Hybrid process of distillation and gas permeation for production of dehydrated ethanol

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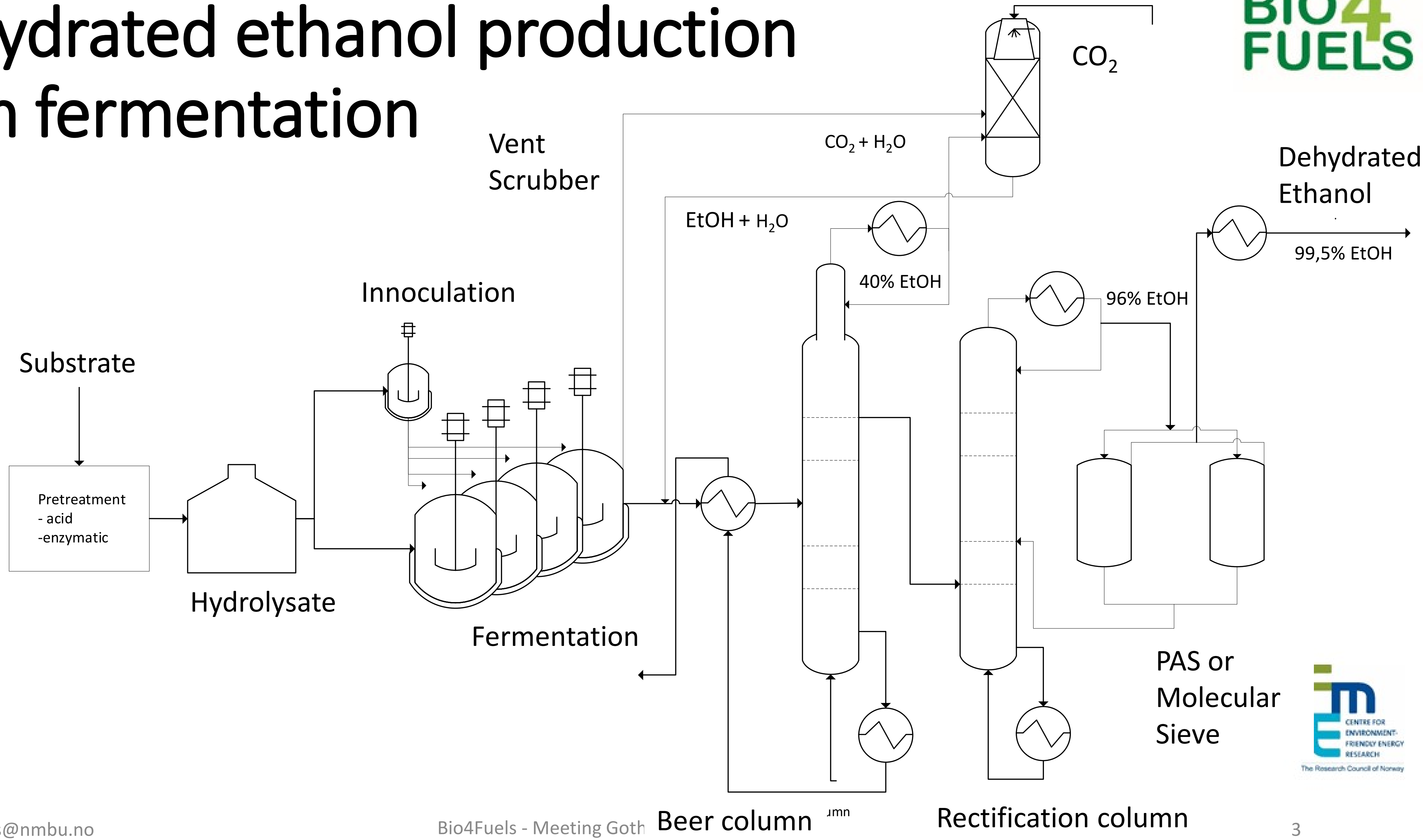
Outline

- Ethanol production
- Dehydration processes
- Experimental work on gas permeation with pervaporation membranes
- Making distillation and gas permeation work together
- Conclusion and outlook

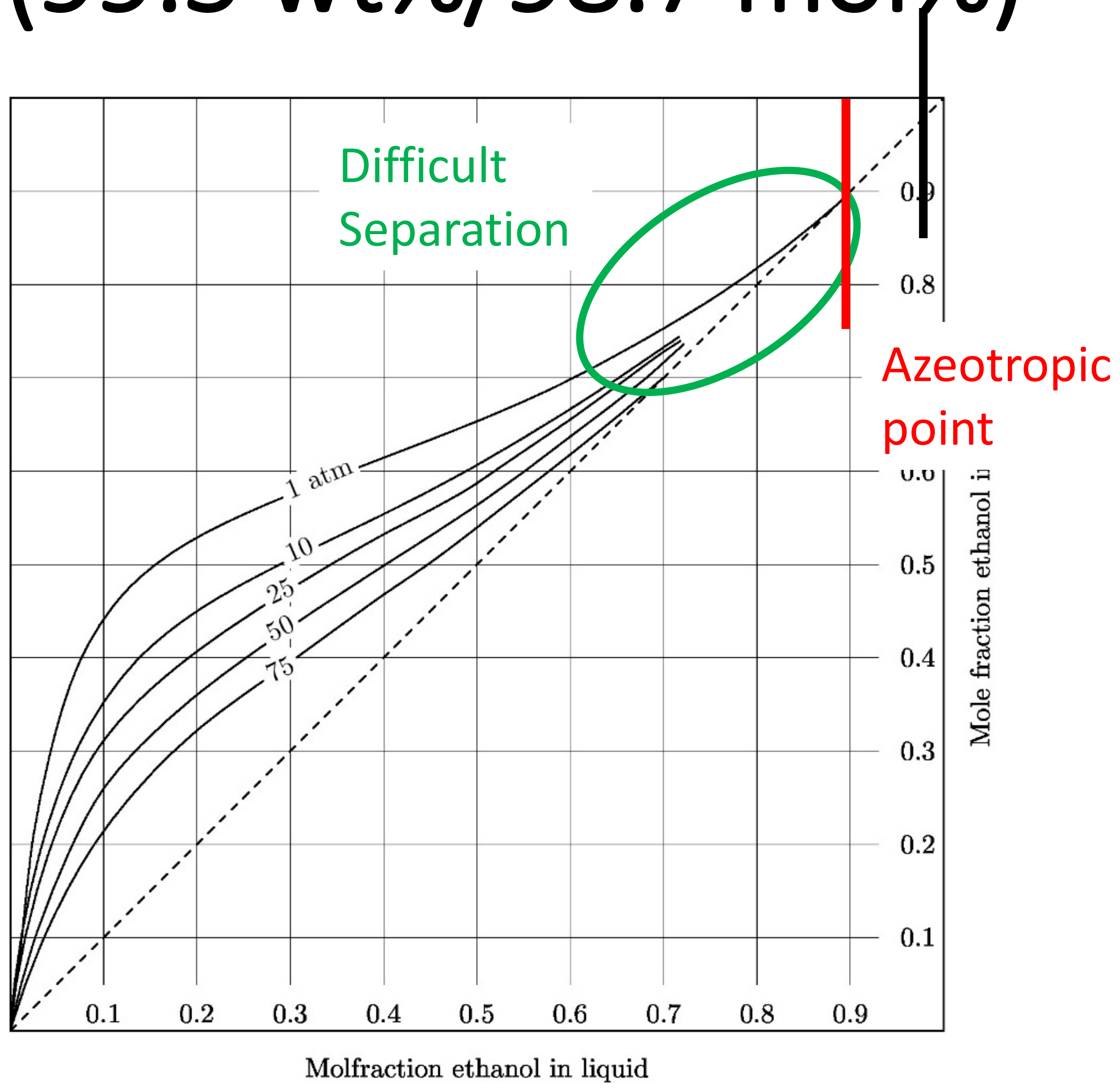
Dehydrated ethanol production from fermentation



Dehydration for fuel quality – (99.5 wt%/98.7 mol%)

Available options

- Pressure swing absorption
- Molecular sieve
- Gas permeation
- Extractive distillation
- Azeotropic distillation



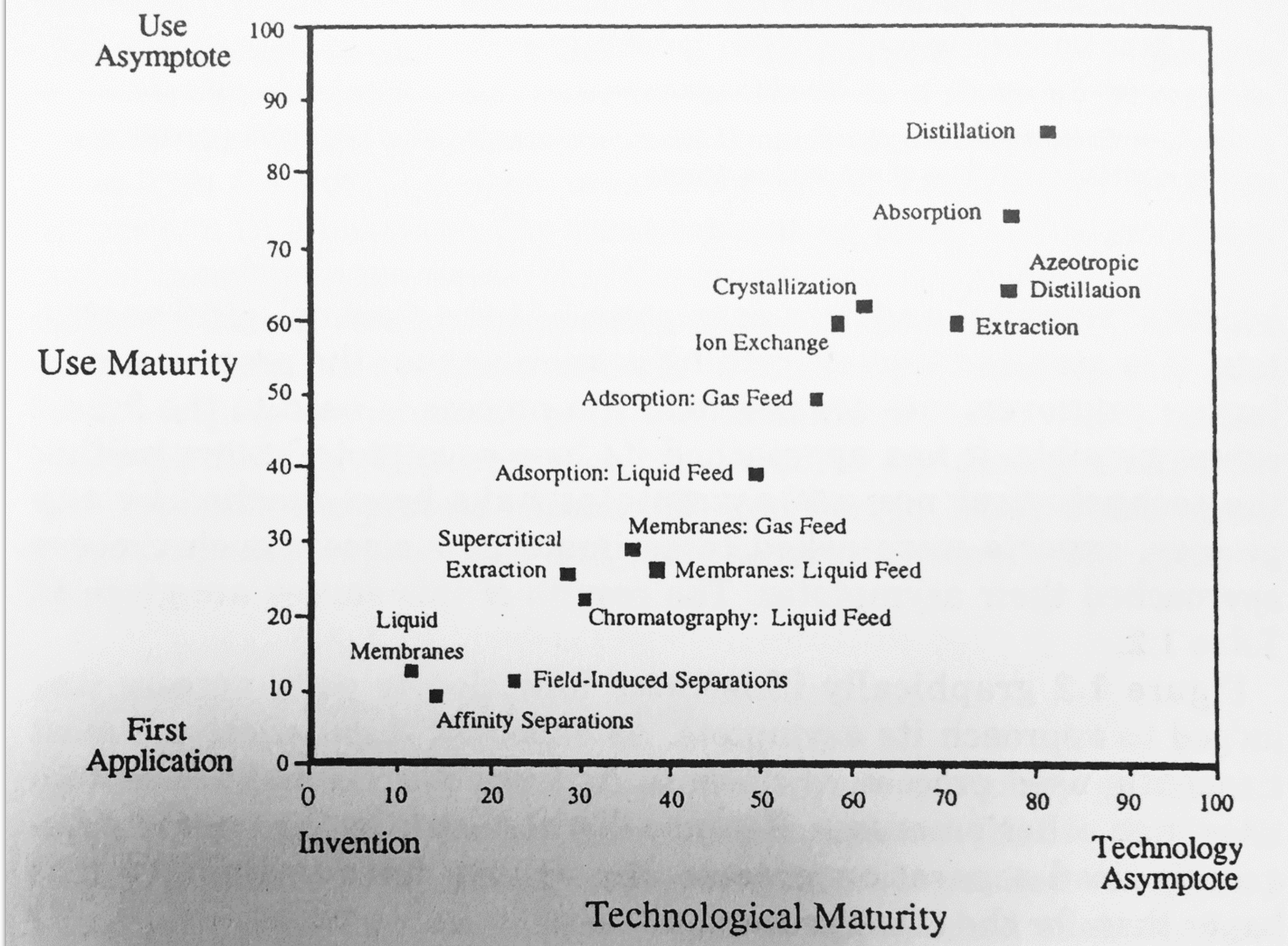


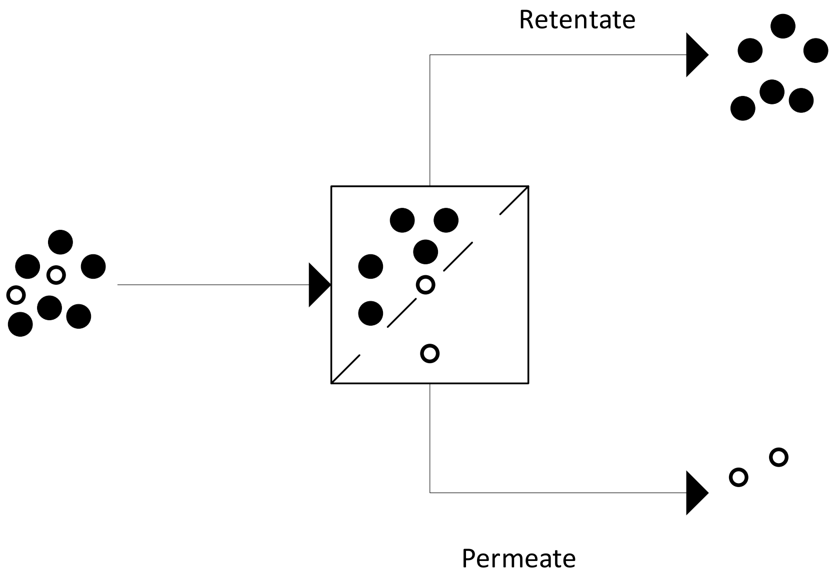
Figure 1.2 Technological and use maturities of separation processes. (*Adapted from Keller, 1987 with permission of the American Institute of Chemical Engineers. Copyright © 1987 AIChE. All rights reserved.*)

Some words about separation

World view anno 1987

3 decades later this is still valid

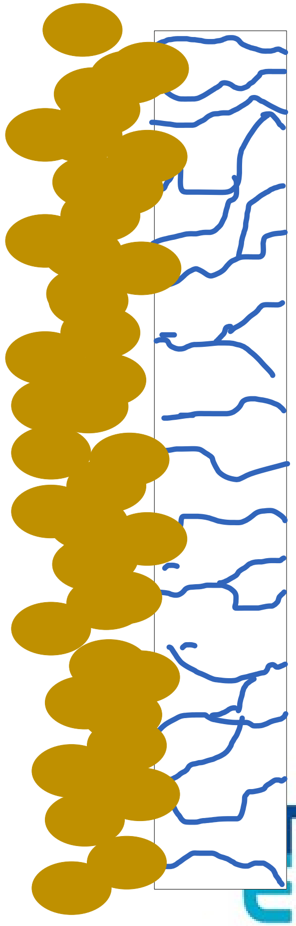
Membranes Separation



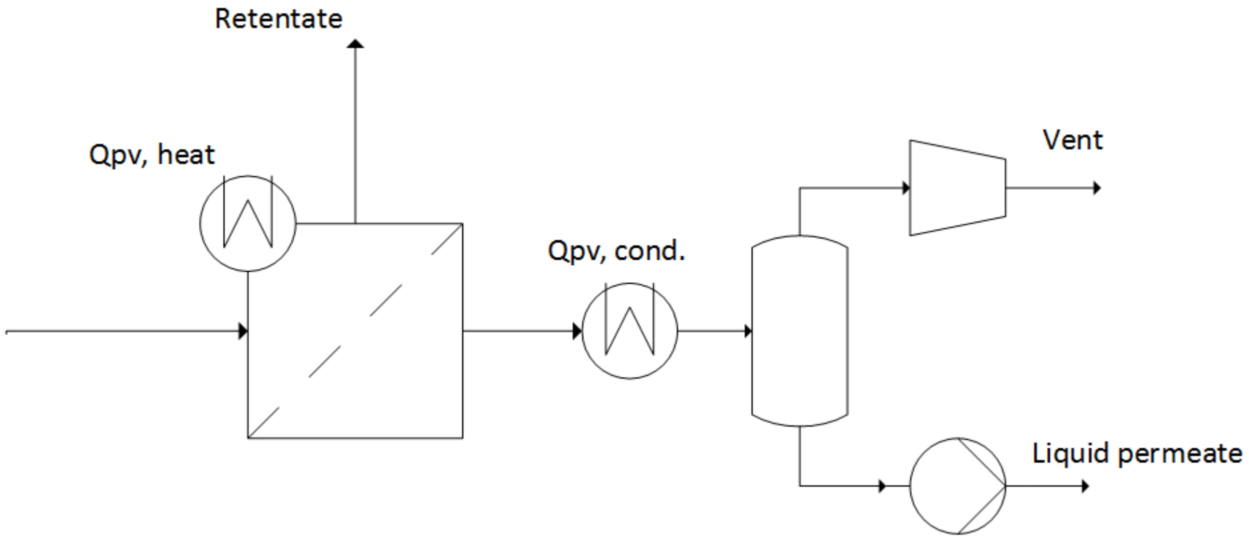
Challenges pervaporation from broth directly

- fouls membrane
- poor driving force: 5 wt% → 70-80 wt% permeate
- requires condensing the product at low pressure

5 wt% ethanol
cells
proteins



Problems with direct pervaporation



- Liquid feed side requires re-heating to compensate for the heat of evaporation

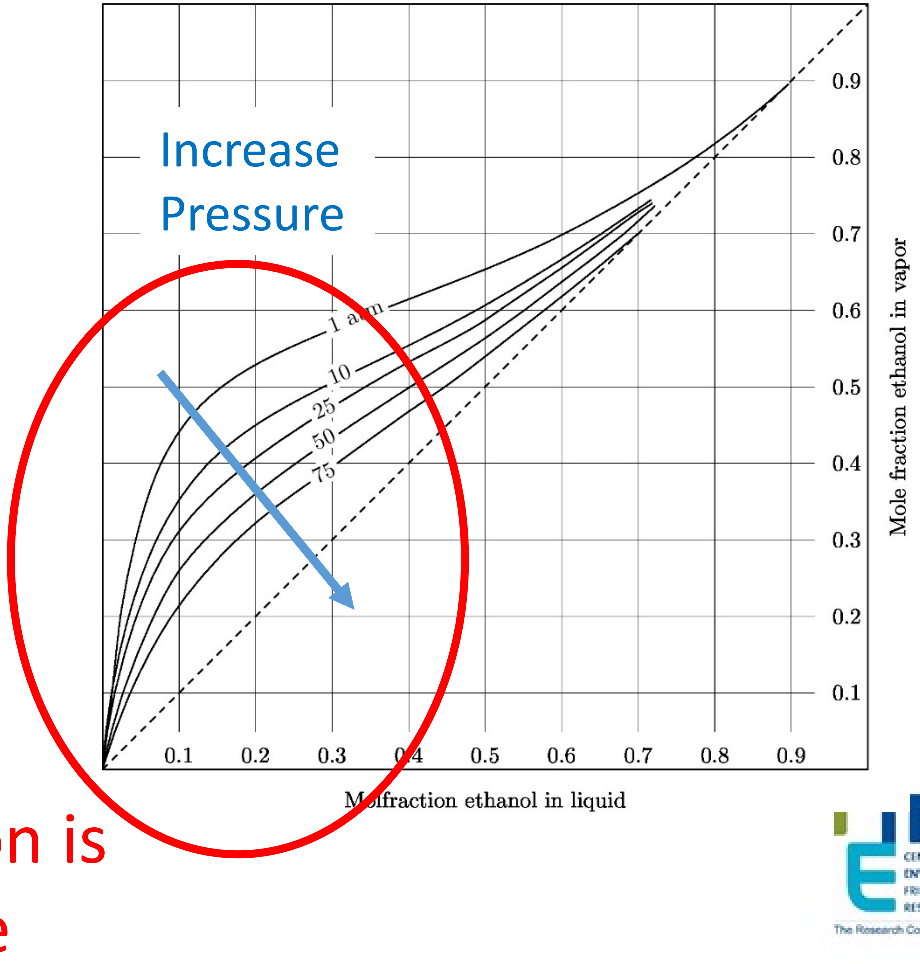
- Low permeate pressure (~20 mbar) requires vacuum pumps

- Refrigeration for condensing the product? - $$$

Trade-off in driving forces

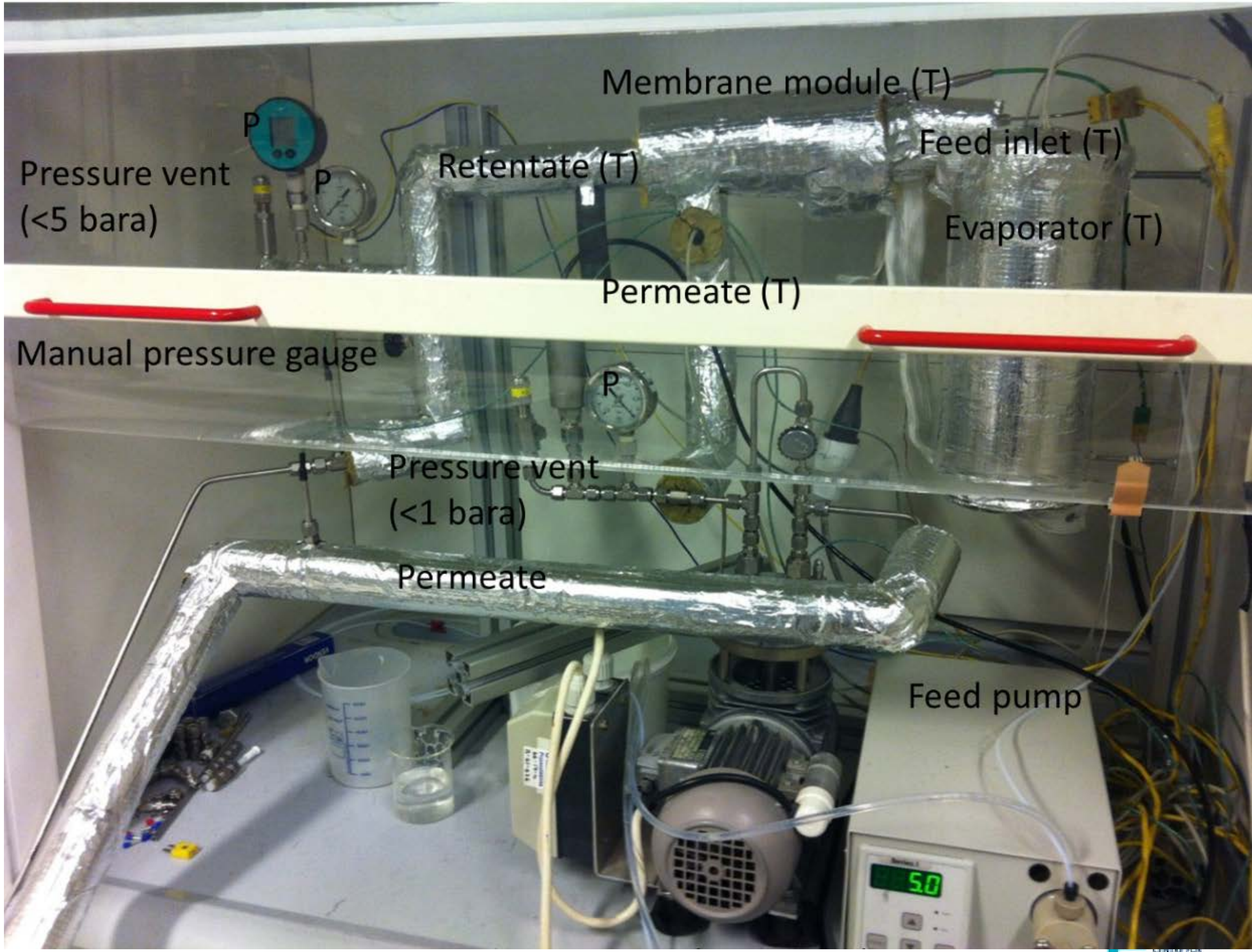
- Ethanol is the light boiling liquid
- Separation in the lower range is easy

- Increasing from 1 atm to 10 atm pressure
  - can be done cheaply with pump
  - only marginal impact on lower range distillation
  - increases temperature in boiler
  - gives driving force for gas permeation



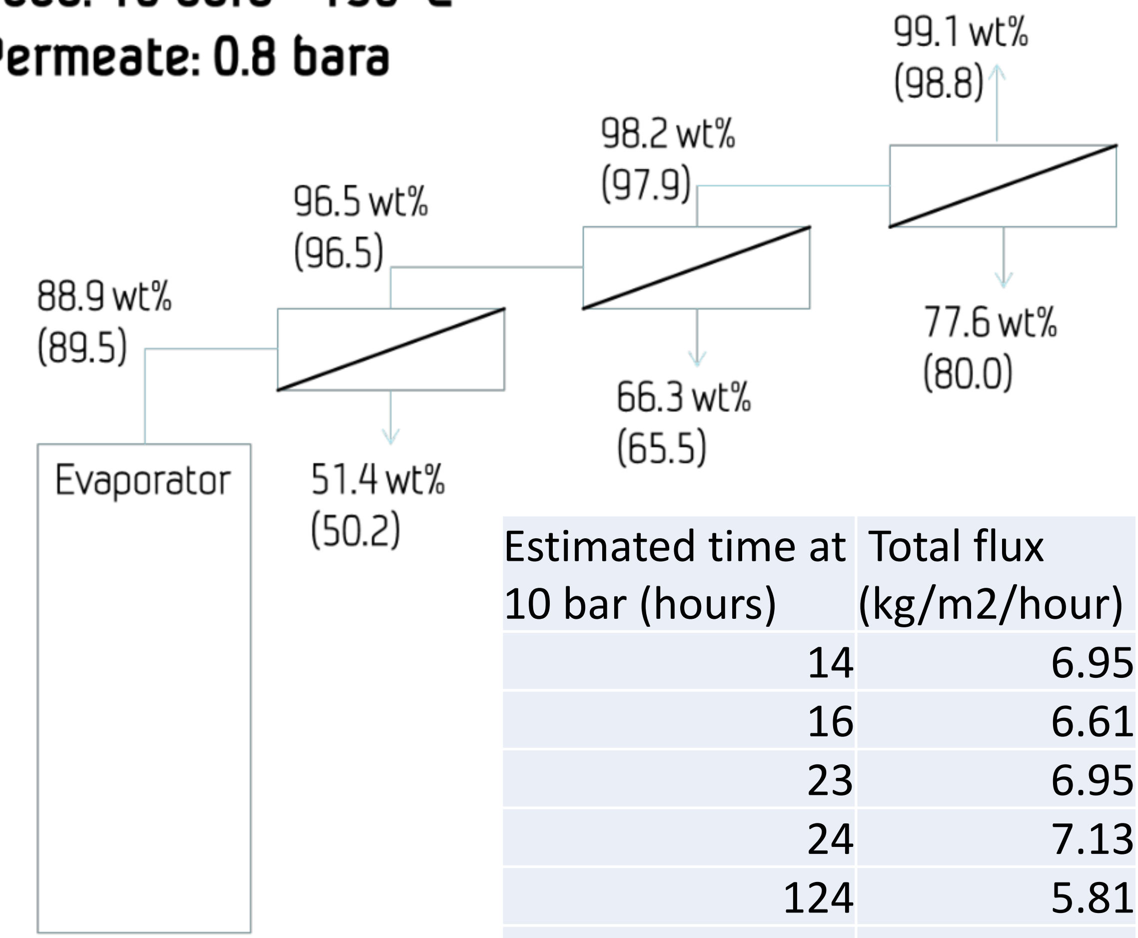
Testing gas permeation

- Commercially available pervaporation membranes
- Organic-inorganic hybrid silica (HybSi ®) from Pervatech
- Run in gas-permeation mode



Permeation results

Feed: 10 bara - 150°C
Permeate: 0.8 bara

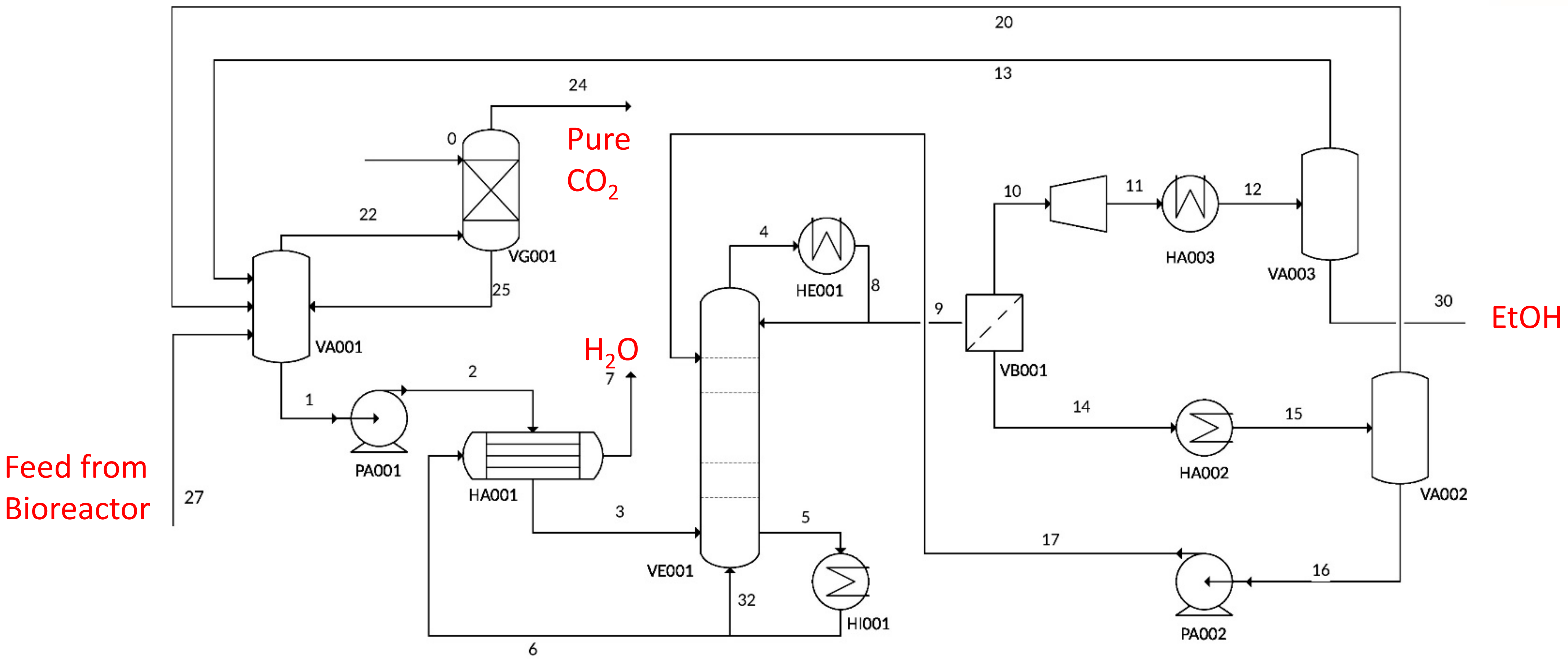


Estimated time at 10 bar (hours)	Total flux (kg/m2/hour)	Separation factor	Water permeance (kmol/m2/hour/bar)	Ethanol permeance (kmol/m2/hour/bar)
14	6.95	26.1	0.7	0.009
16	6.61	29.3	0.7	0.008
23	6.95	27.0	0.84	0.009
24	7.13	31.8	1.15	0.009
124	5.81	38.8	0.77	0.006
125	5.18	47.3	1.29	0.005
290	7.11	6.2	0.10	0.013
295*	85	3.9	0.90	0.064

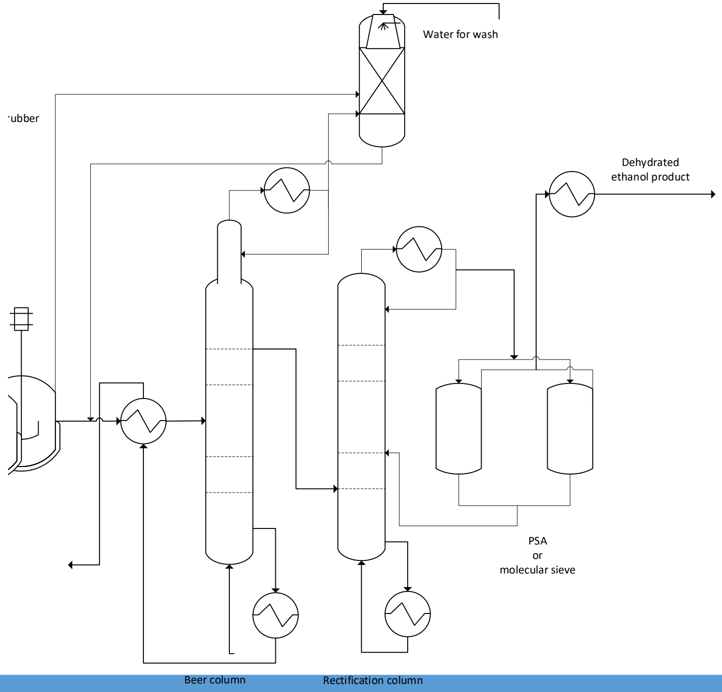
*Cracked and delaminated end glazing

Cracked, delaminated end glazing

Process design: distillation + gas permeation



Note: Pressure in the system is generated by liquid pumping (€) instead of compression of a vapour (€€€)



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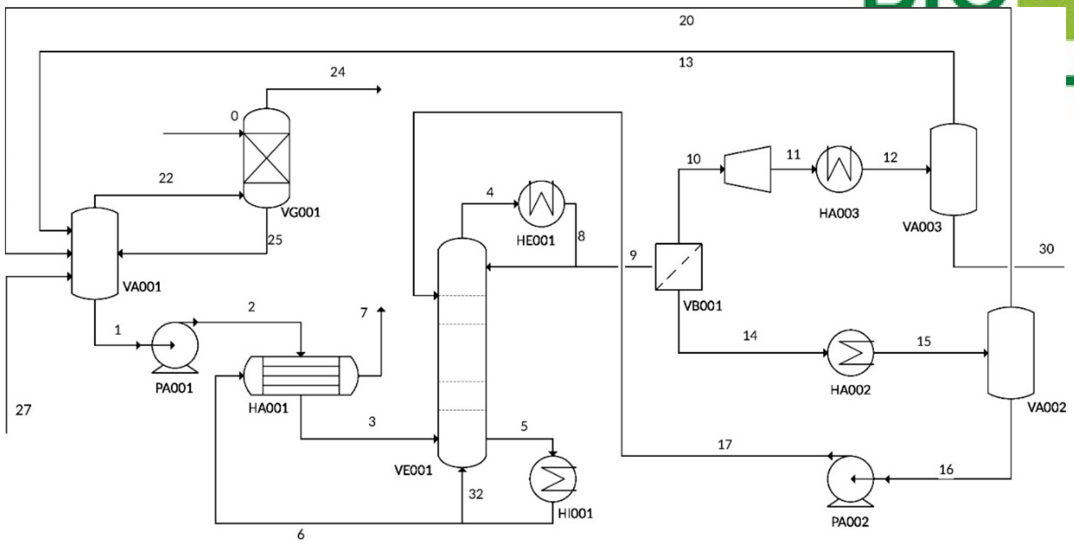

Traditional process (NREL*)	Distillation + gas permeation
Two distillation columns	One distillation column
Molecular sieve section	Gas permeation membrane 9 kg/h dehydrated product pr. m2 membrane area
7.4 MJ/kg separation cost (fuel eqv.)	6.2 MJ/kg separation cost (fuel eqv.) 18 % reduction compared to base case

* Humbird, D.; Davis, R.; Tao, L.; Kinchin, C. Process design and economics for biochemical conversion of lignocellulosic biomass to ethanol: dilute-acid pretreatment and enzymatic hydrolysis of corn stover ; 2011

Conclusion
- Integration of Distillation and Pervaporation

- Trade off separation efficiency in distillation column but gain in driving force for permeation
- Simplified process without membrane fouling problems
- Better energy performance with proposed scheme
- Comparable or lower capital costs with proposed scheme
- Only works for low boiling alcohols
  - distill off alcohol, not the solvent

Outlook

- Lowering cost of membrane modules
- Improved membrane module design
- Rigorous TEE is on-going