SECTOR COUPLED SYSTEMS FOR HEAT, INDUSTRY, FUELS AND TRANSPORT IN CHILE

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Project Final results, 10.03.2026
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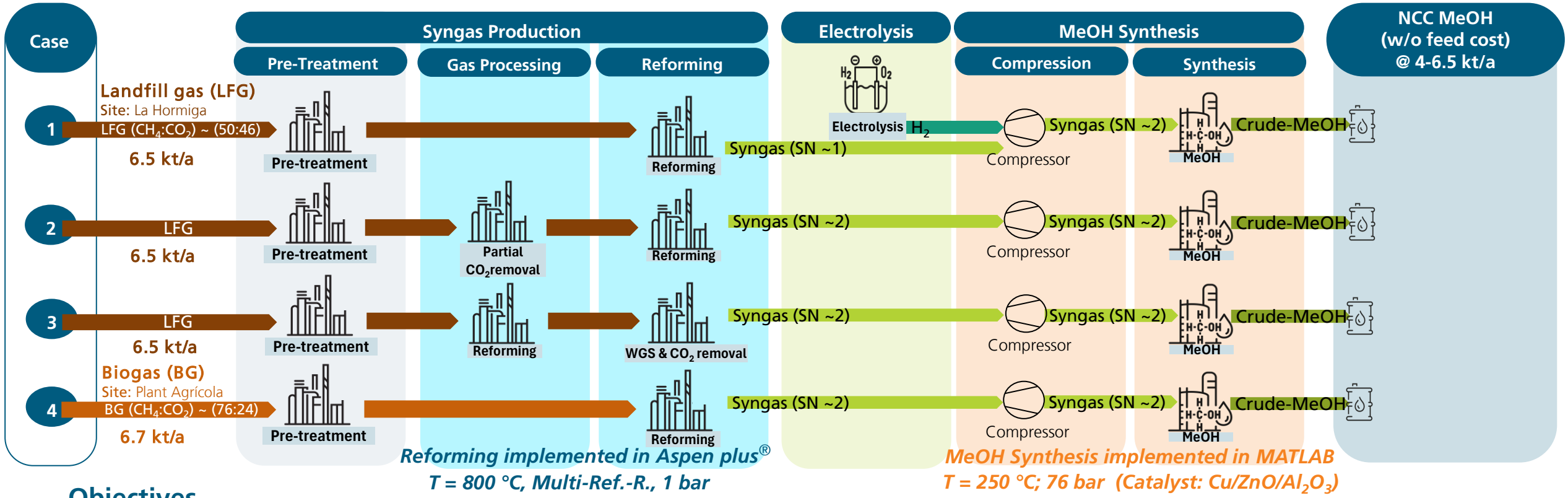
Case Study on Low-Carbon Fuels - Available Biogenic Gas Sources in Chile

Production Bio-based MeOH



Objectives

- Evaluate the potential of low-carbon methanol and cost drivers along the process chain.
- Consider different process steps for syngas-production, downstream synthesis ~ const. SN.
- Process development of innovative production pathways and evaluate their economic potential.

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- *State-of-the-Art evaluation of Pretreatment by Elwell et al., CO_2 removal technologies and their associated Costs.*
- *Process simulations of reforming and MeOH synthesis are performed by Fraunhofer ISE using Aspen Plus® & MATLAB.*
- *Net conversion cost of MeOH is based on Fraunhofer ISE economic models for reforming, electrolysis, and MeOH synthesis.*

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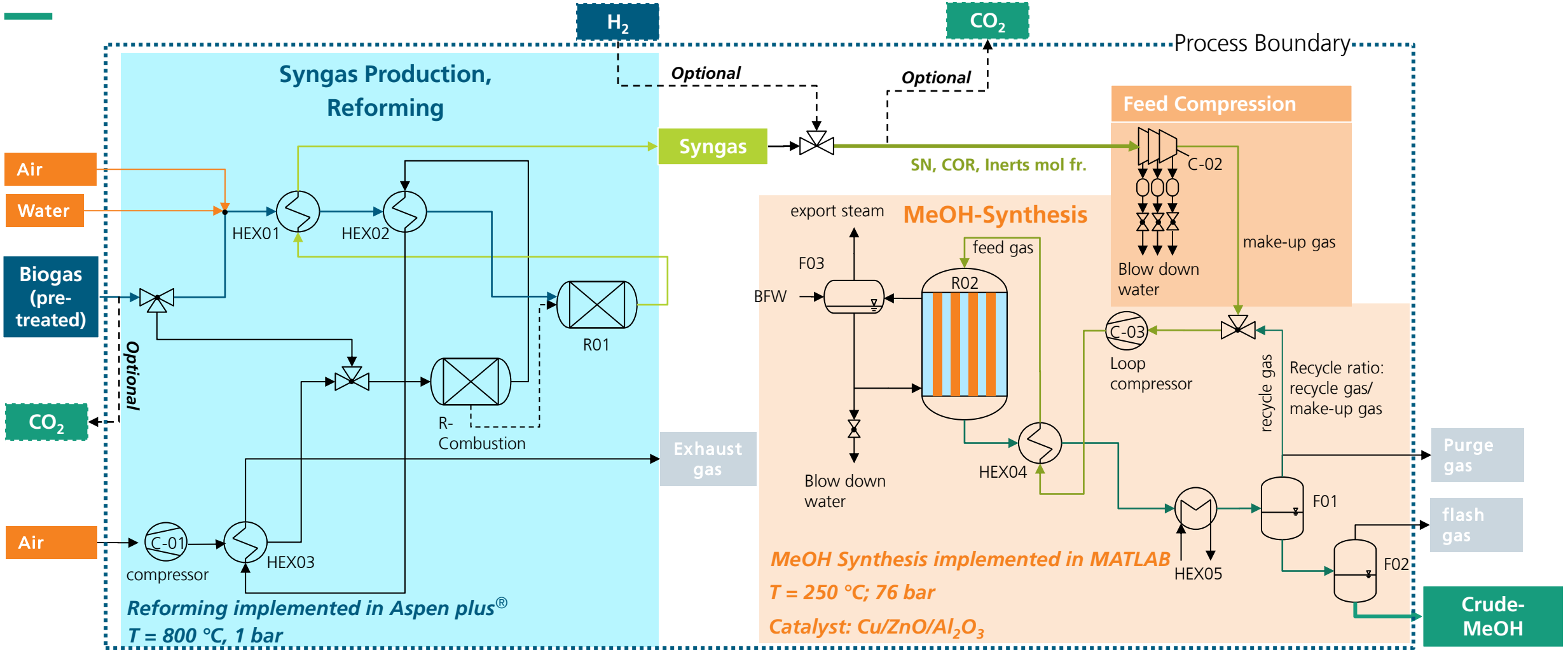
Conversion of Methane-rich Biogenic gas – Conceptual Engineering

Biogas case – simplified process flow diagram (PFD)



- *Optimization of reforming (SN ~ 2) and methanol synthesis (kinetic model)*
- *Reformer at 1 bar, 800°C, H_2 from electrolysis at 30 bar*
- *Methanol synthesis operated at 76 bar, 250 °C*

Feed | Utilities | Product | Purge

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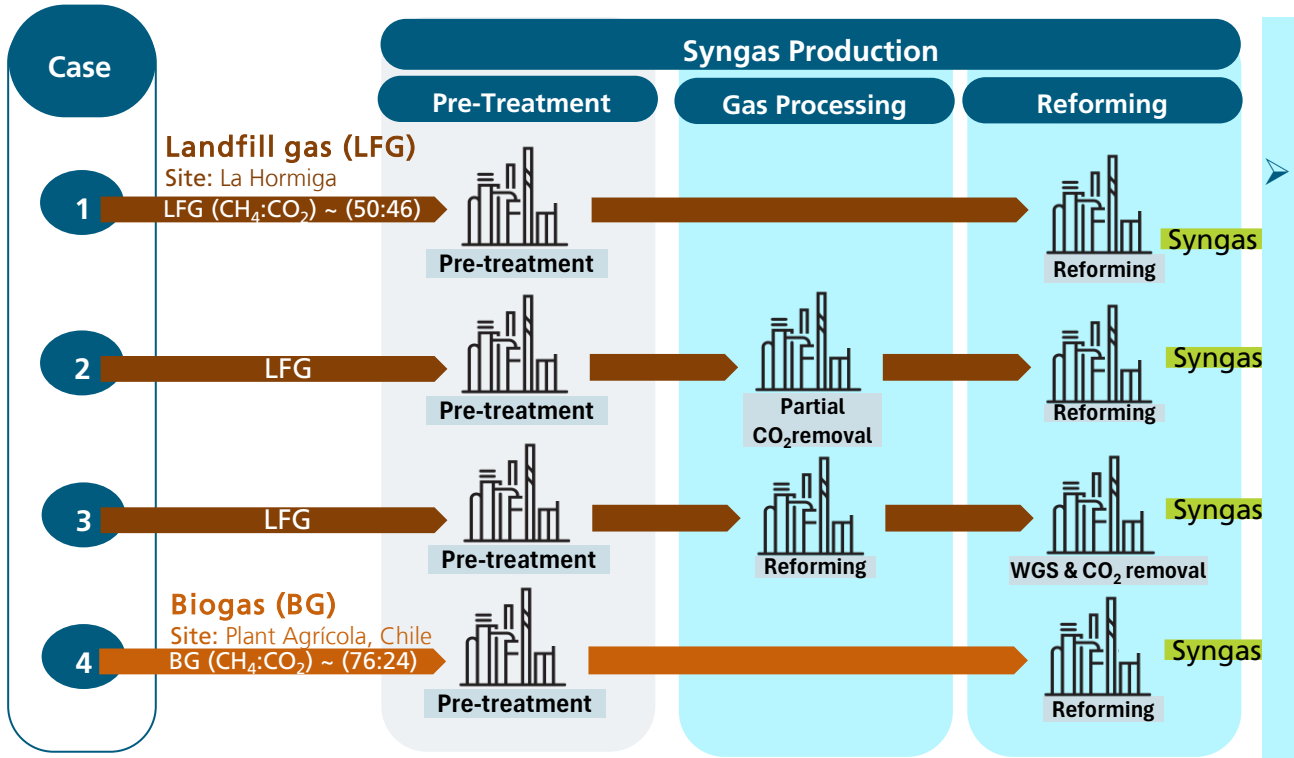
Gas Pretreatment and Conversion of Methane-Rich Biogenic Gases

Syngas production I



Multi – Reforming

Dry reforming (DR): $CH_4 + CO_2 \rightleftharpoons 2CO + 2H_2$
Steam reforming (SR): $CH_4 + H_2O \rightleftharpoons CO + 3H_2$
Partial oxidation (POX): $CH_4 + ½\ O_2 \rightleftharpoons CO + 2H_2$

➢ **Reforming:**

- An equilibrium reactor is implemented in *Aspen plus*® to predict equilibrium compositions of the produced syngas.
- Multi-reforming prevents carbon formation and reduces the high energy use of dry reforming
- **Fixed input:**
  - LFG (CH_4:CO_2) = (50:46)
  - Biogas (CH_4:CO_2) = (76:24)
- **Operating parameters:**
  - Reformer T = 800 °C; 1 bar
  - Reactant ratios (O_2/CH_4, steam ratio)
- **Output:**
  - Syngas SN ~ 2; COR range and inert gases (CH_4, N_2) range

➢ ***Reactor model should be rigorously validated against reliable experimental data to ensure its accuracy.***

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[1]: Zhao, Xianhui et al., Conversion of landfill gas to liquid fuels through a TriFTS (tri-reforming and Fischer–Tropsch synthesis) process: a feasibility study, Sustainable Energy & Fuels, The Royal Society of Chemistry, https://doi.org/10.1039/C8SE00344K

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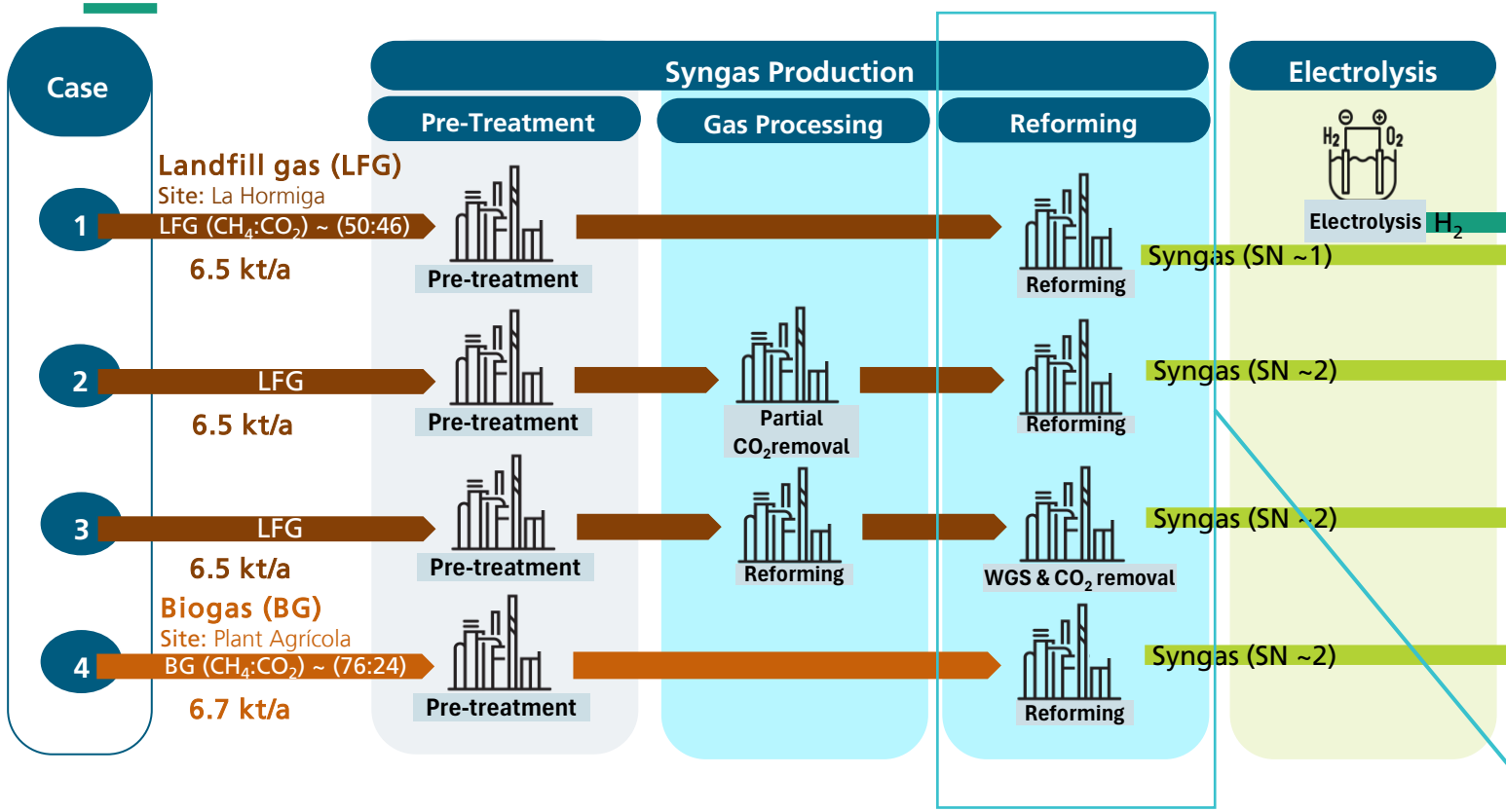
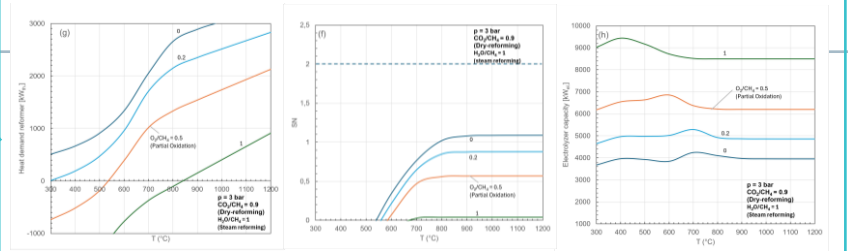
Gas Pretreatment and Conversion of Methane-Rich Biogenic Gases

Syngas production II



	H_2-demand [kt/a]	COR [-]	SN [-]	H_2O [-]	Syngas / MeOH [-]
1	0.41	0.19	~2	0.11	1.35
2	-	0.09	~2	0.05	1.34
3	-	0.95	~2	0.22	1.75
4	-	0.08	~2	0.05	1.28



Multi-Reforming – Effect of O_2 and H_2O addition on H_2/CO, COR and SN

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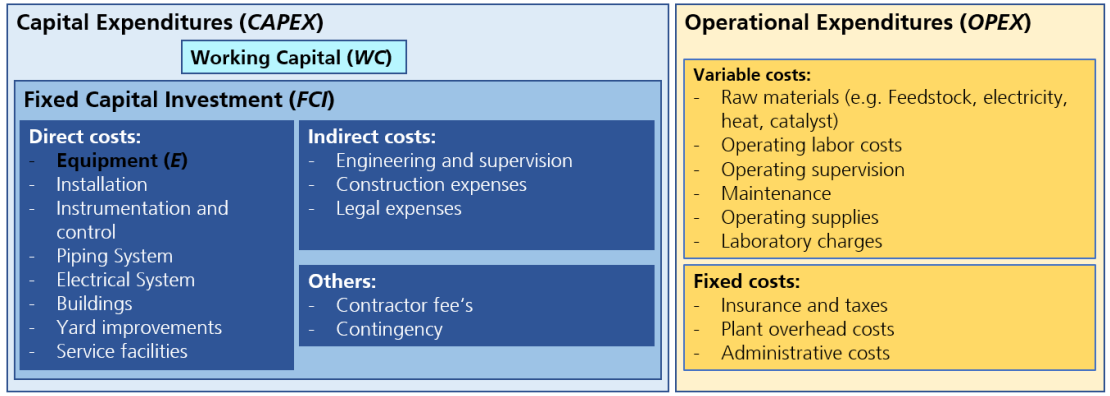
Methodology: Techno-Economic Eval

Costing factors of CAPEX, OPEX and NCC



- **Capital Expenditures (CAPEX)** from costs of individual purchased equipment cost
  (Refered to reference year via CEPCI) and lang factors[1].
- **Operational Expenditures (OPEX)** from utility costs, other variable and fixed operating costs
  (factorial method, estimation of labor hours according to[1]).
- **Net conversion cost (NCC)** from annual capital costs (annuity method[1]) and total OPEX.
  - $NCC = ACC + \sum OPEX_U + \sum OPEX_{variable} + \sum OPEX_{fixed} + h_{Labor} c_{Labor}$
- **Estimation uncertainty** ±30% according to AACE (class IV)[2].

Equipment cost and Lang factors from Peters et al.[1]:

Capital Expenditures (CAPEX)	**Factor**
Direct costs	
Equipment cost	**1**
Installation	0.47
Instrumentation and control	0.36
Piping system	0.68
Electrical system	0.11
Buildings	0.18
Yard improvement	0.10
Service facilities	0.70
Sum	***3.60***
Indirect costs	
Engineering and supervision	0.33
Construction expenses	0.41
Legal expenses	0.04
Sum	***0,78***
Contractor fee's	0.22
Contingency	0.44
Sum	***0.66***
Total FCI	**5.04**
Working Capital	17%
Total	**6.07**

Operational Expenditures (OPEX)	**Factor**
Variable costs	
Utilities	f(steam, air, etc.)
Operating labor costs (OL)	f(plant capacity, processing steps)
Operating supervision (OV)	0.15*OL
Maintenance (M)	0.02*FCI
Operating supplies (OS)	0.15*M
Laboratory charges	0.20*OL
Fixed costs	
Insurance and taxes	0.02*FCI
Plant overhead costs (PO)	0.5*(OL+OS+OV)
Administrative costs	0.25*PO

Specific-Assumptions	
Reference year [-]	2025
Depreciation period [a]	15
Interest rate Chile [%]	5
Labor cost in Chile [€/h]	7.72
Electricity in Chile [€/MWh]	108
Low-Medium pressure steam [€/t]	22.8-23.5
Cooling water supply [€/m³]	0.0035
Waste water [€/m³]	3.8

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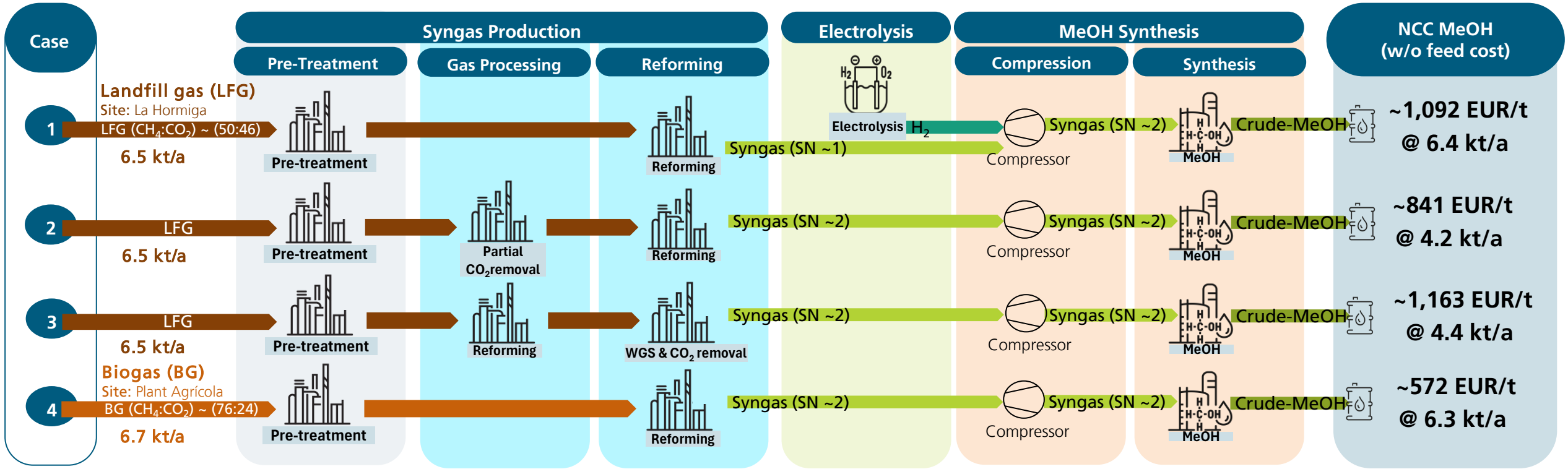
[1] M. S. Peters, K. D. Timmerhaus, R. E. West, Plant Design and Economics for Chemical Engineers 2003, McGraw-Hill Higher Education, New York.
[2] Association of the Advancement of Cost Engineering, Cost estimate classification system - as applied in engineering, procurement, and construction for the process industries 2011, AACE International, Morgantown.

Case Study on Low-Carbon Fuels - Available Biogenic Gas Sources in Chile

Net Conversion Costs MeOH-Production



- **LFG:** Electrolysis and CO_2-removal from syngas with WGS increases NCC costs.
- **LFG:** Highest production capacity with electrolysis.
- **LFG:** Lowest NCC costs with CO_2-removal form feed.
- **BG:** Higher CH_4 concentration beneficial, no electrolysis or CO_2-removal → lowest NCC costs

Estimation uncertainty ±30% according to AACE (cost estimate classification system)

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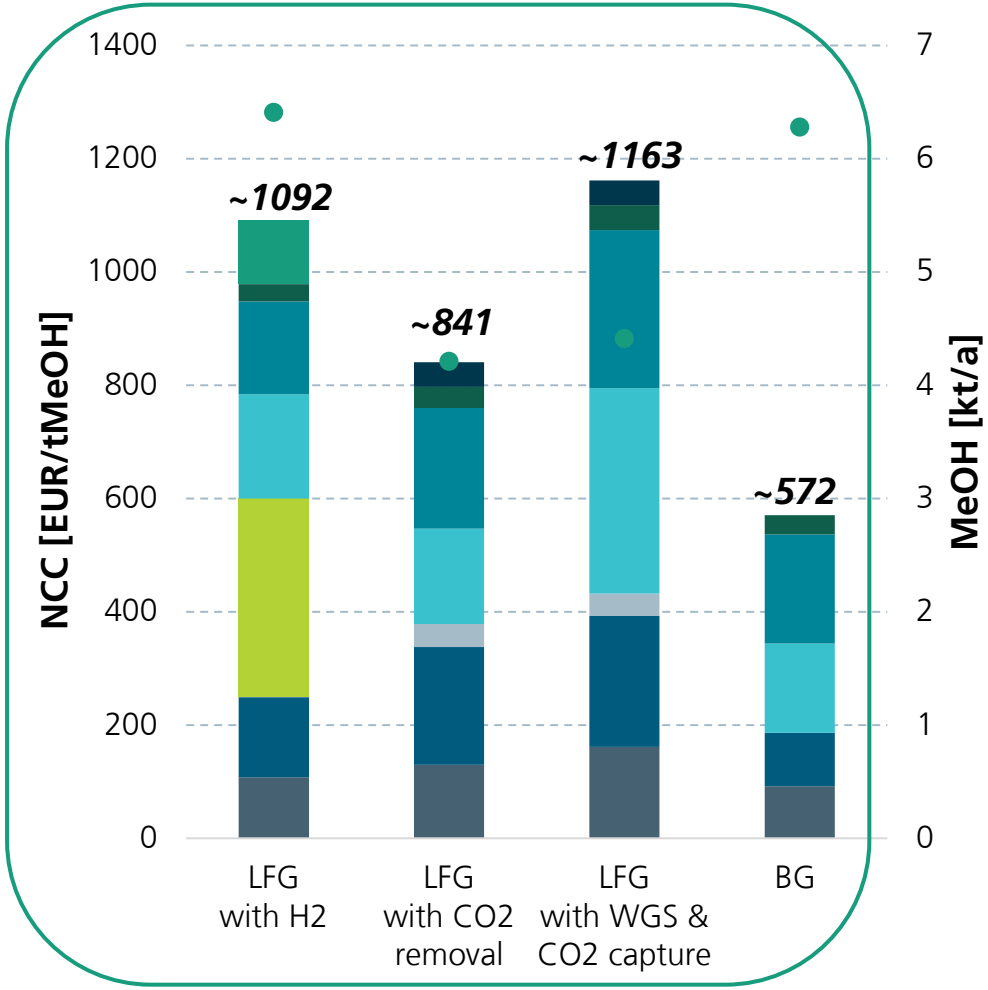
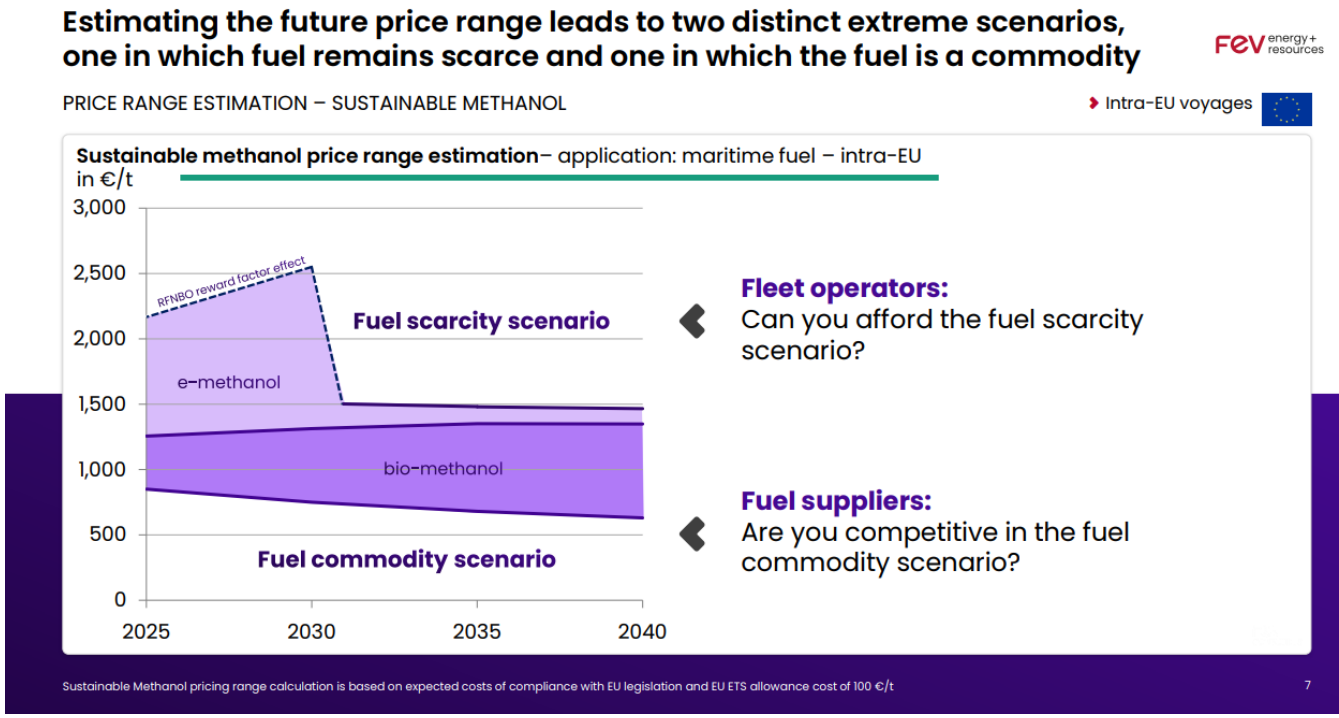
Results: Techno-Economic Evaluation I

Net Conversion Costs (NCC) of MeOH in EUR/t_{MeOH} w/o feedstock costs





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Case 1 2 3 4

For simplicity, the **cost bar chart** does not show CAPEX and OPEX for pretreatment, as they represent only a small share; however, they are included in the NCC.

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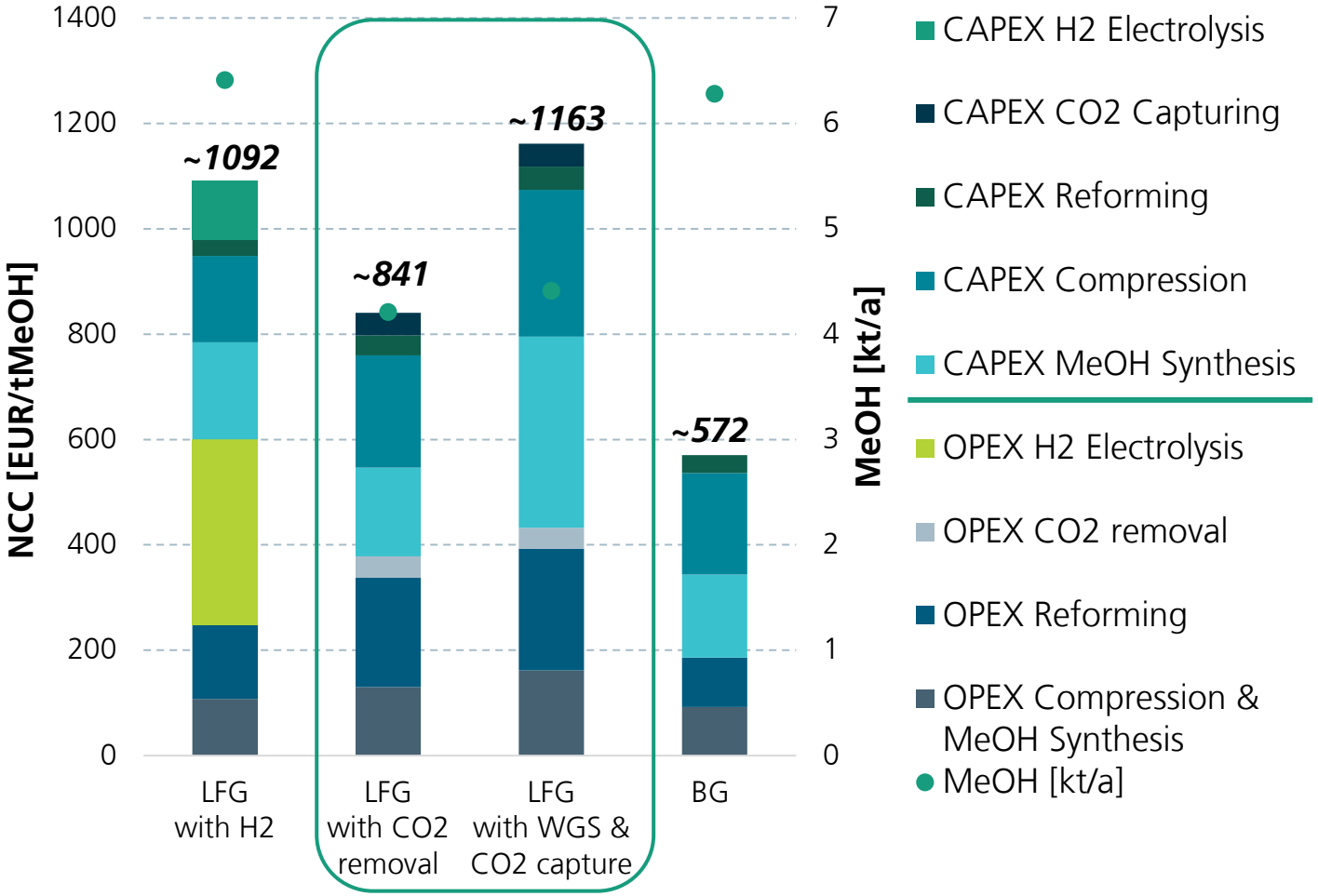
Results: Techno-Economic Evaluation II

Net Conversion Costs (NCC) of MeOH in EUR/t_{MeOH} w/o feedstock costs



COR [-]	SN [-]	H_2O [-]	Syngas / MeOH [-]
0.09	~2	0.05	1.34
0.95	~2	0.22	1.75

- **Landfill gas with CO_2 removal and biogas with optimal CO_2 utilization appear to be the most promising options in terms of net conversion cost.**
- **Further optimization and experimental validation** must be performed to assess the possibility for a near-term business-case.

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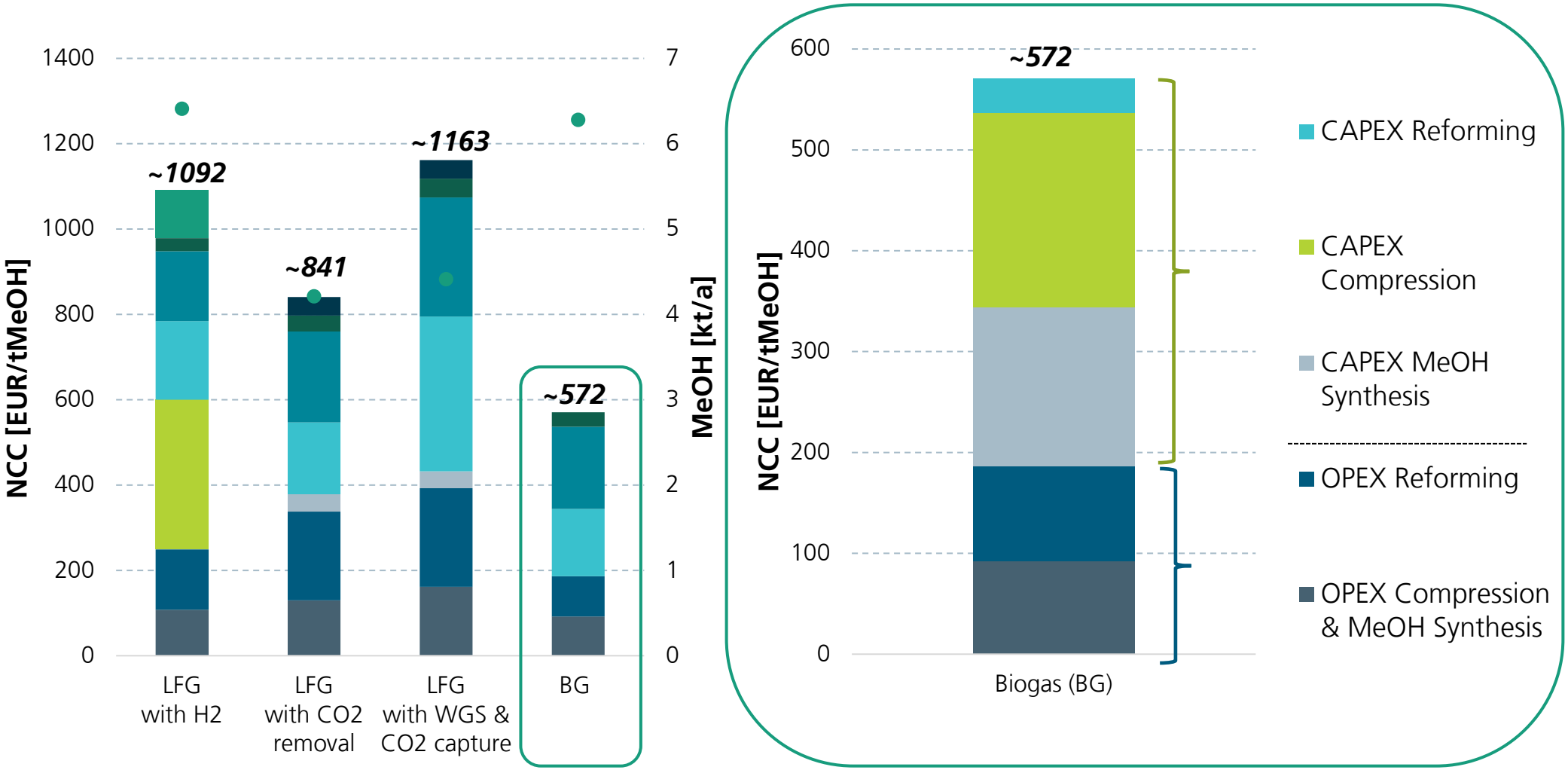
Results: Techno-Economic Evaluation III

Net Conversion Costs (NCC) of MeOH in EUR/t_{MeOH} w/o feedstock costs



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Conclusions

1. **Biogenic gas sources** and different process steps for low-carbon MeOH production were techno-economically evaluated.

2. **Two CO_2-handling options were considered**: removal upstream reforming (lower CO_2/C ratio, bigger scrubbing unit) and removal downstream reforming/WGS (higher H_2 yield, smaller scrubbing unit).

3. **Landfill gas with CO_2 removal and biogas with optimal CO_2 utilization** appear to be the most promising options in terms of net conversion costs.

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Thank you for your kind attention



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Regulatory framework – Part 2

Use cases for export

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Regulatory framework

EU – Fuel categories for methanol

Biogenic feedstock

Electricity source for hydrogen supply	**Scenario I** Biogas from residues	**Scenario II** Wastewater treatment gas	**Scenario III** Landfill gas	**Scenario IV** Wood waste (gasification)
Case A RFNBO-conform renewable electricity (incl. surplus el.)				
Case B Non-RFNBO-conform renewable electricity electrolysis-coupling before 2028				
Case C Non-RFNBO-conform renewable electricity electrolysis-coupling after 2027				
Case D Grid electricity				

LC: Low-carbon fuel RFNBO:Renewable Fuels of Non-Biological Origin RCF: Recycled Carbon Fuel

*: Utilizing grid electricity in 2025 in Chile does not allow to reach the 70% emission reduction threshold to be categorized low-carbon, but increasing share in the near future depending on hourly average emission intensity

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Regulatory framework

EU – EU ETS, ETD & RefuelEU Aviation

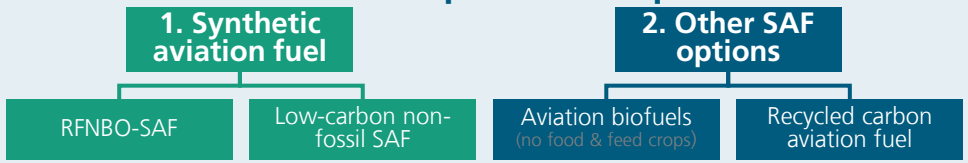
1 **EU ETS: Phase-out of free allowances for aviation**

- Phase-out of ETS allowances until 2026 & introduction SAF allowances, covering the price differential with conventional kerosene
- 20 Mio. free SAF allowances can be distributed until 2030, sufficient to achieve quotas

2 **ETD: Revision removes tax exemption for kerosene**

- Minimum tax rate of 10.75 €/GJ or 462 €/t_{JF} phase-in over next ten years after adoption (adoption pending, expected in 2026)
- Commercial jet fuel currently faces no excise tax in the EU
- SAF will have a zero minimum tax rate until 2033 (and possibly beyond)

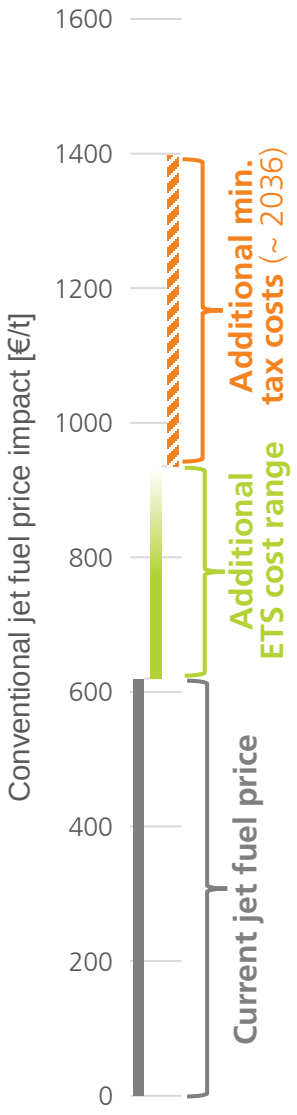
3 **RefuelEU Aviation: SAF options and quotas**



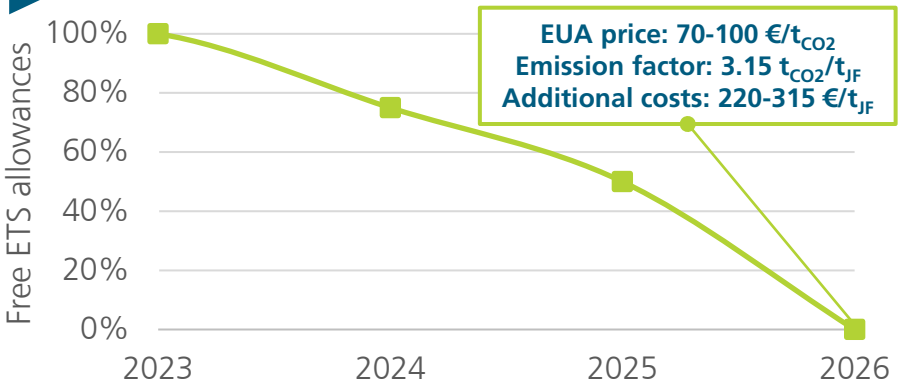
4 **RefuelEU Aviation: Fines for non-compliance**

- Fuel suppliers:
  $\geq 2 \cdot (Price_{SAF} - Price_{JF,conventional}) \cdot Quantity_{non-compliant}$
- Aircraft operators:
  $\geq 2 \cdot Price_{annual,average,aviationfuel} \cdot Quantity_{non-tanked}$

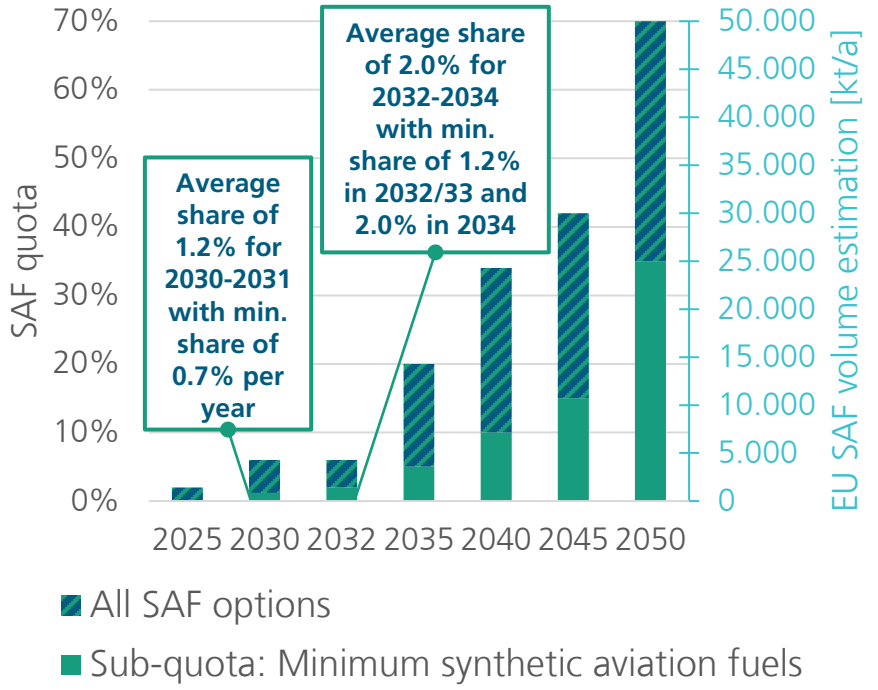
1/2 **ETS + ETD**



1 **ETS:** Phase-out free EUAs in aviation



3 **RefuelEU:** Increasing SAF quotas



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- **Conventional jet fuel is becoming more expensive after 2026**
- **SAF uptake is incentivized by an increasing quota & high penalties for non-compliance**

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Regulatory framework

EU – EU ETS, ETD & FuelEU Maritime

1 EU ETS: Phase-in of maritime sector in the EU ETS

- Depending on ship size and type, shipping companies must buy EUAs for a portion of relevant emissions from 2025 onwards
- Surrendering of EUAs takes place in following year
- Other GHG gases than CO_2 are introduced from 2026 onwards

2 ETD: Revision removes tax exemption for kerosene

- Minimum tax rate of 10.75 €/GJ or 462 €/tFuel phase-in over next ten years after adoption (adoption pending, expected in 2026)
- Shipping fuel currently faces no or minimal excise tax in the EU
- Alternative fuels have a zero min. tax rate until 2033 (possibly beyond)

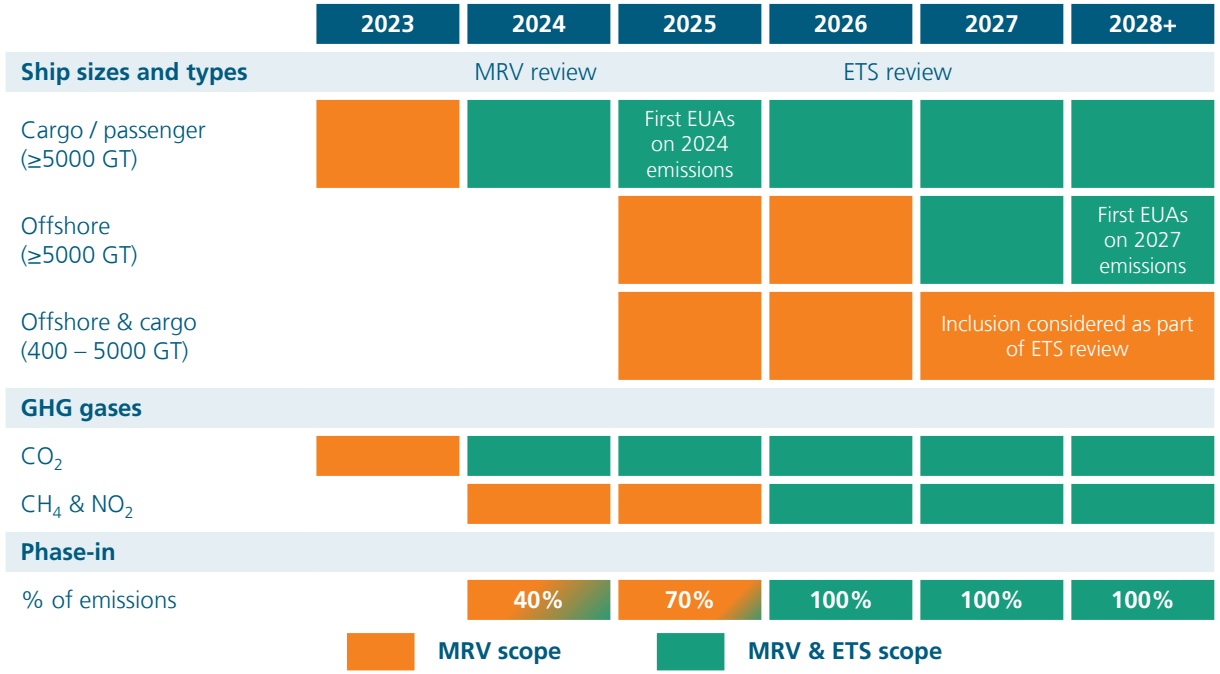
3 FuelEU Maritime: GHG emission reduction

- Obliges vessels > 5,000 GT in commercial passenger transport or cargo to reduce their well-to-wake GHG intensity
- RFNBO subtarget of ≥ 1% in 2031
- Zero-emission requirements for energy used at berth after 2030
- Flexibility mechanism (banking + borrowing & pooling for rewards)

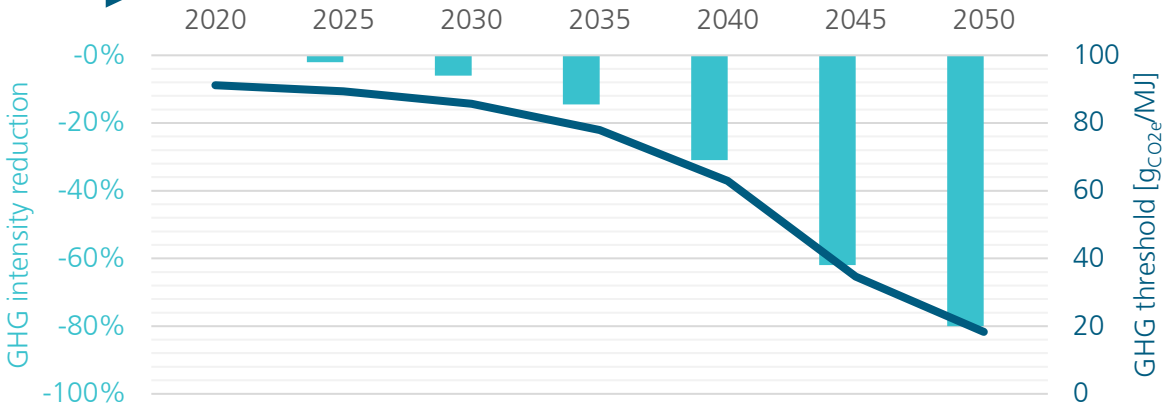
4 FuelEU Maritime: Fines for non-compliance

- Deviations from the GHG compliance balance of ships and for nonfulfillment of the RFNBO sub-target:
  2,400 €/t of VLFSO energy equivalent or roughly 60 €/GJ of non-compliant energy

1 EU ETS: Phase-in of maritime sector



3 FuelEU: Increasing GHG intensity reduction



- **Conventional maritime fuel is becoming more expensive after 2025**
- **Alternative fuels are incentivized by reduction quota & high penalties for non-compliance**

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