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School of Engineering

Energy Storage team
Approach to Power to X

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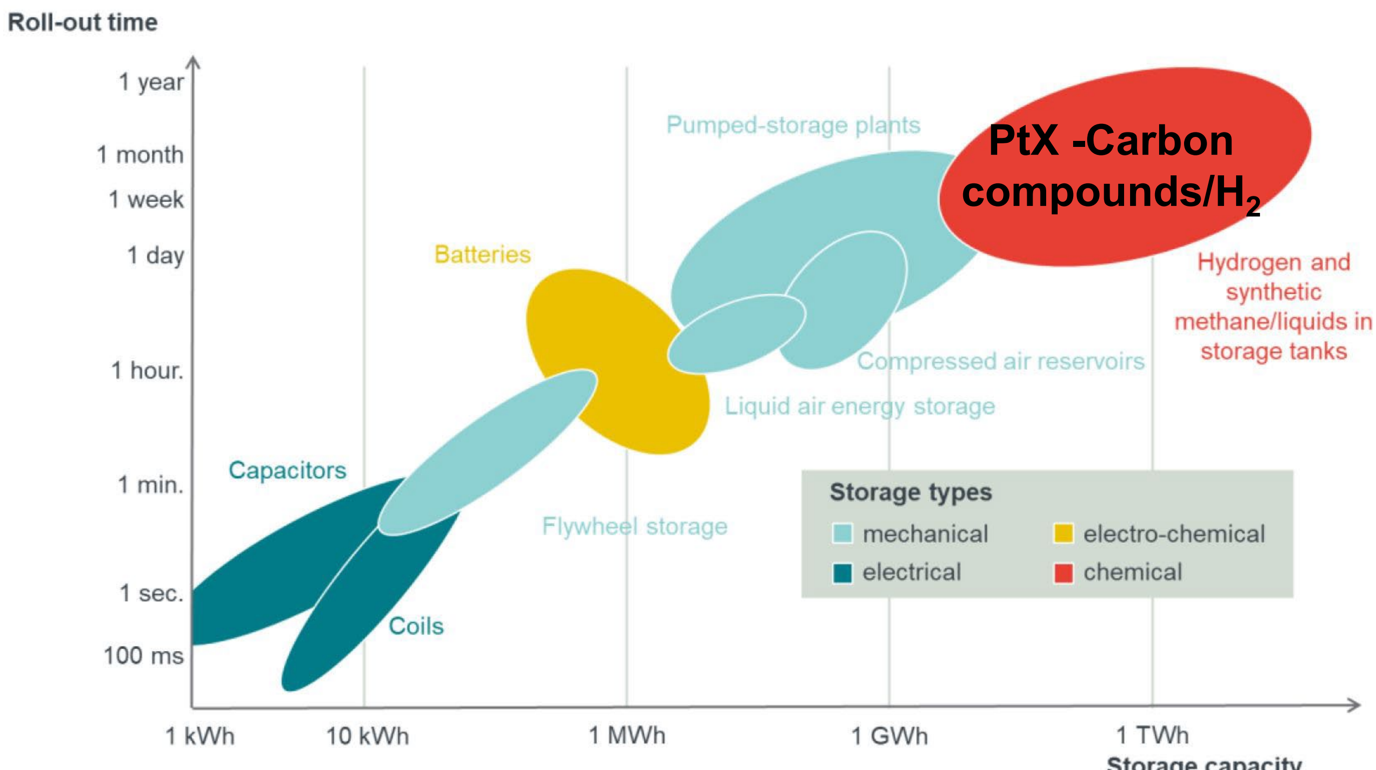
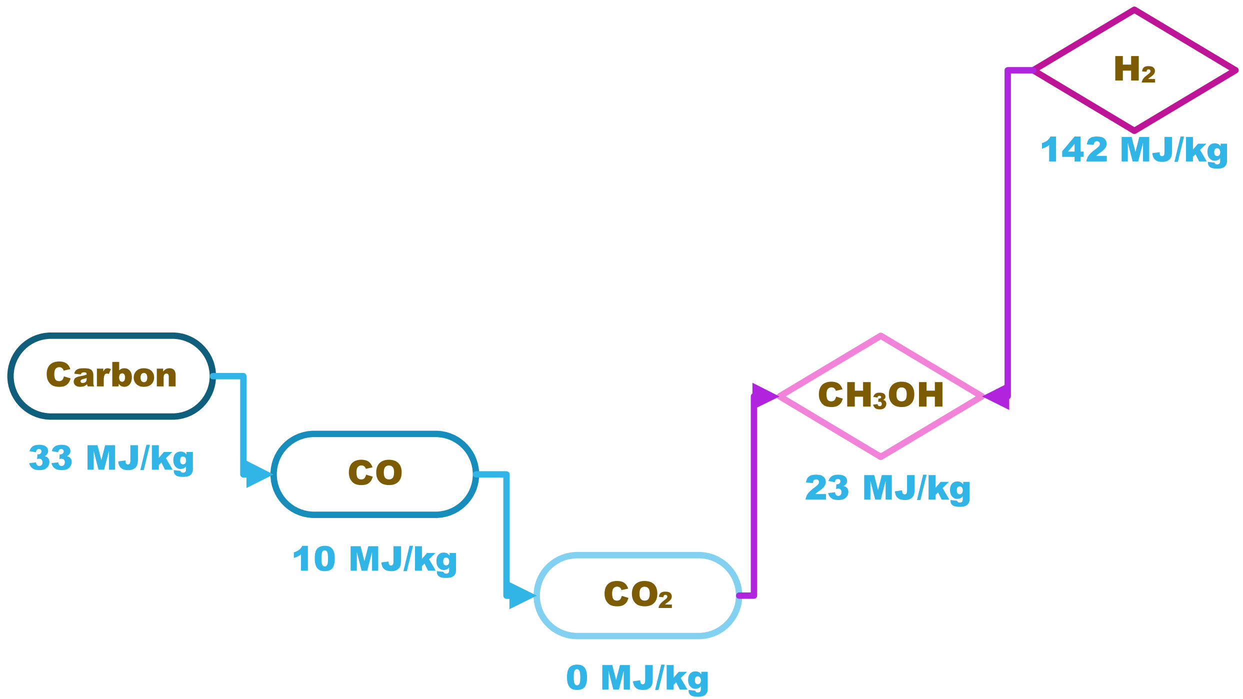
Power to X
Why hydrogen?

Power to X – where do we need that?



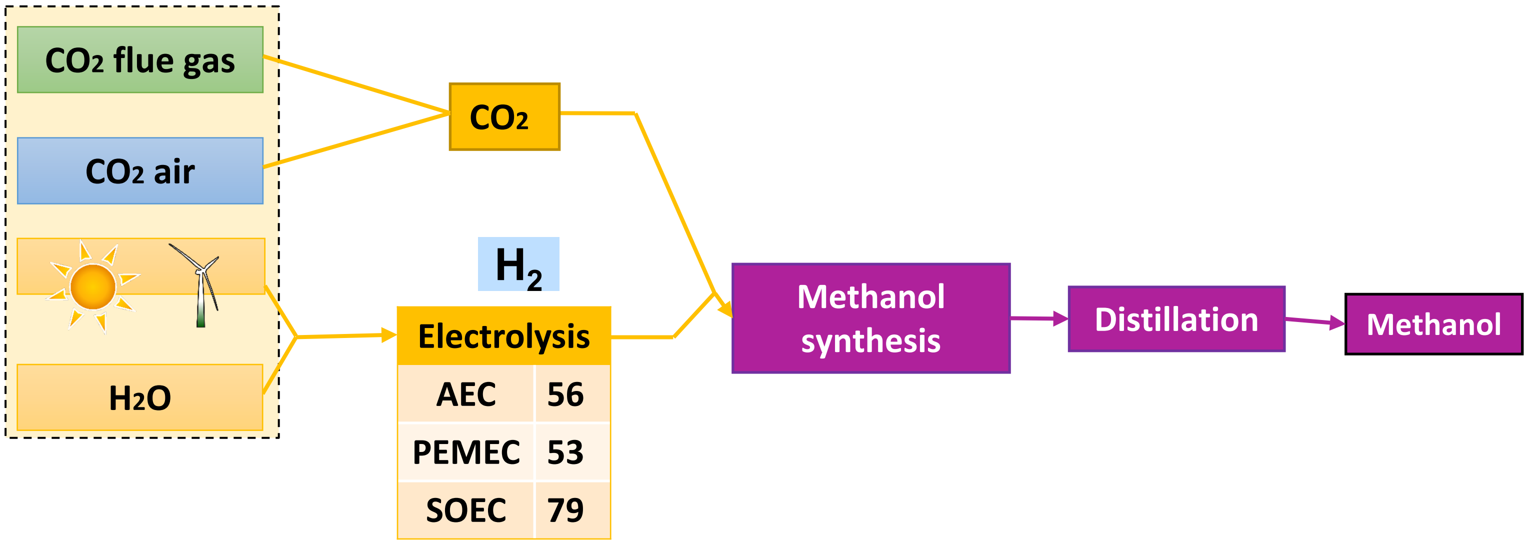
The World Energy Council Germany:
INTERNATIONAL ASPECTS OF A POWER-TO-X ROADMAP (2019)
https://www.weltenergierat.de/ptxstudie/

CO_2 has no energy content

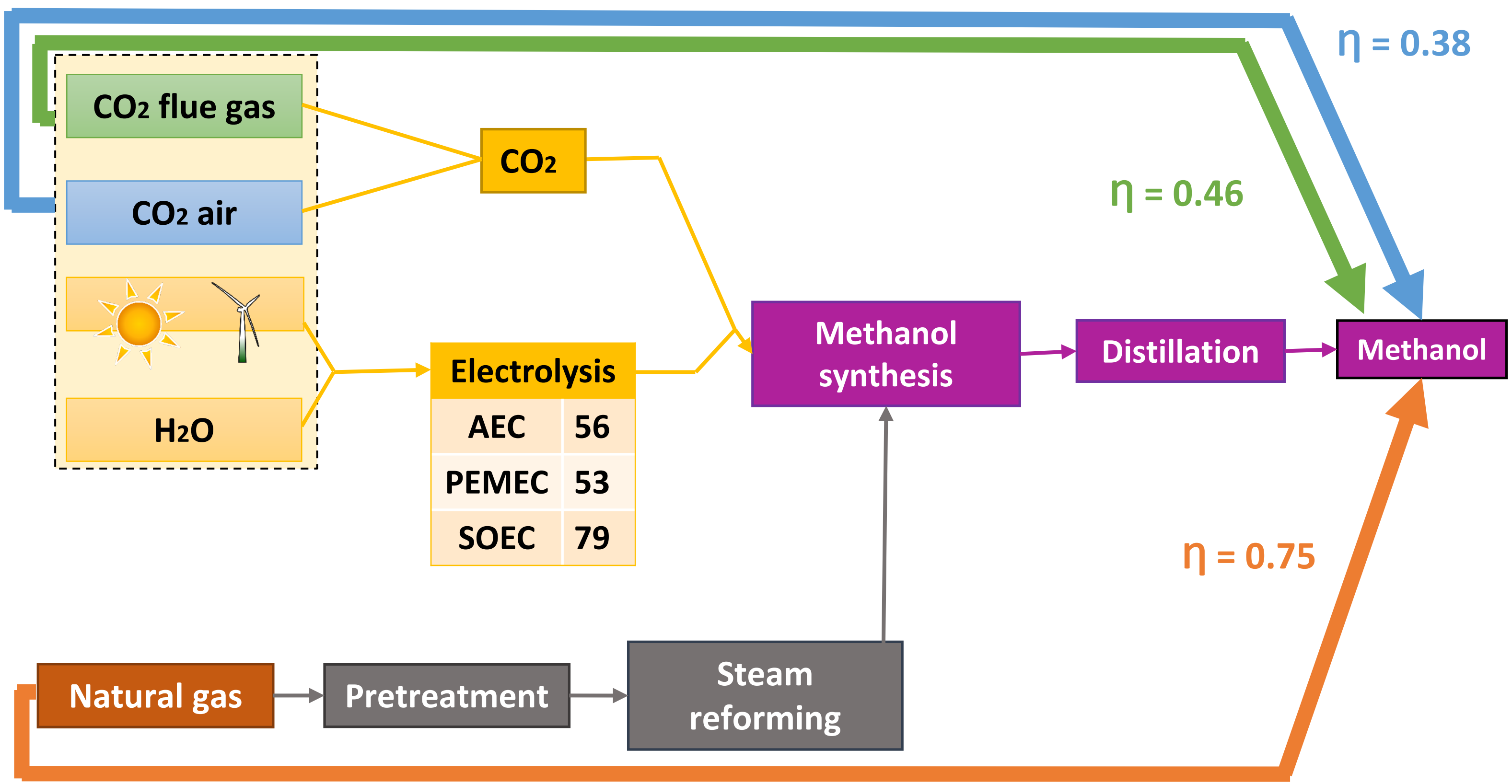


Higher heating value

Power to X (Methanol)



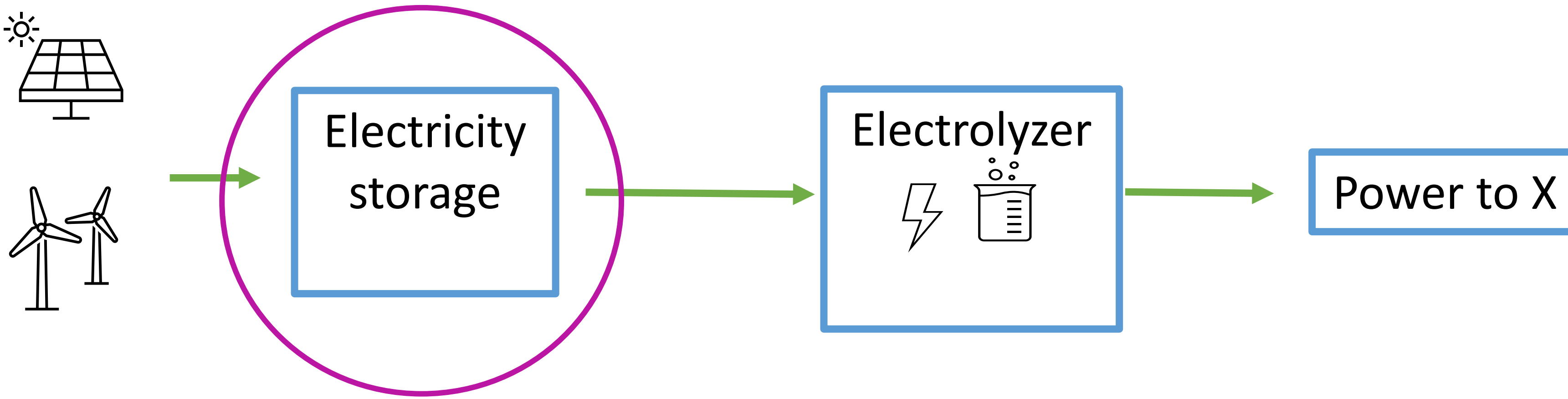
Electrolysis efficiency references:
Buttler, A. & Spliethoff, H.: Current status of water electrolysis for energy storage, grid balancing and sector coupling via power-to-gas and power-to-liquids: A review , Renewable and Sustainable Energy Reviews 82 (2018) 2440-2545.



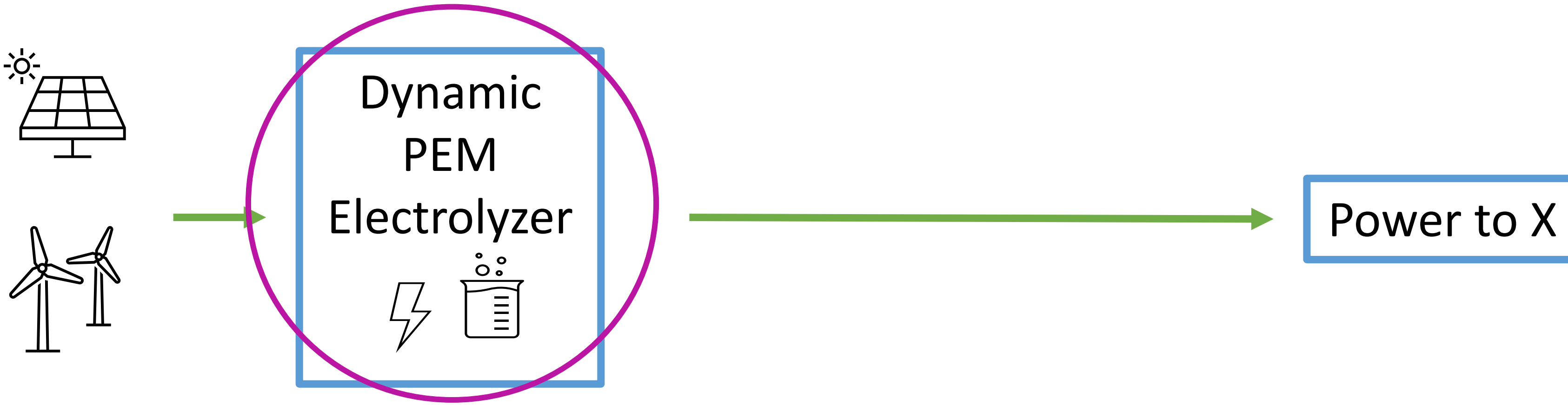
Process efficiency:
P. Galindo Cifre and O. Badr, Renewable hydrogen utilisation for the production of methanol, Energy Conversion and Management, 48 (2007) 519-527.

Power to X Flexibility

Intermittency of Renewable Energy

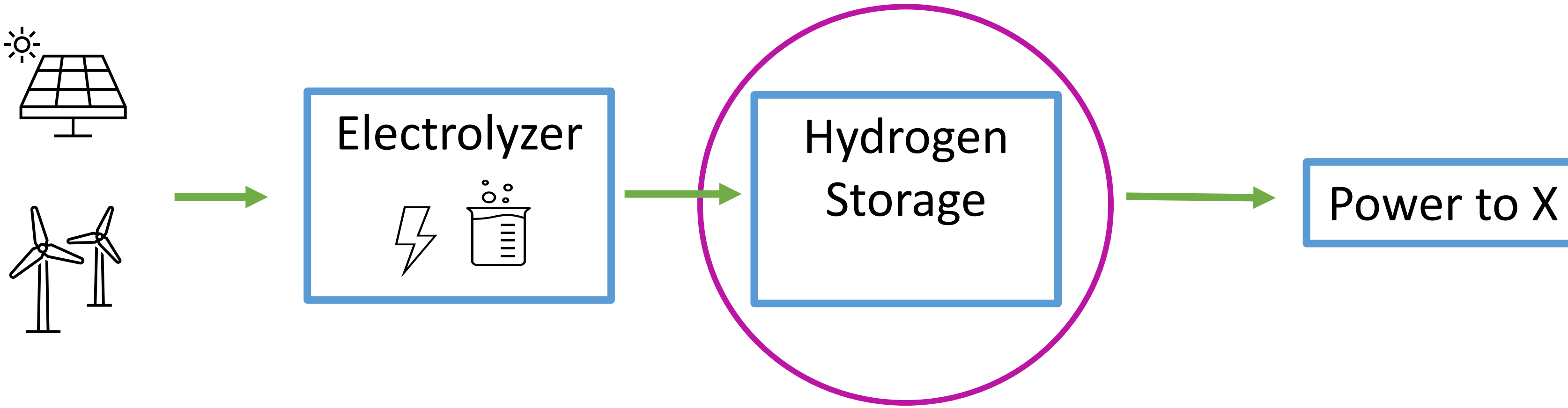


Intermittency of Renewable Energy



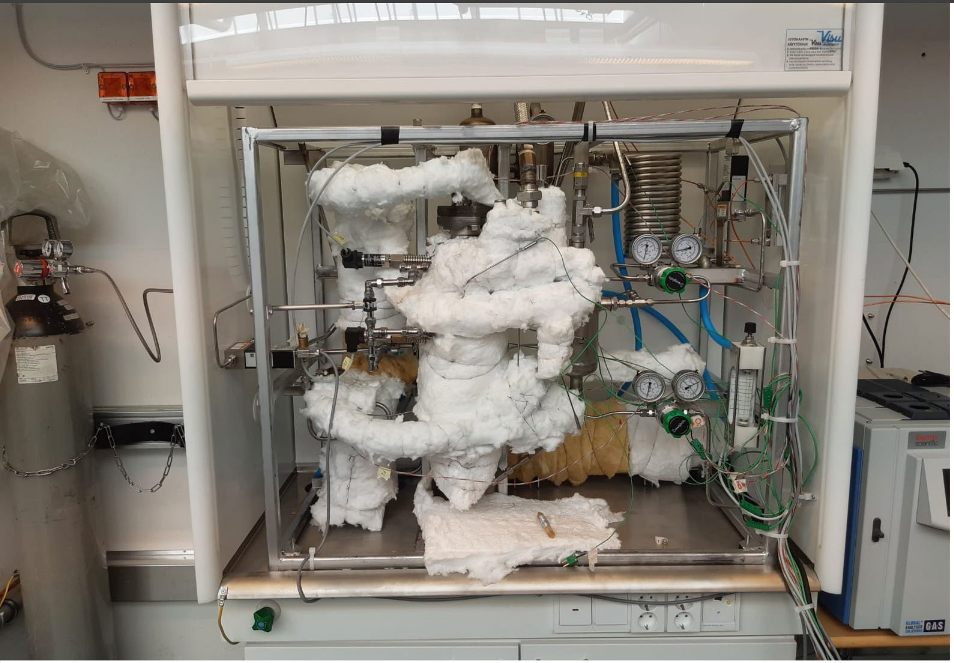
Check our new paper: *H. Sayed Ahmed, A. Toldy, A. Santasalo-Aarnio,*
Dynamic operation of proton exchange membrane electrolyzers —Critical review
Renewable and Sustainable Energy Reviews 189 (2024) 113883
https://doi.org/10.1016/j.rser.2023.113883

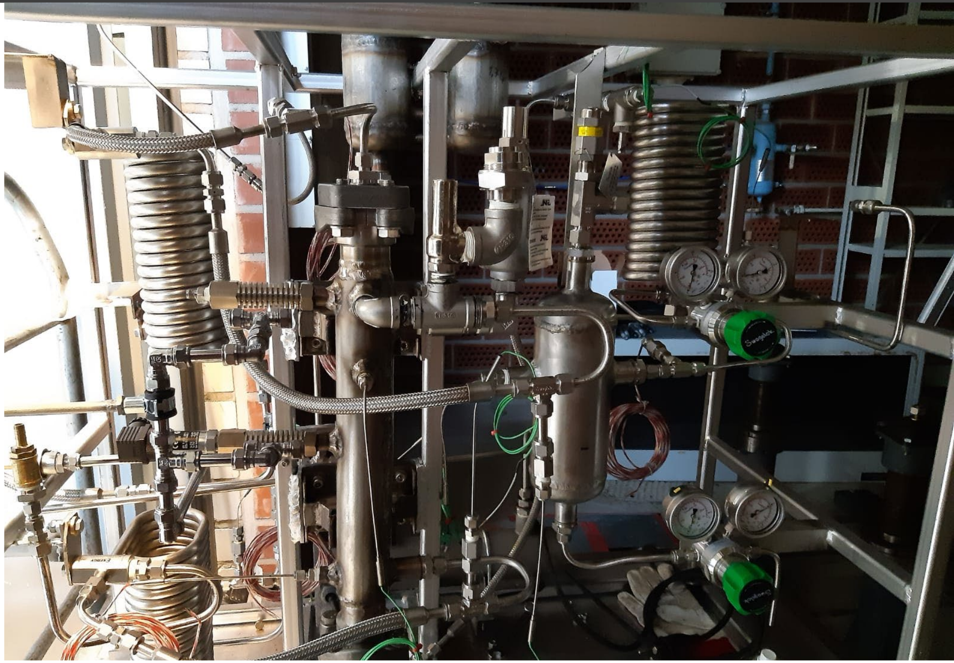
Intermittency of Renewable Energy



Nessling Foundation Funding (2024-2026):
Simo Pekkinen: Storing of green hydrogen as an enabler for hydrogen economy – practical challenges and scaling

Power to Methanol Activities





The experimental reactor for methanol synthesis from CO_2

Our experimental reactor setup

Methanol synthesis from CO_2 and H_2

$CO_2 + 3xH_2 \leftrightarrow CH_3OH + H_2O$

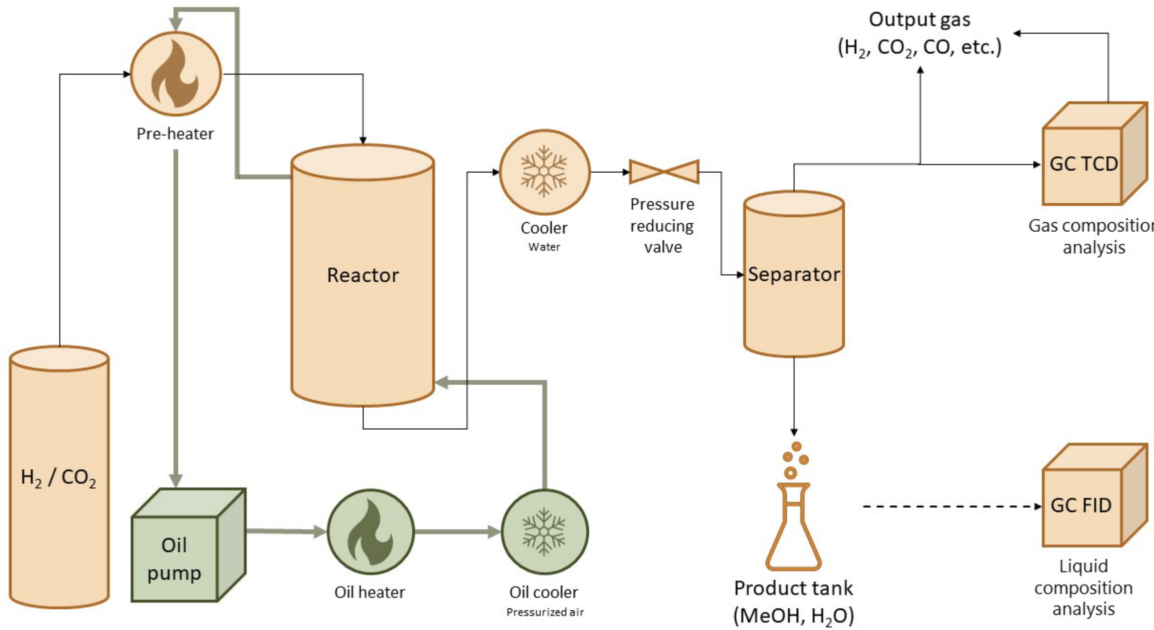
Process conditions

T: 200 – 250 °C

p: 30 – 50 bar

Catalysts used

CuO, ZnO, Al_2O_3, MgO



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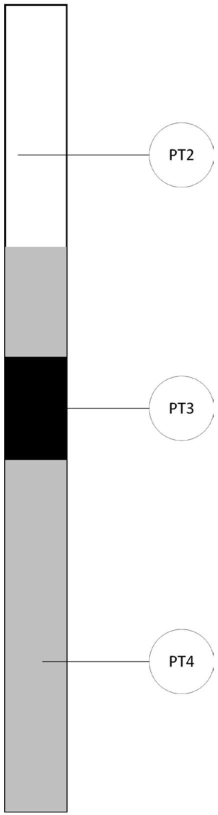
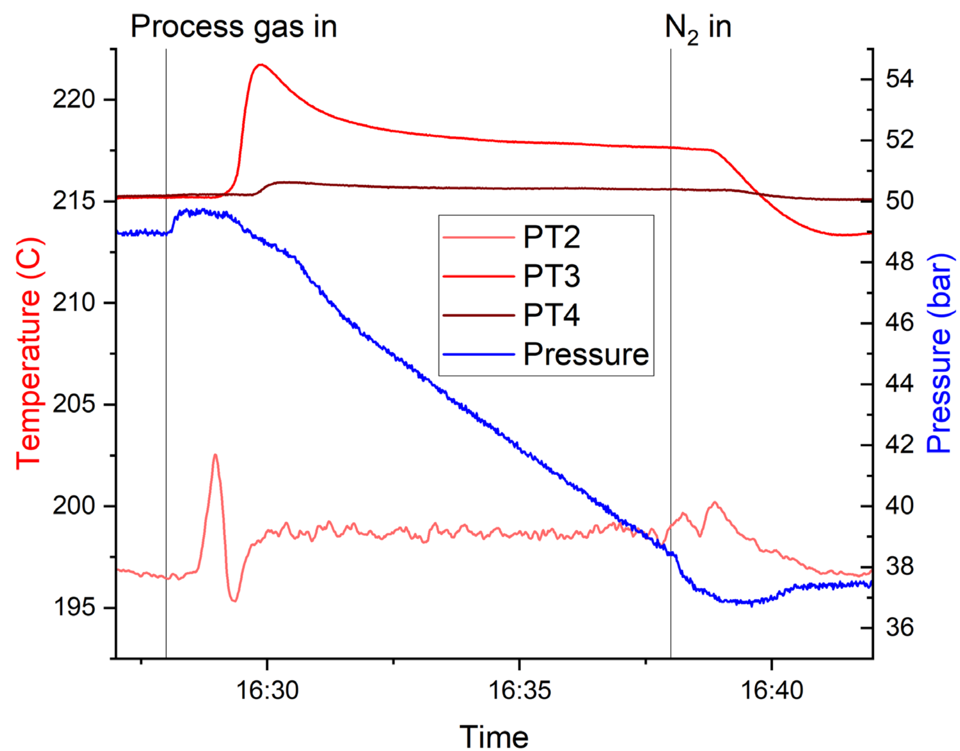
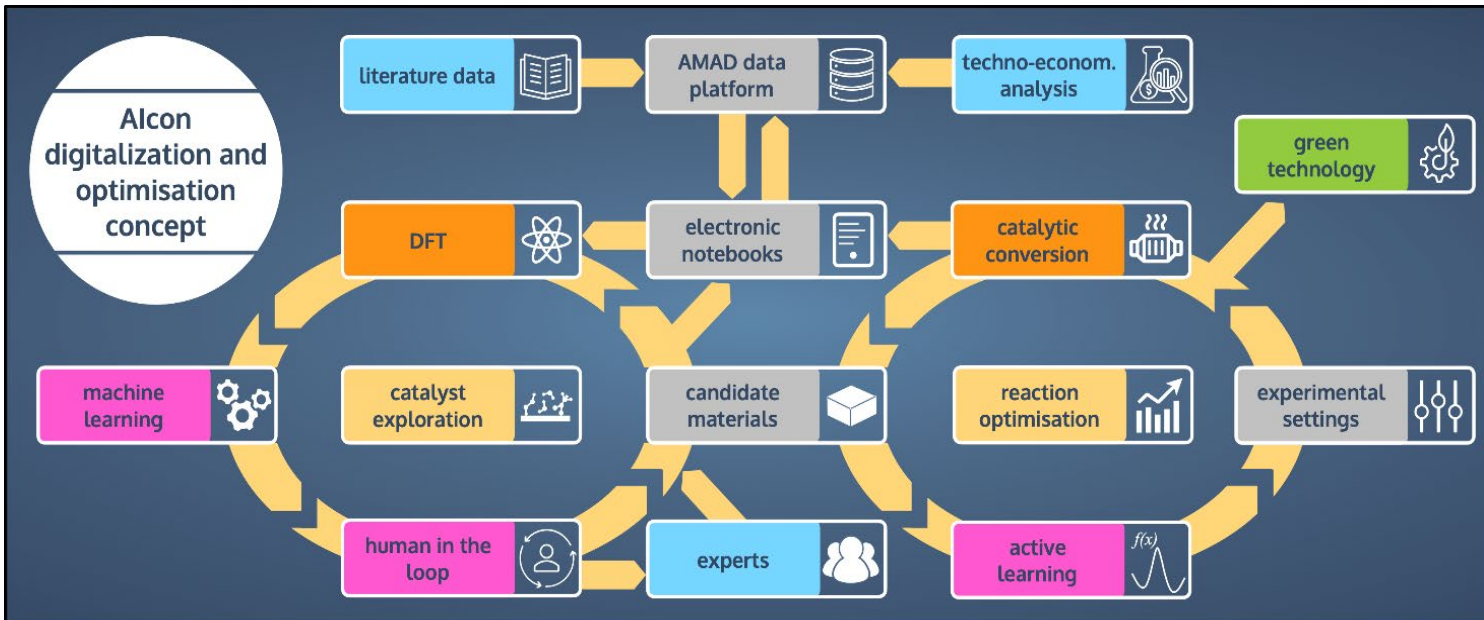
Heat transfer along reactor length



- Pulses of process gas to the reactor in a steady N_2 flow
- Figure on the right from a 10 minute injection
- Temperature increases much more in the catalyst layer than in the bottom of reactor bed
  - Radial temperature distribution in the catalyst layer is unknown

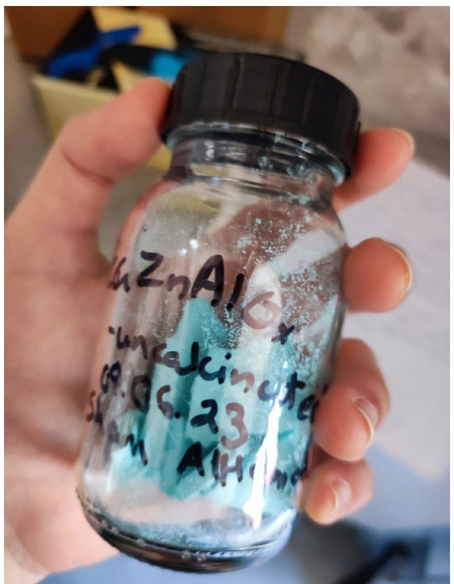


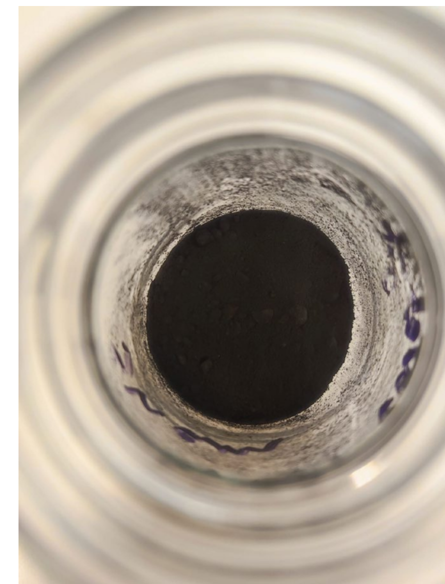
Digitalization to speed up Technology Development



Research council of Finland: AIcon project

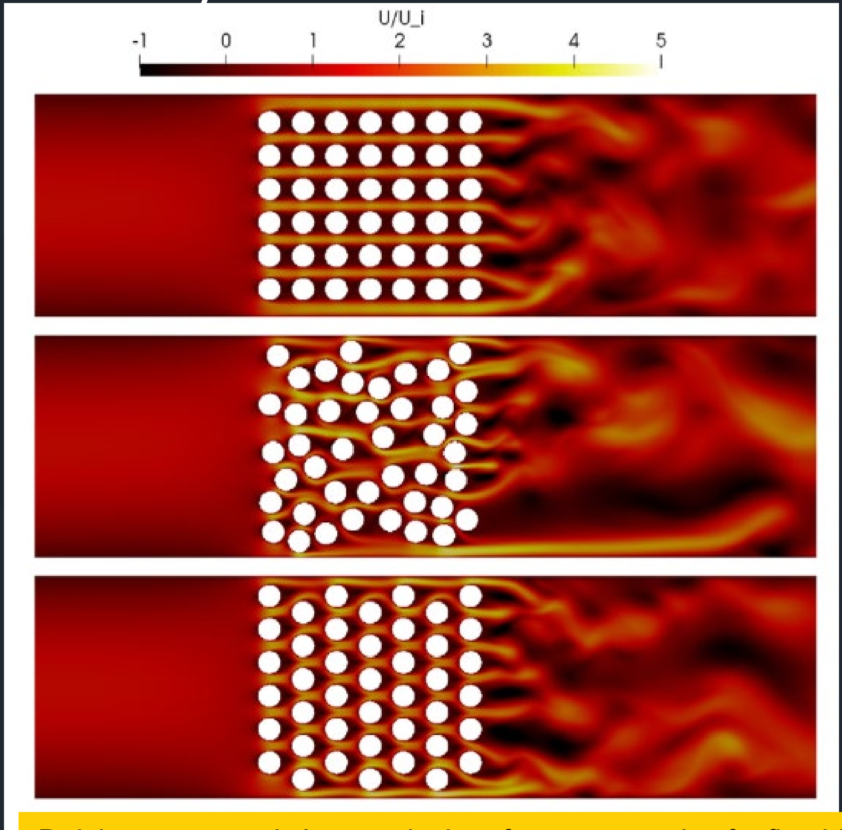
New catalyst materials
AI aided search

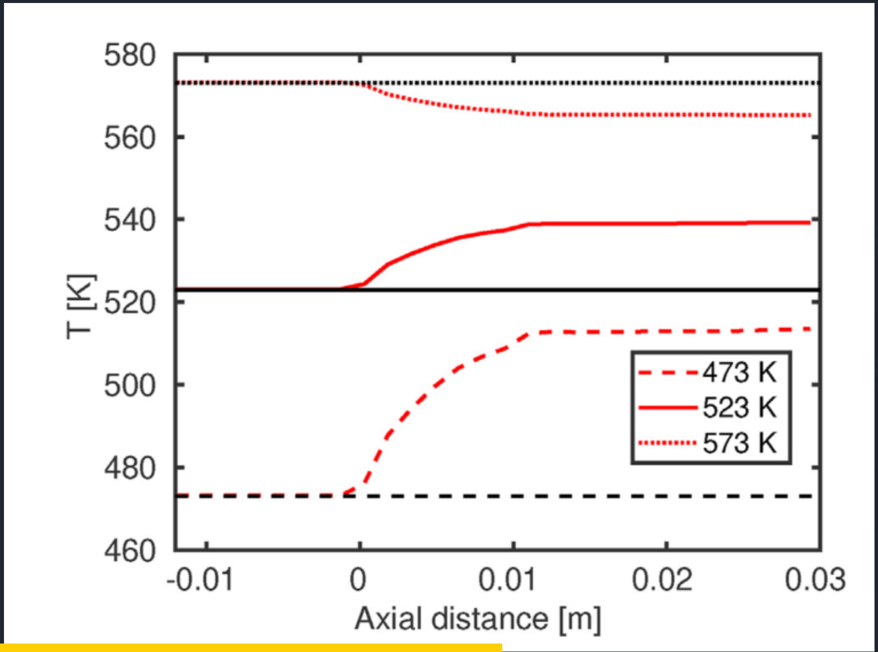




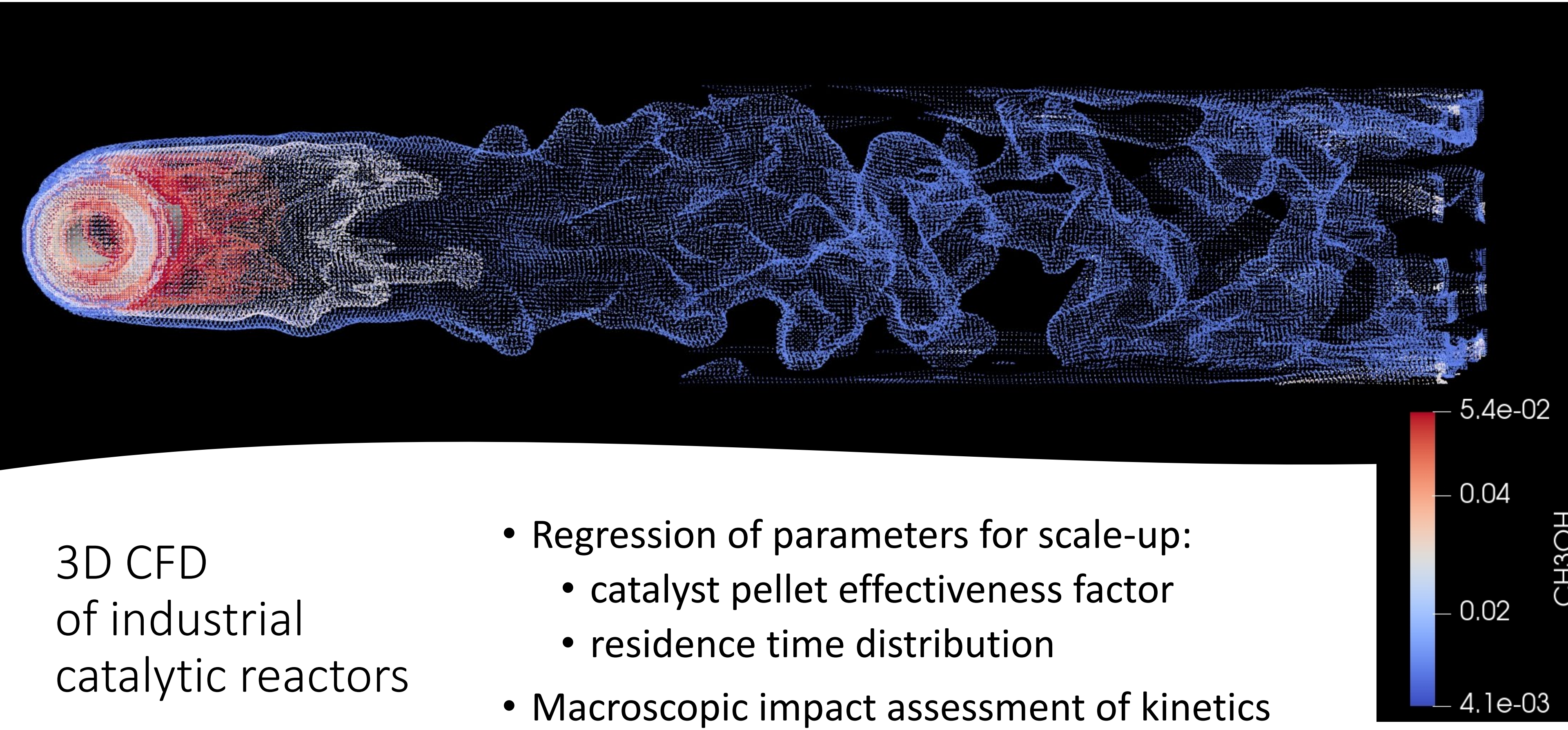
CFD of industrial catalytic reactors

- Process scale up:
  - Heating/cooling strategy
  - Axial & radial dispersion of heat & species
  - Recirculation & bypass ratios





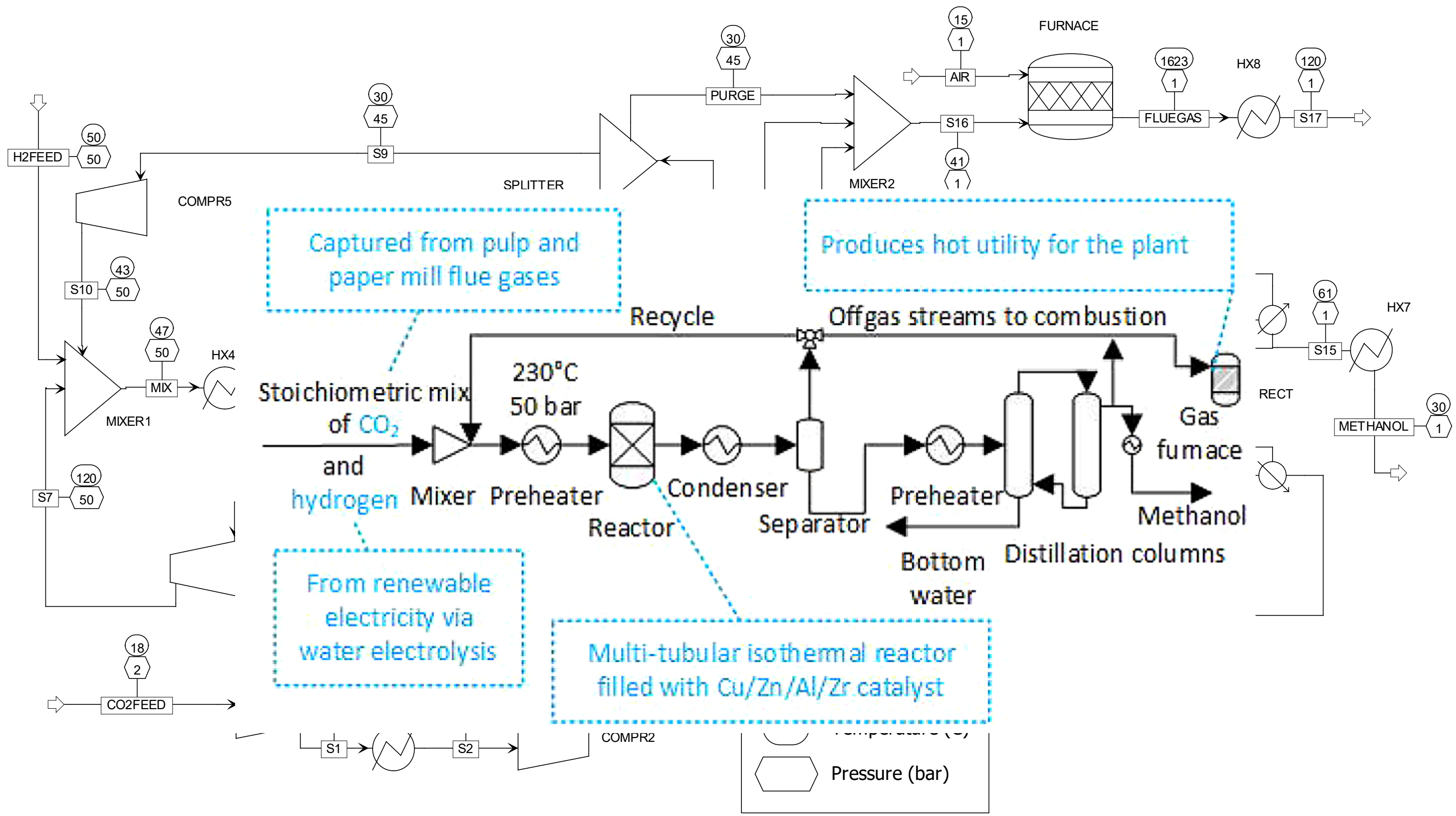
D. Izbassarov et al. A numerical performance study of a fixed-bed reactor for methanol synthesis by CO_2 hydrogenation. International Journal of Hydrogen Energy, 46 (2021) 15635.
https://doi.org/10.1016/j.ijhydene.2021.02.031



3D CFD
of industrial
catalytic reactors

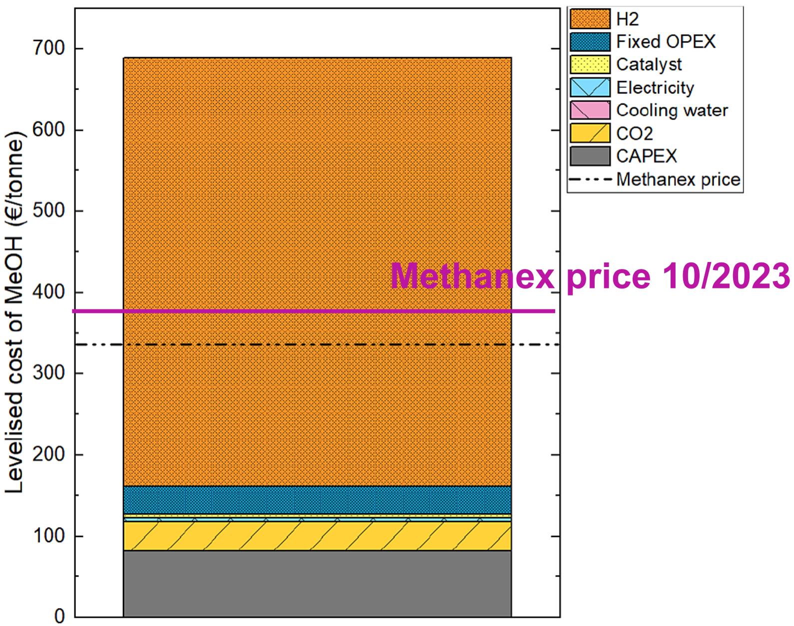
- Regression of parameters for scale-up:
  - catalyst pellet effectiveness factor
  - residence time distribution
- Macroscopic impact assessment of kinetics & flow conditions

Process model of synthetic methanol plant

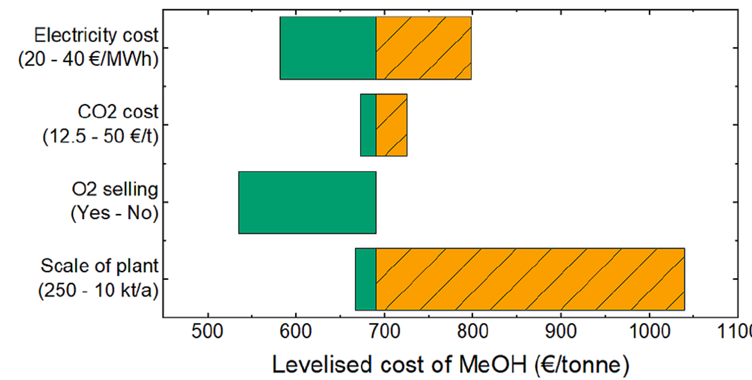


Nyári, J., Magdeldin, M., Larmi, M., Järvinen, M., Santasalo-Aarnio, A. 2019 Techno-economic barriers of an industrial-scale methanol CCU-plant, Journal of CO_2 Utilization, DOI: 10.1016/j.jcou.2020.101166

Cost component distribution of levelized cost and sensitivity



	Value	Unit
CO_2 usage	1.41	kg/kg methanol
H_2 usage	0.194	kg/kg methanol
Overall CO_2 conversion	97.09	%
Overall H_2 conversion	100	%
Methanol purity	99.9	wt%
Hot utility	0	kWh/kg methanol
Cooling utility	1.51	kWh/kg methanol
Electricity usage	0.16	kWh/kg methanol
CO_2 emission	0.041	kg/kg methanol
Energy efficiency	83.51	%



Annual output of MeOH plant [kta]	Cost of electricity [€/MWh]	$LCoH_2$ [€/t]
50	20	2190
50	30	2740
50	40	3290
10	30	3120
250	30	2650

Santasalo-Aarnio, A., Nyari, J., Wojcieszyk, M., Kaario, O., Kroyan, Y., Magdeldin, M., Larmi, M., and Järvinen, M., "Application of Synthetic Renewable Methanol to Power the Future Propulsion," *SAE Technical Paper Series*, 2020, doi:10.4271/2020-01-2151

RoPax passengers’ acceptance and awareness of climate mitigation tools in the sector

28 questions

- Demographics
- Ideal fuel characteristics
- Knowledge & impression of fuels
- Willingness to pay for low-carbon fuels

1914 responses

- 66% male
- 75% above the age of 55
- 44% higher education
- 2500-4000€ median income
- 4 main countries

Travelling habits

- 30% travel more than 3 times/year
- Price most important factor
- 35% spend more than 200€/trip

Climate concerns

- Most passengers are worried about environmental issues
- Environmental friendliness most important fuel characteristic

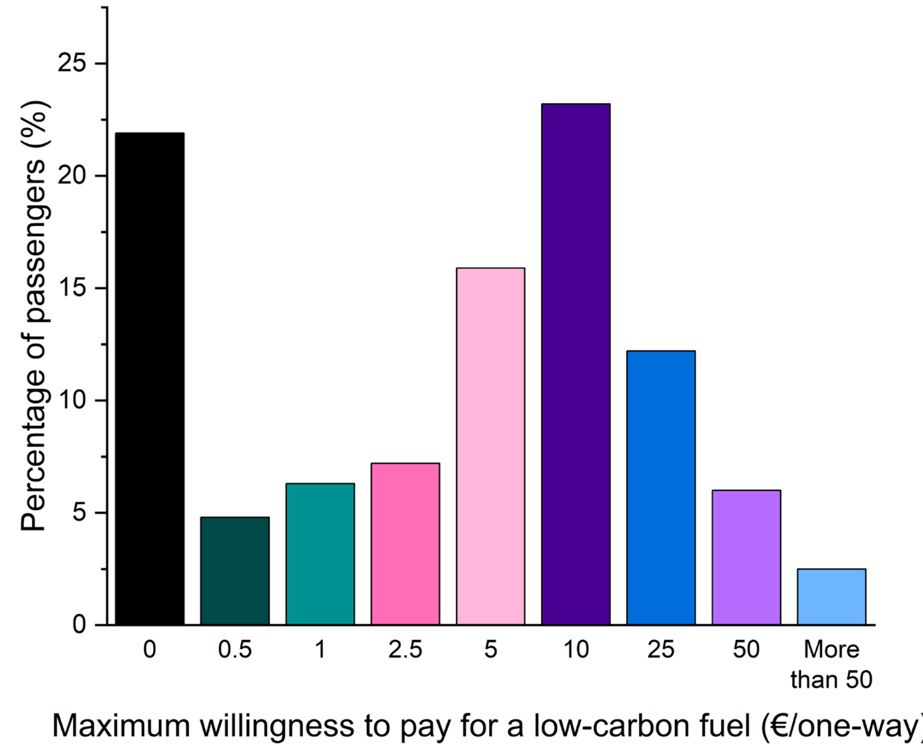
50% support LC fuels

- Electricity and hydrogen most popular fuels
- Most favoured production methods waste and renewable electricity-based

LC = low-carbon

Half of the passengers are willing to pay at least 5€ extra

- 80% of passengers are willing to pay more for their tickets
- Overall average is 11.3€, while the median of payers is 10€
- Non-payers reason that the surcharge will not have any real impact
- Many would leave the decision to the law of supply-demand with a built-in price



Nyári et al. *Awareness increases acceptance and willingness to pay for low-carbon fuels amongst marine passengers*
Energy Research & Social Science, (Review process completed waiting for editor decision)

Let’s innovate together

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