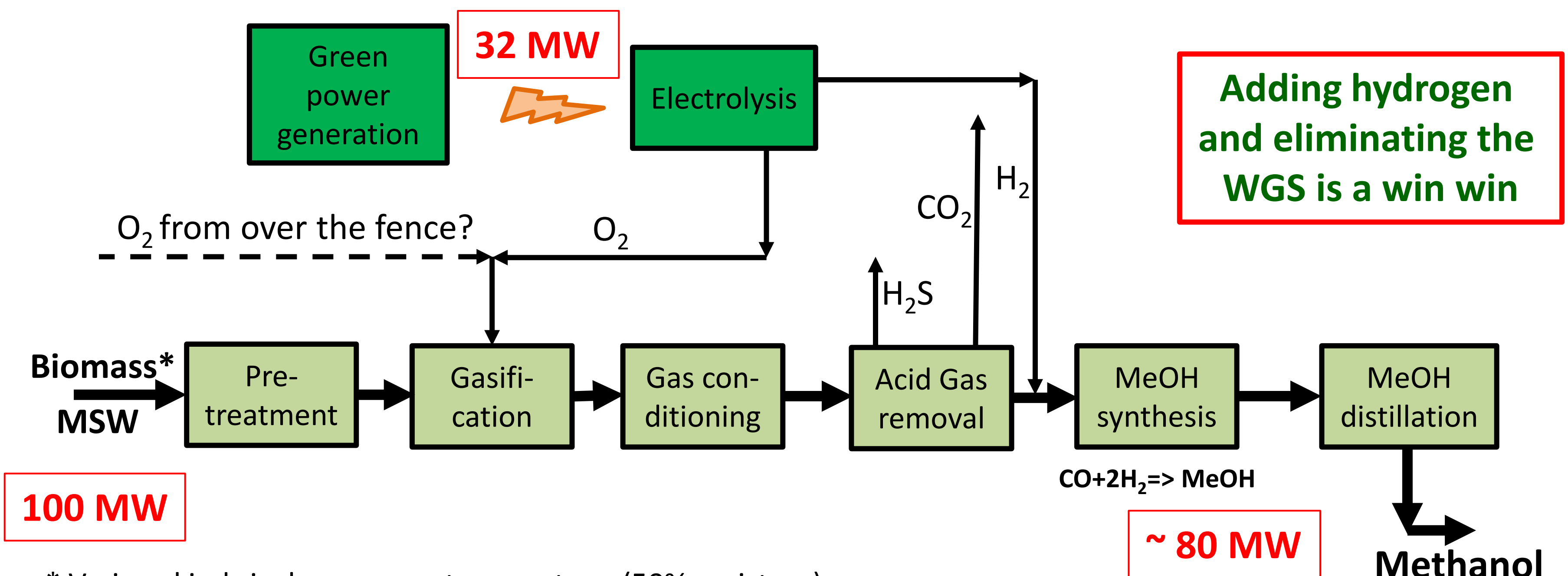


* Various kinds incl. e.g. corn stovers, straw (50% moisture)
** Water Gas Shift

Combined Bio- and e-Methanol, Step 1

(WGS** is replaced by imported hydrogen)

- Increased methanol production from the same amount of feedstock
- Simpler & more efficient process scheme because:
  - No WGS => increased syngas by 5-6%
  - Lower CO_2 emission
- No oxygen plant (potentially)
- No HP steam demand for WGS
- No new process developments
- Very efficient use of hydrogen
- Use of all CO in raw syngas
- Only 2 mole H_2 per recovered mole C

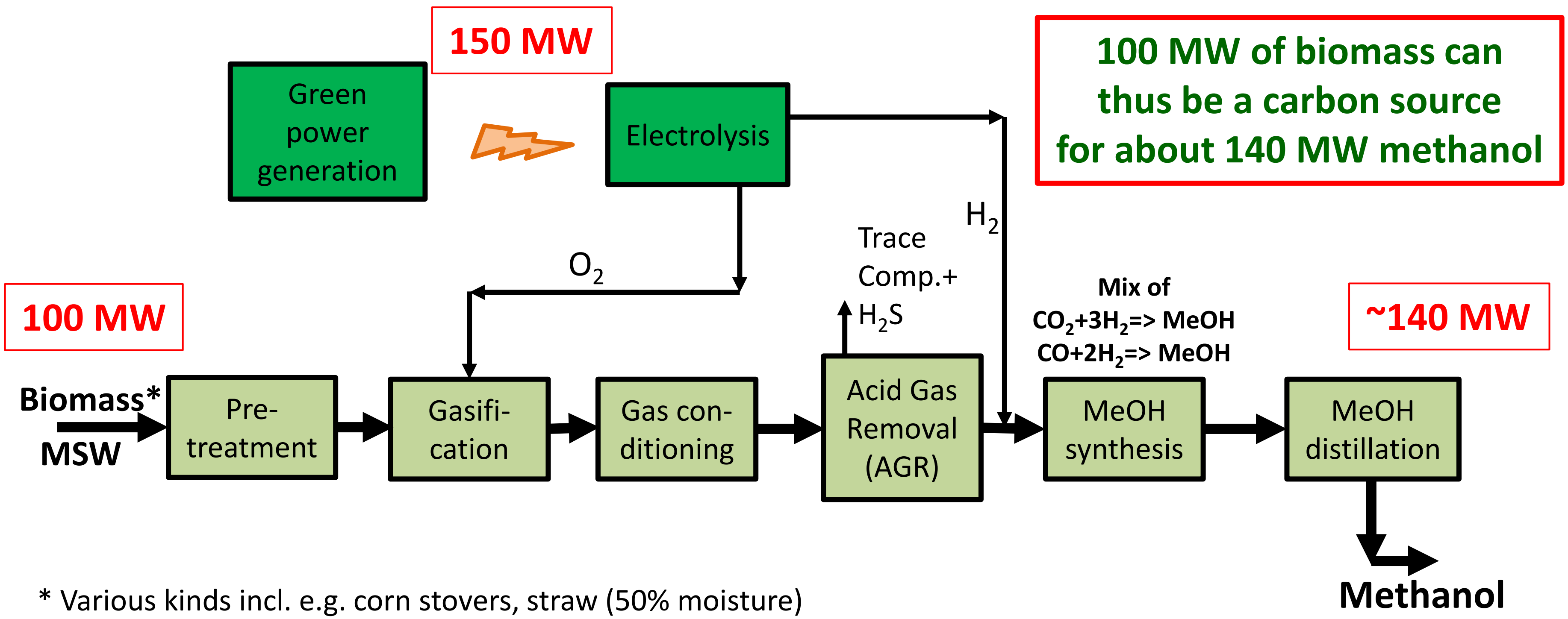


* Various kinds incl. e.g. corn stovers, straw (50% moisture)

** Water Gas Shift

Combined Bio- and e-Methanol, Step 2

- Methanol plant fed with a mixture of CO, CO_2 and H_2 .
- Altered methanol catalyst
- CO_2 is kept at syngas pressure.
- AGR only removes sulphur components and other traces
- No oxygen plant
- Close to all carbon in biomass converted to methanol => More energy in produced methanol than in biomass feedstock



* Various kinds incl. e.g. corn stovers, straw (50% moisture)

List of Bio-methanol Projects, 3Q 2020

in various stages of planning

#	Project / study	Status	Capacity (tpy)	CAPEX (Million USD)	CAPEX (USD/ tpy)	CAPEX (USD/kW)	Source
1	Trans World Energy (TWE), Florida (USA)	FEED done, Startup 2Q 2023	875 000	430	490	710	TWE
2	ENI Refinery, Livorno, Italian (I)	Basic Engineering ready 3Q,2020	115 000	330	2900	4280	NextChem
3	LowLand Methanol (NL)	Startup early 2023	120 000	130	1110	1620	LowLand Methnaol
4	Södra (SE)	Operation	5000	11	2220	3230	Södra
5	Enerkem, Rotterdam (NL)	Engineering	215 000	580	2690	3840	Enerkem
6	Enerkem, Tarragona (SP)	Engineering	215 000	580	2690	3840	Enerkem
7	VTT	Detailed study	265 000	385	1450	2070	VTT
8	Chemrec, Domsjö	Prel. Eng.	147 000	390	2640	3400	Chemrec
9	Chemrec, n^{th} plant	Concept	290 000	540/270*	1880/920*	2740/1430/ 1290*	Chemrec
10	New Hope Energy, Texas (USA)	Investment decision 4Q,2020	715 000	500	700	1020	New Hope Energy

List of Bio-methanol Projects, 3Q 2020

In Operation

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List of Bio-methanol Projects, 3Q 2020

Large capacities

#	Project / study	Status	Capacity (tpy)	CAPEX (Million USD)	CAPEX (USD/ tpy)	CAPEX (USD/kW)	Source
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List of Bio-methanol Projects, 3Q, 2020

MSW to bio-Methanol

#	Project / study	Status	Capacity (tpy)	CAPEX (Million USD)	CAPEX (USD/ tpy)	CAPEX (USD/kW)	Source
1	Trans World Energy (TWE), Florida (USA)	FEED done, Startup 2Q 2023	875 000	430	490	710	TWE
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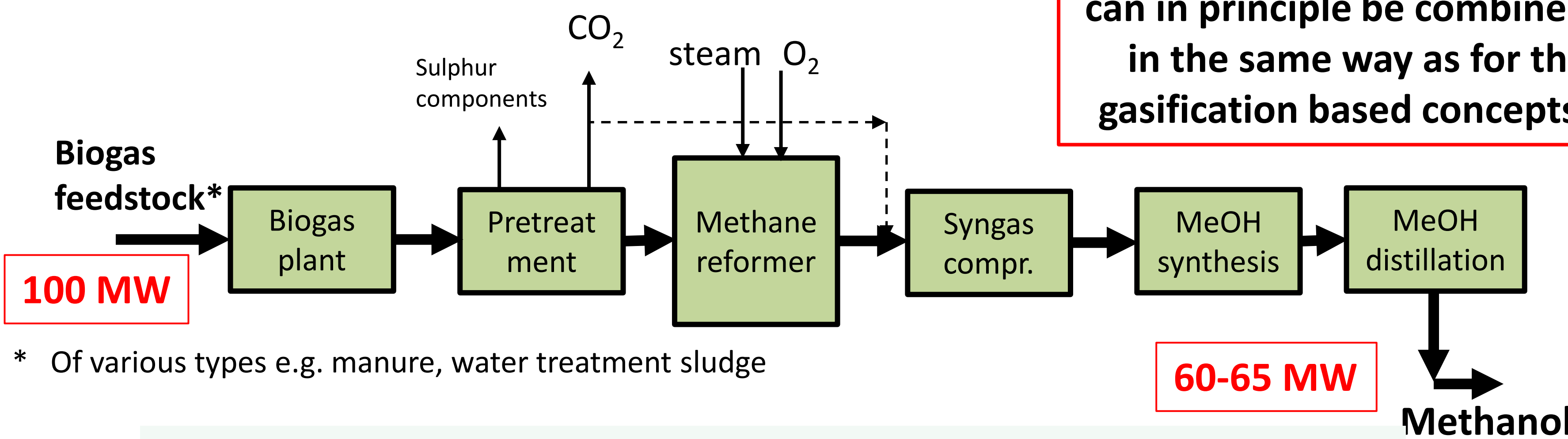
Reformer-based Methanol Plant

general scheme

Bio- and e-methanol can in principle be combined in the same way as for the gasification based concepts.



In operation

Technology	Feedstock	Project, reference	Project phase	Product	Plant capacity
Steam reforming	Natural gas/ biomethane	BASF, Ludwigshafen (DE)	Operational	Methanol	480 kt/y* (2018)
Steam reforming	Natural gas/ biomethane	OCI/BioMCN Groningen (NL)	Operational	Methanol	60 kt/y** (2017)
Steam reforming	Natural gas/ biomethane	OCI Beaumont Texas (US)	Operational	Methanol	1 075 kt/y (2020)***

** Plant capacity (Saygin and Gielen, forthcoming). Bio-methanol share is around 15%.*

*** Bio-methanol part (Compagne, 2017).*

**** Plant capacity (OCI, 2020). Bio-methanol share not given.*

Total production cost for bio-methanol from biomass and MSW

		Biomass as feedstock				MSW as feedstock			
		Low		High		Low		High	
CAPEX/y, USD/t MeOH		206		293		264		367	
Overall conversion efficiency, %		60	70	60	70	50	60	50	60
Feedstock cost element for methanol at various level, USD/t MeOH	At USD 15/GJ	498	426	498	426	-	-	-	-
	At USD 10/GJ	332	284	332	284	-	-	-	-
	At USD 6/GJ	199	171	199	171	-	-	-	-
	At USD 3/GJ	100	85	100	85	119	100	119	100
	At USD 1.5/GJ	50	43	50	43	60	50	60	50
	At USD 0/GJ [a]	-	-	-	-	0	0	0	0
OPEX at 5%, USD/t MeOH		78		111		100		139	
OPEX at 10%, USD/t MeOH		156		222		200		278	
Cost of methanol (USD/t MeOH)	Feedstock cost below USD 6/GJ	327-561		447-714		414-583		556-764	
	Feedstock cost at USD 6-15/GJ	455-860		575-1 013		-		-	
Carbon credit (USD/t MeOH)	At USD 50/t CO_2 [b]	-82		-82		-82		-82	
	At USD 100/t CO_2 [b]	-164		-164		-164		-164	

- **Energy Efficiency varies from 50-70%**
- **Feedstock price varies from 0 to 15 USD/GJ**
- **Other OPEX varies from 5-10% of investment per year**
- **Carbon credit at 50-100 USD/t CO_2 corresponds to 82-164 USD/t MeOH**

(Swedish carbon tax is about 125 USD/t CO_2. That applied would lead to cost competitive production today)

CAPEX*

* Investment calculated for 15y/10% => IRR of 13.2%

		Biomass as feedstock				MSW as feedstock			
		Low		High		Low		High	
CAPEX/y, USD/t MeOH		206		293		264		367	
O... s		60	70	60	70	50	60	50	60
Fe... el... m... various level, USD/t MeOH	.../GJ	498	426	498	426	-	-	-	-
	.../GJ	332	284	332	284	-	-	-	-
	...GJ	199	171	199	171	-	-	-	-
	At USD 3/GJ	100	85	100	85	119	100	119	100
	At USD 1.5/GJ	50	43	50	43	60	50	60	50
	At USD 0/GJ [a]	-	-	-	-	0	0	0	0
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OPEX

Total production cost for bio-methanol from biomass and MSW

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Cost of methanol (USD/t MeOH)	Feedstock cost below USD 6/GJ <100 EUR/ dry tonne	327-561		447-714		414-583		556-764	
	Feedstock cost at USD 6-15/GJ	455-860		575-1 013		-		-	
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Total prod. Cost

Carbon Credit

- Energy Efficiency varies from 50-70%
- Feedstock price varies from 0 to 15 USD/GJ
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(Swedish carbon tax is about 125 USD/t CO_2. That applied would lead to cost competitive production today)

Total production cost for bio-methanol after potential cost reduction

Total prod. Cost
Feedstock
< 100 EUR/t

		Biomass as feedstock		MSW as feedstock	
		Low	High	Low	High
Before cost reduction USD/t MeOH (from Table 17)	Feedstock below USD 6/GJ	327-561	447-714	414-583	556-764
	Feedstock at USD 6-15/GJ	455-860	575-1 013	-	-
CAPEX/y reduction, USD/t MeOH		-82	-118	-106	-147
OPEX reduction, USD/t MeOH		-18 to -36	-26 to -51	-23 to -46	-32 to -64
Cost of methanol (USD/t MeOH) at feedstock cost below USD 6/GJ < 20 EUR/MWh or 100 EUR/ dry tonne	With no carbon credit	227-443	303-545	285-431	377-553
	With a credit of USD 50/t CO_2 *	145-361	221-463	203-349	295-471
	With a credit of USD 100/t CO_2 *	63-279	139-381	121-267	213-389
Cost of methanol (USD/t MeOH) at feedstock cost at USD 6-15/GJ > 20 EUR/MWh or 100 EUR/ dry tonne	With no carbon credit	355-742	431-844	-	-
	With a credit of USD 50/t CO_2 *	273-660	349-762	-	-
	With a credit of USD 100/t CO_2 *	191-578	267-680	-	-

- Investment calculated for 20y/8% => IRR of 10.2%. Decrease 23%
- "Learning curve" cost reduction: 20%
- Combined: - 40% used in calculations

OPEX assumed to follow the investment reduction

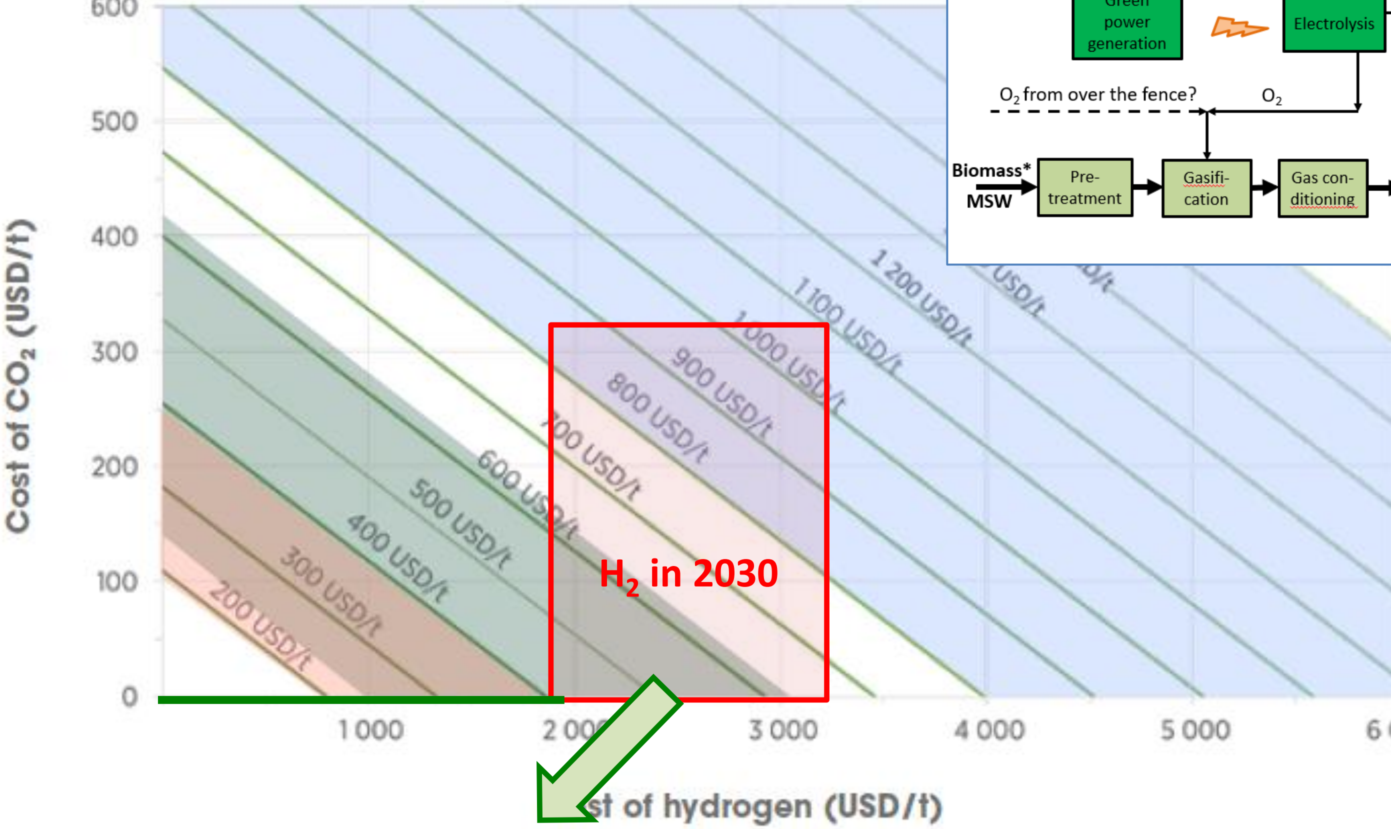
Even without carbon credit methanol production cost can compete with today's methanol prices

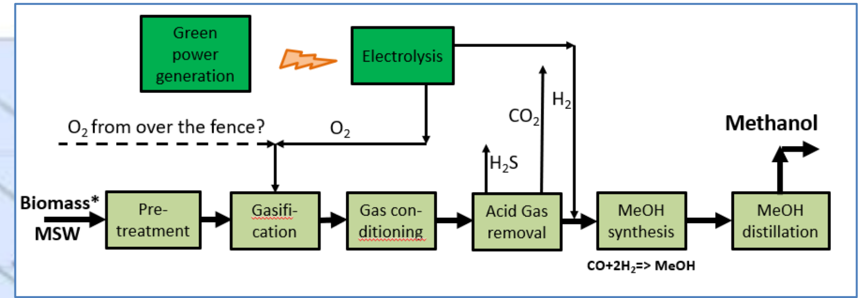
Including Carbon Credit

Impact of feedstock price in production of methanol from methane/biomethane

Table 19: Impact of feedstock price in production of methanol from methane/biomethane

	Biomethane price	Feedstock cost in production cost of methanol (conversion efficiency 65%)		Impact on production cost
	USD/GJ biomethane	USD/GJ MeOH	USD/t MeOH	USD/t MeOH
Natural gas in western Europe	10.8	16.6	329	+ 377
Biomethane	23.1	35.5	706	





Hydrogen added to the syngas in a bio-methanol plant is a win win

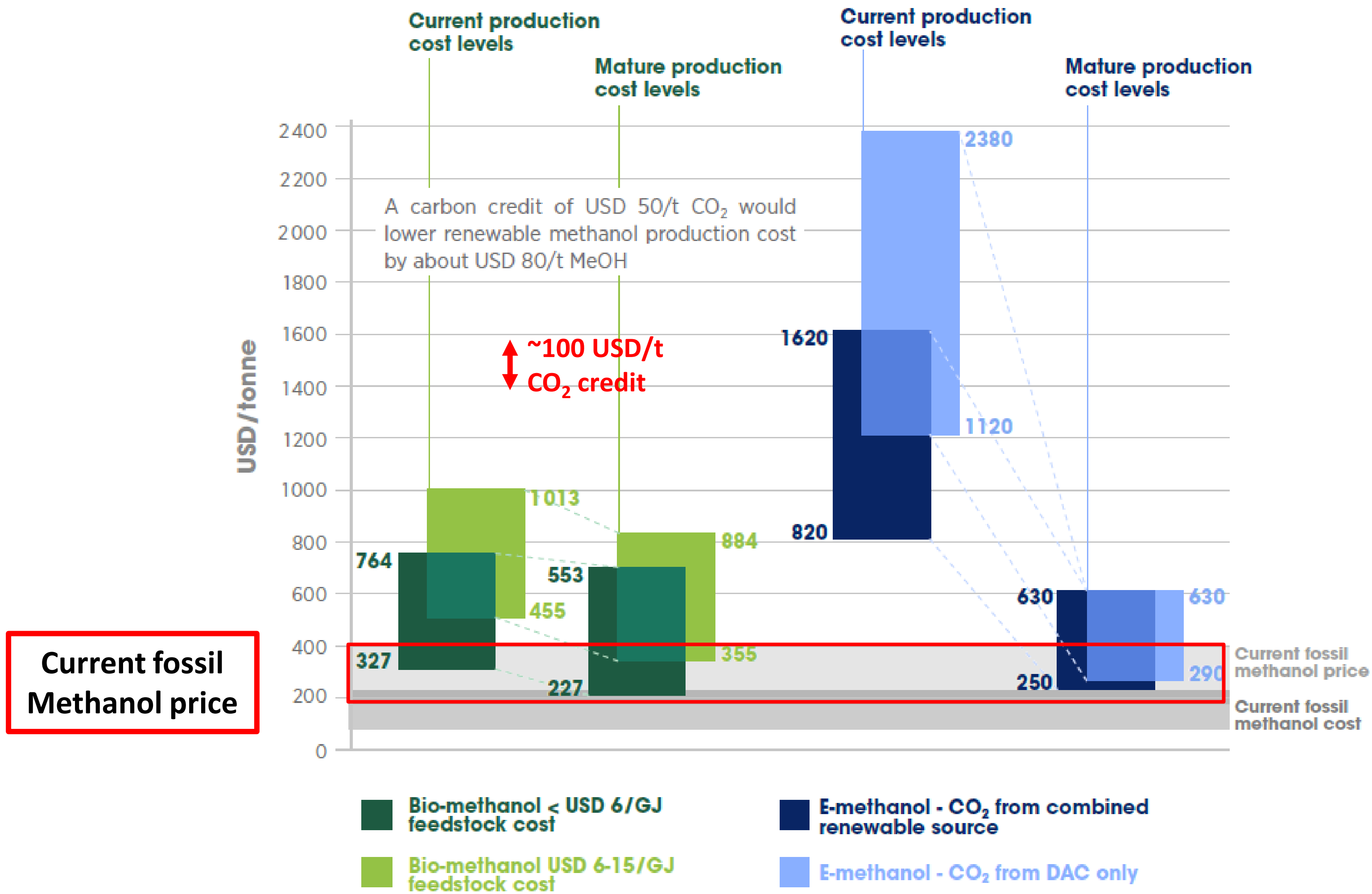
Green line:

Zero cost CO2

Green arrow:

Hydrogen replacing the so called WGS unit comes with a credit => lowering production cost of methanol as the arrow points

SUMMARY:
Production cost for Bio- and e-methanol



Recent reports covering today's topic

Where to Find the Reports

1. **Cost of Biofuels (SGAB, 2017):**
https://publications.europa.eu/en/publication-detail/-/publication/13e27082-67a2-11e8-ab9c-01aa75ed71a1/language-en/format-PDF/source-71250236
2. **Methanol as a renewable Fuel – A knowledge Synthesis (f3, 2017):**
https://f3centre.se/en/research/methanol-as-a-renewable-fuel-a-knowledge-synthesis/
3. **Tech Brief: Production of bio-methanol (IRENA, 2013):**
https://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20I08%20Production_of_Bio-methanol.pdf
4. **Advanced biofuels – Potential for Cost reduction (IEA Bioenergy, 2020):**
https://www.ieabioenergy.com/wp-content/uploads/2020/02/Screenshot-2020-02-11-at-11.36.35.png
5. **Innovation outlook: Renewable Methanol (IRENA/Methanol Institute, 2021):**
https://www.irena.org/publications/2021/Jan/Innovation-Outlook-Renewable-Methanol