LARGE SCALE RENEWABLE METHANOL

CHANCES AND CHALLENGES FROM AN INDUSTRIAL PRODUCERS VIEW

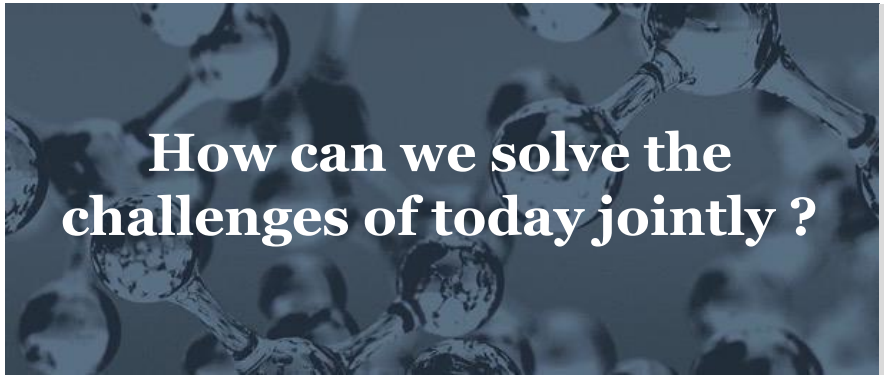
Dr. Jens Schmidt, DOW Deutschland Anlagengesellschaft mbH

DOW RESTRICTED

Content

- Intro to DOW
- Key facts around Hydrogen production
- Large scale renewable methanol production
  - DOW Green MeOH Project
  - Economic evaluation
  - Regulatory hurdles

Dow



It always starts with passion and a goal in mind. Dow combines integrated production facilities and global outreach, focused innovation and strong market position and aims for profitable growth, to be the most innovative, customer focused, inclusive and sustainable Material-Science-Company.

2019 Revenue	Employees	Locations	Global Reach
$ 43 Mrd.	**~36,500**	**109 Sites**	**31 Countries** where we manufacture products

DOW HAS THE MOST COMPETITIVE GREEN HYDROGEN AVAILABLE

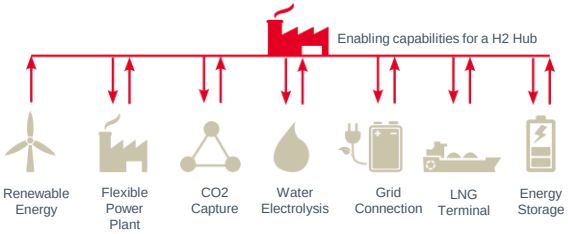
DOW Stade Site

- Production:
  ~ **4 Mio.** mt in 2019
- Total Invest:
  ~ **3.5 Mrd.** Euro
- Employees Dow:
  ~ **1.100**
- 3. largest harbor
  + **5 Mio.** Tonnen

H2 Capabilities Dow Stade

Production and Storage capacity at World Scale

- **Dow produces ~ 50.000 t/a Hydrogen with salt water electrolysis from existing chlorine plant**
  - Equivalent of 200.000 H-cars being refueled weekly
- **Equivalent to electrolysis-capacity of ~ 280 MW**
  ~3-400 MM € Capital Invest equivalent
  ~ 100 MM €/a power costs at 8000 h/a and 60 €/MWh (already included in Chlorine production)
- **Direct access on site to northern German wind power**
- **Transformer station of German grid operator on site**
- **DOW operates several salt caverns**
  - Generating 1 MM m3/a cavern capacity
  - Long lasting experience in storing propylene and ethylene in salt domes
  - Caverns are reasonable solution for H storage

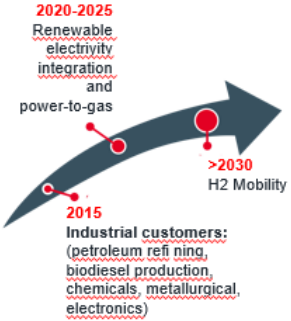


EU Green H2 Demand Forecasts

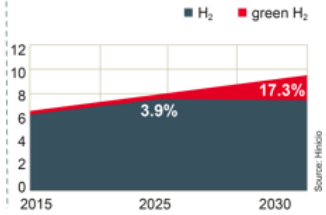
Green hydrogen demand – Market shares by 2030

- Power to gas
- H2 mobility
- Chemical
- Refineries
- Metal Processing
- Others
  (food, glass production, semiconductors, aerospace)

Green Hydrogen: Main demand markets overtime



Total H2 demand



Why Renewable Methanol in Dow Stade/Germany ?

- Dow Stade produces ~1.6MM t/a of Chlorine in Europe‘s largest electrolysis
- Second largest power consumer in Germany after Deutsche Bahn

- Dow also operates a gas fired power plant in Stade to supply steam and electricity

- Opportunity to use renewable power to make green hydrogen and convert captured CO2 into **sustainable carbon neutral base chemicals** or green jet fuel, etc.

- Green Hydrogen production happens through salt water electrolysis

- Physically 40% of elec. power is green already, can be turned entirely green (for slightly higher power price)

Several eMeOH Projects announced…

5kta

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NOURYON AND GASUNIE TO SUPPLY GREEN HYDROGEN FOR BIOMCN RENE METHANOL PRODUCTION

By Mary Page Bailey | February 28, 2019

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Nouryon (formerly AkzoNobel Specialty Chemicals; Amsterdam; www.nouryon.com) and G
green hydrogen to BioMCN for the production of renewable methanol from CO2. The compa
in the sustainability of processes in the industry.

Nouryon and Gasunie are currently investigating the possible conversion of sustainable ele
using a 20-megawatt water electrolysis unit in Delfzijl, the Netherlands. A final decision or
this year.

BioMCN will combine hydrogen from the intended facility with CO_2 from other processes t
a raw material for bio-fuels and a variety of chemical feedstocks. Compared to fossil-based
emissions by up to 27,000 tons of CO_2 per year.

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Green Car Congress

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CRI awarded €1.8M EU grant to scale CO2-to-methanol technology

11 April 2019

Carbon Recycling International has been awarded a €1.8-million (US$2.0-million) grant under the EU Horizon 2020 Research Programme to increase the scale of its CO_2-to-methanol technology, marketed under the trademark Emissions-to-Liquids (ETL).

The grant will allow CRI to accelerate efforts to commercialize large scale production plants, expanding the market for ETL technology and use of renewable methanol in Europe.

The project is referred to as "CirclEnergy" as CRI's technology is designed to support and enable the transition to circular economy.

CRI's ETL technology consist of five process modules.

4 – 8kta

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Port of Antwerp embarking on sustainable methanol production

The Port of Antwerp will embark on an ambitious project on the sustainable production of methanol, followed by the introduction of a methanol-powered tug in the near future.

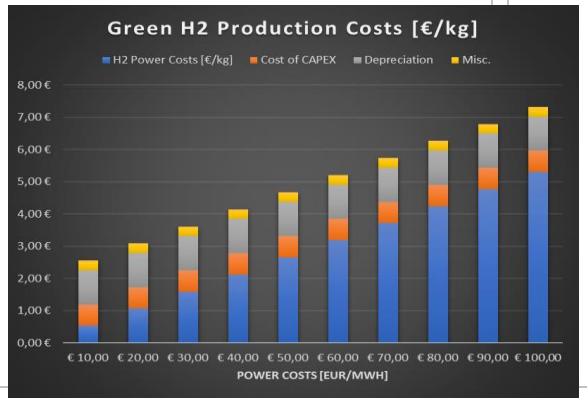
The pilot project is aiming to produce 4,000-8,000 tonnes of sustainable methanol a year, an important step in the transition to alternative energy sources and a carbon-neutral port.

To achieve this, Port of Antwerp is bringing various experts together. ENGIE, Oiltanking, Indaver, Vlaamse

BioMCN, etc.

Cost of Hydrogen from Water Electrolysis

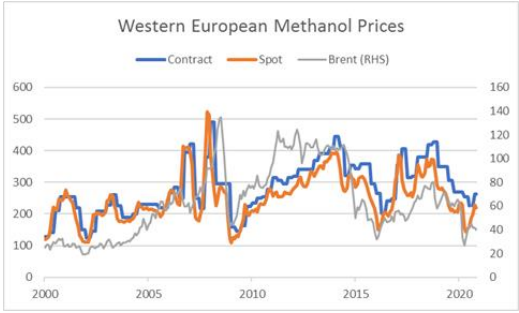
- Electrolysis ~ 75% efficient
  - ✓ ~53MWh / 1 t H_2
- CAPEX ~ 1000€/kW installed
  - ✓ Stack life ~ 50.000h
- Other costs
  - ✓ S&W, Maintenance
  - ✓ Water purification
- CO2 footprint:
  - ✓ Low to zero (power mix)
- Costs:
  - ✓ Min 4-5 €/kg



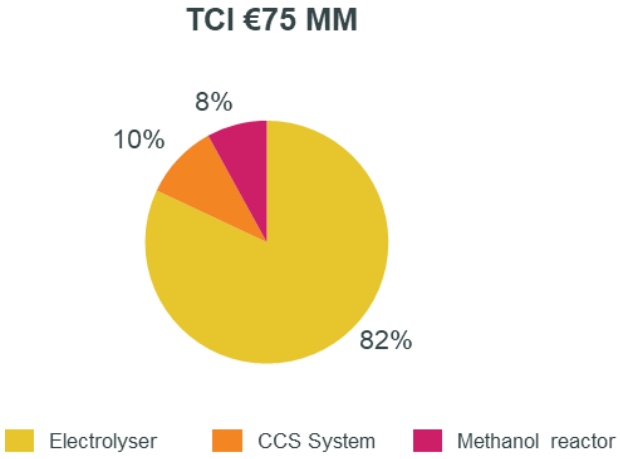
- Production from natural gas reformer
  - ✓ 90 % production through steam reforming
  - ✓ Use of natural gas, biomass, etc.
- CO2 footprint:
- For natural gas:
  - ✓ 1 mol CO2 per 4 mol H2 = 5.5t CO2/t H2
  - ✓ Energy input for SMR: +4 - 5t CO2/t H2
- Costs:
  - ➢ 1-2 €/kg

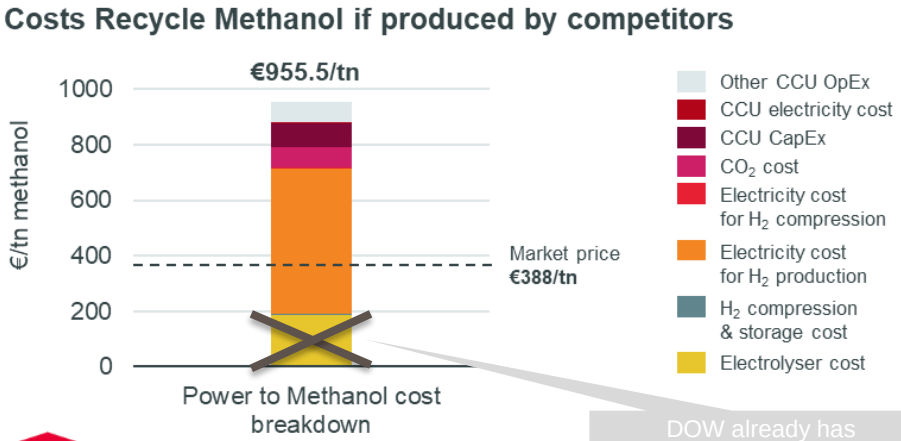
DOW Stade: sign. lower eMeOH costs vs. competition

- Recycling MeOH needs climate neutral hydrogen
- 1 mt Methanol needs ~200kg H2 -> @ 4€/kg = 800€/t just for H2
- CAPEX H_2 Electrolyser ~$10 – 15MM / 1mt/h MeOH
- Existing hydrogen in Stade saves sign. CAPEX and OPEX



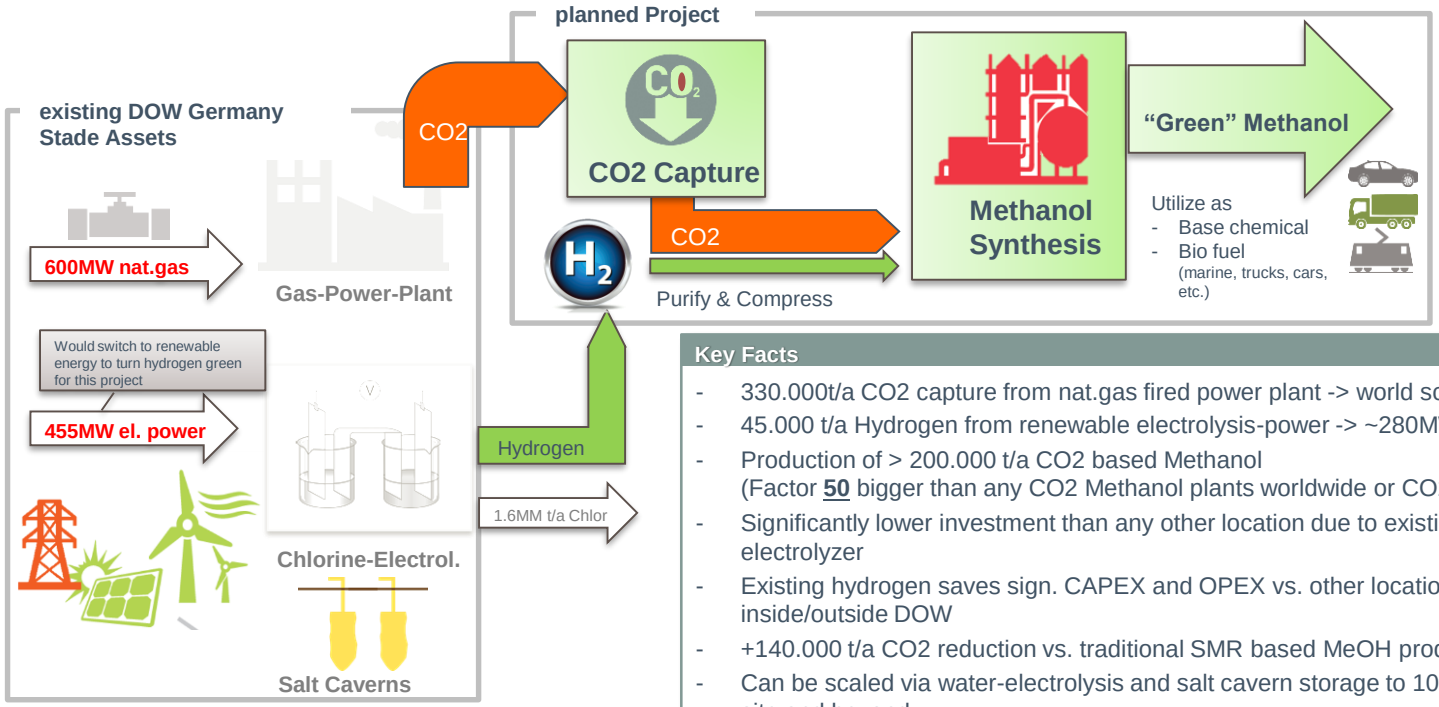
Open Literature Data (not DOW project specific):





DOW already has electrolyzer for Cl2 production

LIGHTHOUSE-PROJECT: "GREEN METHANOL"



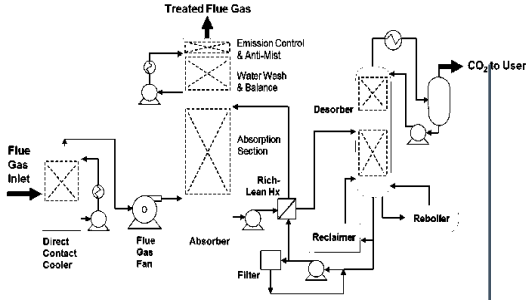
Key Facts

- 330.000t/a CO2 capture from nat.gas fired power plant -> world scale CO2 capture plant
- 45.000 t/a Hydrogen from renewable electrolysis-power -> ~280MW water-electrolysis
- Production of > 200.000 t/a CO2 based Methanol
  (Factor **50** bigger than any CO2 Methanol plants worldwide or CO2 utilizing plants)
- Significantly lower investment than any other location due to existing hydrogen electrolyzer
- Existing hydrogen saves sign. CAPEX and OPEX vs. other locations in the world inside/outside DOW
- +140.000 t/a CO2 reduction vs. traditional SMR based MeOH production alternative
- Can be scaled via water-electrolysis and salt cavern storage to 100% CO2 Utilization on site and beyond

Project Capacity

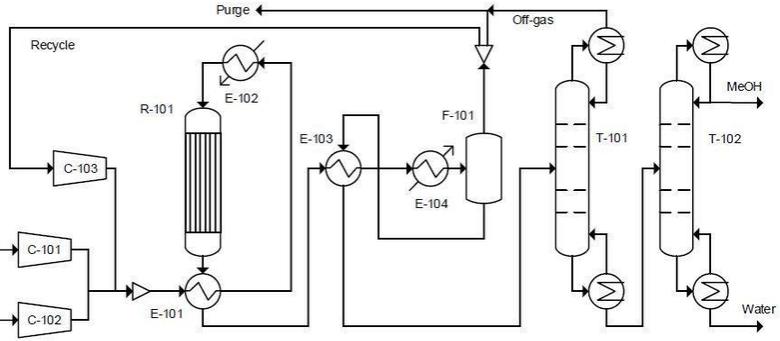
- Two capacity options have been evaluated
  - Use of 8 kta H2 and 58 kta CO2 to produce 42 kta of green MeOH
  - Use of 45 kta H2 and 330 kta CO2 to produce 210 kta MeOH

CO2 Capture Unit



MeOH Synthesis

$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$



Hydrogen Purification

H2 from Chlorine plants

Summary and Outlook

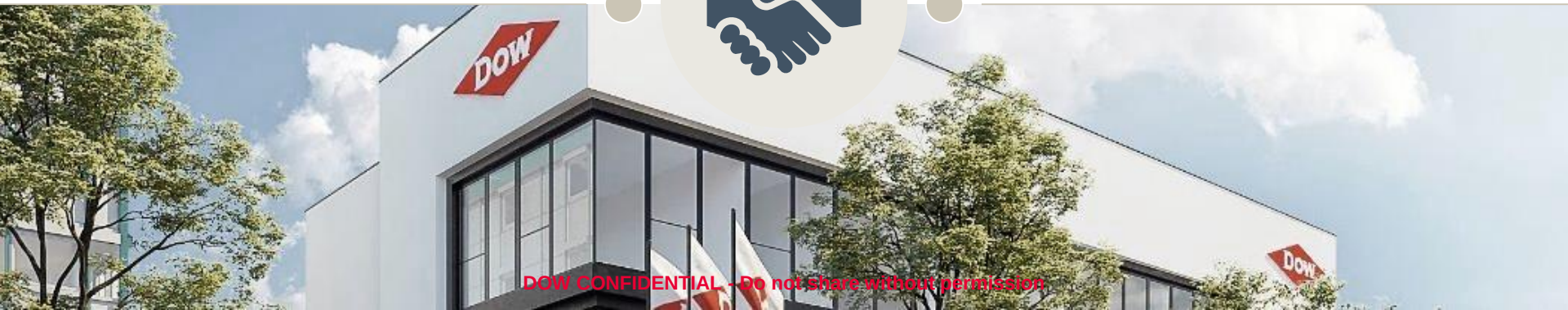
- Production of Green Methanol from Green H2 and CO2 significantly cost disadvantaged
- Even with ideal setup like DOW Stade we cannot compete with fossil methanol prices

- Discussions with several potential downstream market players:
  - Marine fuel (heating value 50% of diesel, so need 2x more)
  - Cars/trucks
  - Chemical use (internal and external DOW)

- Approaches to make CCU to Methanol competitive:
  - RED 2 would allow to produce @ cost recovery (14% renewable fuel mandated -> value ~1000€/t)
  - CAPEX funding (German H2 Economy Fund, IPCEI program, etc)
  - CO2 penalty (unlikely to compensate 800€/t difference at 1t CO2/t MeOH offset)
  - CCU to be accepted under ETS (currently not the case !)
  - End consumer preference resulting in higher price for green products

- DOW project is ready to push the invest button
  - Combination of subsidies (required level lower than anywhere else), early movers (Brand Owners)
  - Strategic partnerships to spread risk over multiple players

Thank You



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