Impact of membrane material properties on the performance of a combined pervaporation and distillation process for biobutanol concentration

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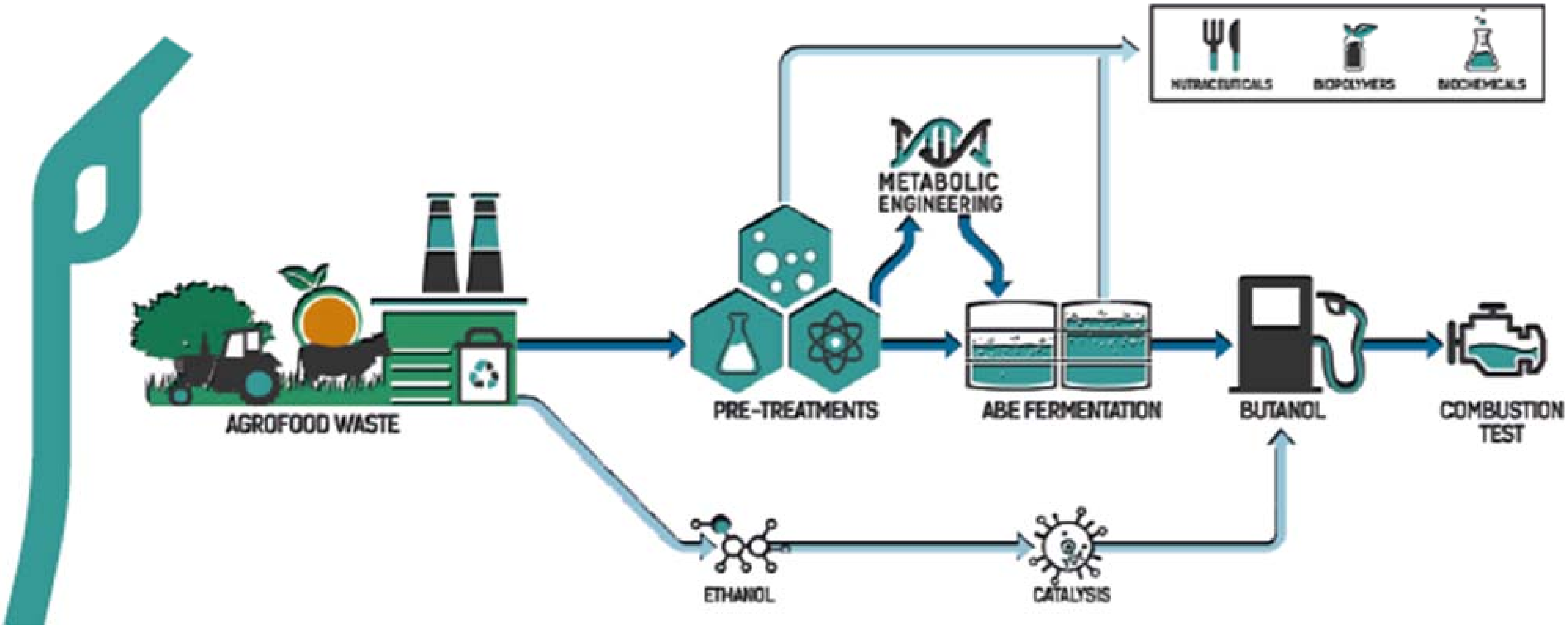
10th World Congress of Chemical Engineering, Barcelona,

1. – 5. October 2017

Project „Waste2Fuels“

- Production routes for **next generation biofuels**
- Possible biomass feedstock basis, like **unavoidable agrofood waste streams (AFW)**
- Conversion to **bio-butanol**
- Contribute to **decentralized energy production**

Project „Waste2Fuels“



www.waste2fuels.eu

Biofuels – Why Butanol?

- High specific energy of 35 MJ/kg
- Blends well with conventional fuel
- Low corrosivity
- Low water absorption and volatility

But…

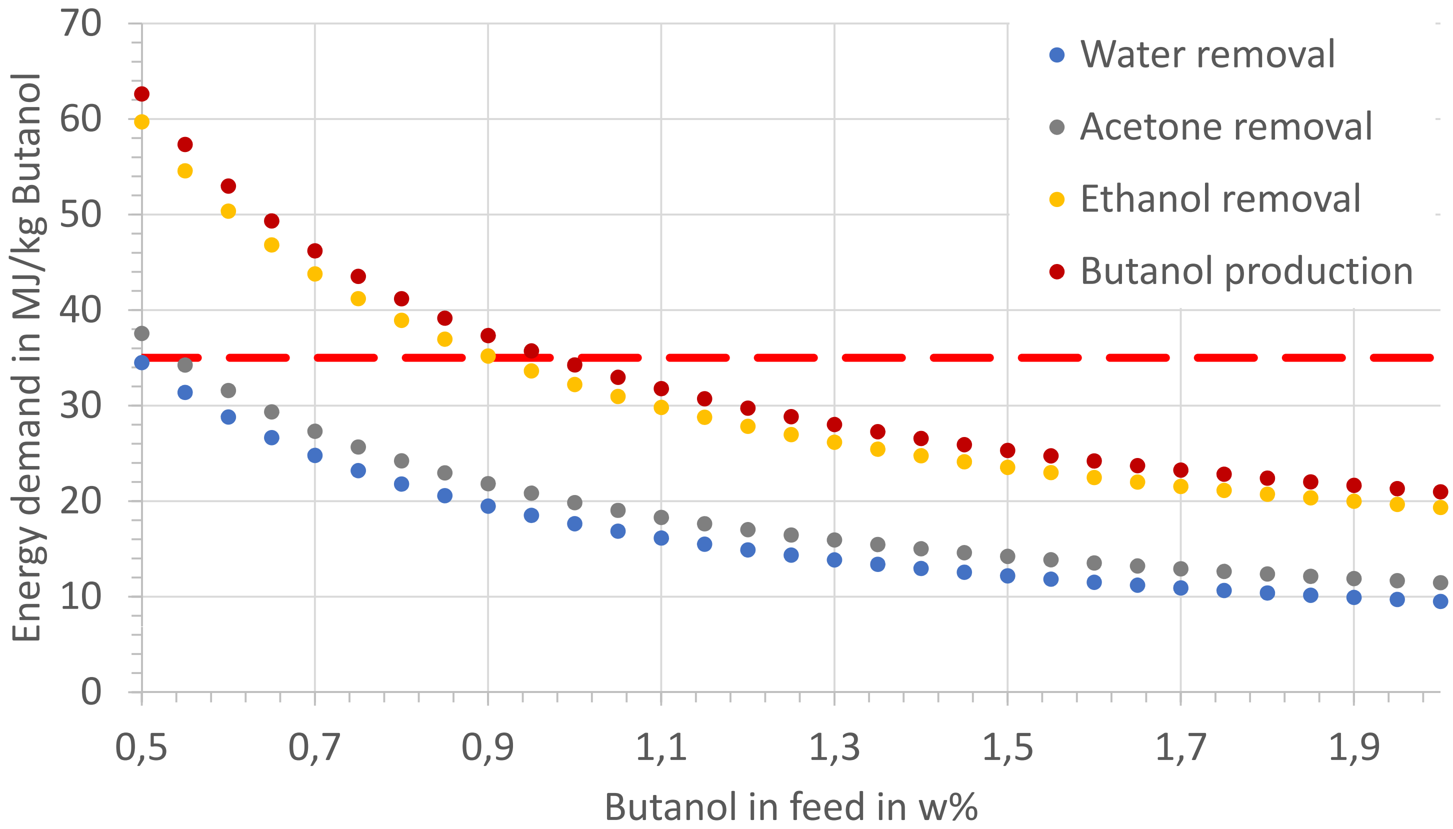
- Low productivity due to product inhibition

Butanol from ABE – the basics

- Fermenation of biomass to acetone, butanol and ethanol (ABE)
  - Maximum 1.5 w% Butanol due to self-inhibition
  - Ratio A:B:E = 3:6:1

- Separation by distillation
  - 4-step process with final concentration of more than 99 w% butanol
  - Well researched process

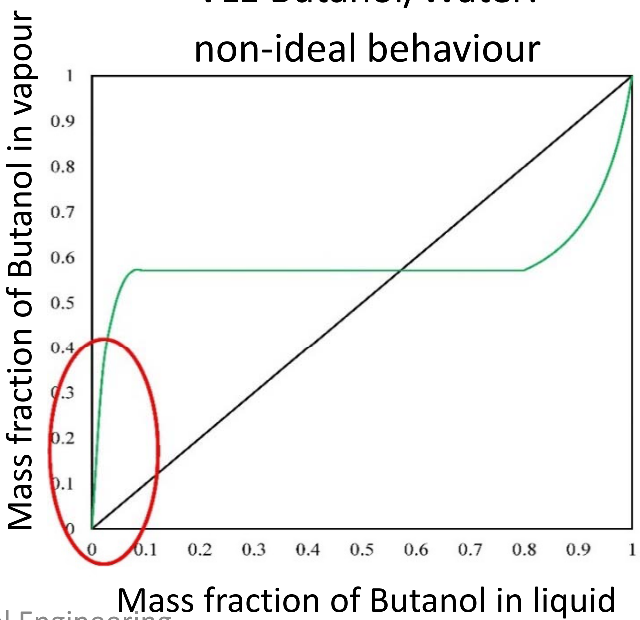
Distillation – Energy demand



Pervaporation – an alternative

- Pervaporation = permeation + evaporation
- Membrane based separation process
- Can be used in an in-situ approach
- Non-ideal VLE of Butanol/Water
- Needs additional upgrading step

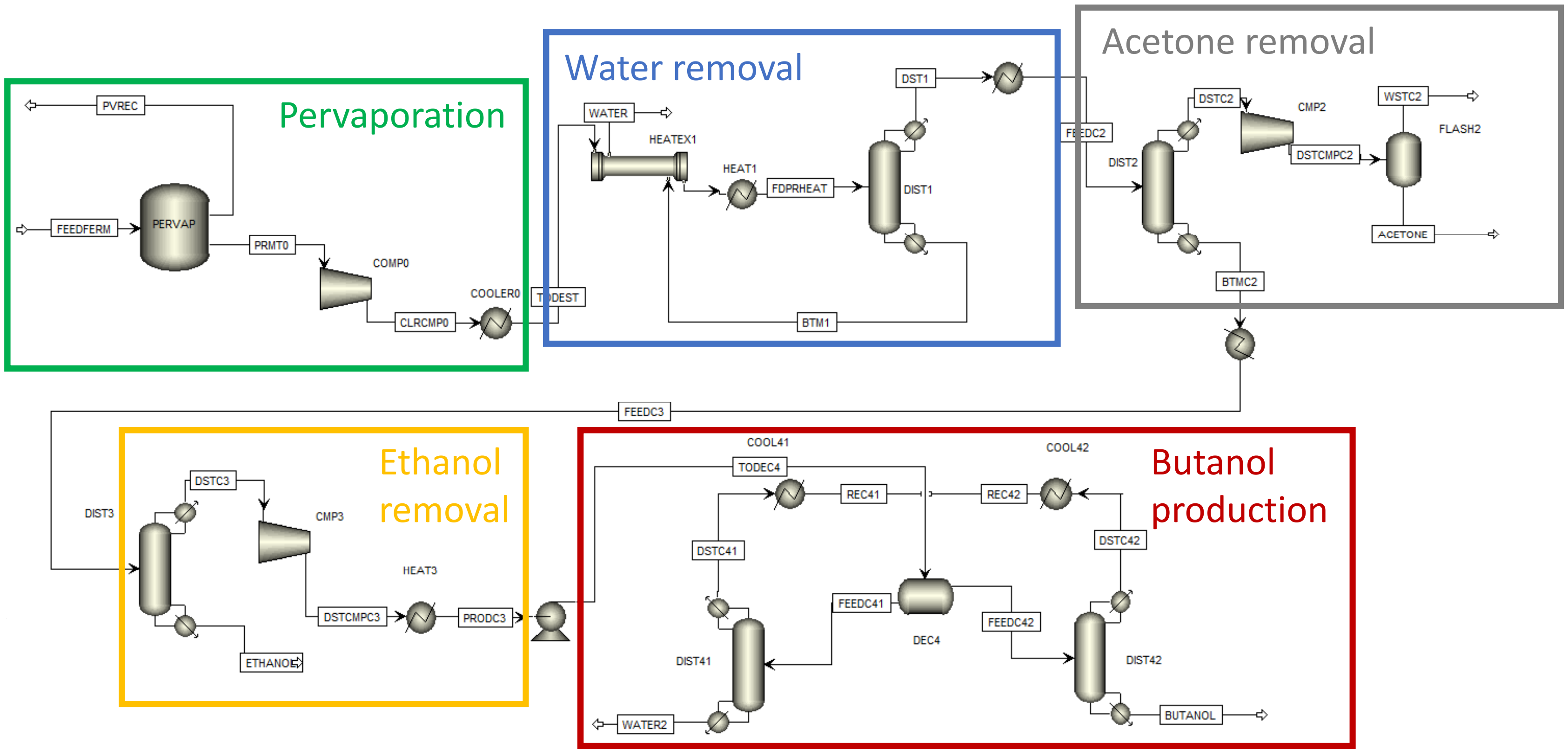
VLE Butanol/Water:
non-ideal behaviour



Disitillation and pervaporation

- Estimation of energy consumption
  - Combination of experiments and simulation (Aspen Plus®)
  - Variation of feed concentration
- Comparison of membrane materials
  - POMS (Polyoctylmethylsiloxane) – experimental
  - PDMS (Polydimethylsiloxane) – commercial
- Variation of membrane properties
  - Influence of selectivities

General set-up

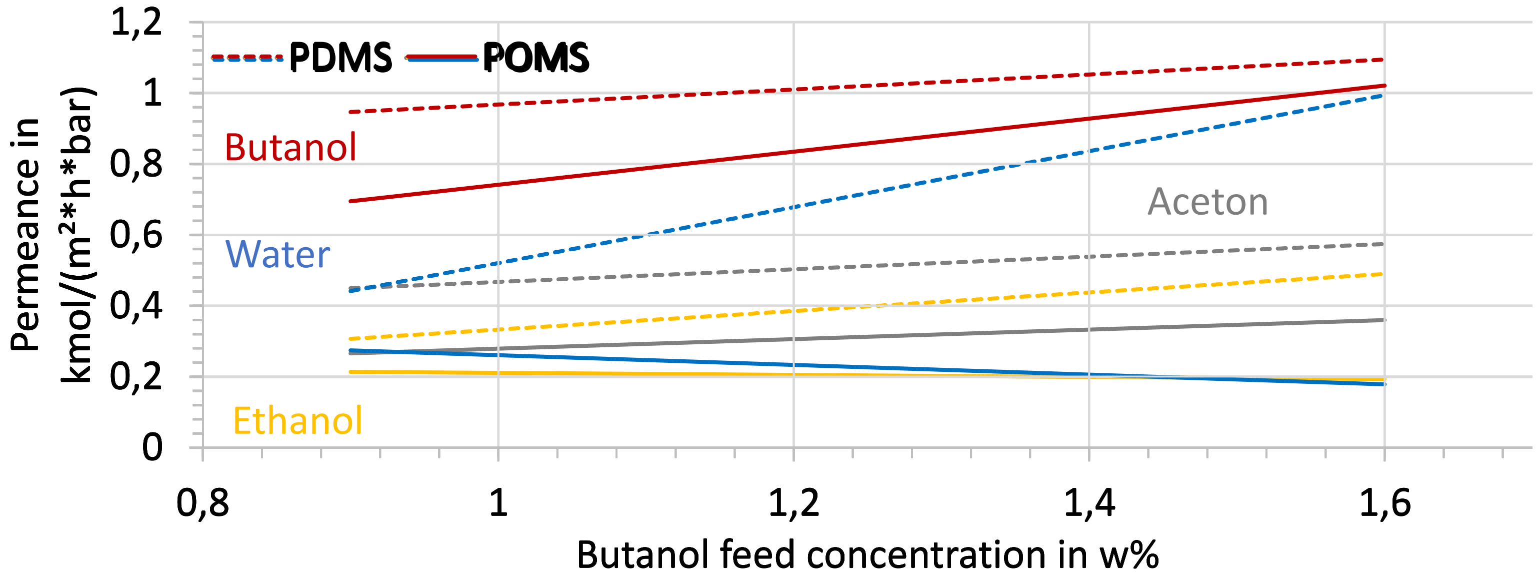


General set-up

- Pervaporation
  - In-house, cross-flow, multicomponent model
  - 1.00, 1.25, 1.50 w% Butanol in Feed, A:B:E =3:6:1
- Distillation
  - Broth column: 45 stages, feed stage=1, 97.5% ABE recovery
  - Acetone column: 30 stages, feed stage=15, 99.5% acetone recovery, 99.5 w% acetone in product stream
  - Ethanol column: 40 stages, feed stage=10, 98% ethanol recovery, 60 w% ethanol in product stream
  - Butanol column: 2 columns, 10 stages, feed stage=1, 99.5% butanol recovery, 99.5 w% butanol in product stream

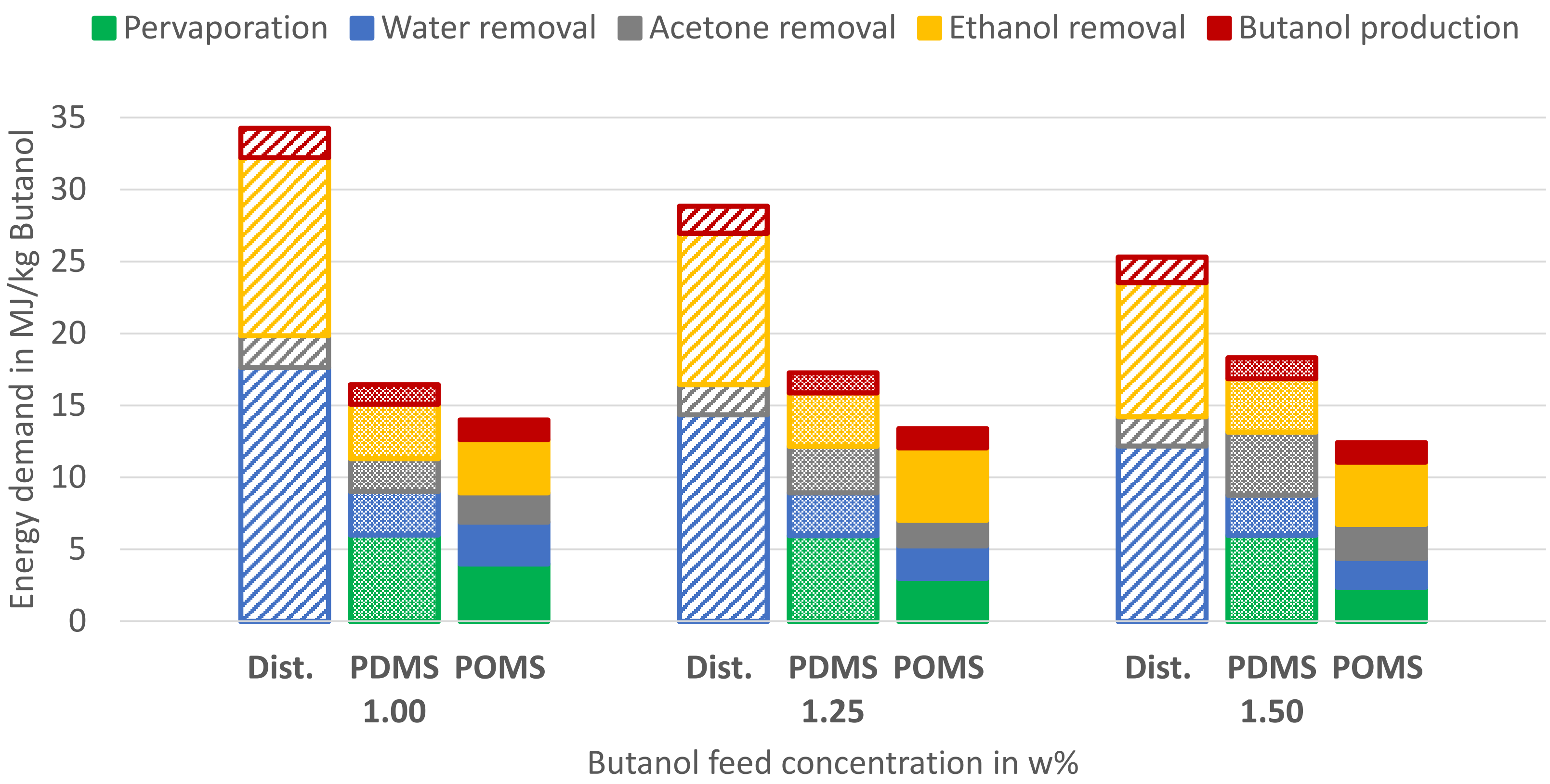
Membrane configuration

- Permeances (concentration dependency)



- T_{Feed}=35 °C, p_{Feed}=1 atm, $p_{Permeat}$=10mbar

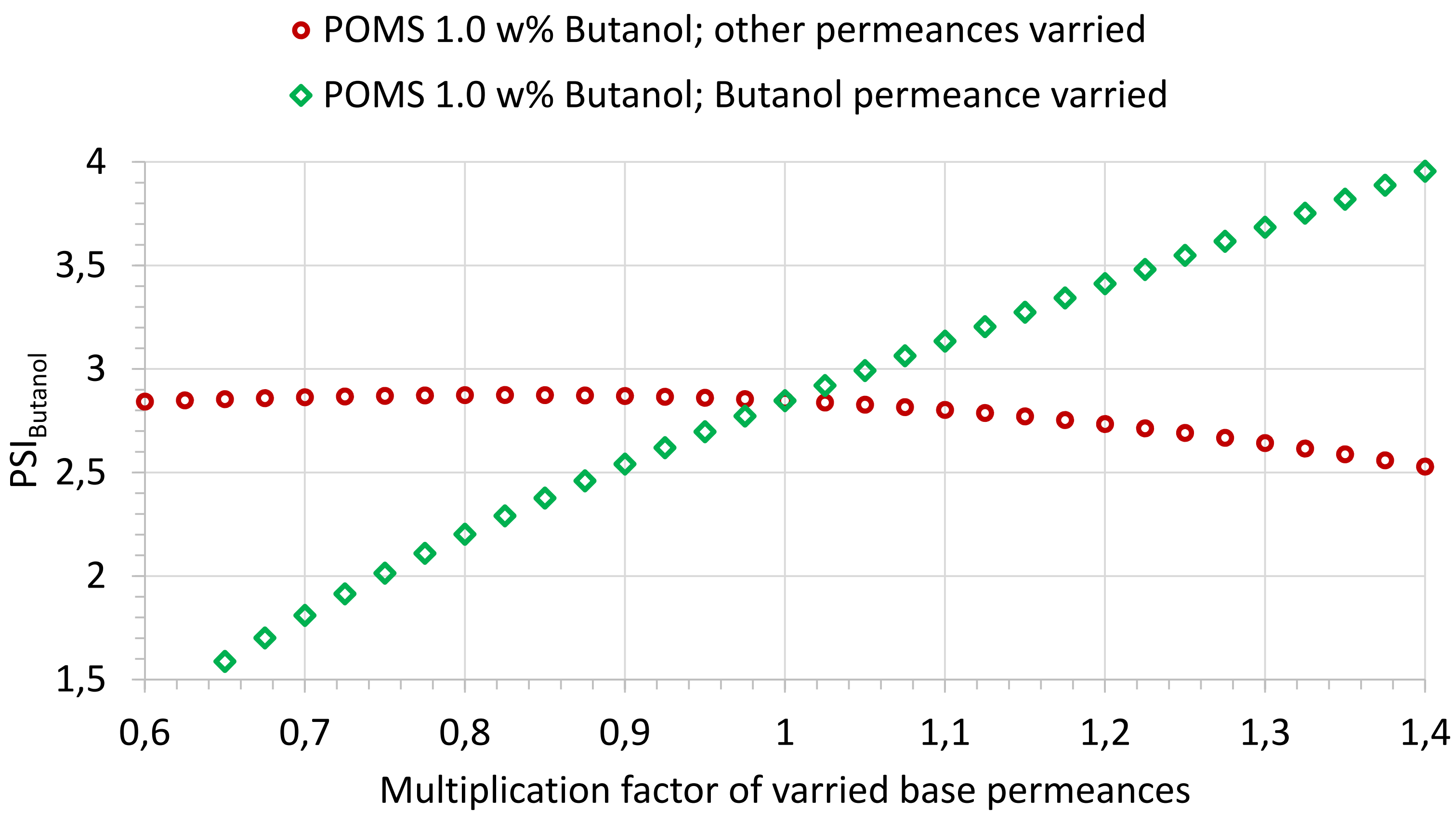
Base case - results



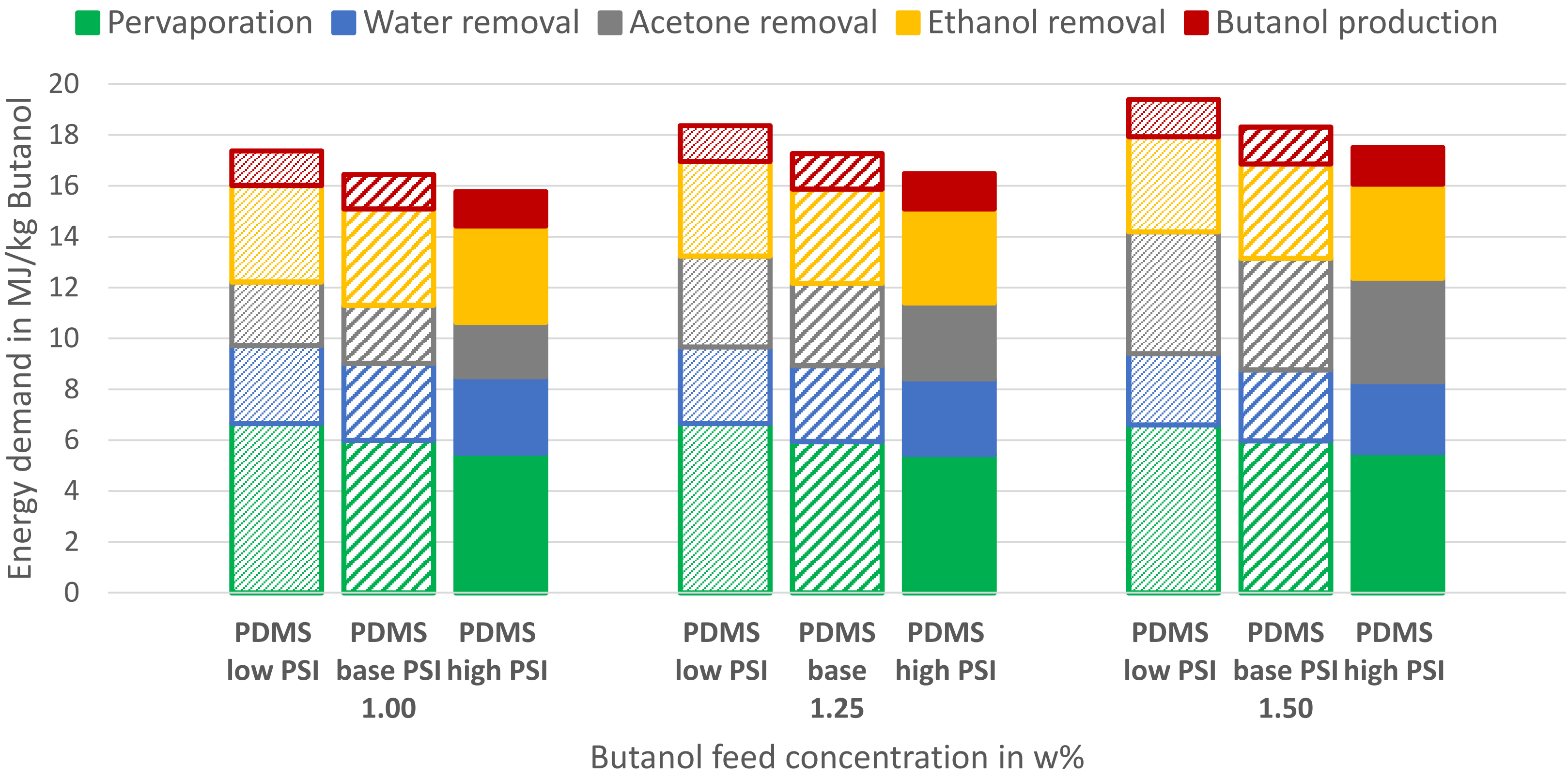
Membrane performance parameters

- Multiple options
  - Selectivities, enrichtment factor, transmembrane flux,…
- Pervaporation separation index (PSI)
  - $PSI_i\left[\frac{kmol}{h\cdot m^2}\right] = J_i\left[\frac{kmol}{h\cdot m^2}\right]\cdot(1-\alpha[-])$
  - $\alpha = \frac{w_i^{Permeate}/(1-w_i^{Permeate})}{w_i^{Feed}/(1-w_i^{Feed})}$
- Variation of permeances to achieve $PSI_{base\ case}$ ±20%

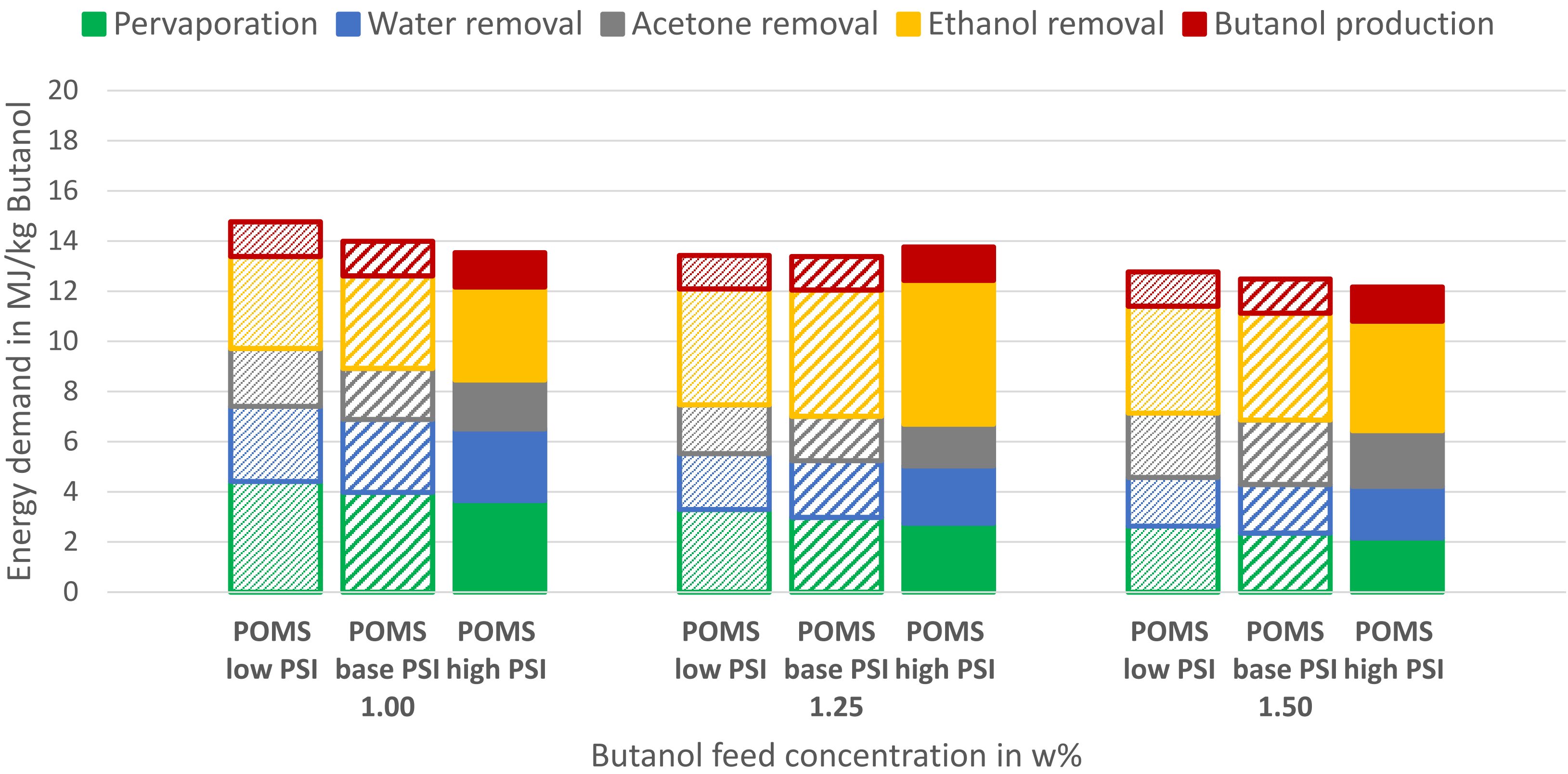
Varying selectivities and effects on PSI



Variation of PSI – PDMS membrane



Variation of PSI – POMS membrane



Conclusion

- Pervaporation offers potential to **reduce energy demand** for butanol recovery **by 50%**
- Main **energy consumption shifts** from water removal to acetone removal due to pervaporation
- Preferable **feed concentration** of butanol depends on used **mebrane material**
- **POMS reduces energy demand** compared to PDMS
- **Increase of PSI by 20%** can lead to additional **10% of energy savings**

What‘s up next

- Effects of the changed composition of the fermentation broth by using an in-situ separation
- Experimental assessment and implementation of additional membrane materials
- Addition of co-components to the simulation
- Economical evaluation of pervaporation/distillation process

Thank you for your attention!

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654623.

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