Qeshm – Hamburg
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E-Ammonia and E-Methanol

A techno-economic assessment

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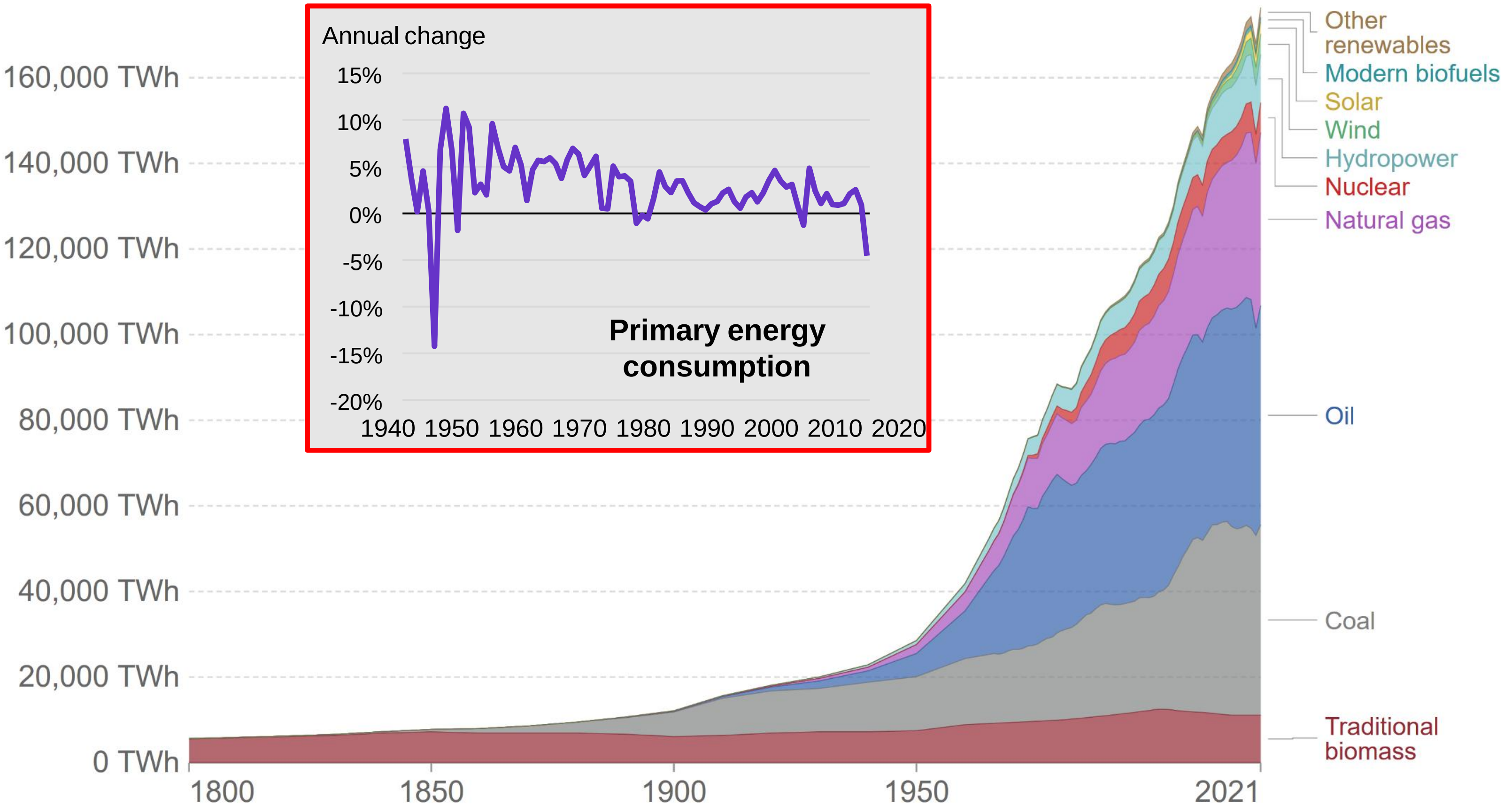
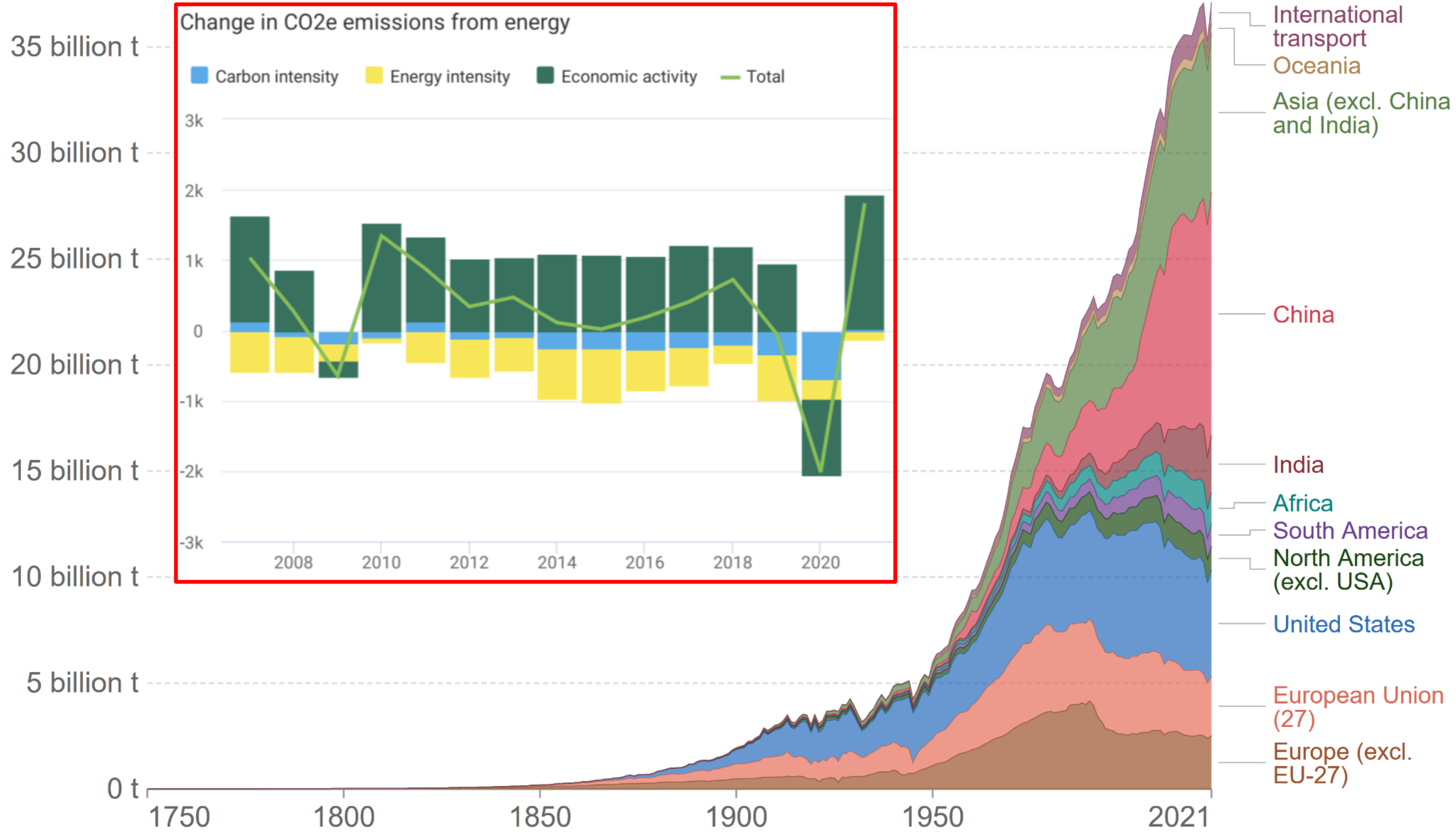
Background



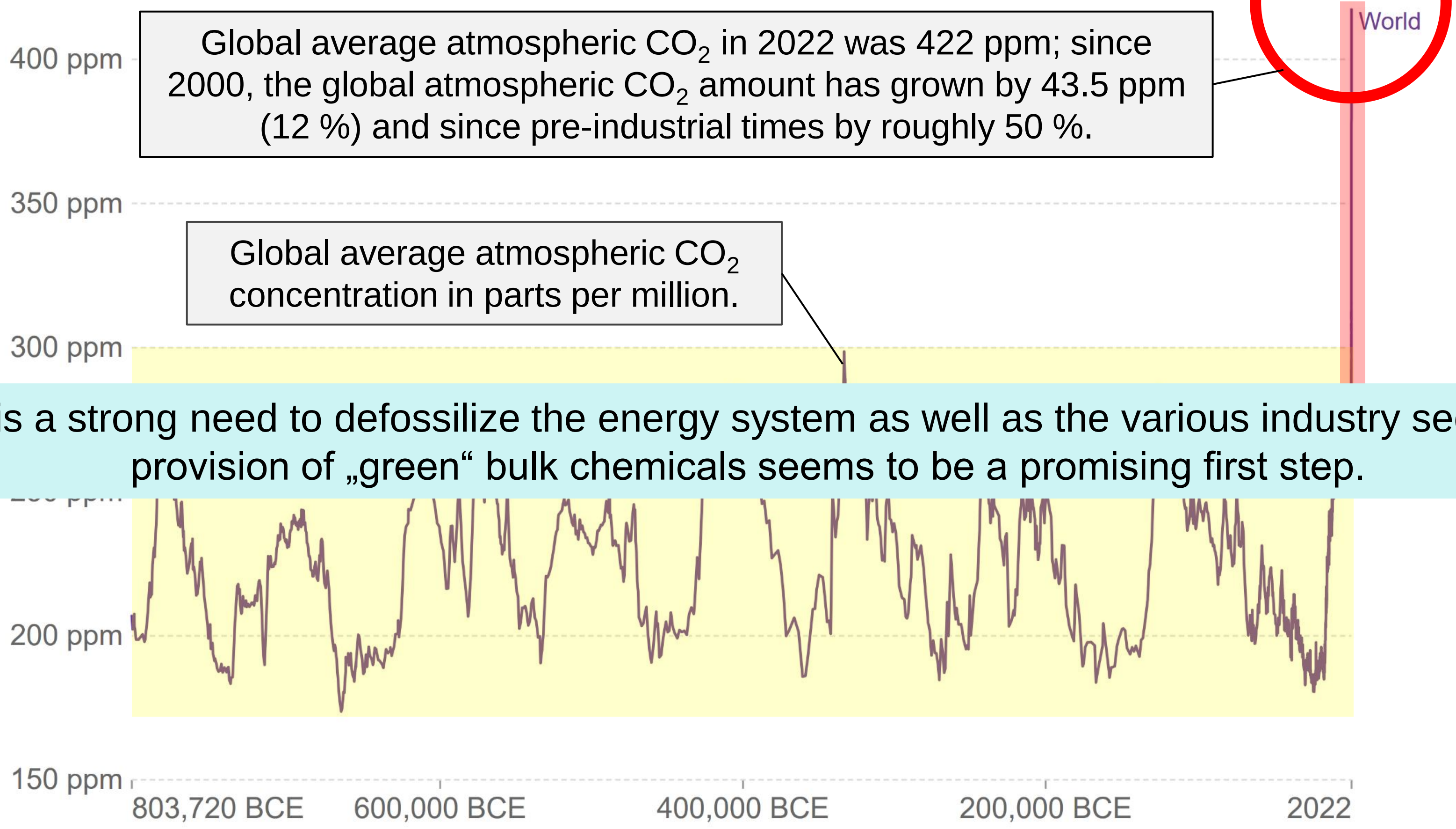
Annual change
15%
10%
5%
0%
-5%
-10%
-15%
-20%
1940 1950 1960 1970 1980 1990 2000 2010 2020
Primary energy consumption
160,000 TWh
140,000 TWh
120,000 TWh
100,000 TWh
80,000 TWh
60,000 TWh
40,000 TWh
20,000 TWh
0 TWh
1800
1850
1900
1950
2021
Other renewables
Modern biofuels
Solar
Wind
Hydropower
Nuclear
Natural gas
Oil
Coal
Traditional biomass

Background



Our world in data 2022 / BP Statistical Review of World Energy

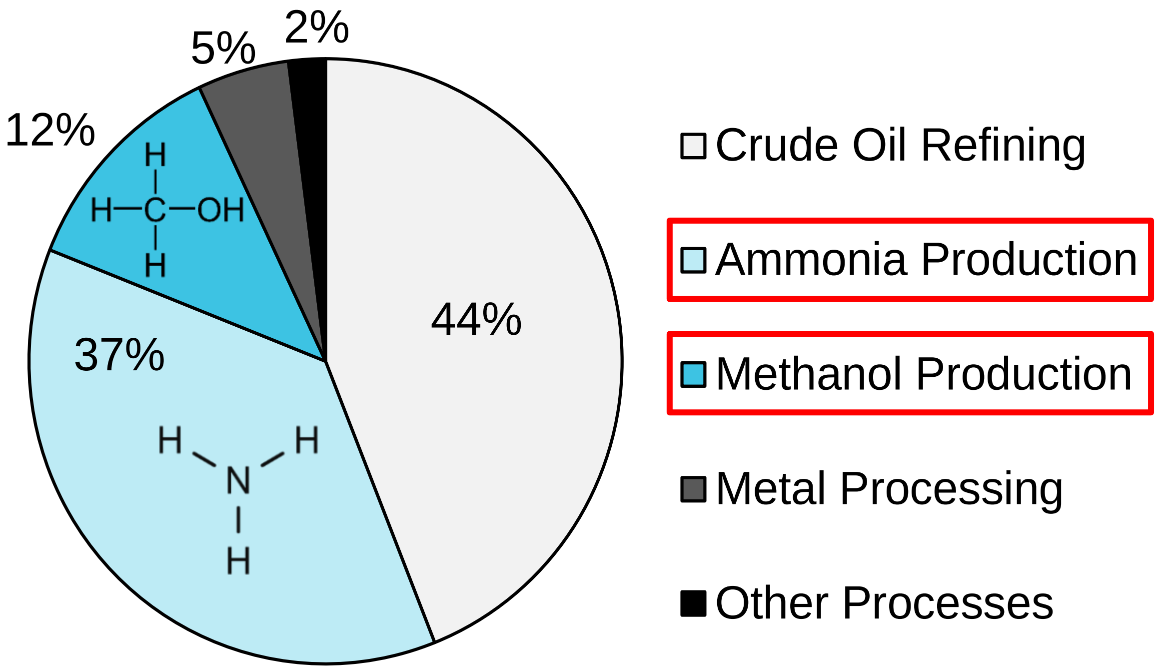
Background



There is a strong need to defossilize the energy system as well as the various industry sectors; the provision of „green“ bulk chemicals seems to be a promising first step.

Switch to power-based Ammonia and Methanol production

- Current Ammonia (NH_3) and Methanol (CH_3OH) production accounts for 500 and 300 Mt_{CO2}/a corresponding to > 2.5 % of global CO_2 emissions
- Ammonia and Methanol are globally traded bulk chemicals useable within the energy and the chemical sector
- Both commodities can be provided based on power-to-X technologies



Global Hydrogen Consumption by Application

Agenda

- Current status: Demand and use
- Technical Aspects: Production
- Techno-economic and Environmental Aspects
- Applications for E-Ammonia and E-Methanol
- Final Consideration

Current Status

Demand and Use

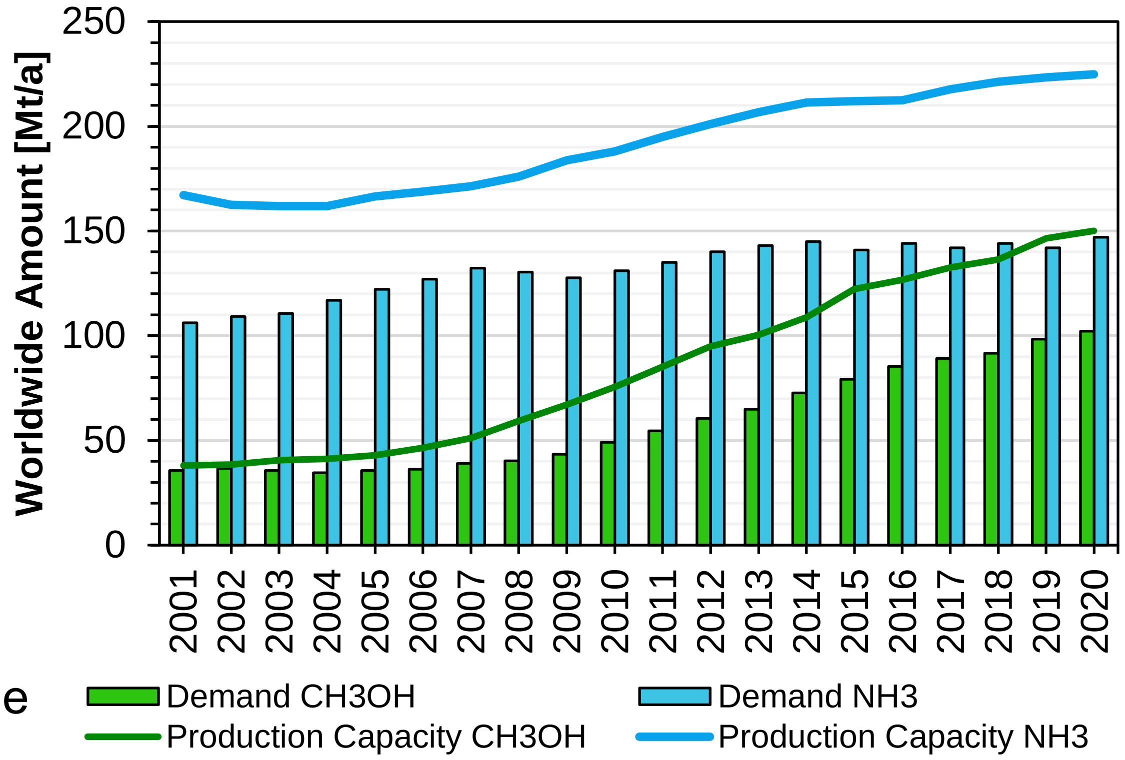
Status – Production

Ammonia > 150 Mt/a$_{2020}$

- Slight growth in demand (12 % in last decade)
- Capacity utilization 65 %$_{2020}$
- Increase broadly in line with rise in population

Methanol > 100 Mt/a$_{2020}$

- Demand doubled within the last decade
- Capacity utilization 66 %$_{2020}$
- China‘s methanol economy is the main driver of this growth



[1]Values vary between sources. Annual production according to [2] 185 t_{NH3}/a

Data[1] from [1][2][4][5]

Status – Demand and Use

Ammonia

- Growth is in line with growth in global population
- Mainly used on-side for a subsequent fertilizer production
- Currently no commercial use as a fuel and/or energy carrier
- International trade on a low level

Methanol

- Strong growth especially in the last decade (especially China)
- Very diverse use; mainly through chemical downstream processing
- Methanol already used to ca. 30 % for fuel purpose
- International trade

Todays production almost entirely based on fossil fuel based feedstock (mainly natural gas and coal)

Huge demand for defossilation already in existing applications

Technical Aspects

Production

Technical Aspects – Basics

- Today's production of Ammonia and Methanol almost exclusively via thermo-chemical synthesis processes[1]
- Generation by synthesis from different synthesis gases typically controlled by heterogeneous catalyst

Ammonia generation from Haber-Bosch Synthesis
(commercial since 1913)

$$0{,}5\ \mathrm{N_2} + 1{,}5\ \mathrm{H_2} \rightleftharpoons \mathrm{NH_3} \qquad \Delta H_R^{298K} = -46\ \mathrm{kJ}/\mathrm{mol}$$

Methanol generation from Methanol Synthesis

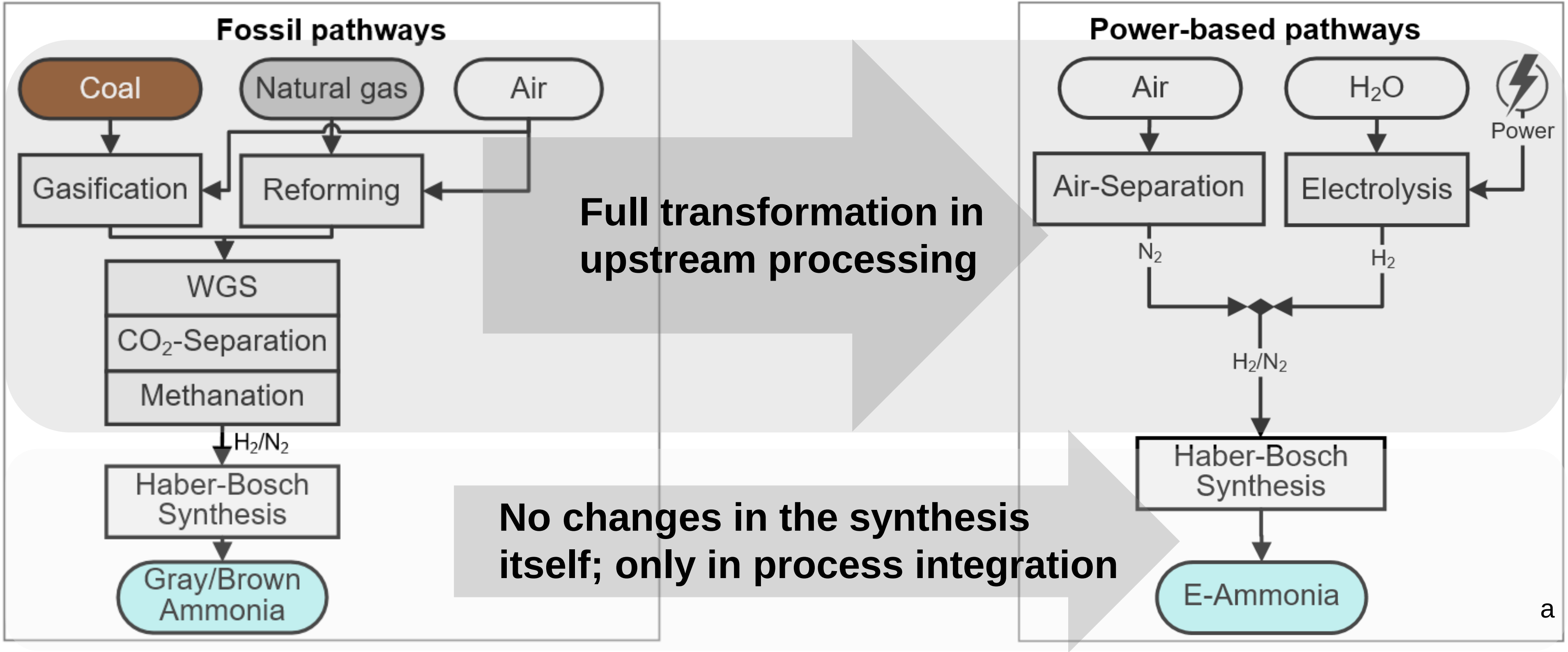
(commercial since 1923)

$$\mathrm{CO}_{(g)} + 2\mathrm{H}_{2\,(g)} \rightleftharpoons \mathrm{CH_3OH}_{(g)} \qquad \Delta H_R^{298K} = -91\ \mathrm{kJ}/\mathrm{mol}$$

$$\mathrm{CO}_{2\,(g)} + 3\mathrm{H}_{2\,(g)} \rightleftharpoons \mathrm{CH_3OH}_{(g)} + \mathrm{H_2O}_{(g)} \qquad \Delta H_R^{298K} = -49\ \mathrm{kJ}/\mathrm{mol}$$

[1]around 10% of ammonia supply through ammonium salts

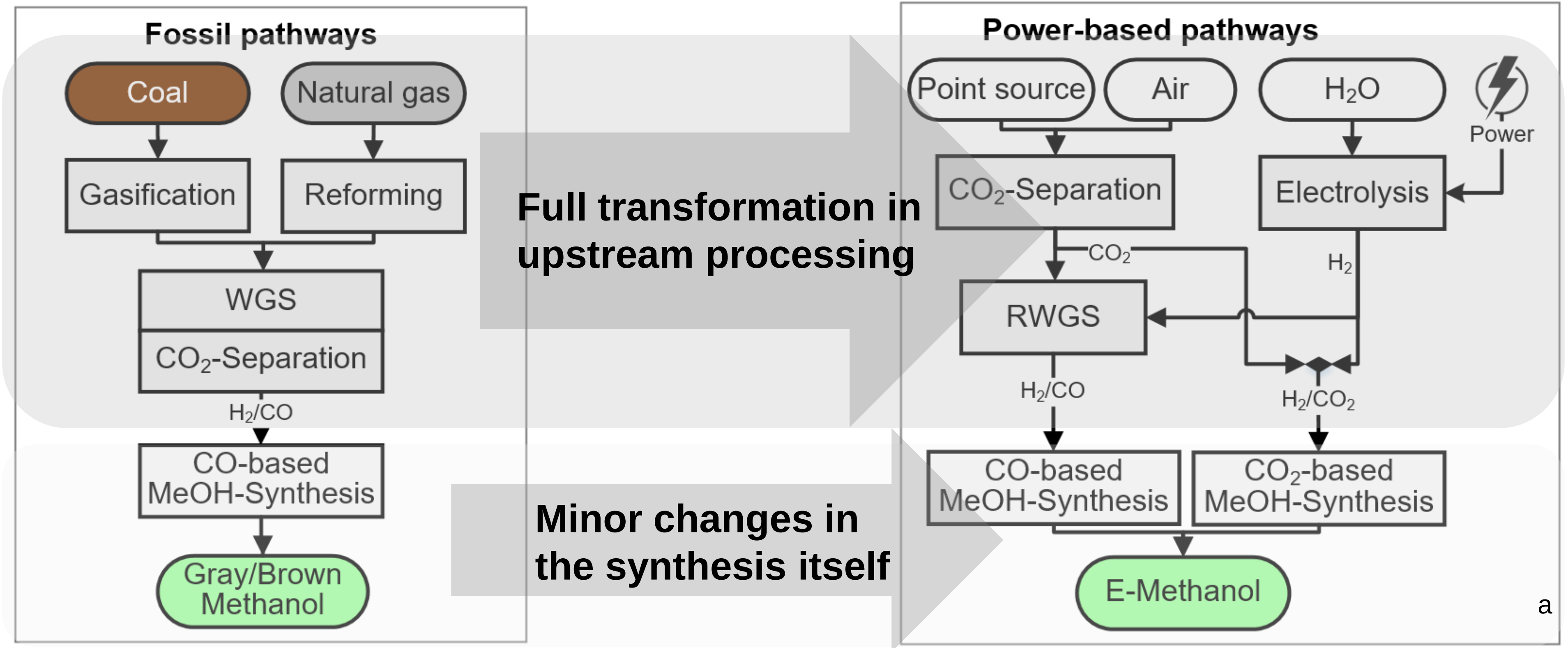
Technical Aspects – Production Concepts



- Switch in syngas production is the most important technical change

WGS: Water Gas Shift; [a]The schematic flow diagram shows simplified only the main process steps and flows.

Technical Aspects – Production Concepts



- ➢ Switch in syngas production is the most important technical change

E-Ammonia and E-Methanol

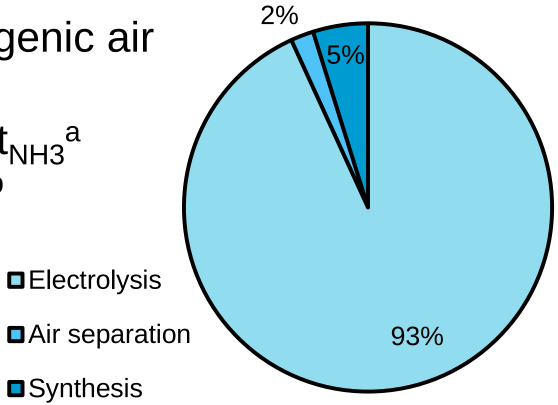
Techno-economic and Environmental Aspects

Technical Aspects – Energy Demands

Energy input for E-NH_3 production

N_2 via cryogenic air separation

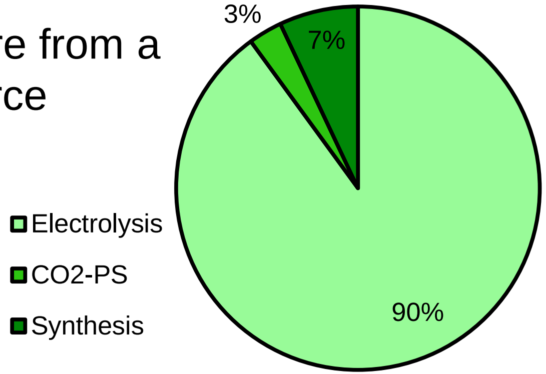
- 10 MWh/t_{NH3}[a]
- η ≈ 50 %[b]



Energy input for E-MeOH production

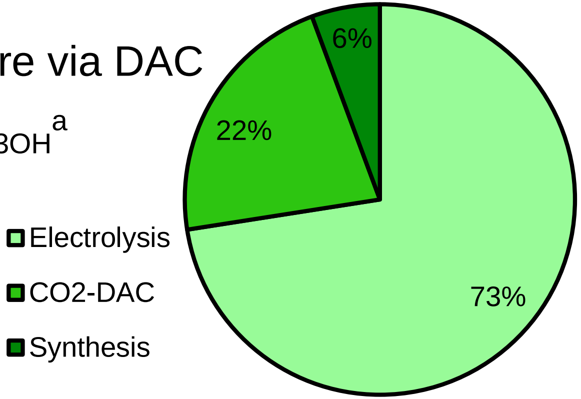
Carbon Capture from a CO_2 point source

- 11 MWh/t[a]
- η ≈ 50 %[b]



Carbon Capture via DAC

- 14 MWh/t_{CH3OH}[a]
- η ≈ 40 %[b]

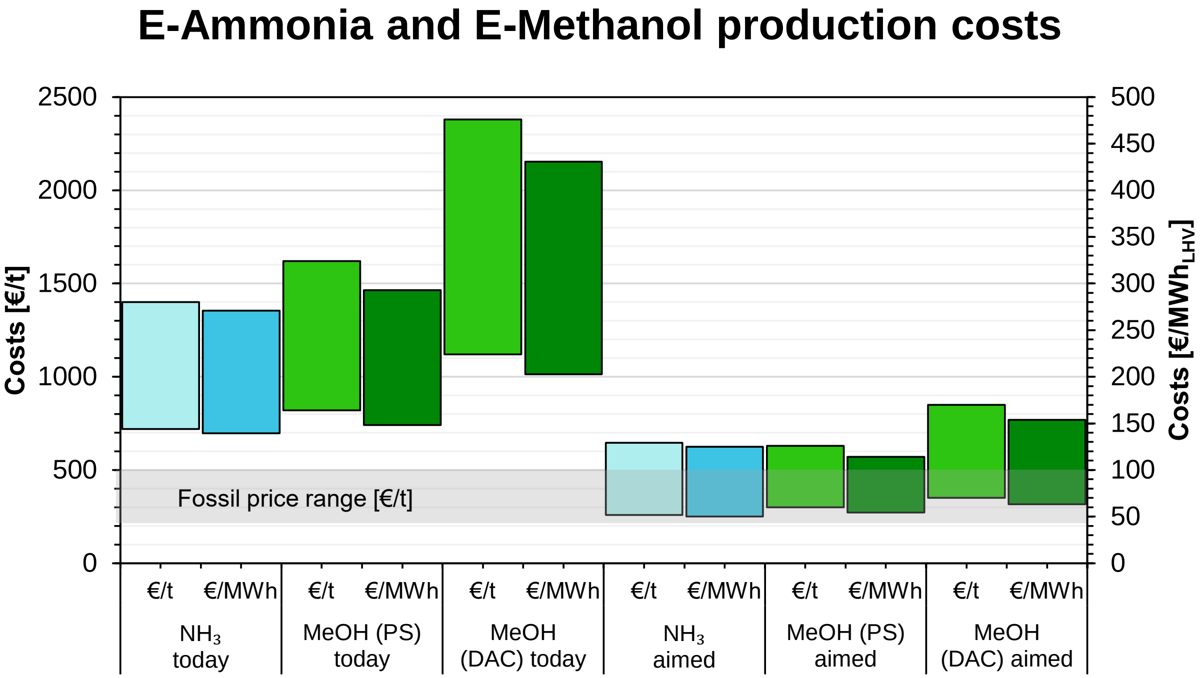


- Energy demand mainly determined by electrolysis (and CO_2 source)
- Availability of CO_2 has a significant impact on methanol production effort

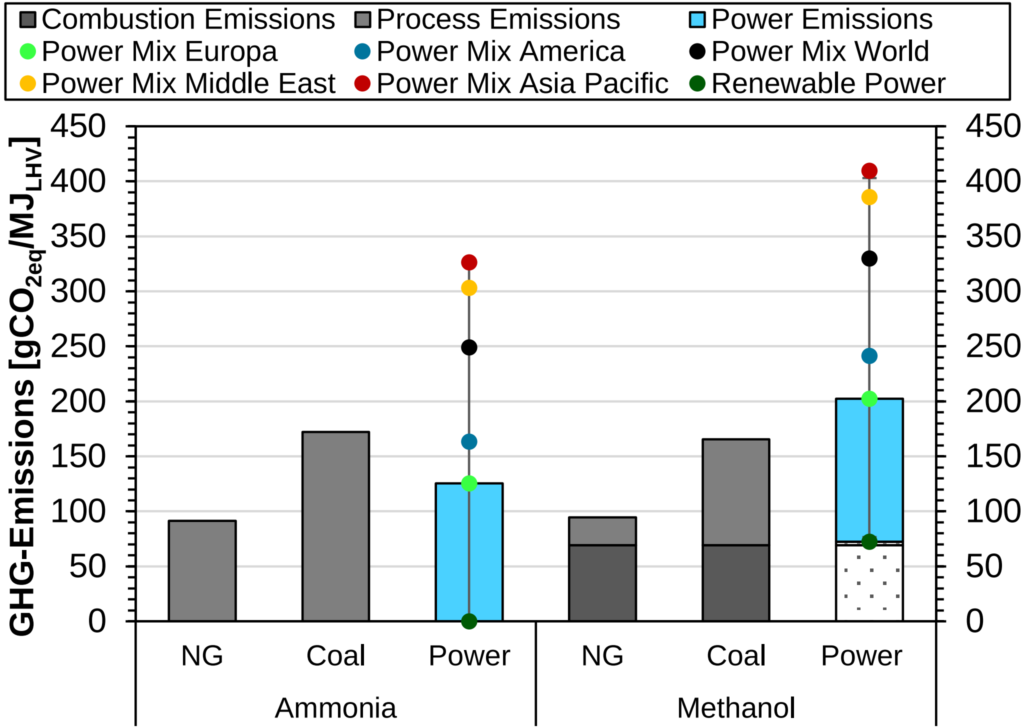
Values strongly depend on process layout.; [a]67 % electrolyzer efficiency; [b]based on Lower Heating Value; DAC: Direct Air Capture; PS: Point Source

Economic Aspects – Production costs

- Values vary mainly through different assumptions on electricity and electrolyzer costs
- Future price targets require strong cost reductions especially for “green” Hydrogen production
- Availability of cheap CO_2 sources is essential for methanol production costs; direct air capture is most likely not the very best solution



Environmental Aspects – GHG emissions



Data based on [1,2,9]; White dotted areas relate to process and combustion emissions where the GHG accounting depends on the fossil or renewable origin of the carbon.

- Power-based production can lead to an **increase** or **decrease** of overall emissions; the GHG footprint of the electricity is the most determining factor
- Energy-based emissions for both products are equal (if “green” CO_2 is used)
- Synthesis based on renewable energy can enable climate neutral production
- Clear regulations / frame conditions are needed to ensure overall GHG reduction
  - Example: EU Renewable Energy Directive II (EU RED II)

E-Ammonia and E-Methanol

Applications for
E-Ammonia and E-Methanol

Applications – Use as a Fuel

Ammonia

- CO_2 free combustion
- Challenging combustion properties
- N_2O formation (GHG-factor 265) and unburned NH_3
- Conventional engines and fuel cells still under development
- ➢ Most combustion concepts only in mixture with other fuels
- ➢ Extensive flue gas treatment necessary (space requirements)

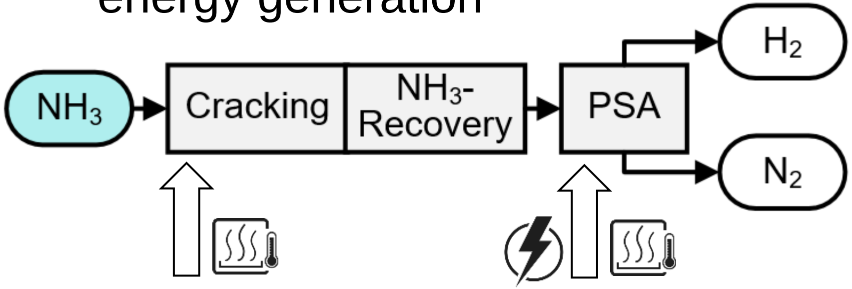
Methanol

- Engines already available today
- Can be blended with conventional fuels
- Easy and safe handling and storage
- Intermediate product for E-Gasoline/Jet Fuel/Diesel production
- CO_2 emissions (sustainability depends on carbon origin)
- ➢ Use as fuel is predominantly limited by availability of renewable MeOH / renewable Carbon

Application – Use as a H_2-carrier

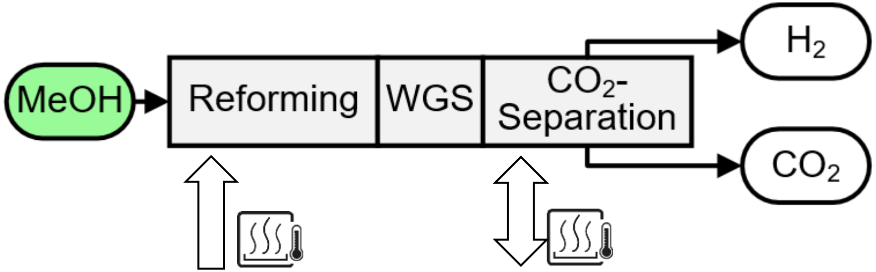
Reconversion of Ammonia

- Challenging Hydrogen purification (losses around 20 %)
- Losses can be used for on-side energy generation



Reconversion of Methanol

- Pure CO_2 output; return transport?
- Simple H_2 separation via well known processes



- Hydrogen purification from Methanol technically easier
- Reconversion of Methanol potentially related to lower energy demand due to high cracking and purification effort of ammonia reconversion

E-Ammonia and E-Methanol

Final Consideration

Summary

	$E\text{-}NH_3$	E-MeOH (PS)	E-MeOH (DAC)
Current demand (general)	++	++	
Infrastructure and handling	+	++	
TRL	++	++	+
Feedstock availability	++	o	++
Economic competitiveness	-	-	--
GHG reduction potential	++	++[a]	++
Reconversion to H_2	o	+	
Use as fuel	-	+	

[a]only for sustainable biogenic sources; PS: Point Source; DAC: Direct Air Capture; TRL: Technology Readiness Level

Key Messages

- Current production of NH_3 and CH_3OH release lots of GHG emissions due to the use of fossil energy
- The integration of “green” electricity enables potentially a fully renewable production of E-NH_3 and E-CH_3OH without significant technical barriers
- Availability of renewable CO_2 might become a limitation for E-CH_3OH production due to the high energy effort for DAC and a priori limited biomass resources
- Economic competitiveness with fossil fuel-based production is currently not given[a]
  - Higher prices for renewable products achievable through regulatory incentives
  - In the future, an equalization of the costs is expected
- Significant technical challenges in using NH_3 for energetic applications

➢ Massive and rapid expansion of E-NH_3 and E-MeOH production required

➢ Prioritize direct substitution of the fossil counterparts; energy applications can potentially increase demand significantly

TRL: Technology Readiness Level; [a]except for extreme market situations

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[1] iea “Ammonia Technology Roadmap “https://www.iea.org/reports/ammonia-technology-roadmap/executive-summary“

[2] IRENA “Innovation Outlook: Renewable Methanol“https://www.irena.org/publications/2021/Jan/Innovation-Outlook-Renewable-Methanol

[3] Hamburg Open Online University. Share of the most important applications in today‘s global hydrogen consumption / based on International Energy Agency - IEA (2020)

[4] argus “Review of global ammonia supply” https://www.ammoniaenergy.org/wp-content/uploads/2020/12/Oliver-Hatfield.pdf

[5] USGS - Mineral Commodity Summaries 2022, US Geological Survey data

[6] TechSciResearch “Global Ammonia Market“ https://refindustry.com/news/market-research/global-ammonia-market-2012-2026/

[7] IRENA “DECARBONISE THE SHIPPING SECTOR“https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_Decarbonising_Shipping_2021.pdf

[8] Dieterich et al. 2020 “ Power-to-liquid via synthesis of methanol, DME or Fischer–Tropsch-fuels: a review”

[9] iea 2022 “Electricity Market Report” https://iea.blob.core.windows.net/assets/660c2410-218c-4145-9348-c782e185dcdf/ElectricityMarketReport-July2022.pdf