Separations Opportunities and Challenges

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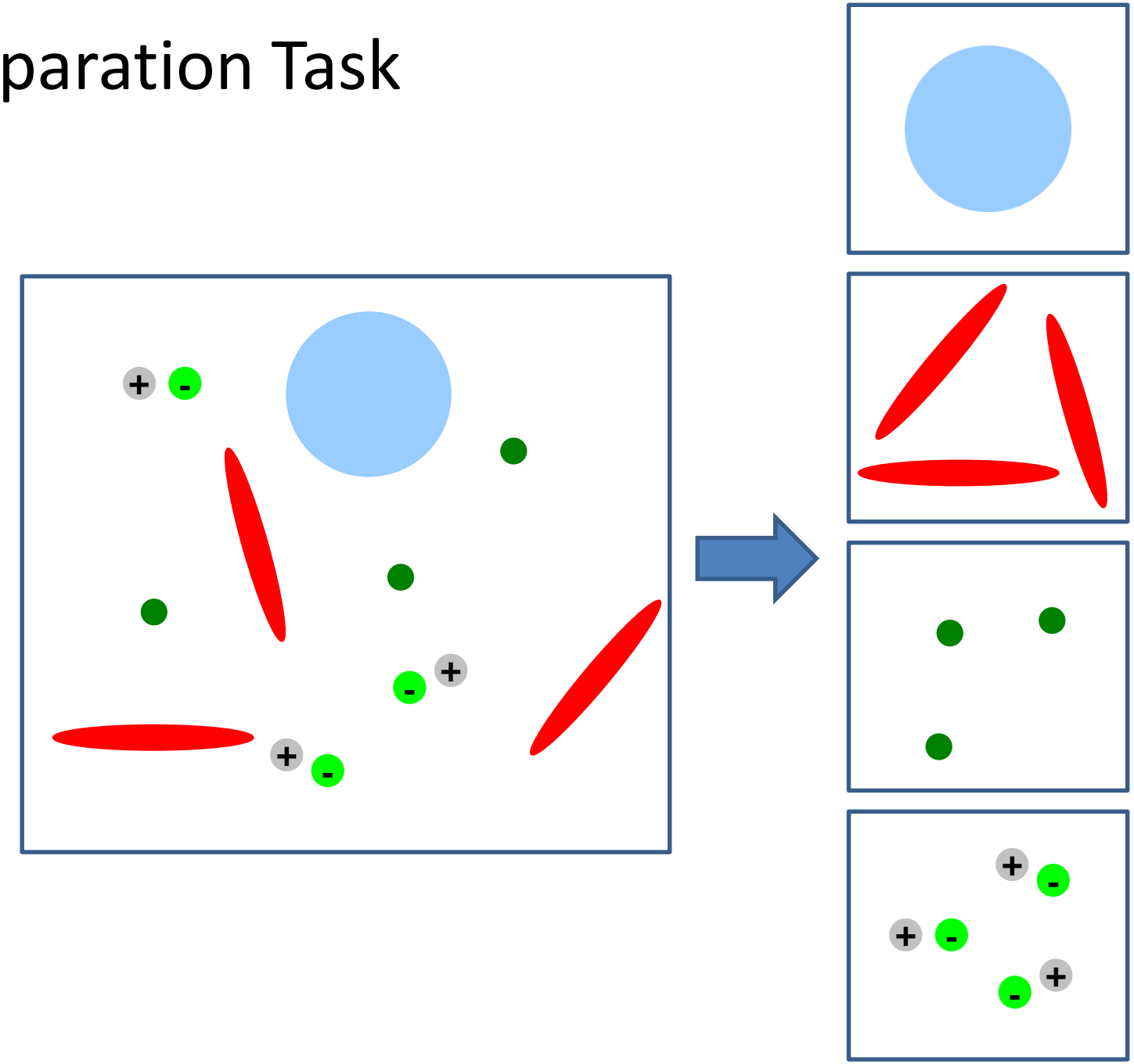
ARPA-E Rewiring Anaerobic Digestion Workshop
Arlington, VA

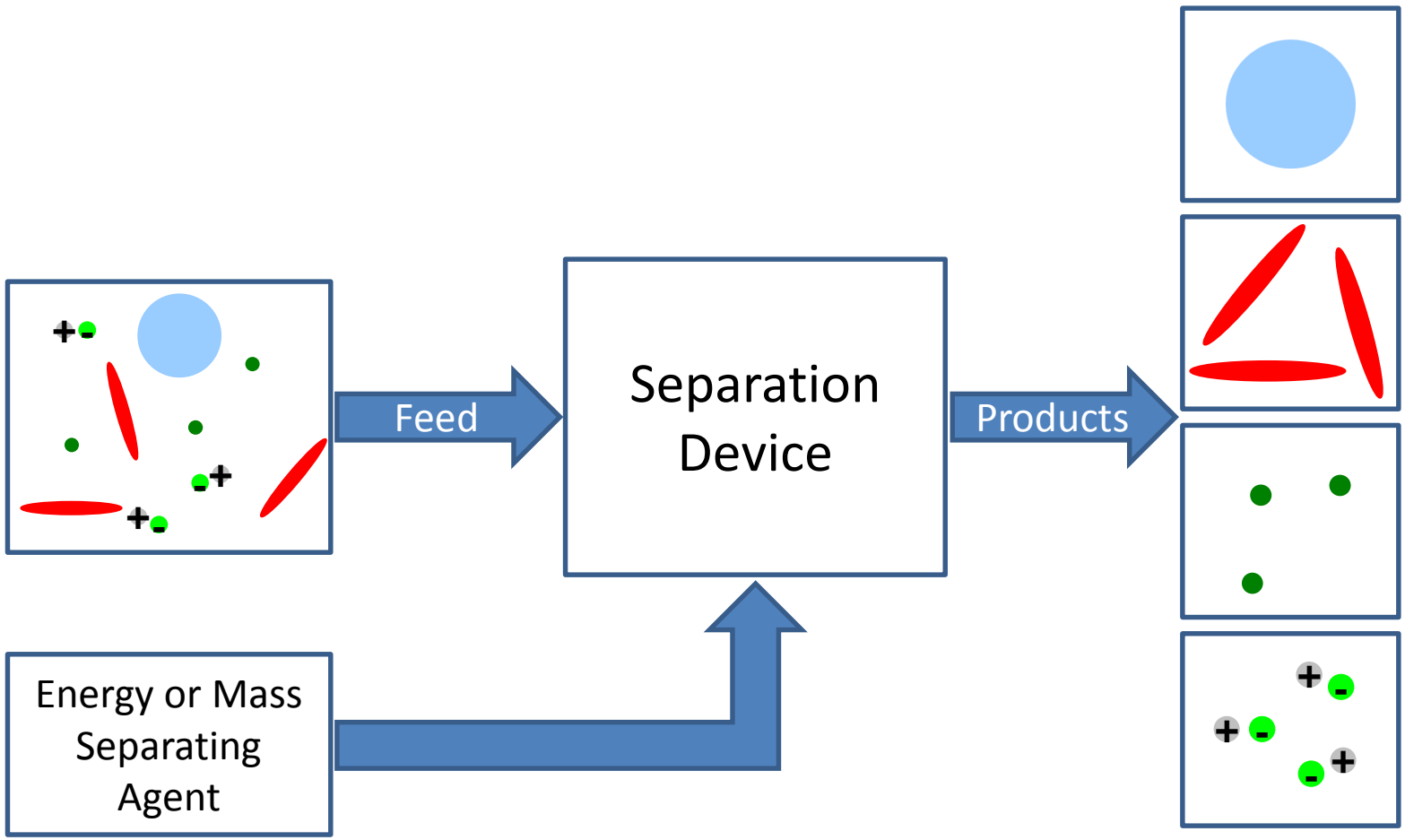
Agenda

- What drives separation processes
- Growth of membrane processes
- Separation opportunities
- Conclusions

Separation Task



Separation Task

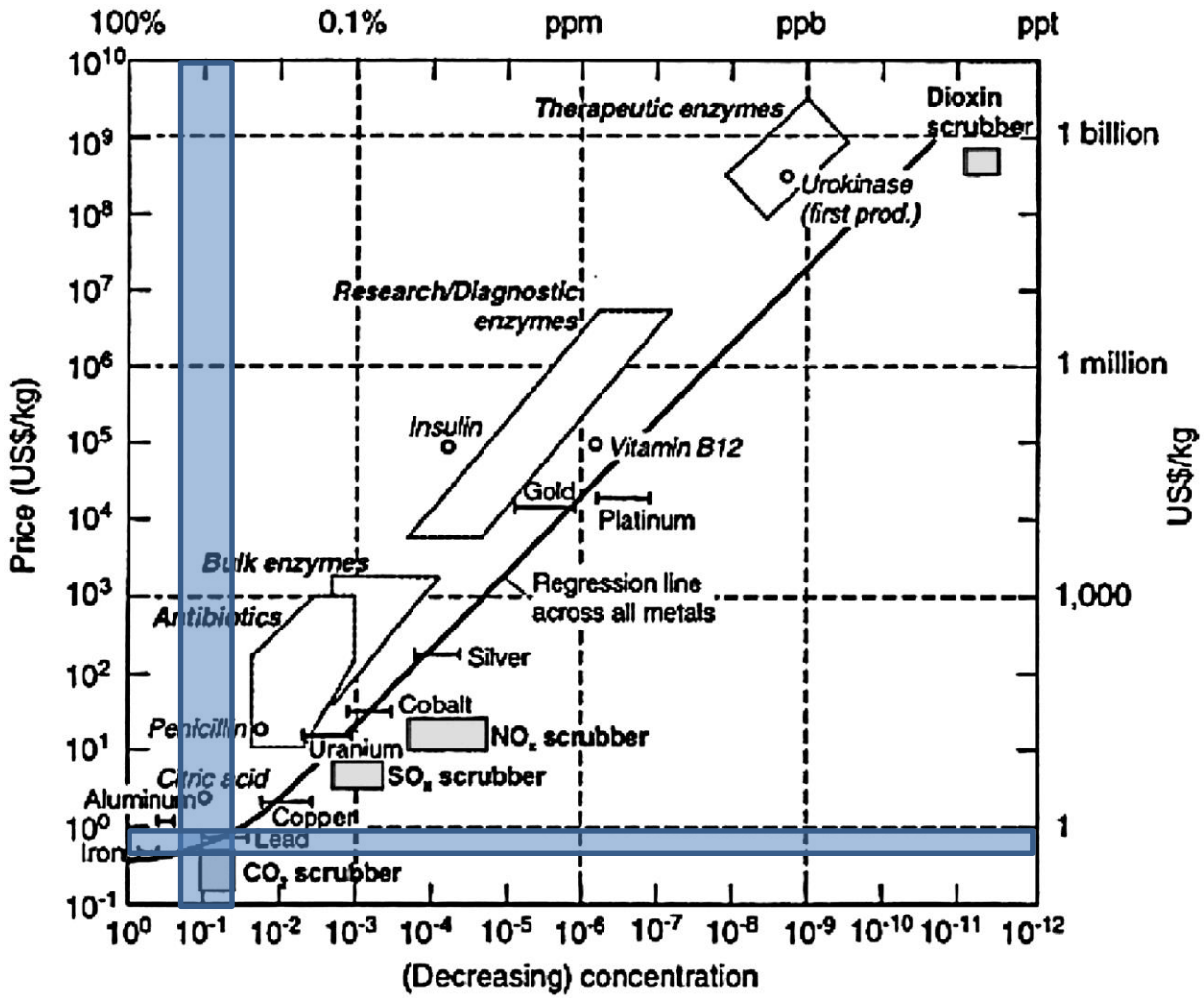


Separation Processes

- Equilibrium
  - Immiscible phases (G/L, G/S, L/L, L/S)
  - Heat commonly drives separation
  - Distillation, ad/absorption, liquid-liquid extraction

- Rate-governed
  - Transport under imposed chemical potential gradient (c, P, T, E)
  - Immiscible phase aided
  - Membrane filtration

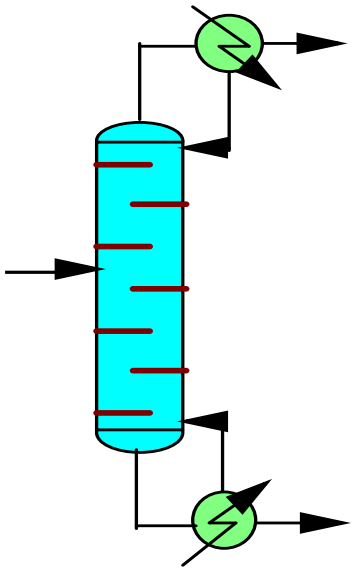
Sherwood Plot

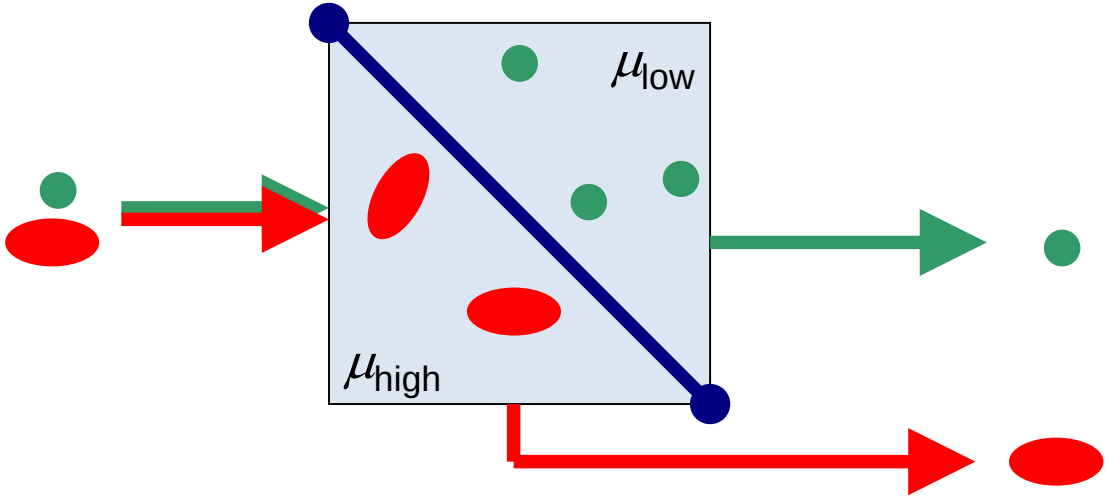


Kurt Zenz House et al. PNAS 2011;108:20428-20433

End of the Thermal Age?

- Conventional thermal separations = ~10% of total global energy consumption

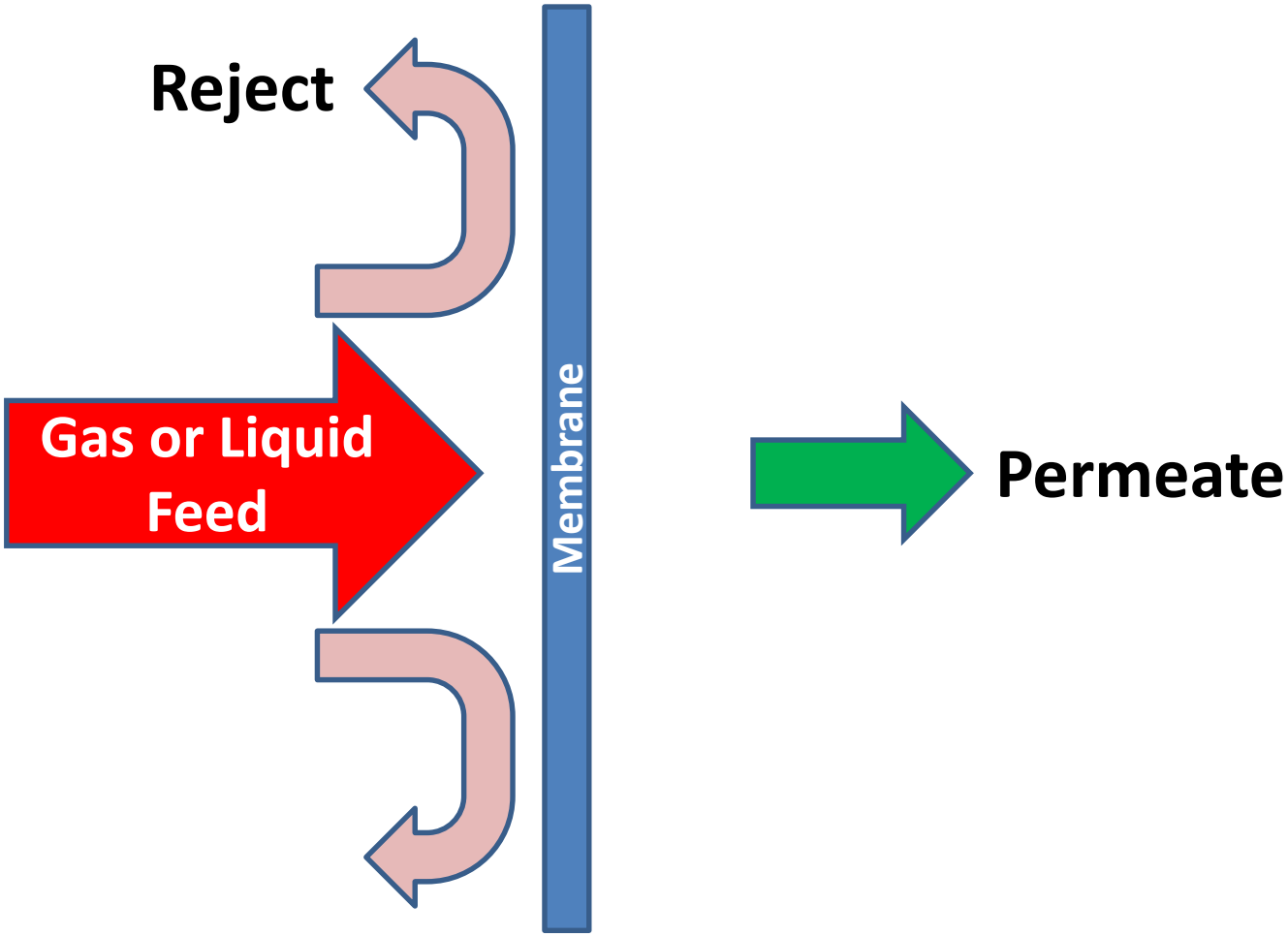




Chemical potential difference driven rate based separations can be more energy efficient if …

Membrane Separations

Materials are available that allow selective transport …



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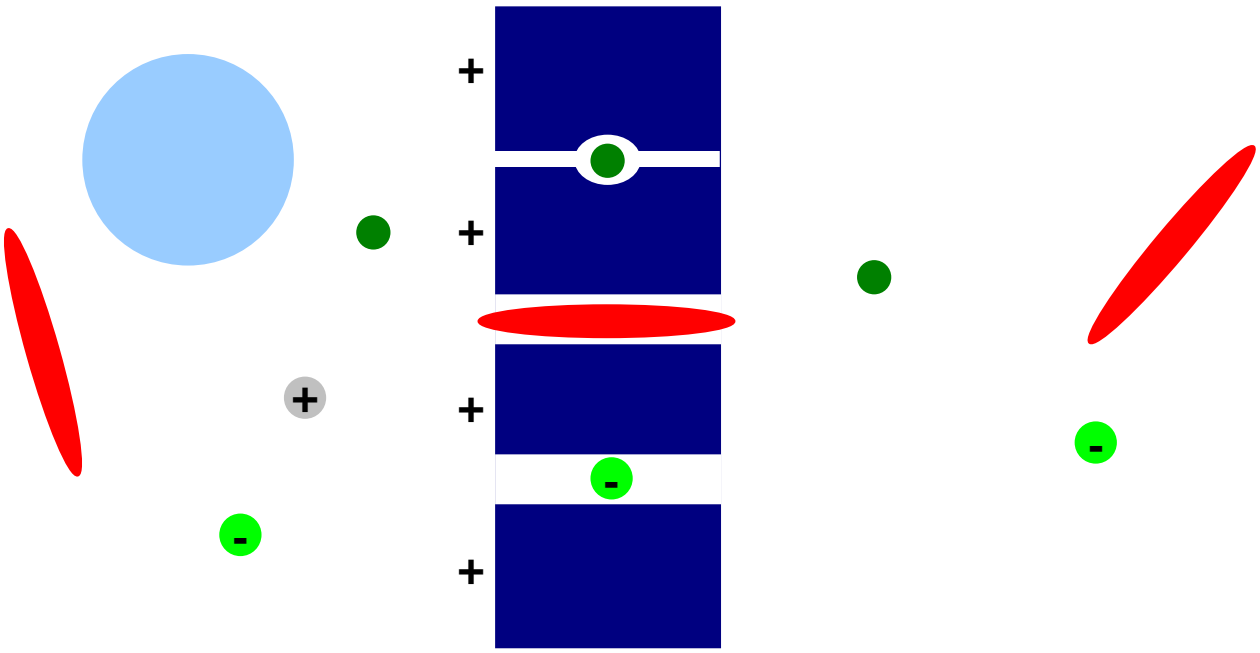
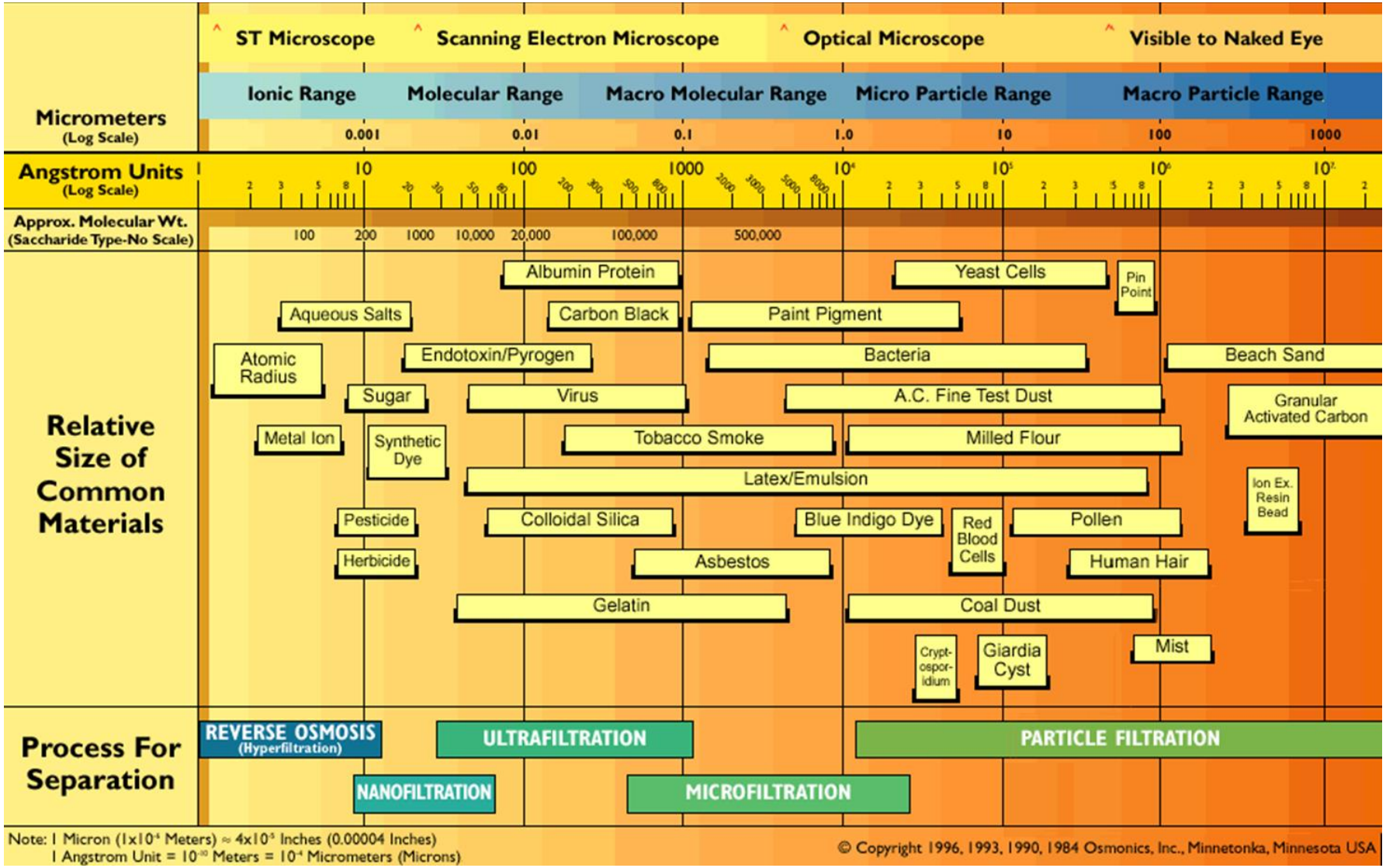


Membrane Separations



Success Story – Desalination

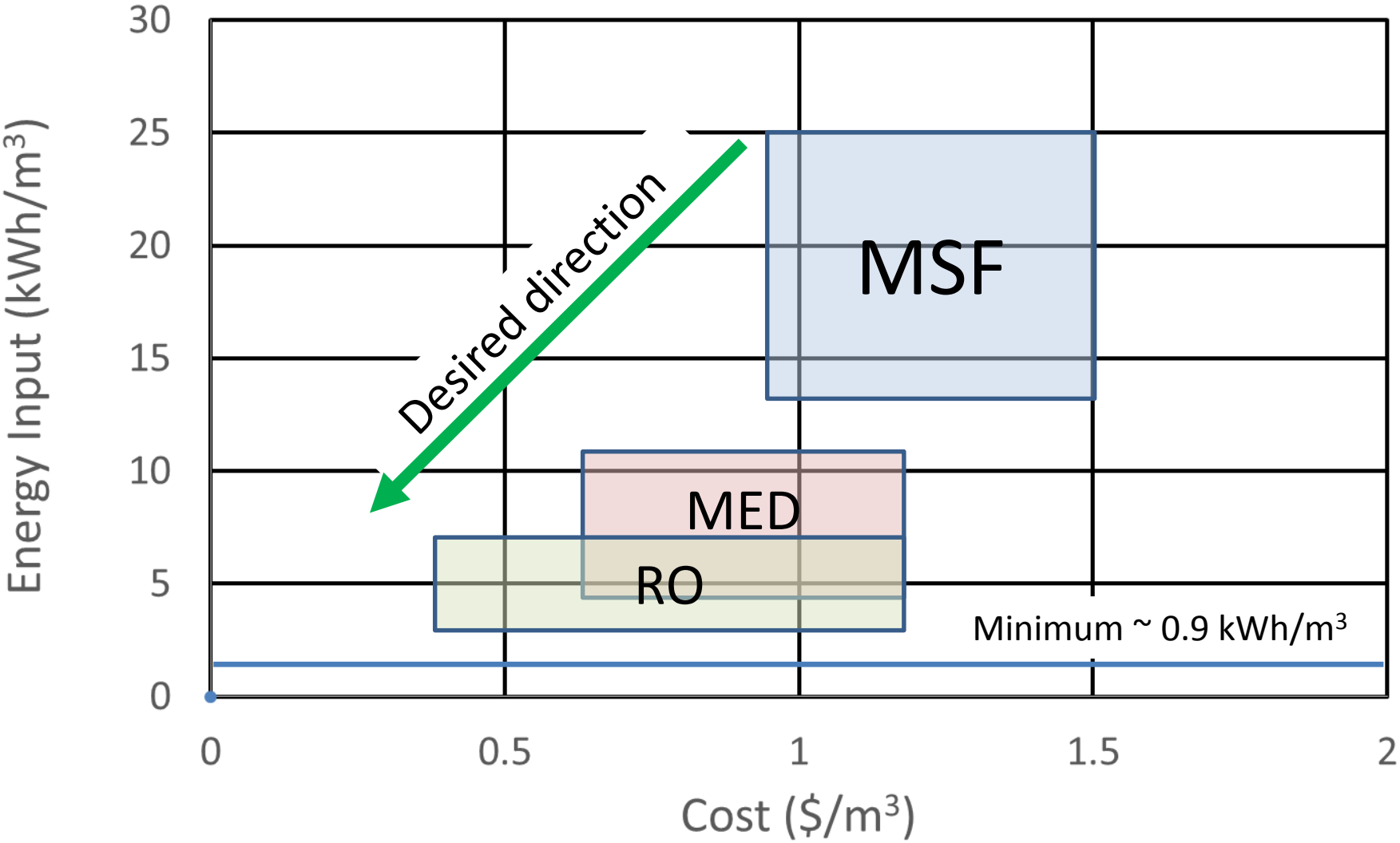
Ashkelon SWRO Plant 100 million m^3/y (2005)

http://www.water-technology.net/projects/israel/

http://www.central-filter.co.jp/english/product/system/s09.html

Hadera (127, 2009), Sorek (150, 2013)

Success Story – Desalination



Desalination 309 (2013) 187-207
Desalination 366 (2015) 2-8
http://www.desware.net/desa4.aspx

Membrane Separation Figures of Merit

$$Permeability = Q_A$$

$$Selectivity = \alpha_{AB} = \frac{Q_A}{Q_B}$$

As Q_A and α_{AB} increase, process performance improves

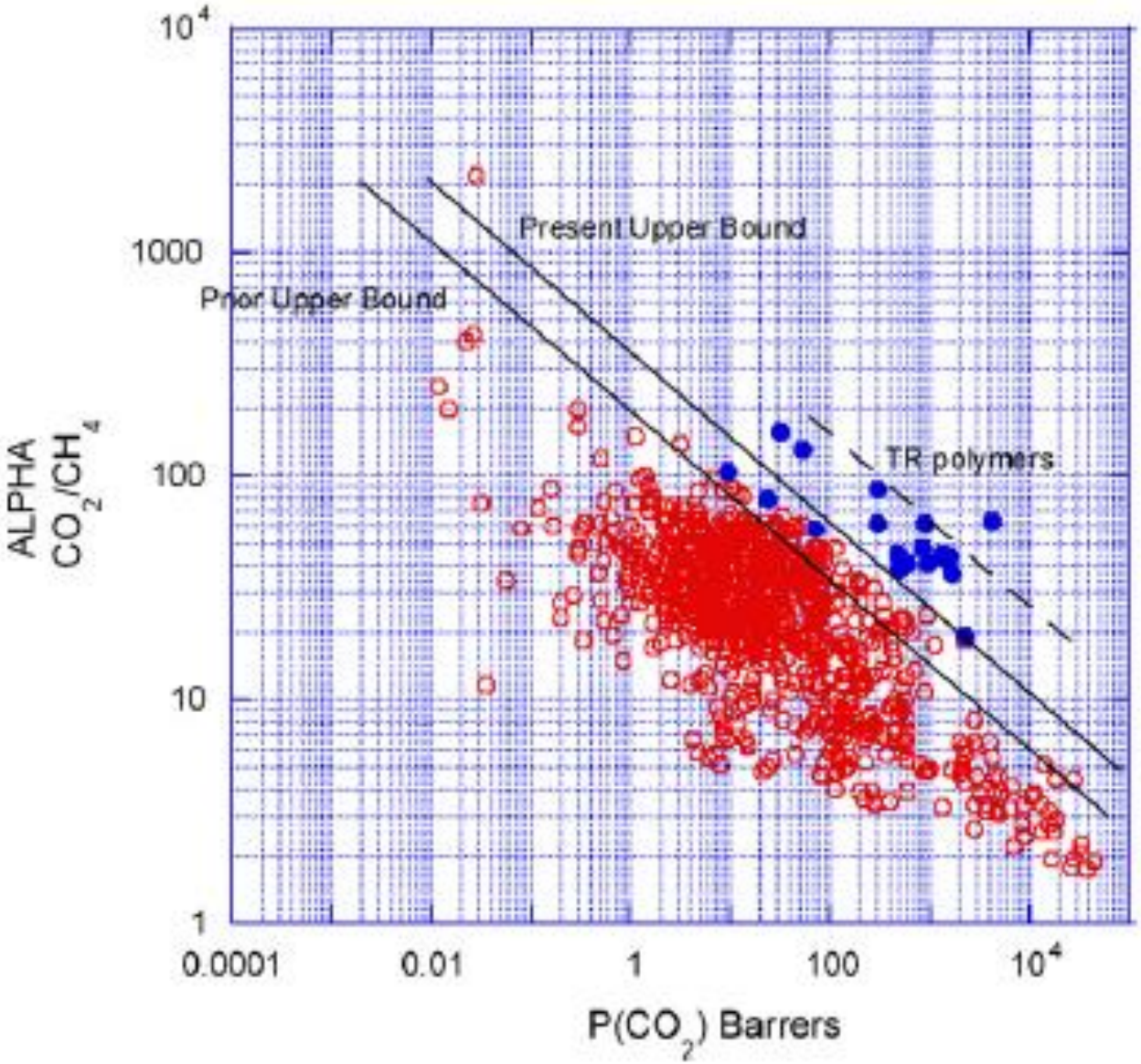
As $Q_A \uparrow$

Membrane area $\downarrow$, Capital costs $\downarrow$

As $\alpha_{AB} \uparrow$

Product recovery $\uparrow$, Energy $\downarrow$

Permeation Upper Bound

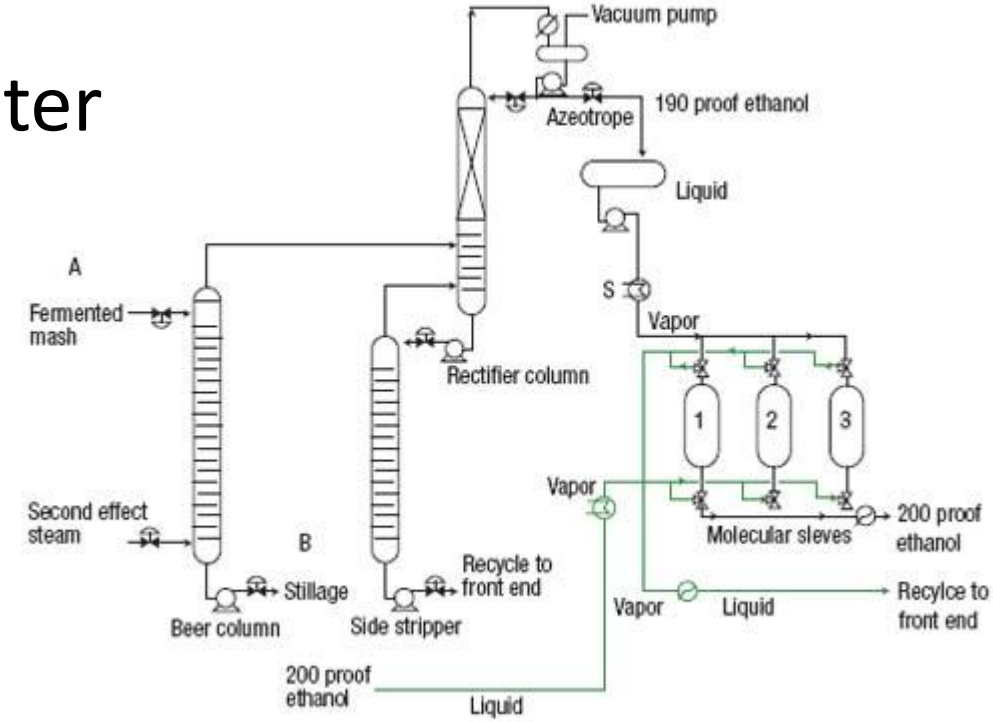


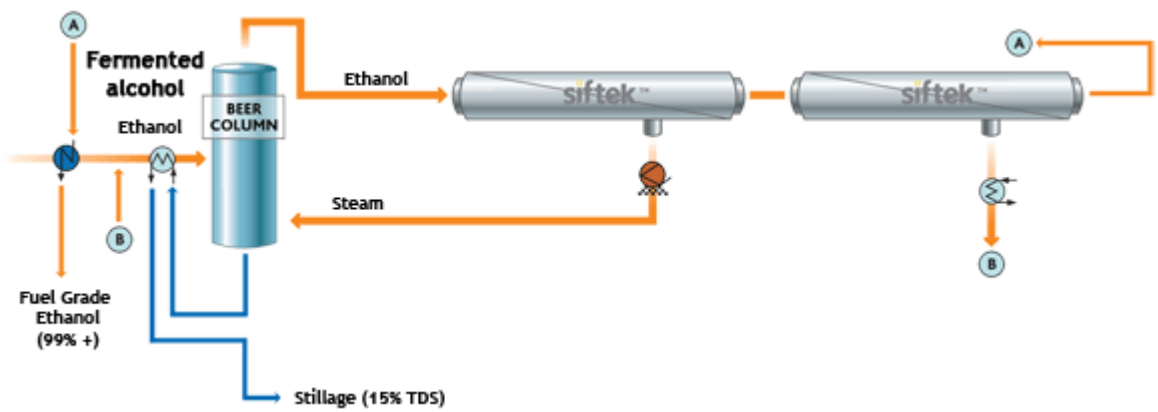
Robeson, Journal of Membrane Science, 320 (2008) 390-400

Bioethanol Production – VP or PV

- Organic/water

Fermented mash

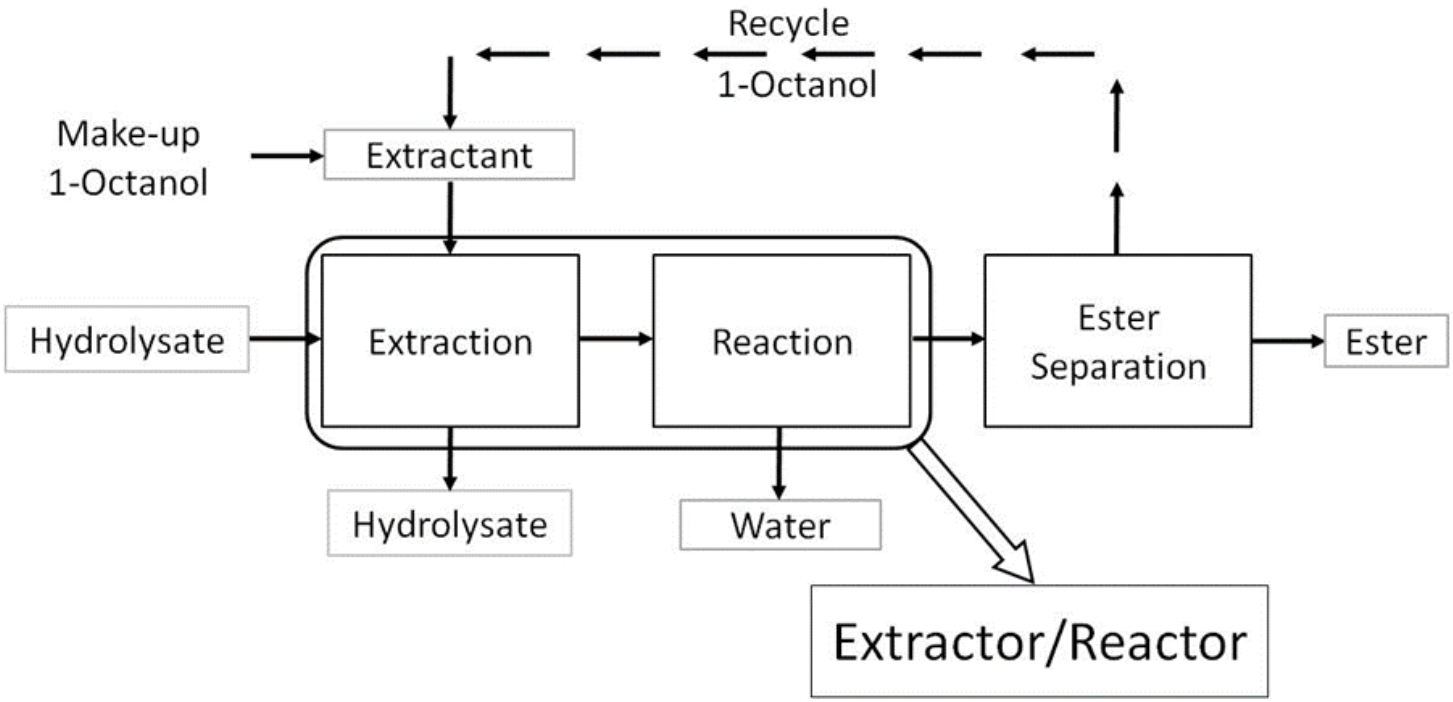




http://www.chemicalprocessing.com/articles/2007/198.html?page=1
Originally from http://www.vaperma.com/

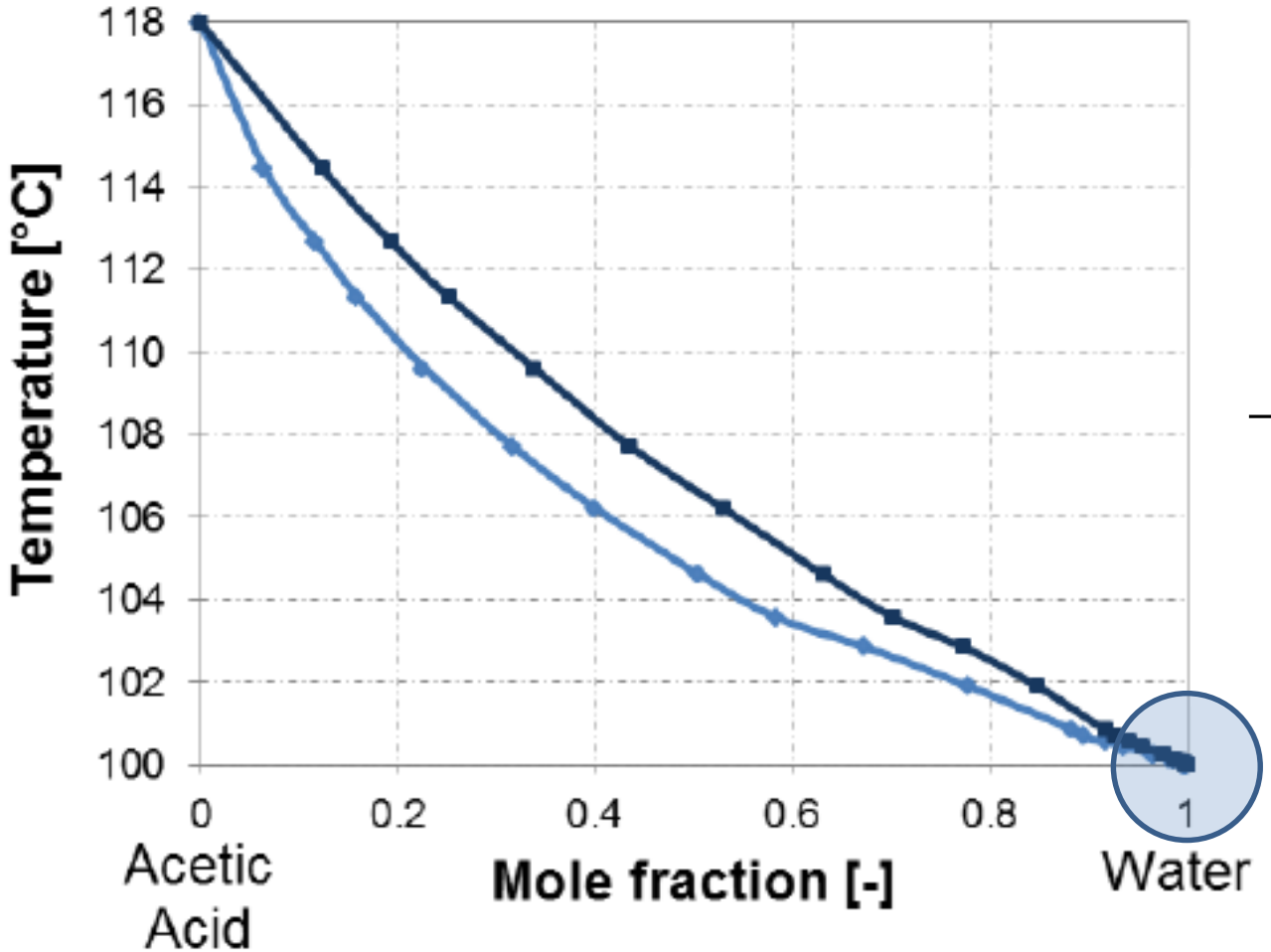
Bioethanol Production – Contactor

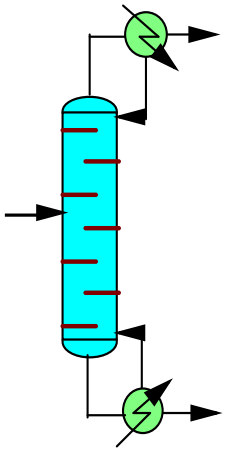
- Reactive extraction of acetic acid inhibitor



R. Patil, PhD Dissertation, University of Toledo

Acid Recovery From Aqueous Solutions





D. Painer et al. /http://www3.aiche.org/proceedings/content/Annual-2013/extended-abstracts/P318747.pdf

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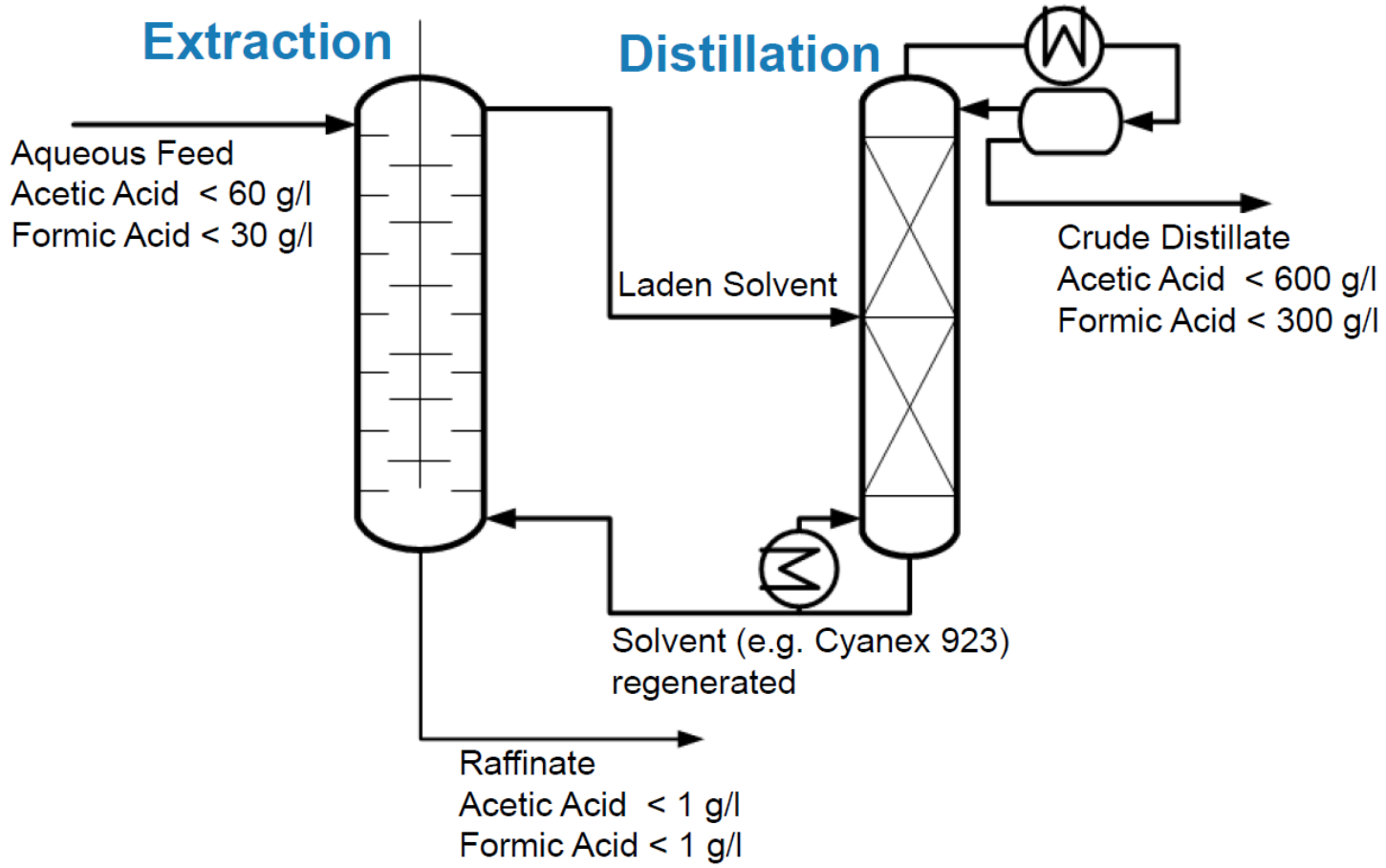

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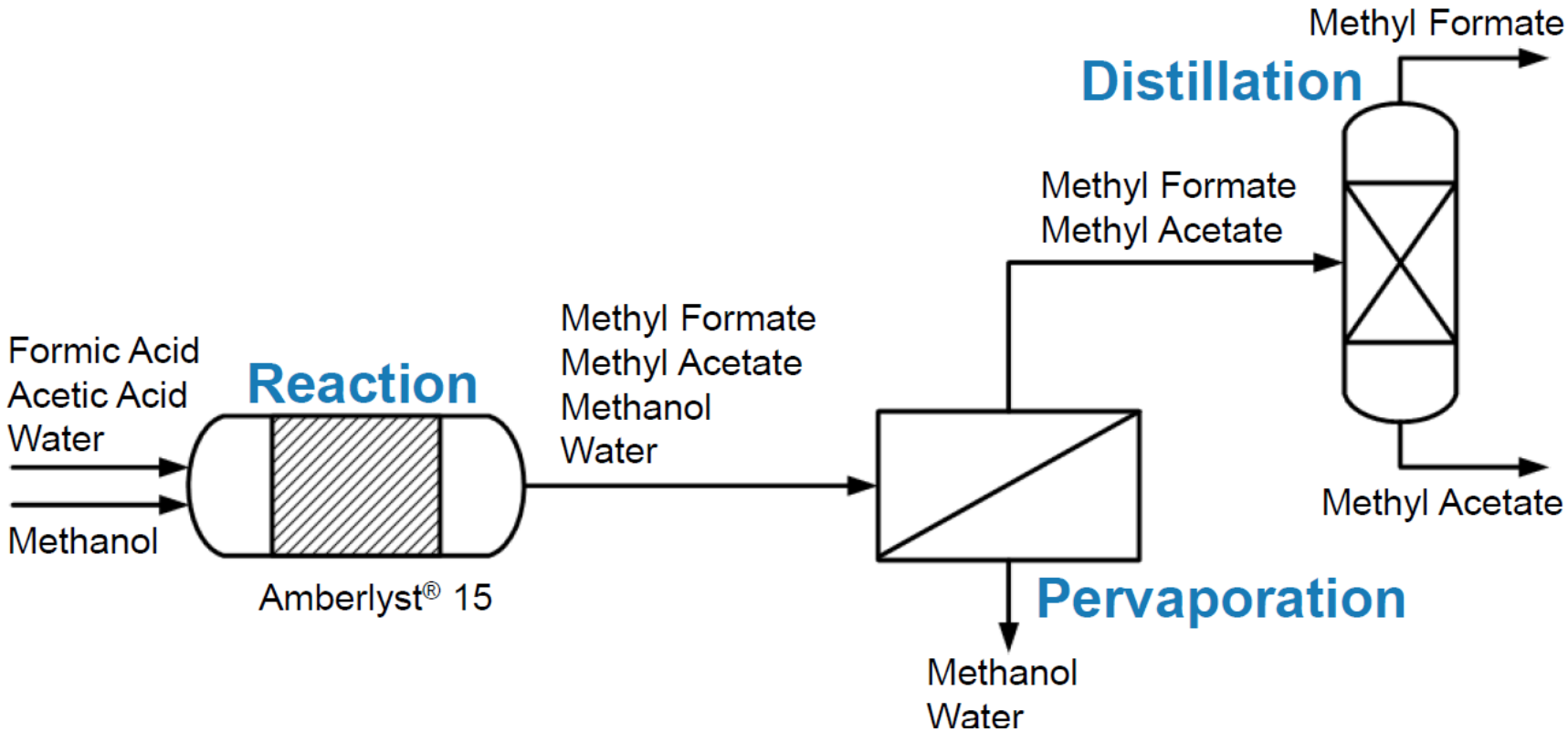

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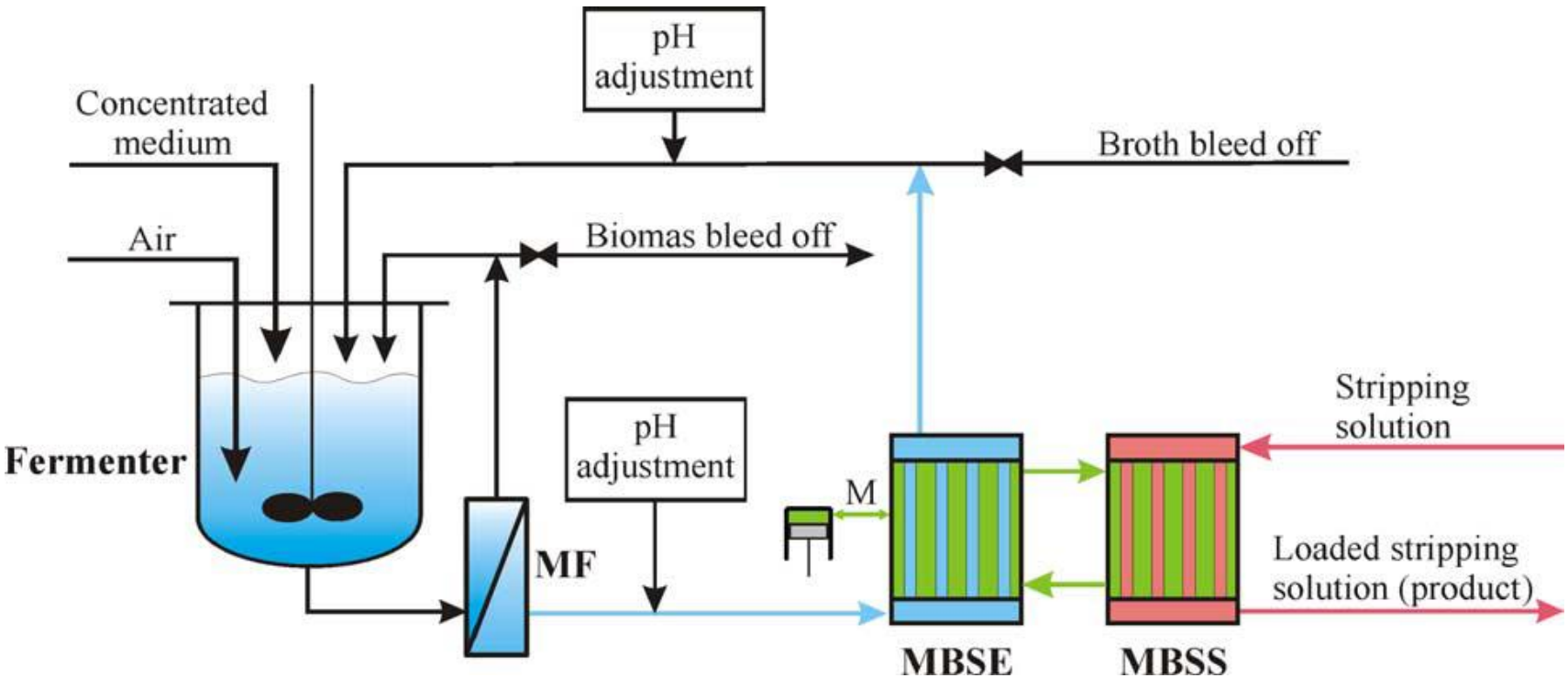
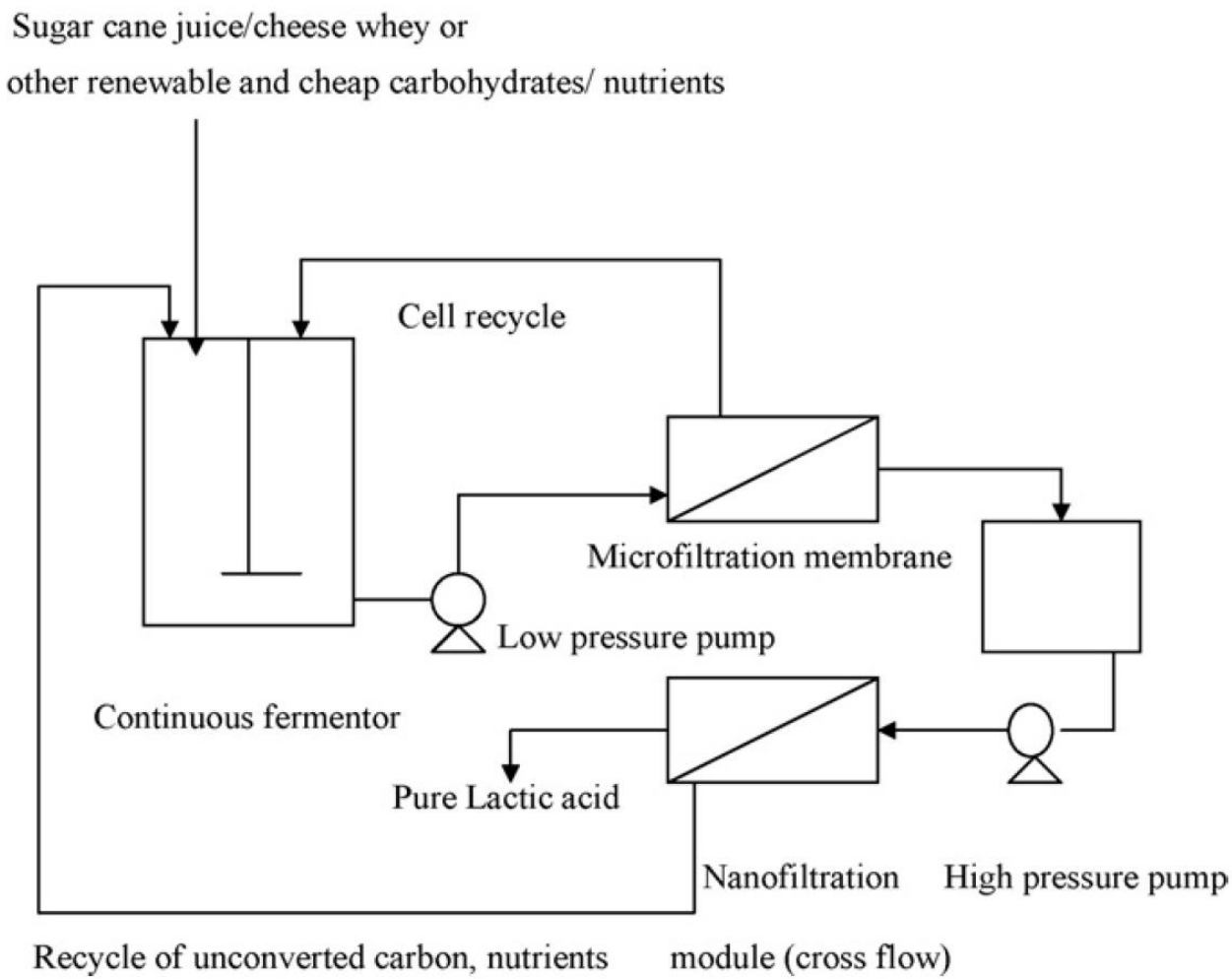


S. Schlosser et al. / Separation and Purification Technology 41(2005) 237–266

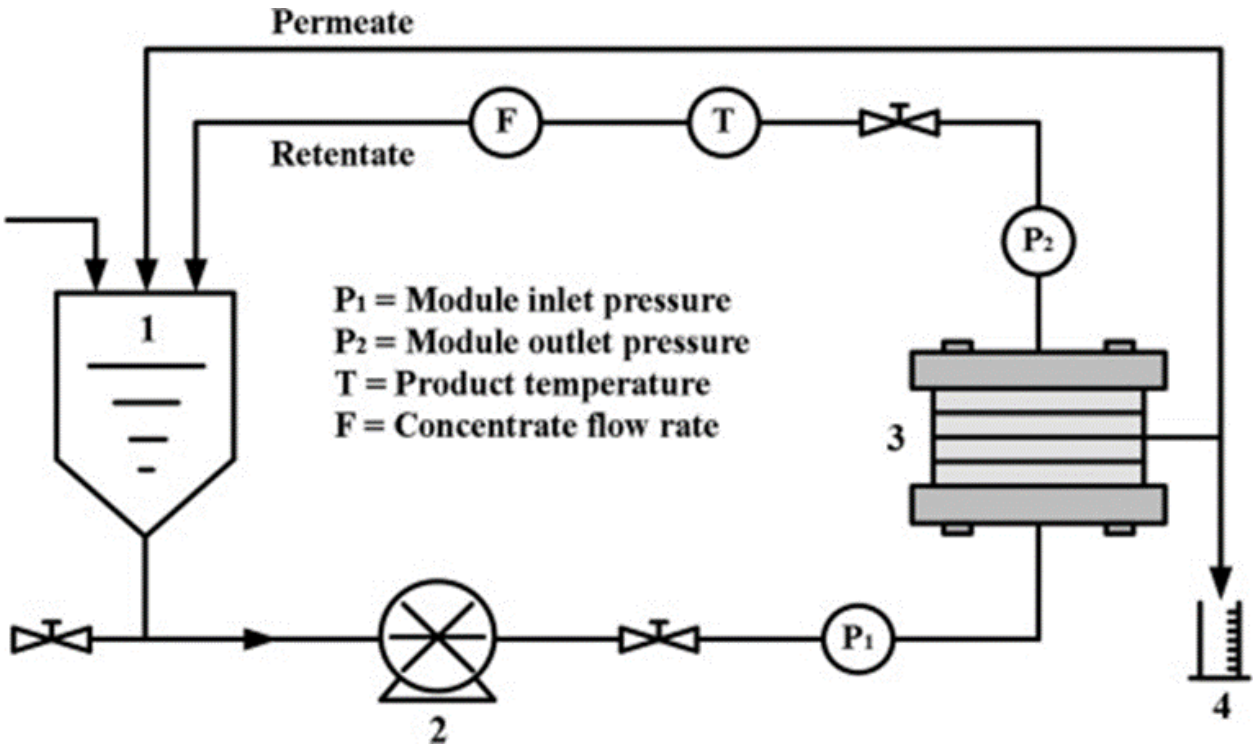
Acid Recovery From Aqueous Solutions



P. Pal et al. / Chemical Engineering and Processing 48 (2009) 1549–1559

Acid Recovery From Aqueous Solutions

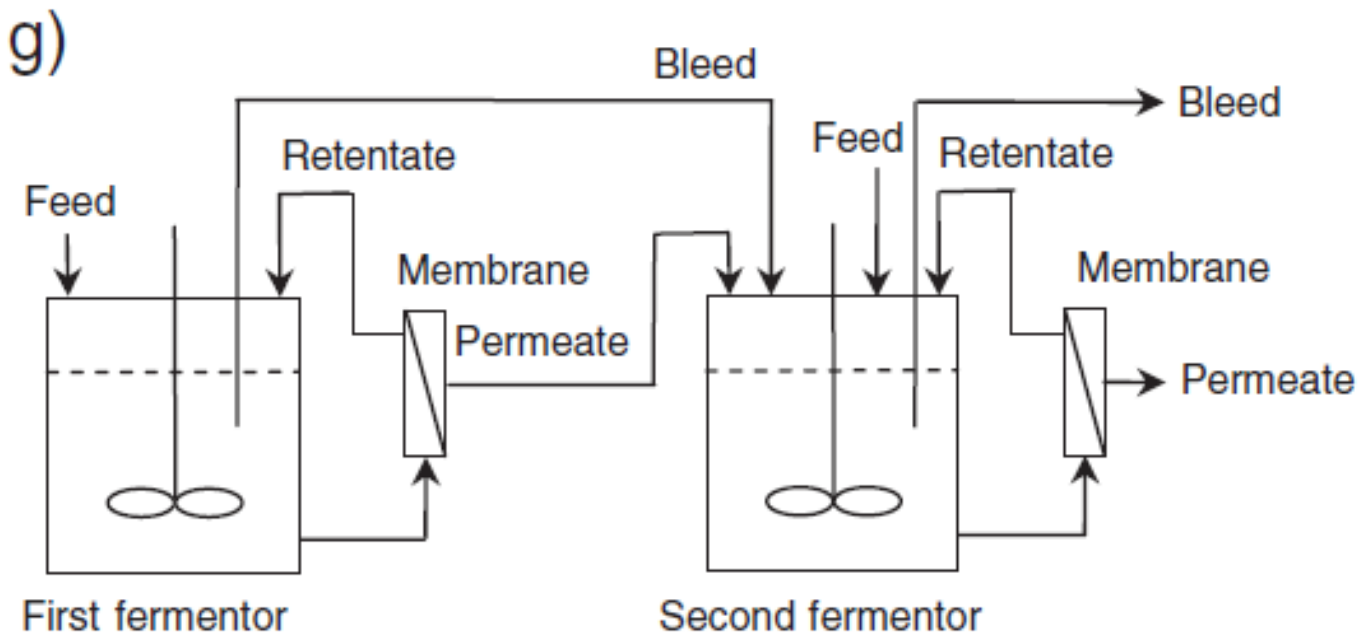
- Acetic acid separation and sugar concentration by RO



F. Zhou et al. / Bioresource Technology 131 (2013) 349–356

Acid Recovery From Aqueous Solutions

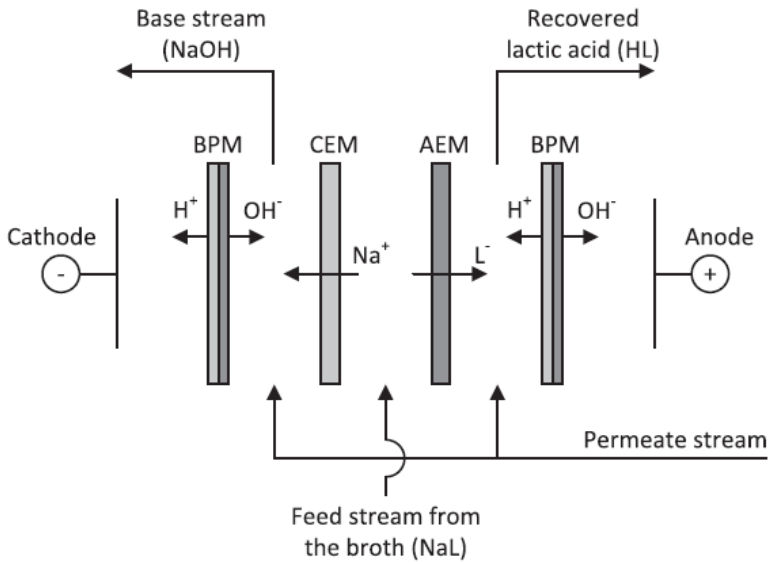
- Two stage acetic acid production

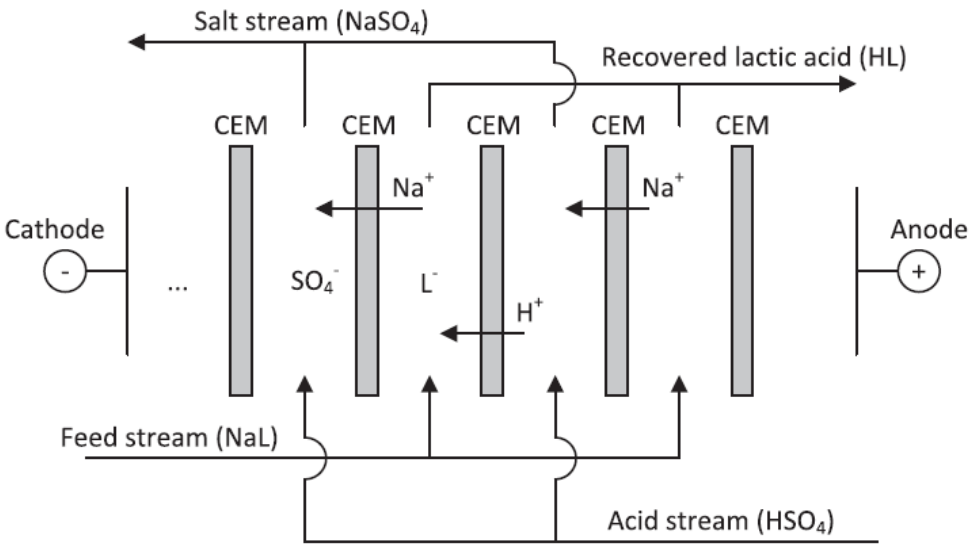


Y. He et al. / Biotechnology Advances 30 (2012) 817–858

Acid Recovery From Aqueous Solutions

- Lactic acid recovery from lactate

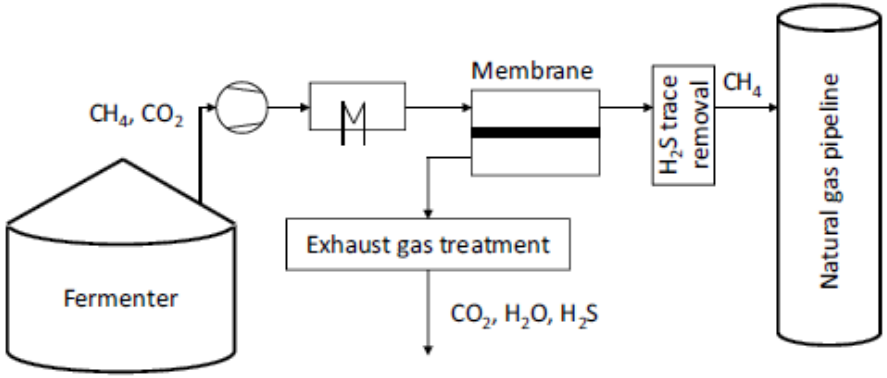


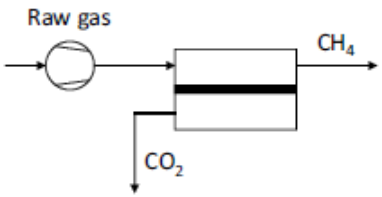


C. Abels et al. / Journal of Membrane Science 444 (2013) 285–317

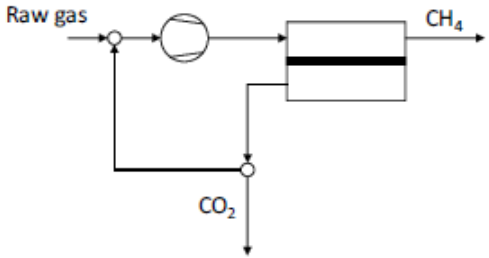
Biogas Production

- Gas purification

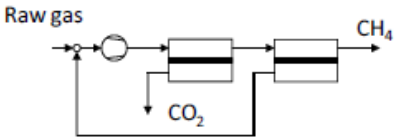




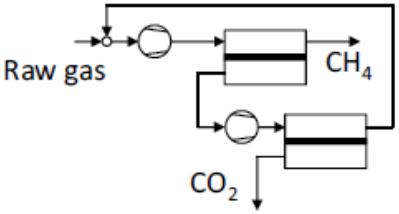
(a) Single stage without recycling.



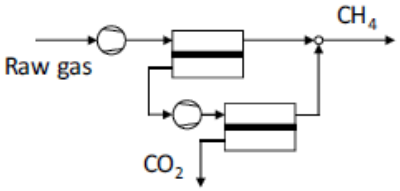
(b) Single stage with recycling.



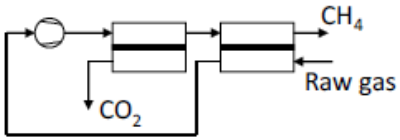
(a) One compressor is required and the permeate of the second stage is recycled.



(b) The process requires two compressors and the retentate of the second stage is recycled.



(c) In the process two compressors are required and the retentate of the second stage is mixed with the retentate of the first stage.

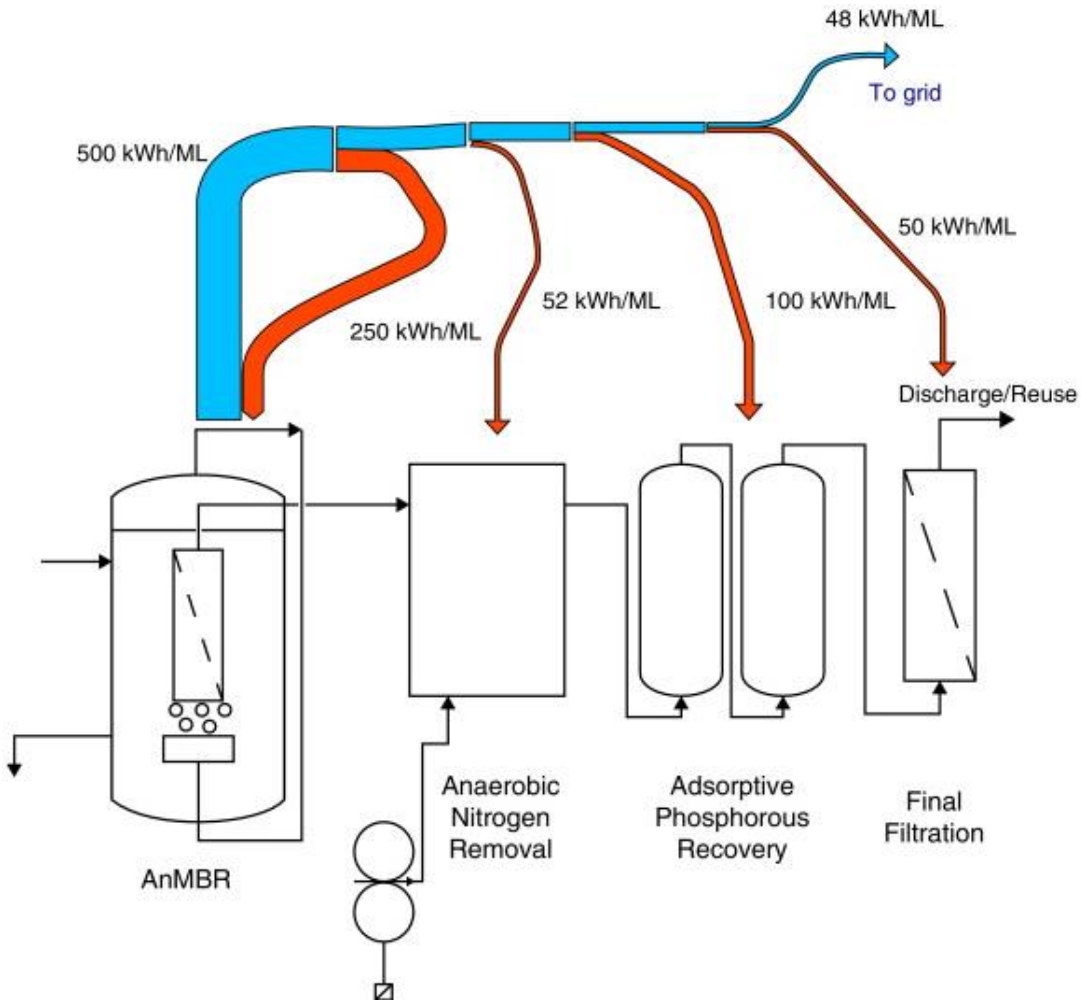


(d) In the process the feed gas is used as a sweep gas on the permeate side of the second stage. Here only one compressor is required.

M. Scholz, Ph.D. Dissertation, Aachen

Biogas Production

- Anaerobic membrane bioreactor (AnMBR)



D. J. Batstone and B. Virdis / Current Opinion in Biotechnology 27 (2014) 142–149

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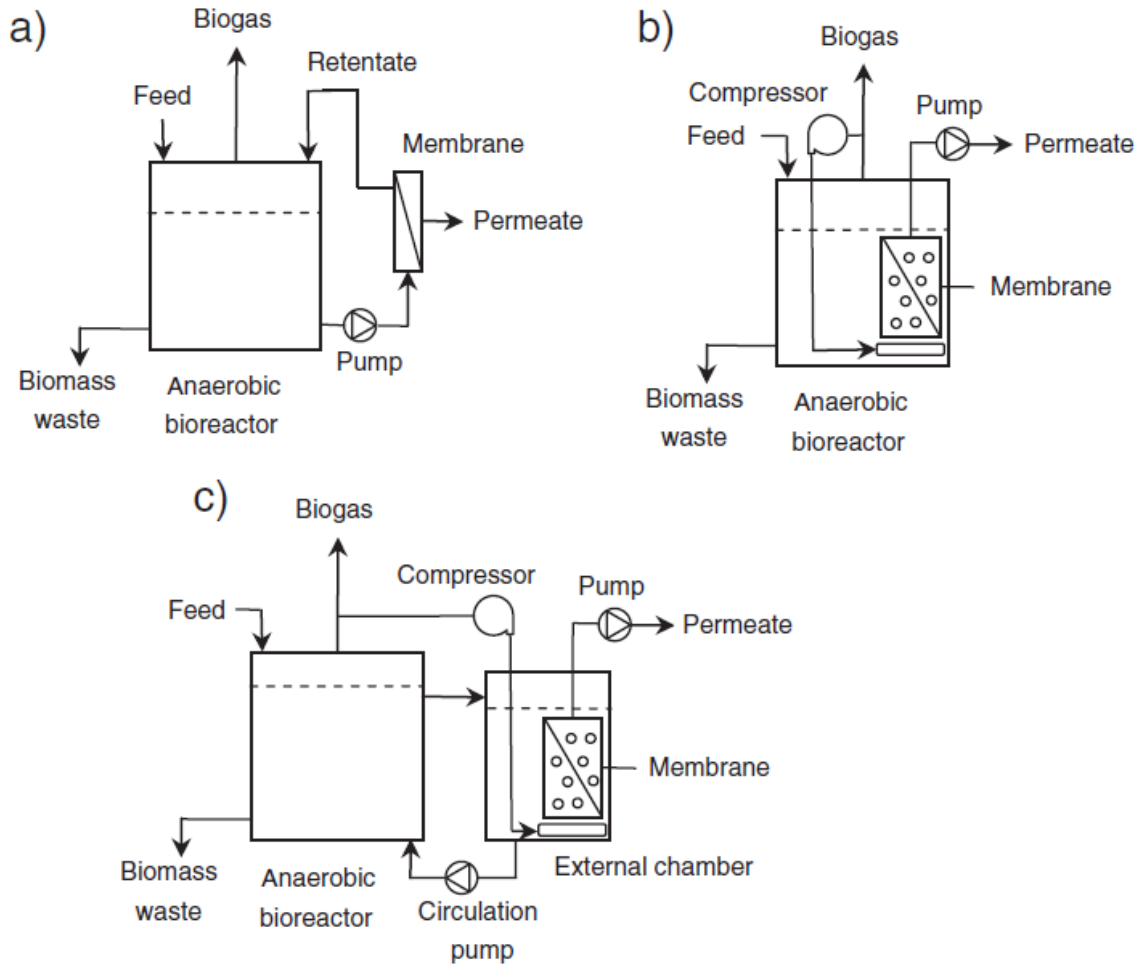

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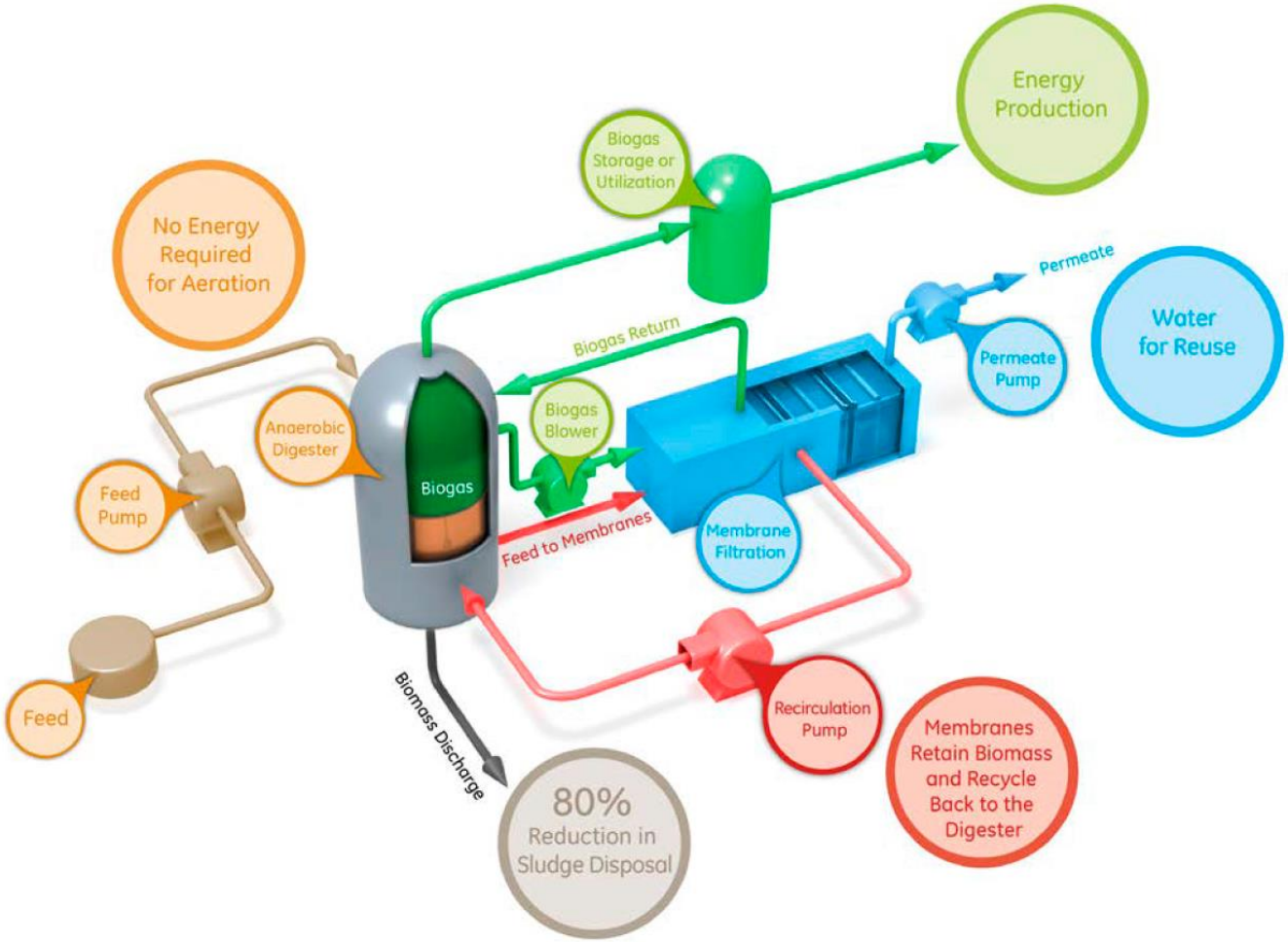
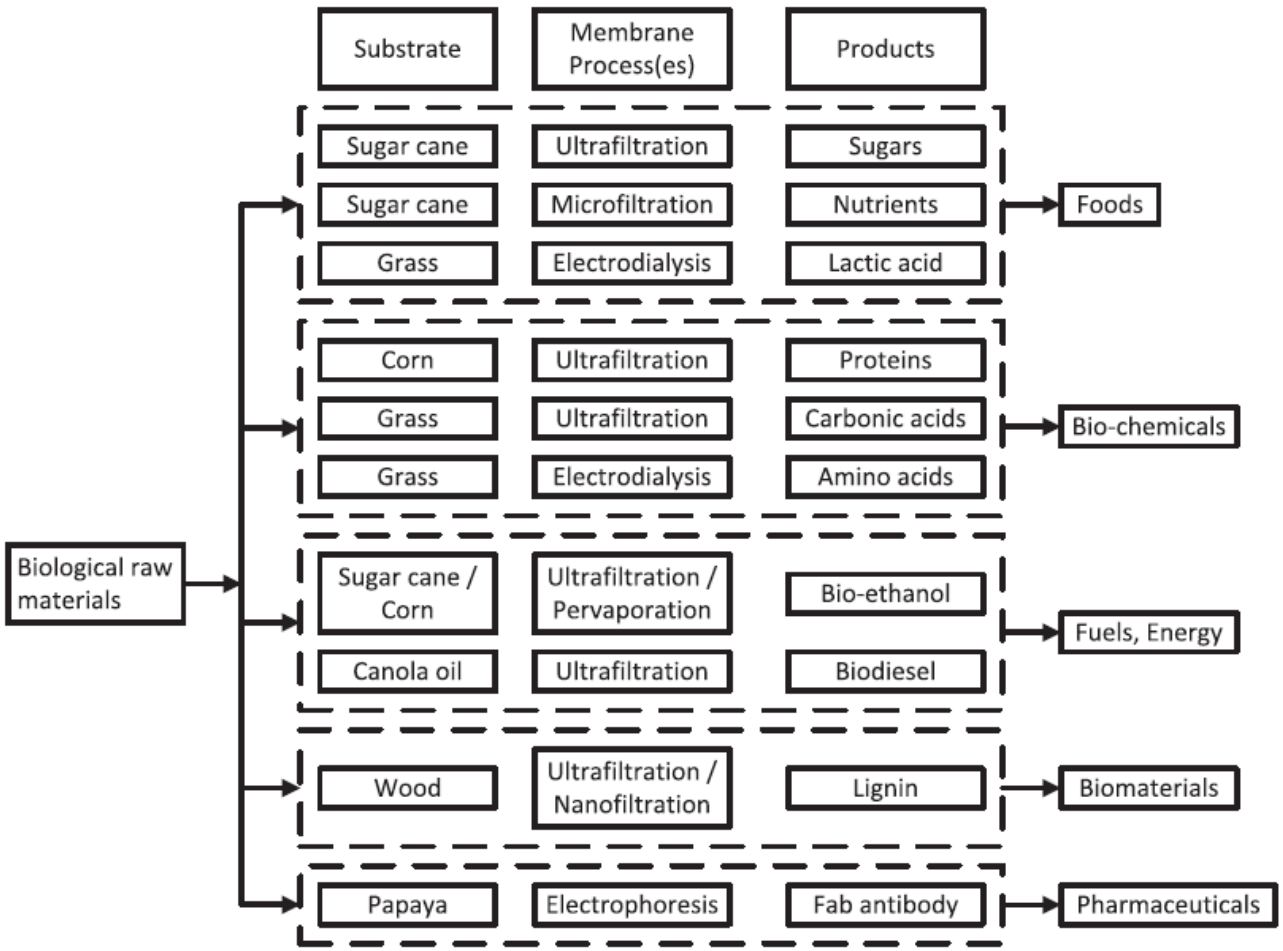
Biogas Production

- GE Water configuration



https://www.gewater.com/sites/default/files/2016-07/FSatAnMBR_EN.pdf

Spectrum of Membrane Applications



C. Abels et al. / Journal of Membrane Science 444 (2013) 285–317

Conclusions

- Separations are critical to chemical industry
- Membranes can improve sustainability of industrial petrochemical, chemical, and pharmaceutical separation processes
- Integration of separations within biorefinery offers unique opportunities for process intensification
  - Product concentration/preparation
  - Feed preparation/impurity removal
  - Water purification/recovery
  - Multi-stage fermentation