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STATUS OF HYDROGEN PRODUCTION WITH CO_2 CAPTURE

- INCLUDING PERSPECTIVES ON EMISSIONS AND SCALE

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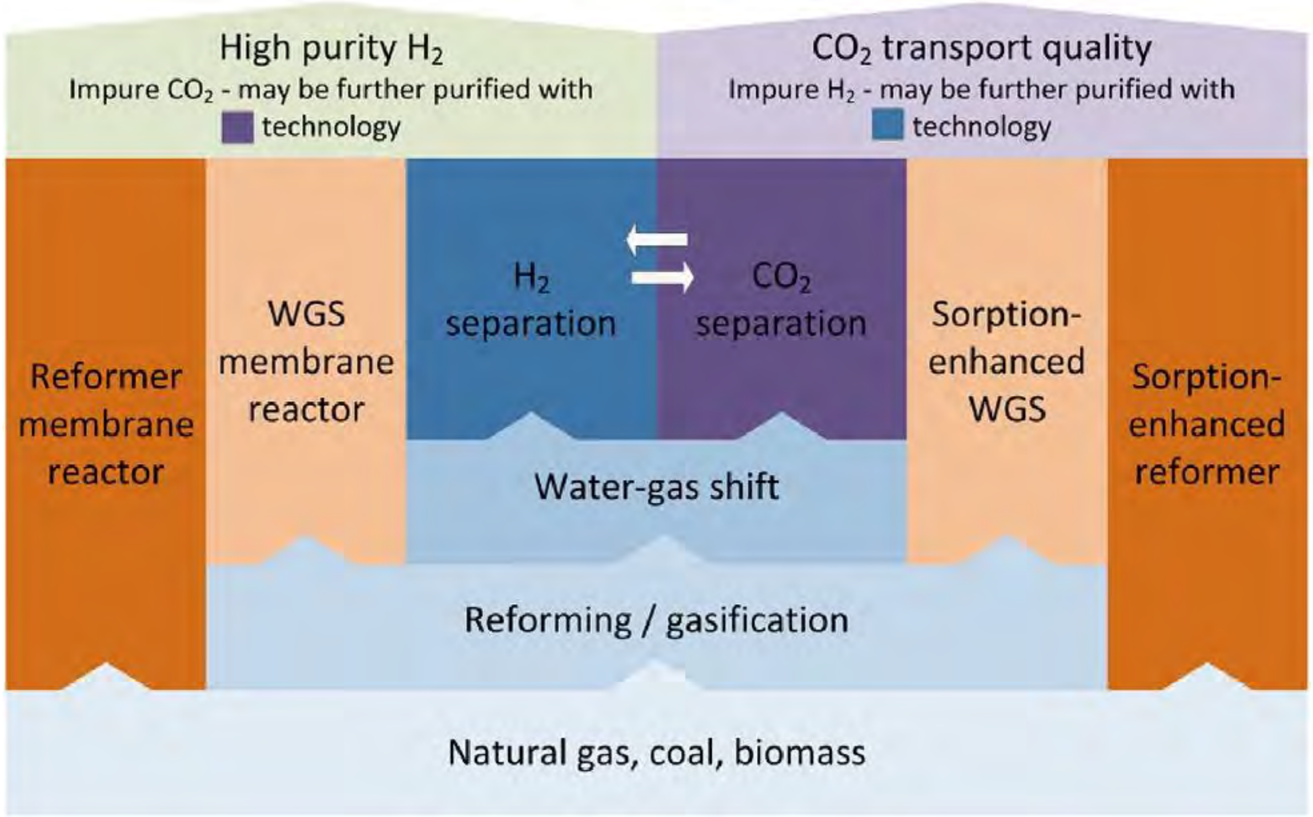
Coorporate Hydrogen Initiative

CSLF Workshop, Chatou Nov. 6 2019

Integrated syngas production & gas separation



Voldsund, M., Jordal, K. and Anantharaman, R. (2016) ‘Hydrogen production with CO_2 capture’, *International Journal of Hydrogen Energy*

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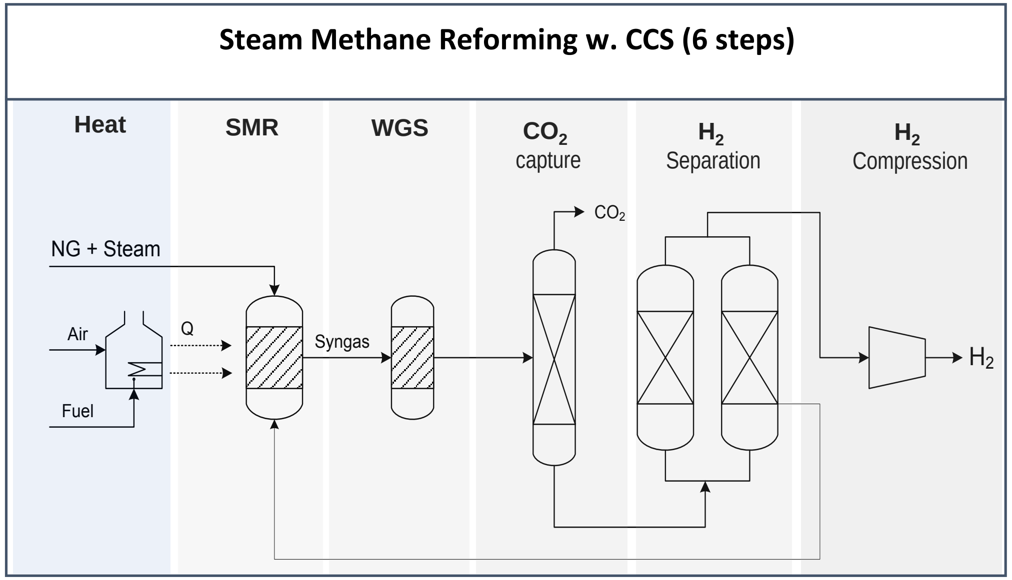
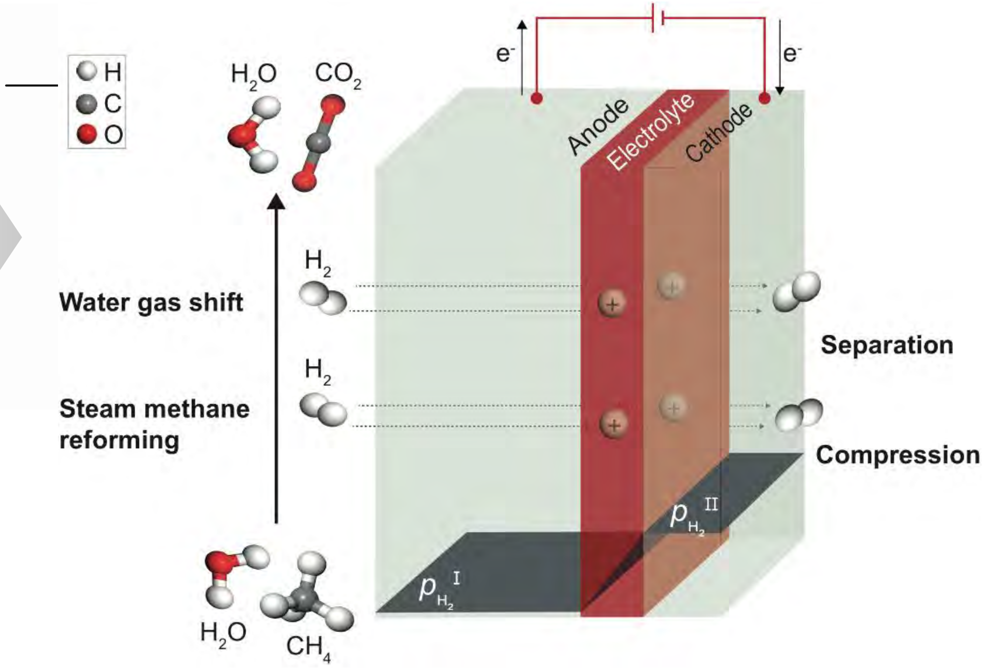
Protonic Membrane Reformer technology

Today's solution → **Protonic Membrane Reformer (PMR)**



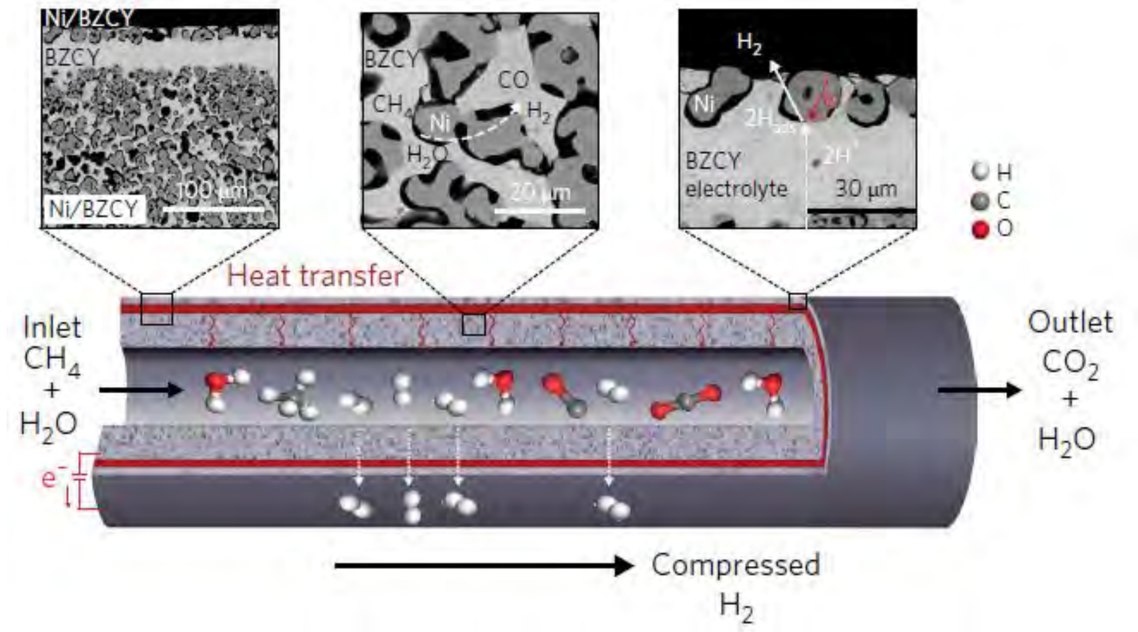
Process Step reduction



Malerød-Fjeld, H. *et al.* (2017) 'Thermo-electrochemical production of compressed hydrogen from methane with near-zero energy loss'. Nature Energy

Protonic Membrane Reformer (PMR) technology

- "Tube-in-shell" membrane reactor producing pure H_2 from natural gas
- Membrane wall has three layers:
  - Anode (thickest layer, porous material - BZCY and Ni)
  - Solid electrolyte (dense proton conductor - BZCY)
  - Cathode (porous material - BZCY and Ni)
- High-pressure H_2 is delivered to shell (electrochemical compression)



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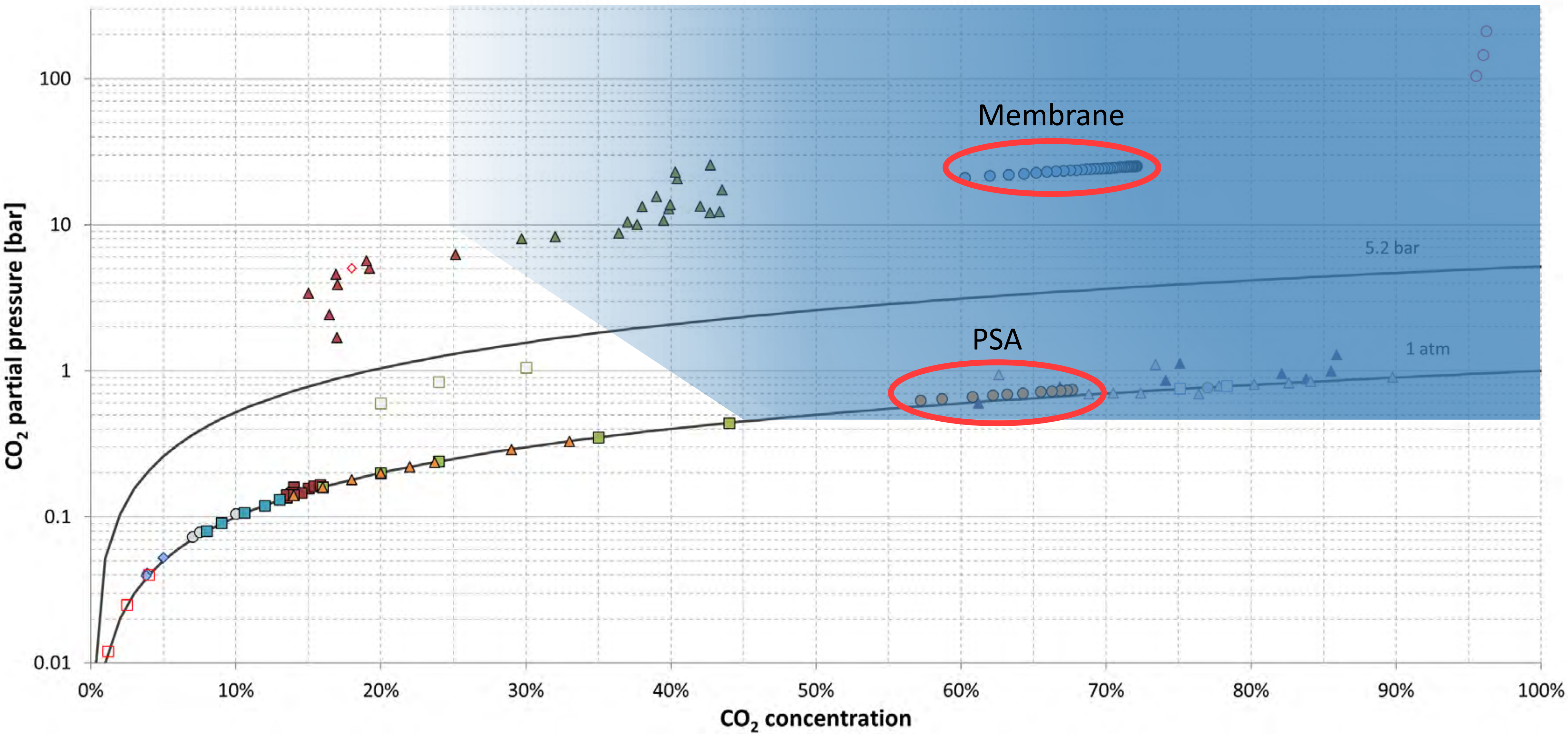
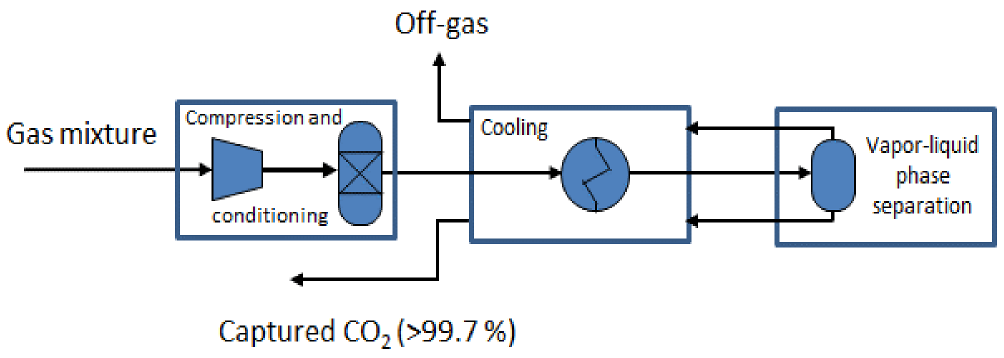
Low temperature CO_2 separation – capture conditions

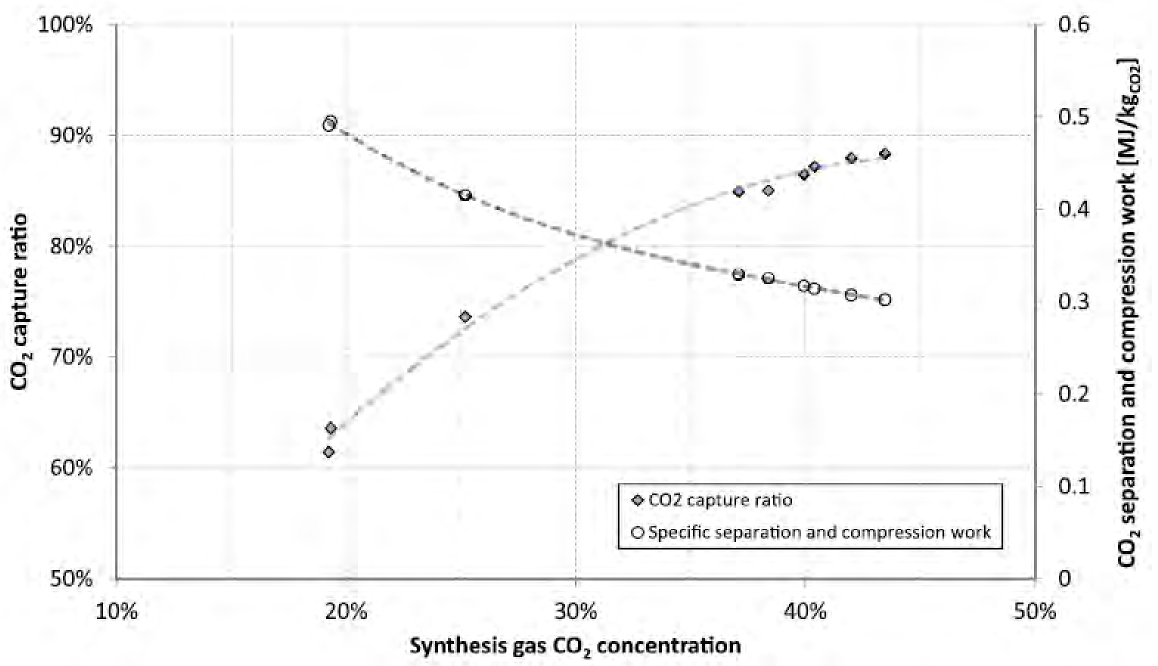


Berstad, D., Anantharaman, R. and Nekså, P. (2013) 'Low-temperature CO2 capture technologies – Applications and potential', *International Journal of Refrigeration.*

Low-temperature separation technology

- Vapor–liquid phase separation after compression and cooling of the gaseous mixture
  - Obtainable CO_2 capture rate, specific separation and compression work, and thus power consumption, are sensitive to the CO_2 concentration of the incoming flue- or syngas

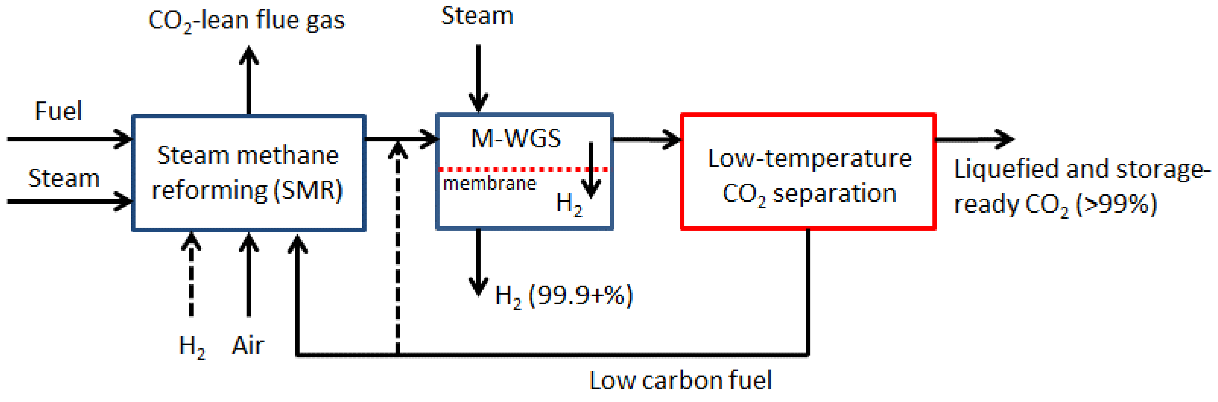


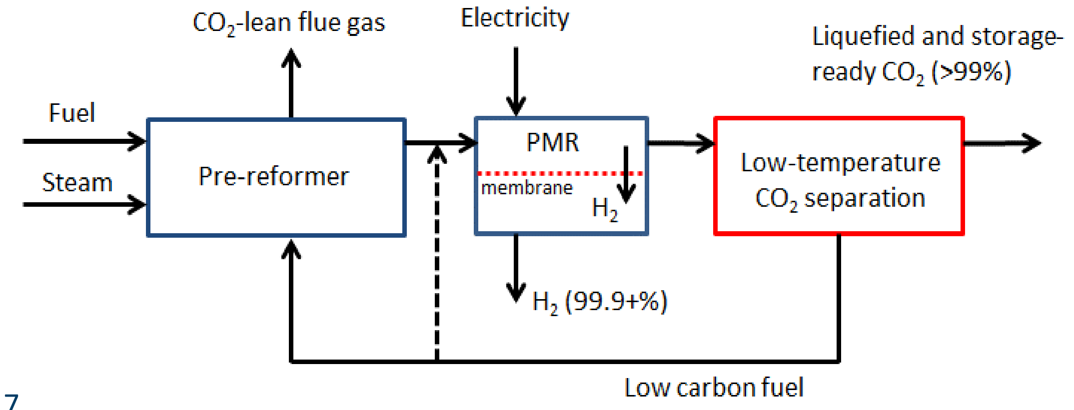


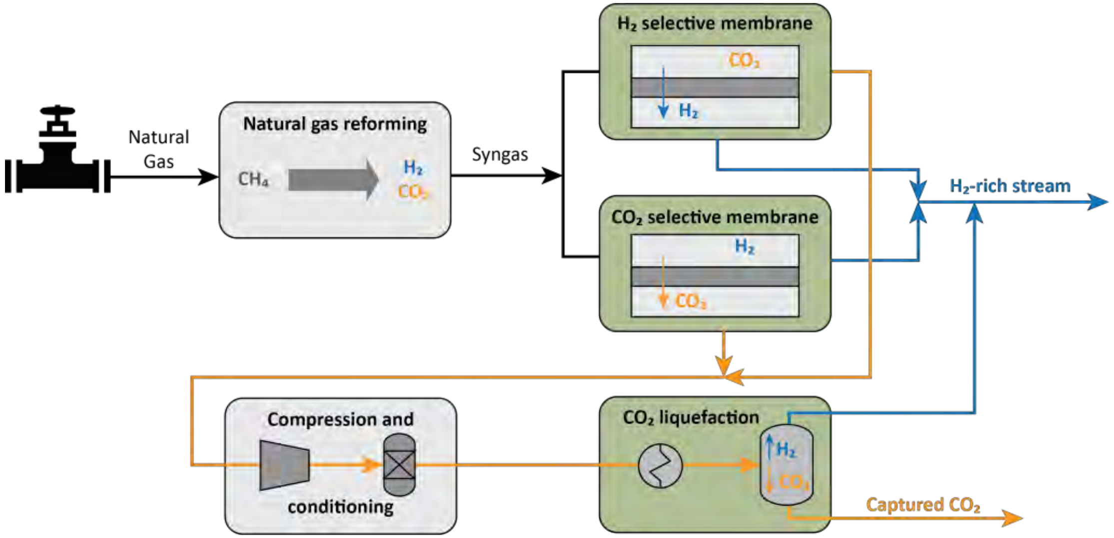
  - CO_2-enhanced retentate stream ideal incoming stream
  - H_2-rich off-gas can be partially recycled to the reactor maximizing the overall HRF and CO conversion

Berstad, D., Anantharaman, R. and Nekså, P. (2013) 'Low-temperature CO2 capture technologies – Applications and potential', *International Journal of Refrigeration.*

Membane + Low temperature process for H_2 & CO_2 production from syngas







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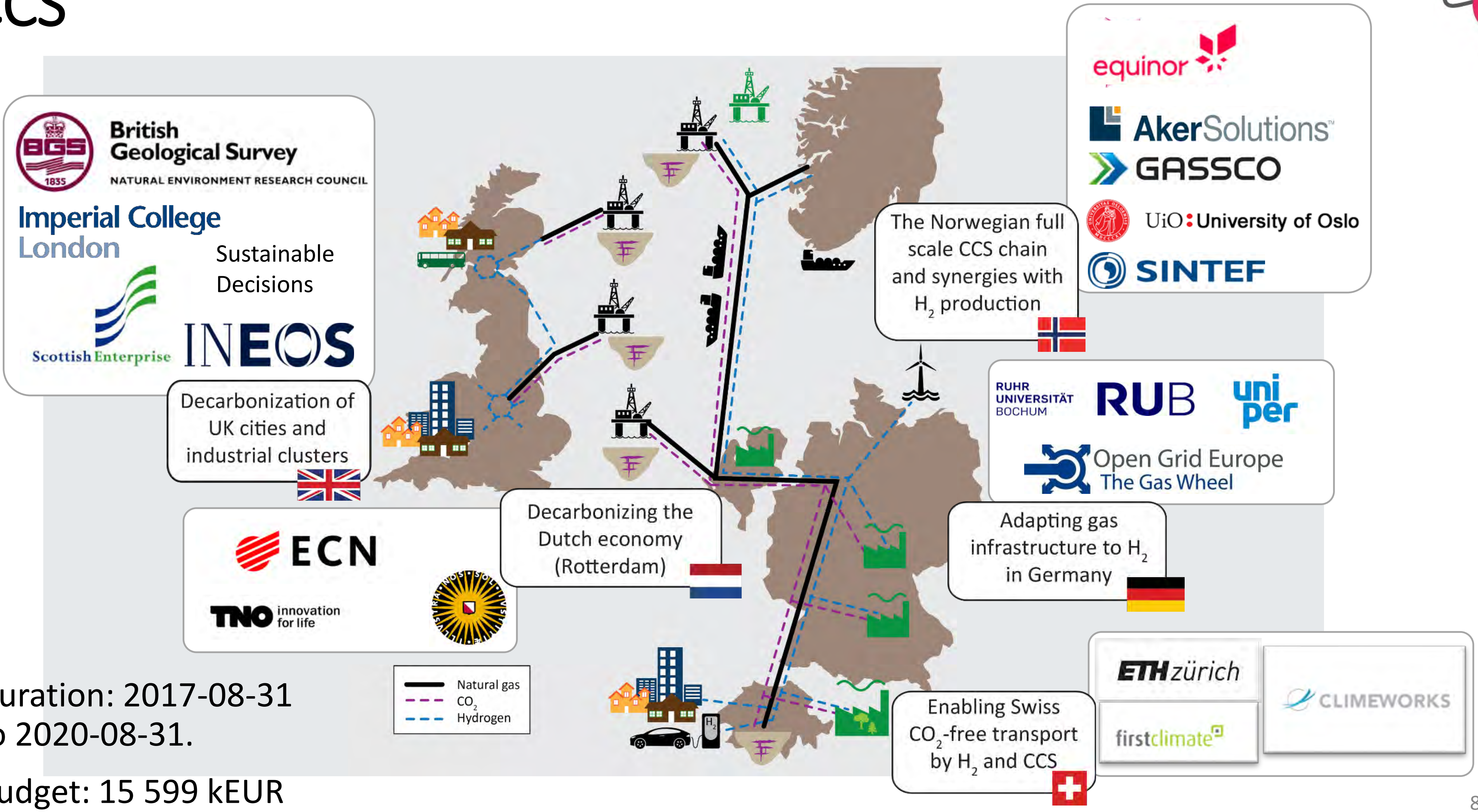
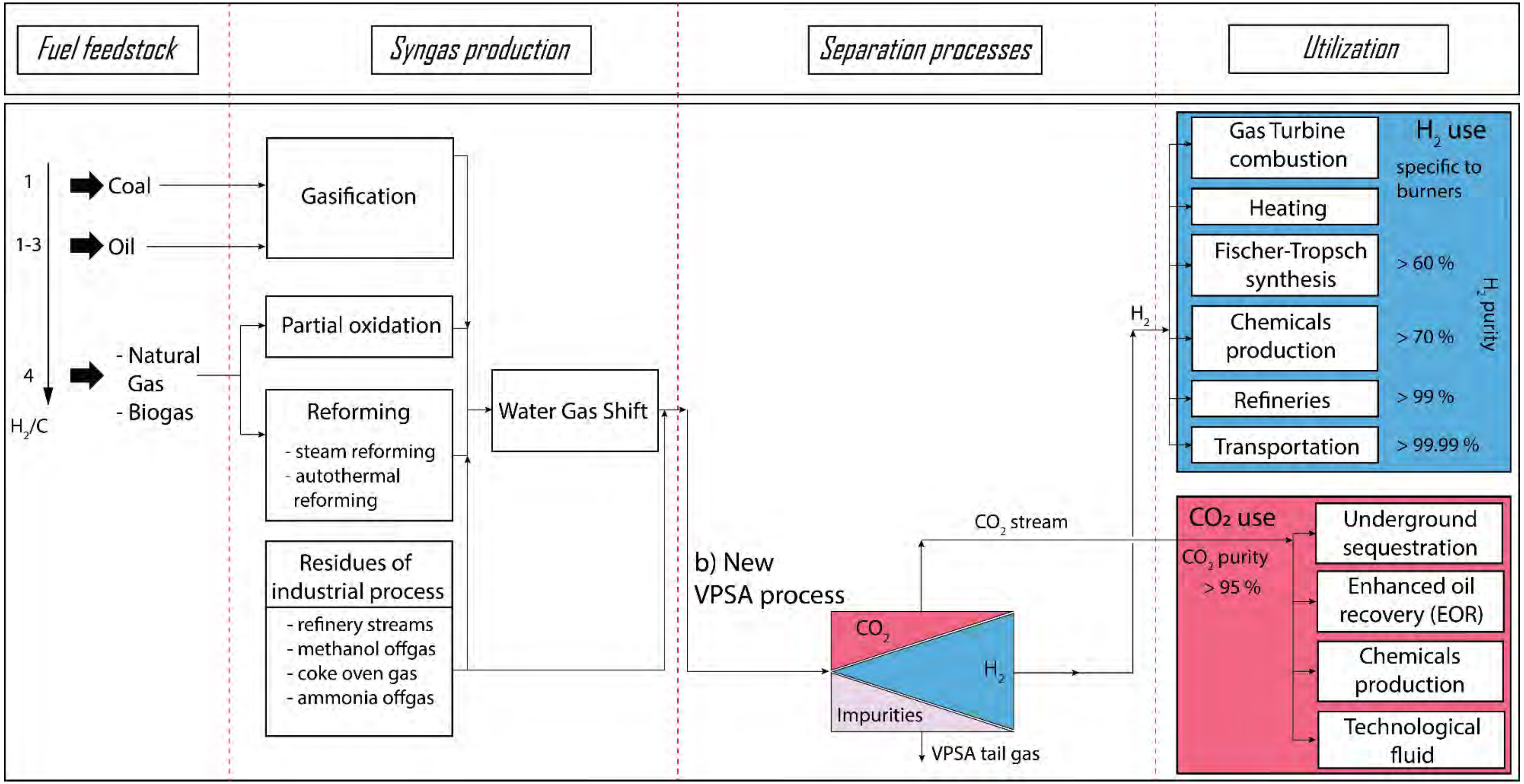
ELEGANCY –Enabling a low carbon economy by H_2 and CCS



- Duration: 2017-08-31 to 2020-08-31.
- Budget: 15 599 kEUR

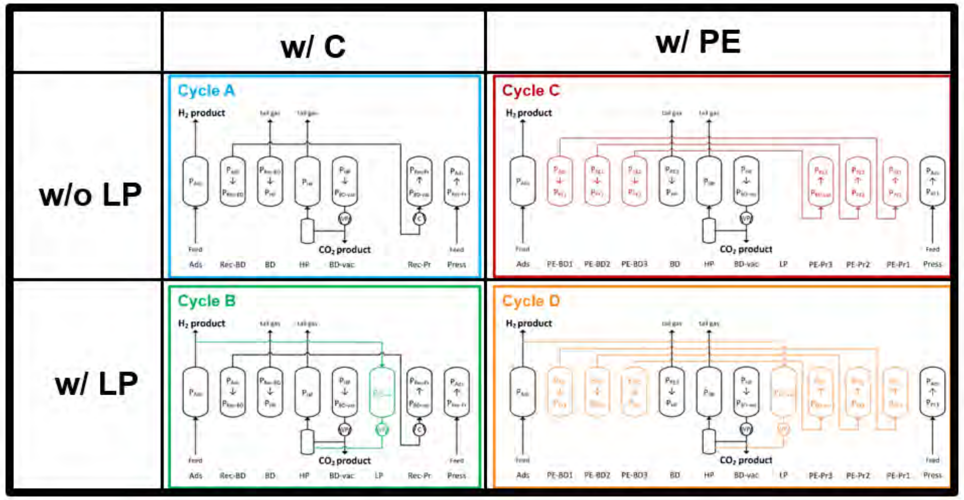
Hydrogen production with CCS

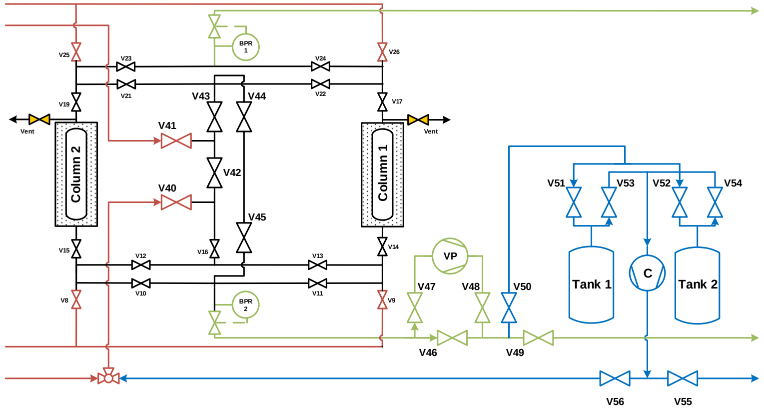


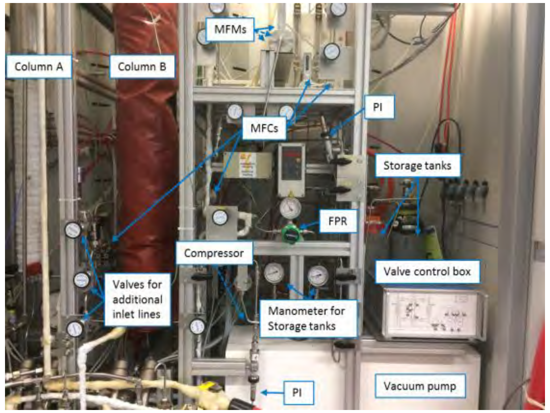
- → VPSA promising for process intensification
- → New adsorption processes are needed for this separation
- → Cycle design for a generic inlet stream and a commercial activated carbon

Hydrogen production with CCS

- Cycle designs developed for generic inlet stream and optimized for case studies:
  - Steam methane reforming (SMR)
  - Autothermal reforming (ATR)
  - High temperature WGS (HT-WGS)
  - High and low temperature WGS (LT-WGS)
- Lab pilot completed and first experimental results obtained

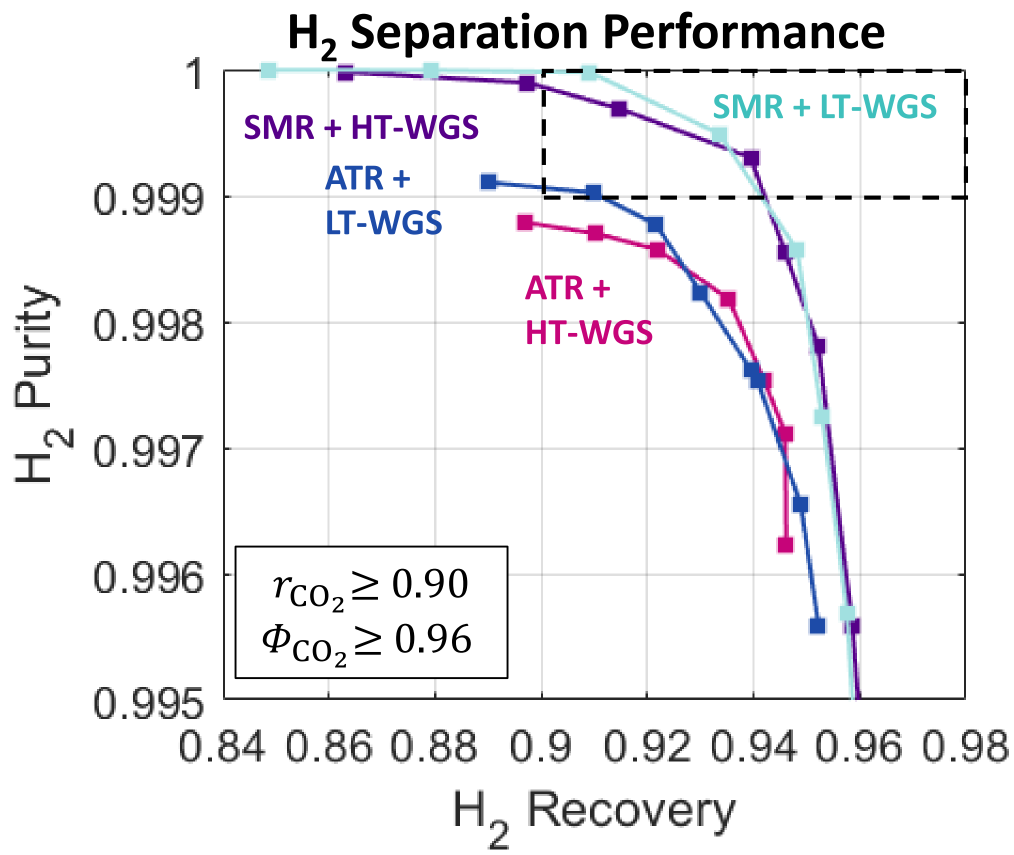






Cycle D application: Separation performance for different case studies

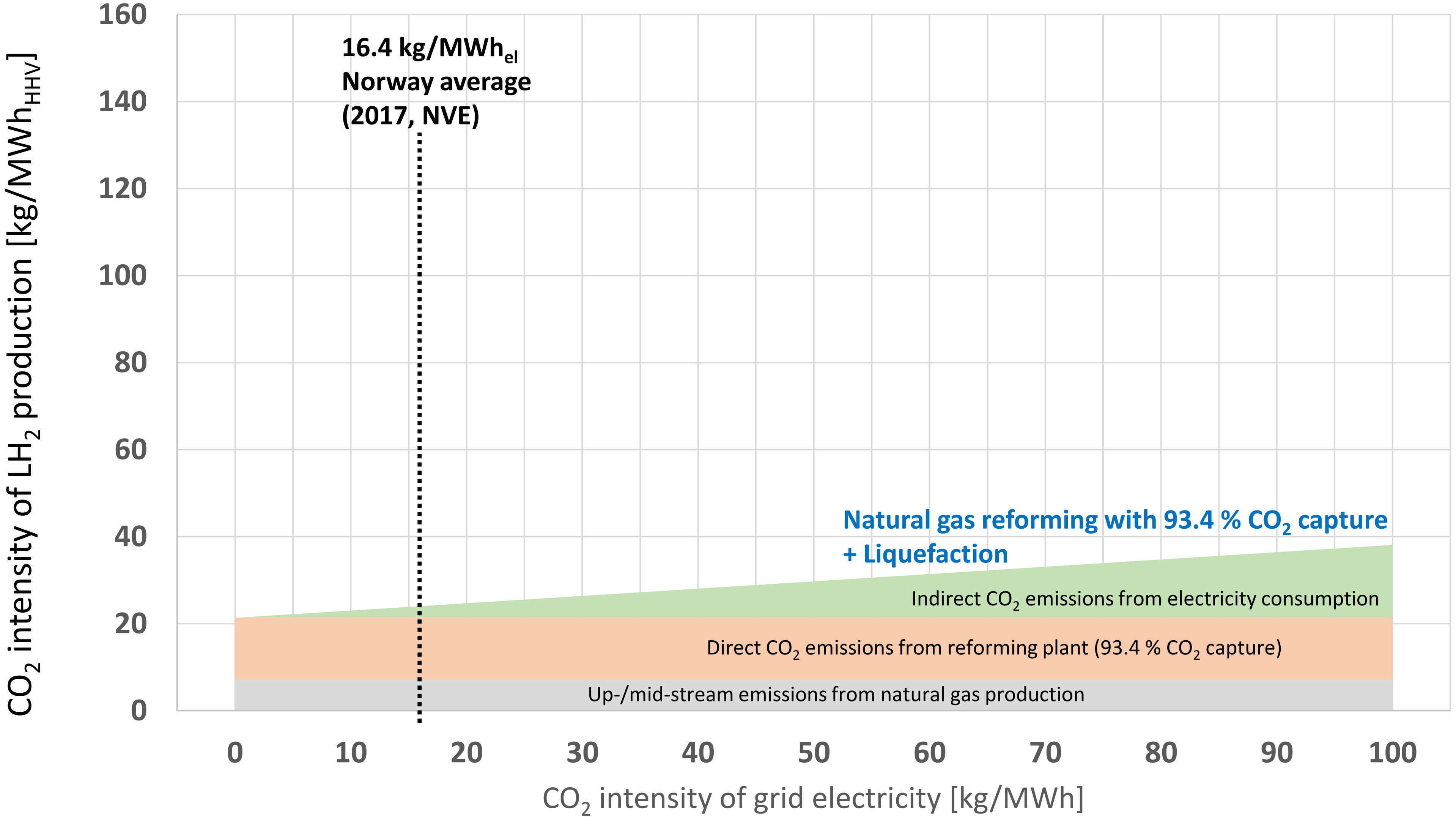
		SMR + HT-WGS	SMR + HT-WGS + LT-WGS	ATR + HT-WGS	ATR + HT-WGS + LT-WGS
H_2	mol%	75.81	76.2	70.6	72.73
CO_2	mol%	16.31	19.6	19.74	25.6
CH_4	mol%	3.03	3.5	0.34	0.5
CO	mol%	4.65	0.4	9	0.9
N_2	mol%	0.2	0.3	0.24	0.2
Ar	mol%	0	0	0.08	0.07
Adsorbent		Zeolite 13X			



- Very high H_2 purity possible
- H_2 purity limited for ATR: Argon in H_2 product

"Green" or "Blue" hydrogen?

Mythbusting: "Blue hydrogen" vs. "Green hydrogen"



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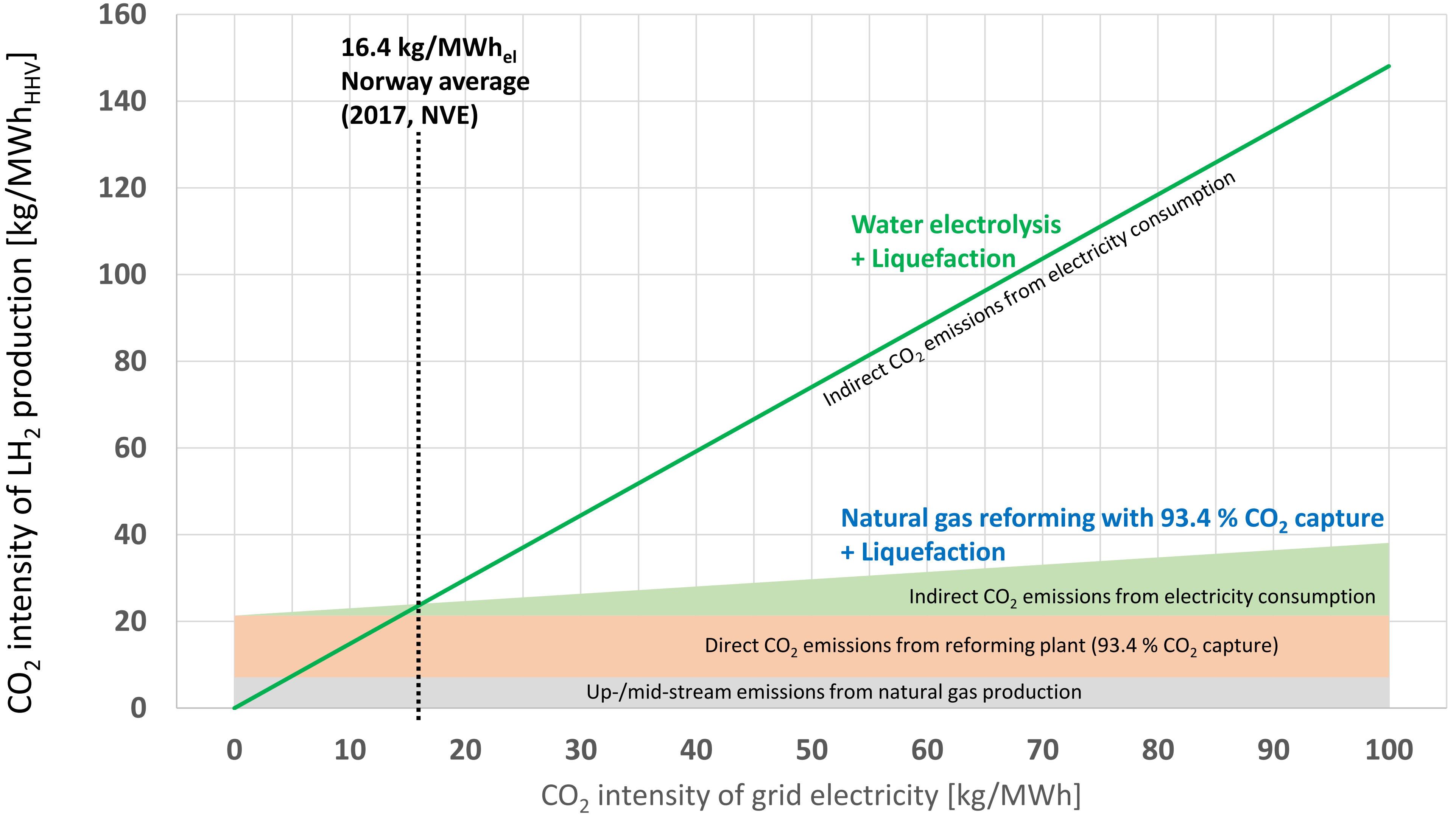
Mythbusting: "Blue hydrogen" vs. "Green hydrogen"



"Green" or "Blue" hydrogen?

= Clean hydrogen?

How large is large is large-scale?
In perspective: 500 ton liquid hydrogen per day

- **820 MW_{HHV}** hydrogen energy flux
- **7 TWh per year** of hydrogen energy output
- Decabonised fossil route (NG with CCS):
  - < 1 % of annual Norwegian natural gas production
- Renewable route (electricity as sole primary energy source):
  - > 1200 MW electric power
  - ≈ 10 TWh_{el} annually (about 7 % of annual Norwegian power generation)

Source: Kawasaki Heavy Industries

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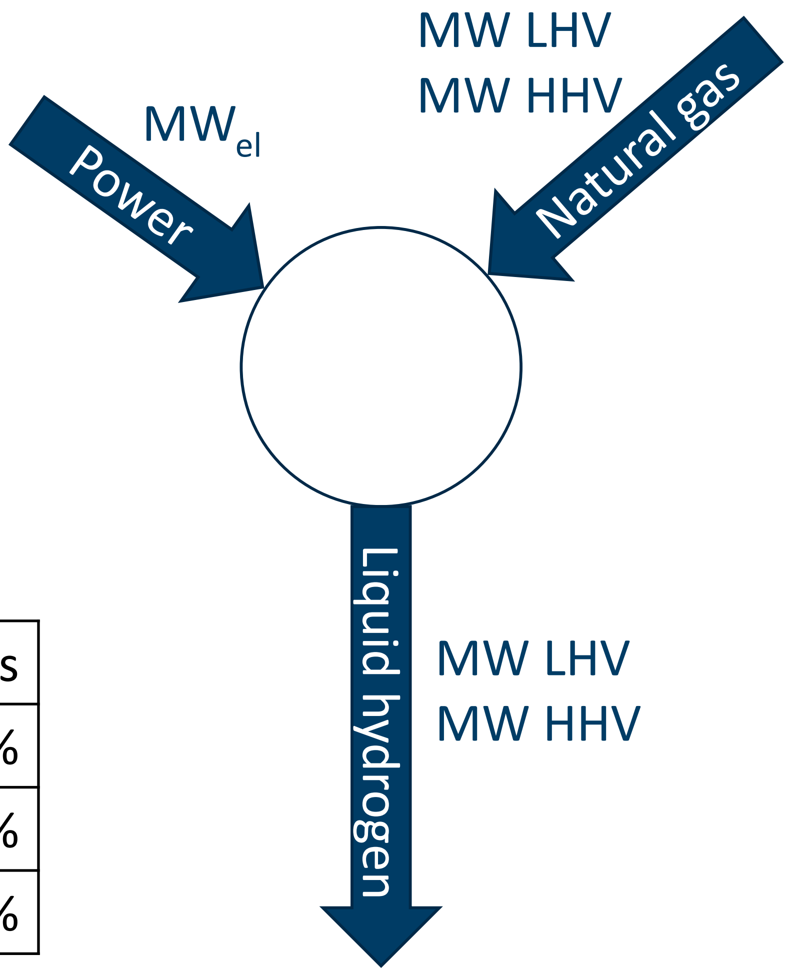
~70% efficiency for H_2 production, CO_2 capture and H_2 liquefcation

Input/Output	MW_{LHV}	MW_{HHV}
Natural gas input	810.9	891.7
Hydrogen LH_2 product output	694.4	821.2
	MW_{el}	
Net power requirement	245.2	

Plant Efficiency **(1st law efficiency)**	LHV basis	HHV basis
Stand-alone for the NG-based system	66.9 %	72.8 %
Stand-alone for the electrolyser-based system	57.1 %	67.5 %
Overall for the 450 + 50 t/d plant	65.8 %	72.2 %



Including > 93 % CO_2 capture ratio

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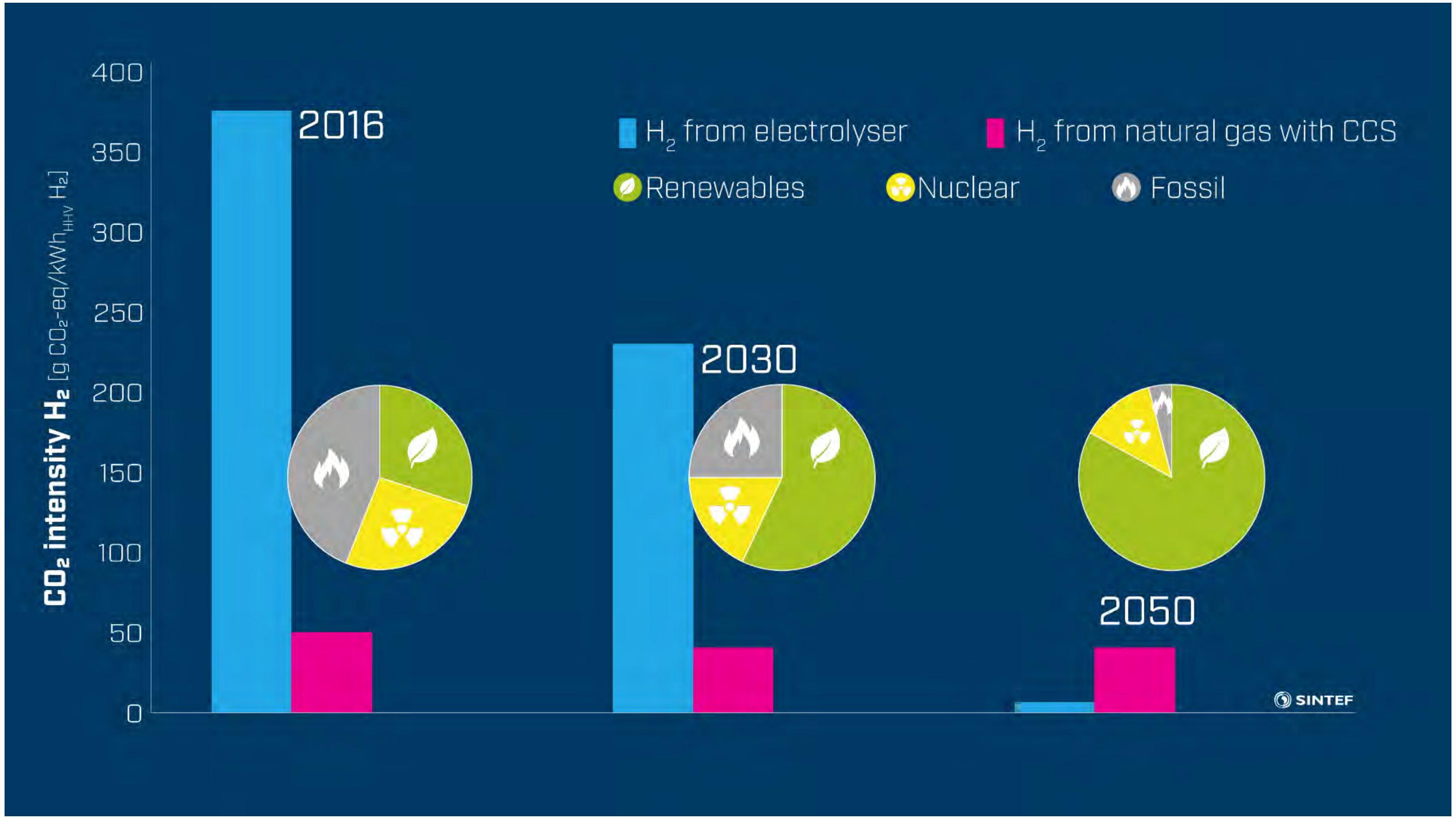
Hydrogen produced from natural gas with CCS will have lower GHG emissions than hydrogen from electricity in the EU grid for decades



- Comparison of greenhouse gas emissions related to production of hydrogen from
  - European grid electricity via electrolysers
  - Natural gas with carbon capture
- Hydrogen production from natural gas using autothermal reformers with 93 % (2016) to 96 % (2030 - 2050) CO_2 capture ratio
- European grid electricity mix shown in the pie-chart – forecasts based upon the IRENA REmap case for 2030 and the decarbonised scenarios from "A Clean Planet for All" for 2050
- Without deep decarbonization of the European power generation, emissions from production of hydrogen from dedicated renewably based electricity must account for potentially reduced emission reductions of the power sector

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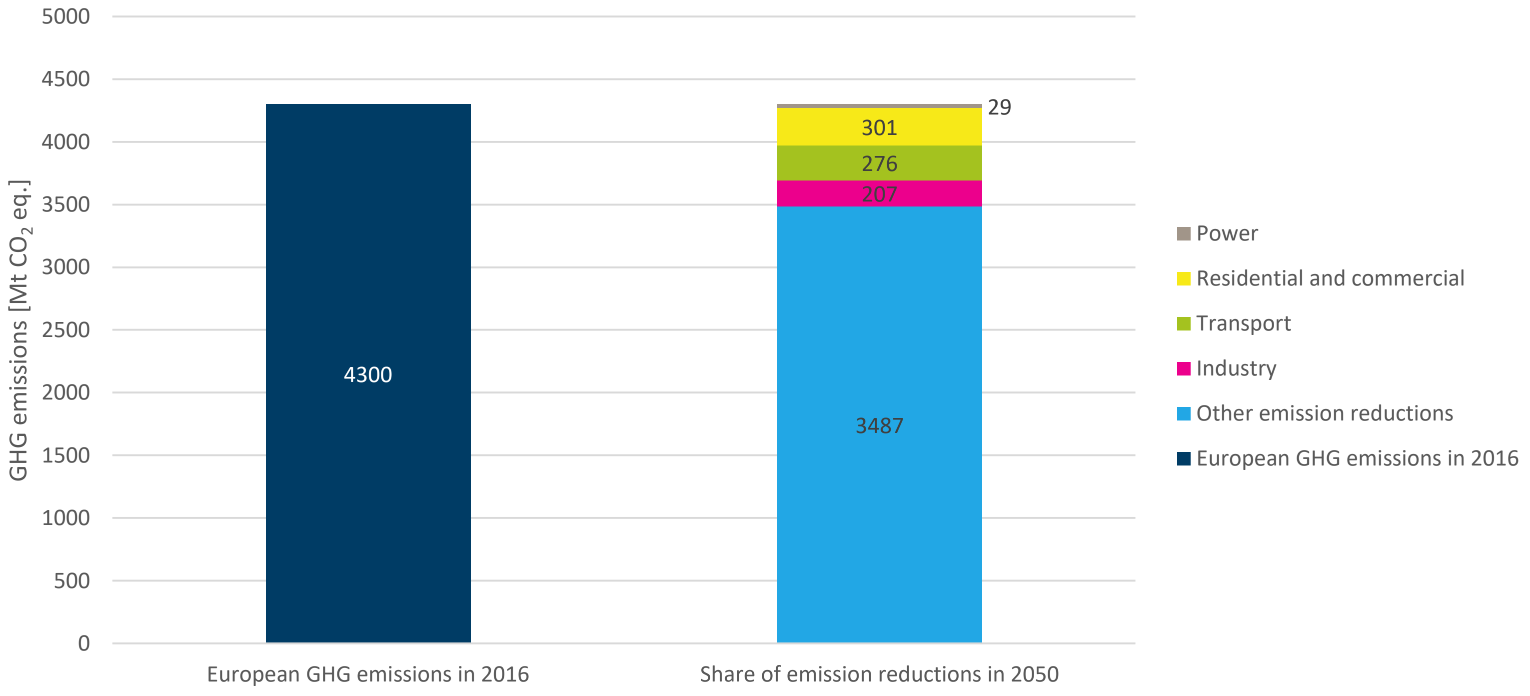
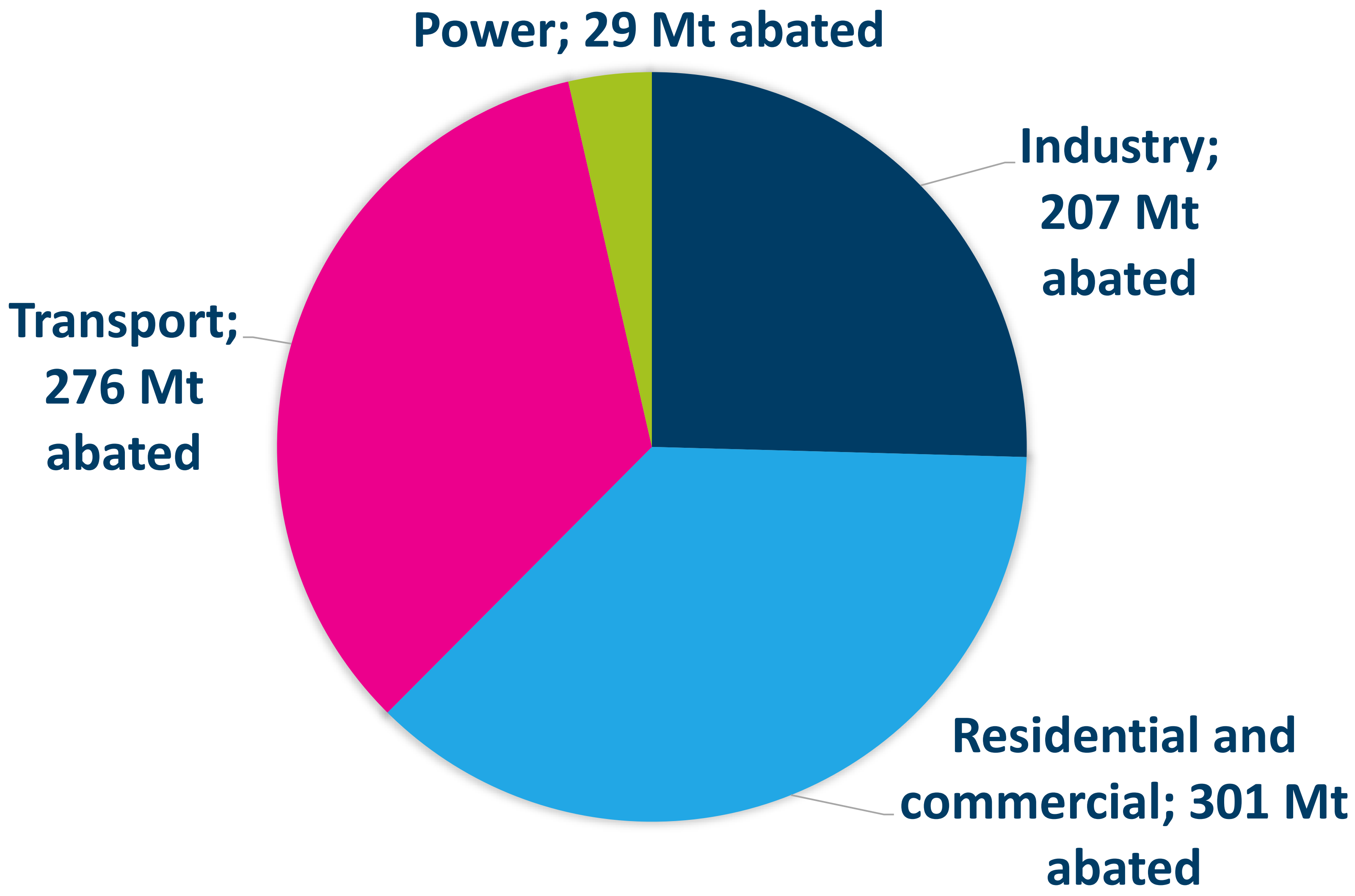
ifp Energies nouvelles

The potential for reducing Europe's greenhouse gas emission by use of clean hydrogen is more than 800 Mt CO_2/year in 2050 (19% of current GHG emissions)



- Estimated upper bounds for annual emission reductions in Europe due to the use of hydrogen to replace fossil fuels
- Hydrogen consumption estimated from predictions for final energy consumption in 2050
- Total potential: 813 Mt CO_2 (2016 emissions: 4300 Mt CO_2)

Almost 20% of current European CO_2 emissions can be abated by clean hydrogen in 2050



Technology for a better society