Institute of Engineering Thermodynamics

Techno-economic assessment of the utilization of CO_2 to produce liquid fuels by electrolysis and Fischer-Tropsch synthesis

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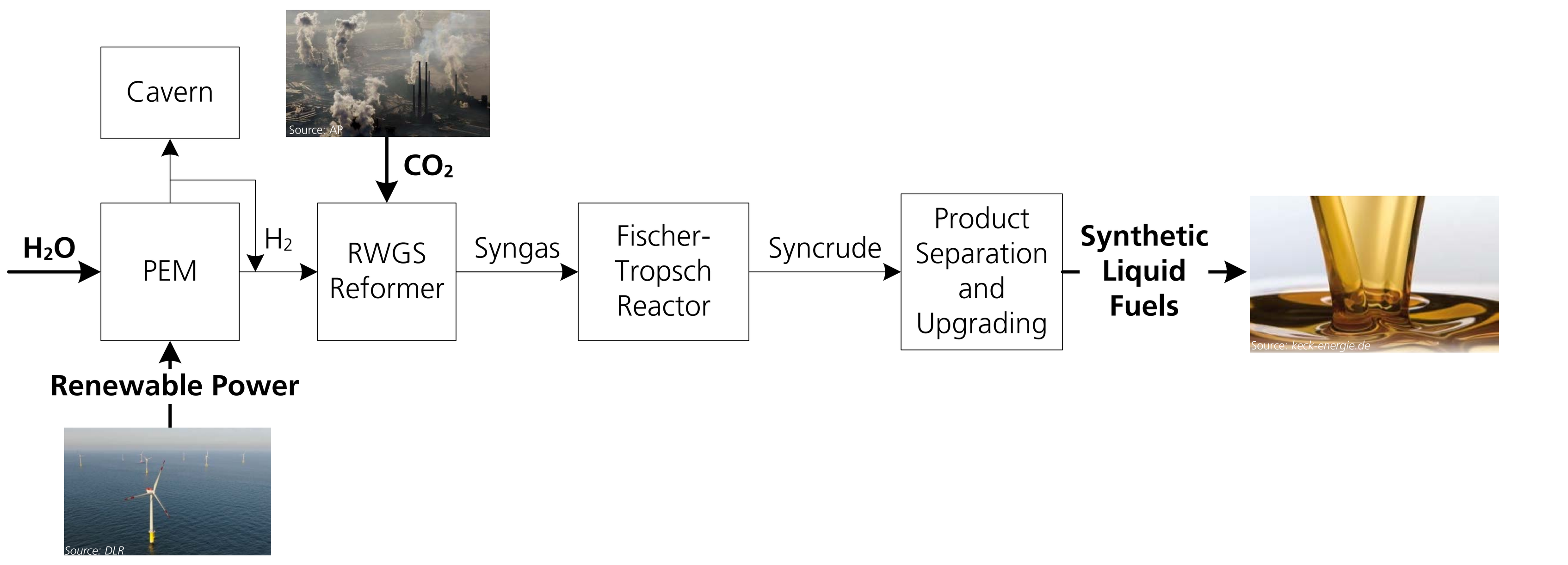
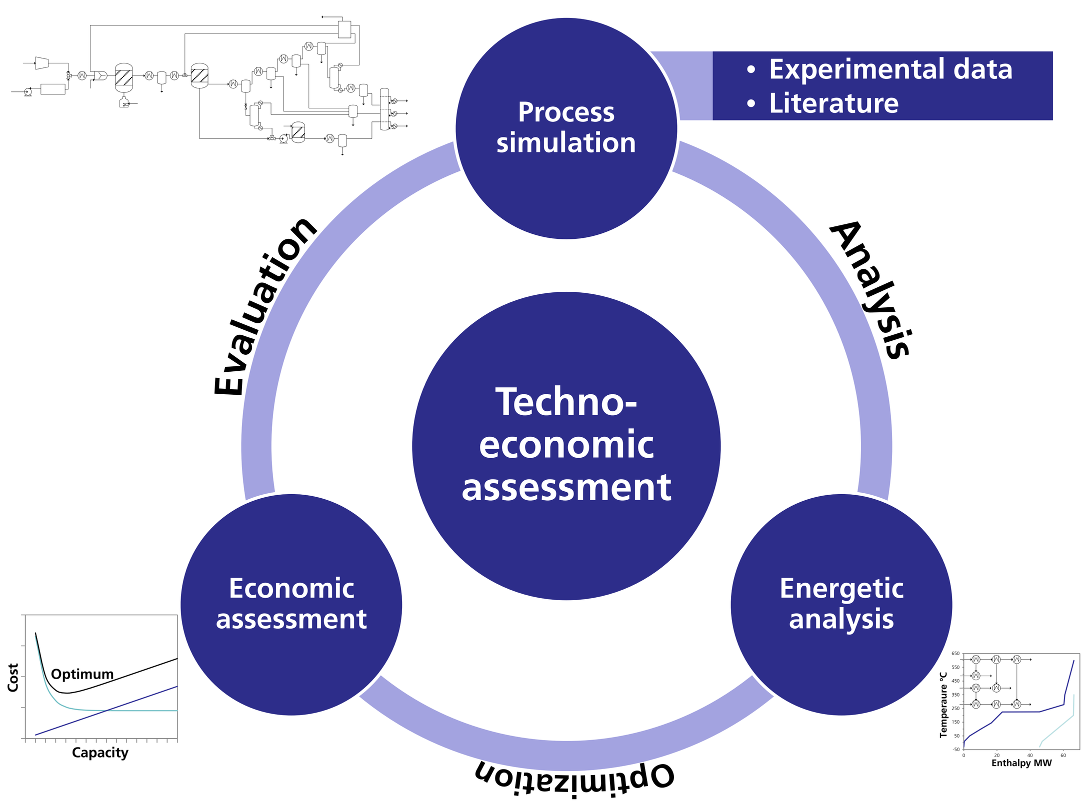
Motivation

Future aviation, shipping and heavy load transportation will continue to depend on energy carriers with a high energy density. Synthetic liquid fuels (SLF) produced by the Power-to-Liquid route are a promising alternative to biofuels and can contribute significantly to sustainable and secure mobility. The conversion of CO_2 and renewable energy into high quality fuels can reduce oil dependence, help reduce global warming, and close the sustainability triangle. A techno-economical assessment of the production process fosters research activities to pave the way to market penetration. Additionally the technical and economic feasibility and the involved hurdles are identified.



Methodology



Process Simulation:
- Determination of the material and energy balances
- Calculation of process efficiencies
- Investigation of various process routes

Energetic analysis:
- Pinch point analysis
- Estimation of utility capacities
- Identification of energy streams

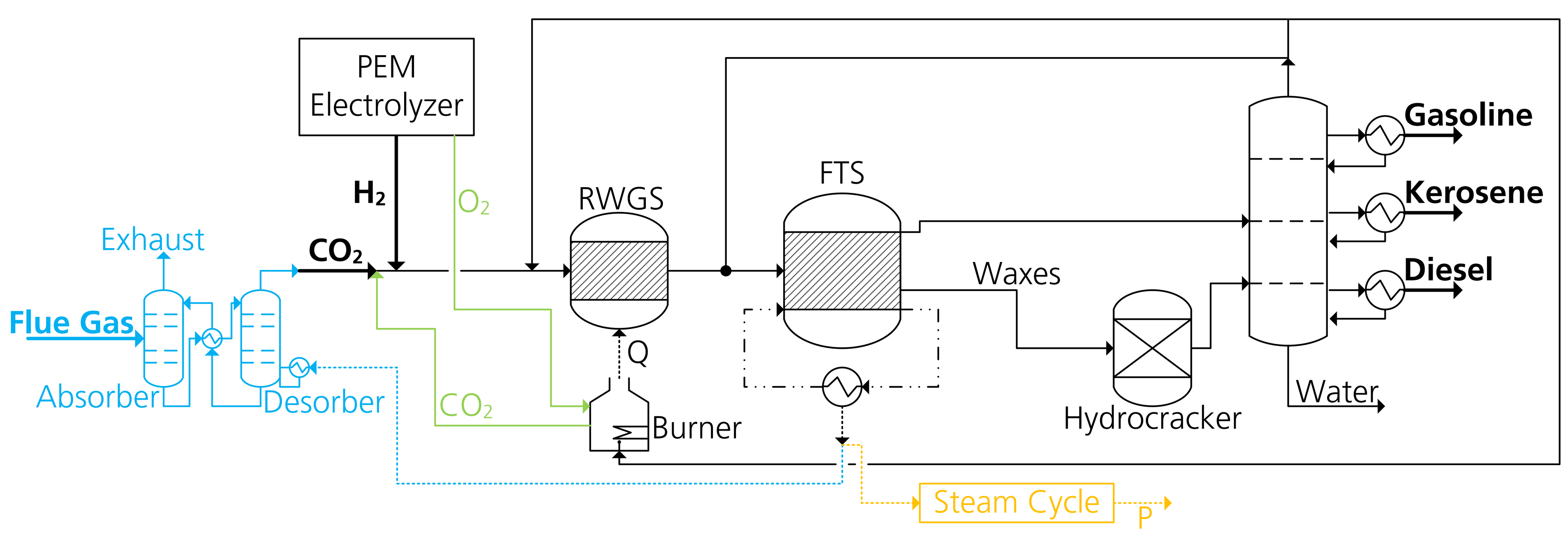
Economic assessment:
- Estimation of component prices and operation costs
- Execution of sensitivity analyses
- Determination of net production cost

Goals:
- Identify performance-critical system components and process equipment
- Identification and appraisal of cost drivers and economic hurdles

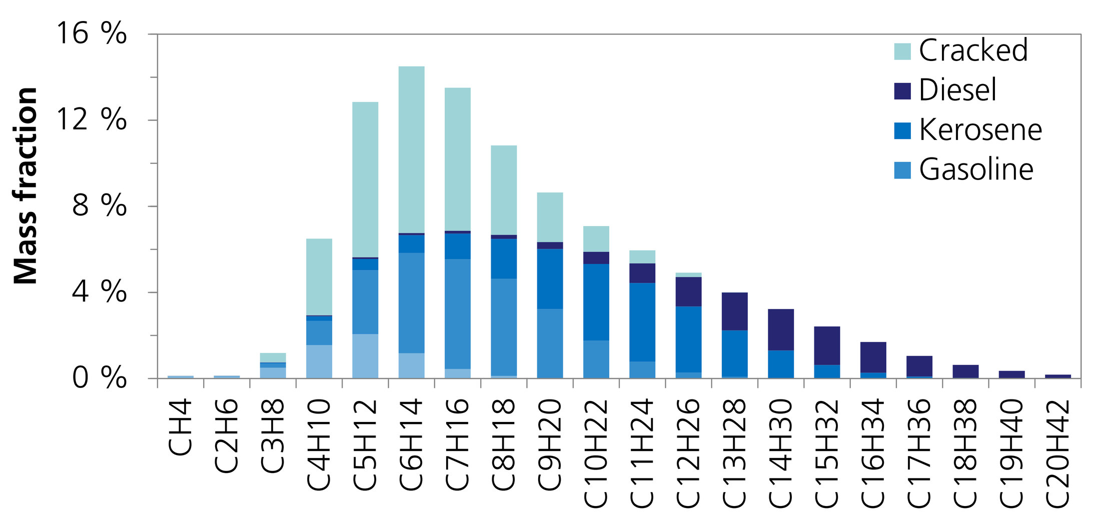
Process Concept

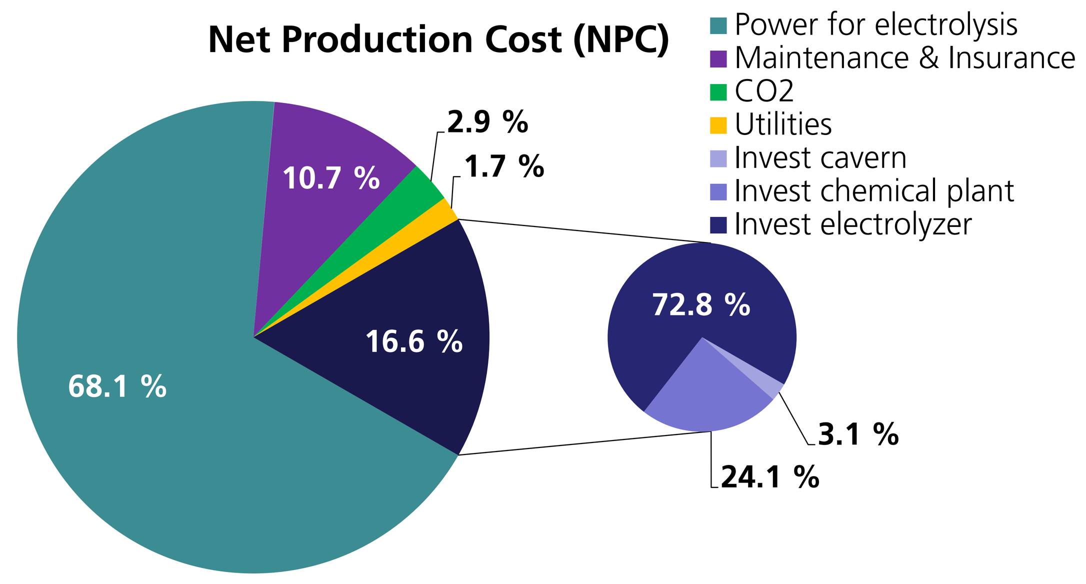
Model assumptions:
- PEM Electrolyzer
  $T = 50$ °C; $p = 25$ bar; $\eta_{AC/DC} = 96$ %
  $\eta_{Electrical} = 4.3$ kWh/Nm^3
- Reverse water gas shift (RWGS) reformer
  $T = 900$ °C; $p = 25$ bar
  Thermodynamic equilibrium reactor
- Fischer-Tropsch synthesis (FTS)
  Fixed bed multi-tubular reactor,
  Co catalyst; $T = 225$ °C; $p = 25$ bar
  Chain growth probability $\alpha = 0.85$
  $x_{H_2}/x_{CO} = 2.05$; $X_{CO} = 40$ %
- Hydrocracker
  $T = 350$ °C; $p = 60$ bar
  Experimental yield distribution[1]

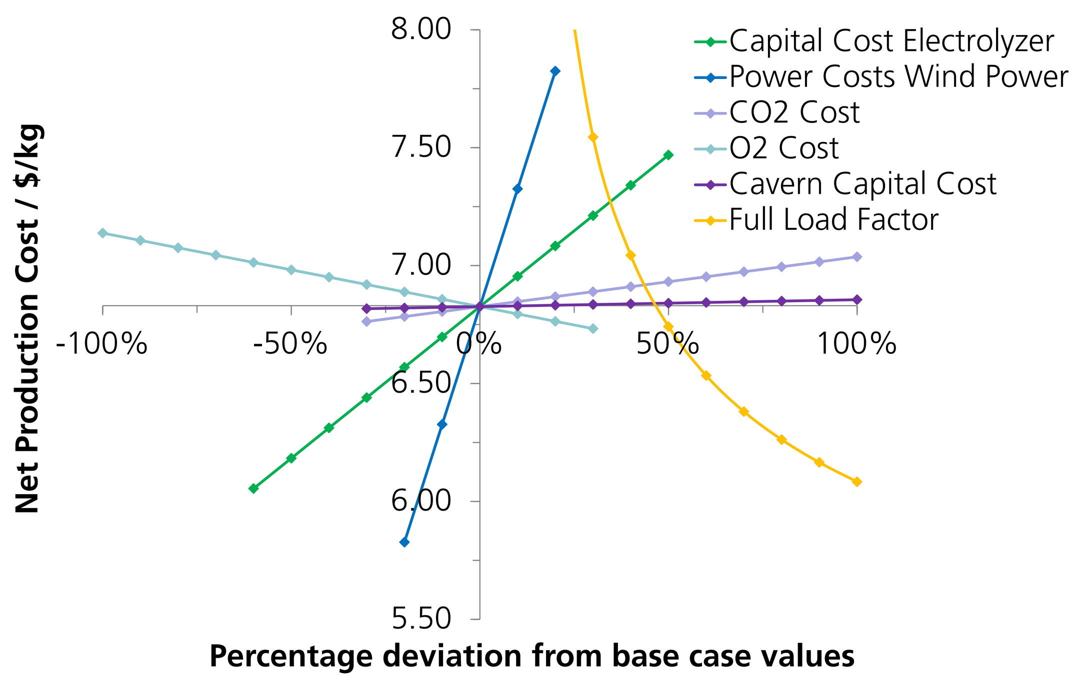
Reference Case	Base case process route for the production of SLF.
Carbon Capture Case	CO_2 is captured on-site using the FT excess heat for absorbent regeneration.
Steam Cycle Case	Internal power generation utilizing FT excess heat for higher efficiency.
Oxy-fuel Case	Oxy-fuel combustion using O_2 from PEM to ease CO_2 recycling.



Results







- Product distribution may be adapted to the future market situation
- NPC are dominated by the electricity prize and electrolyzer capital cost
- NPC range from 5.83 $/kg to 7.82 $/kg depending on the chosen assumptions
- For an optimistic future scenario (1/3 electrolyzer cost, 1/3 electricity prize, operation at 100 %), the NPC can be reduced to 2.29 $/kg

Economic Assumptions:
- Plant capacity is set to 1000 MW$_{LHV}$ input of H_2
- Electrolyzer capital cost are 850 $/kW[2]
- Electricity feedstock price of renewable offshore wind power is assumed to be 186 $/MWh[3]
- Full load fraction of the fluctuating renewable power supply is reported to 47 %[4]
- CO_2 cost are 50 $/t[5], O2 earnings 74 $/t[6]
- Flue gas cost (Carbon Capture Case) is assumed to be available free of charge

	Reference Case	Carbon Capture Case	Steam Cycle Case	Oxyfuel Case
Internal FT excess heat usage	26.1 %	100 %	65.3 %	48.7 %
Carbon conversion	73.0 %	73.0 %	75.7 %	96 %
Power-to-synfuel efficiency	44.6 %	44.6 %	45.0 %	41.8 %
Total capital investment	8,685 M$	8,888 M$	8,601 M$	8,686 M$
Total operation cost	2,805 M$/a	2,777 MM$/a	2,810 M$/a	2,811 M$/a
Net production cost	6.83 $/kg	6.80 $/kg	6.83 $/kg	6.84 $/kg

Conclusion

- The process must run under a high full-load fraction (>70 %) in order to reduce electrolyzer size and storage capacity (due to fluctuating renewable energies)
- Electrolyzer efficiency must be improved in order to reduce electricity demand
- Reduction of electrolyzer capital costs and electricity price decreases net production by 9 % per 10 % cost reduction
- On-site conversion of Fischer-Tropsch excess steam into power has a negligible effect on the economics, but reduces the dependency on steam consuming industries
- The direct thermal use of excess heat in a CO_2 absorption plant can reduce energy demand for CO_2 separation
- On-site O_2 consumption by oxy-fuel combustion is marginal, but allows an almost full CO_2 conversion

Outlook

- Investigation of the technical and economic potential of high temperature steam electrolysis and co-electrolysis of steam and CO_2
- Evaluation of various alternative liquid fuel technologies regarding technical feasibility and costs
- Assessment of introduction cost of new technology in a highly fossil-fuel-based economy (e.g., sunk costs, lock-in effects)

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[1] J. Thiessen, C. Kern and A. Jess, private communication, Chair of Chemical Engineering, University of Bayreuth, Germany.
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[3] International Energy Agency, "Technology Roadmap Wind energy," International Energy Agency, Paris, 2013.
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