BioSep™: A New Ethanol Recovery Technology for Small Scale Rural Production of Ethanol from Biomass

Yu (Ivy) Huang, Ph.D.
Membrane Technology & Research, Inc.
1360 Willow Road, Suite 103
Menlo Park, California

&

Leland M. Vane, Ph.D.
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio

AICHE
San Francisco, California
November 2006

Ethanol production is growing globally

Brazil > 50% sugar cane crop → 40% non-diesel fuel

USA currently, 15% corn crop → 2% non-diesel fuel
> 1/3 oil displacement by 2025

EU 6% biofuel by 2010
20 - 30% replacement of oil by 2030

China Launched a program to use ethanol as a fuel

Table 1. Top Five Fuel Ethanol Producers in 2005

	Production (million liters)
Brazil	16,500
United States	16,230
China	2,000
European Union	950
India	300

Source: Christoph Berg

Table 2. Top Five Biodiesel Producers in 2005

	Production (million liters)
Germany	1,920
France	511
United States	290
Italy	227
Austria	83

Source: F. O. Licht

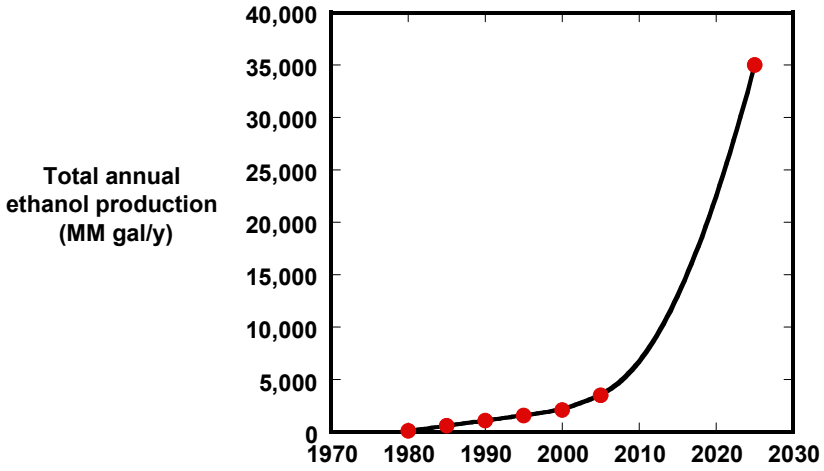
How much ethanol can we produce?

Current:

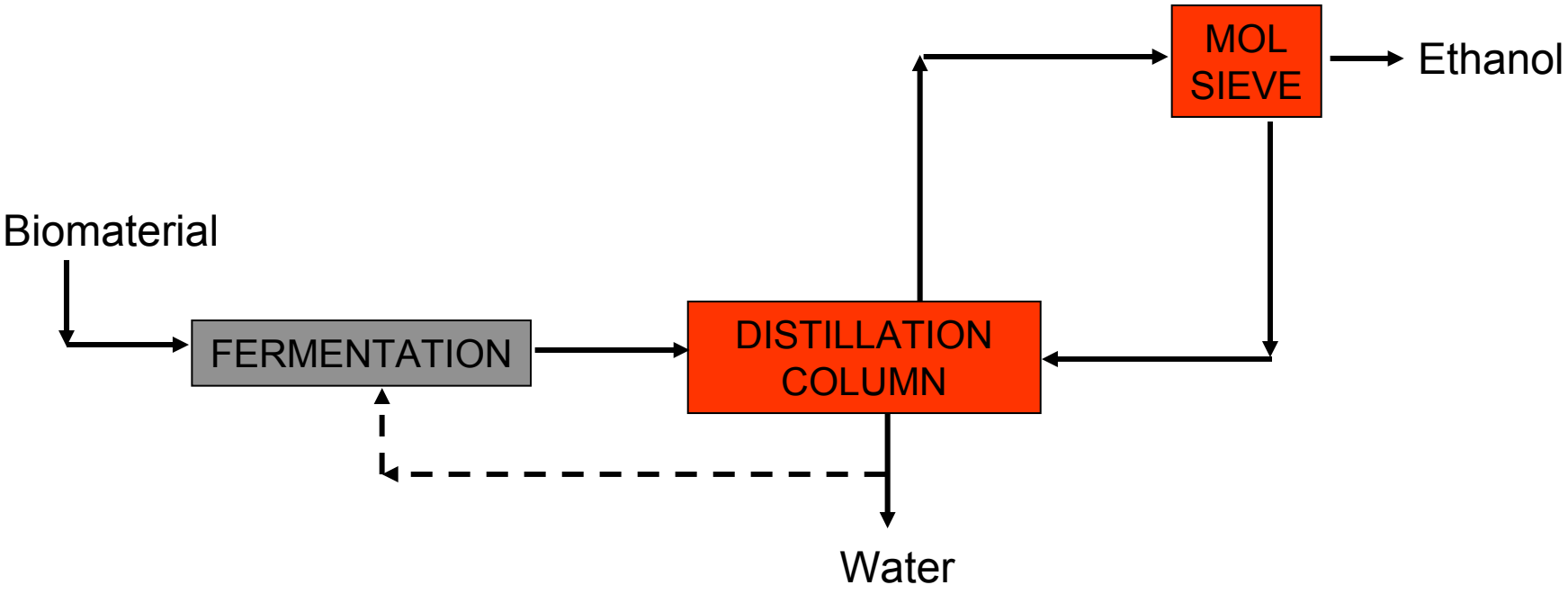
- Oil consumption: 873 MM gal/day, 58% import
- Ethanol production: 12 MM gal/day

Forecast for 2025:

- Oil consumption from import: 870 MM gal/day
- The President's goal: replace 75% import from Mideast – 100 MM gal/day



Conventional Bioethanol Process



Ethanol from Biomass

Two competing driving forces:

- Ethanol concentration/purification by distillation/molecular sieve is only economical at > 40-50 MM gal/year

  → driver for central production

- Transport of biomass over long distances is costly and energy inefficient

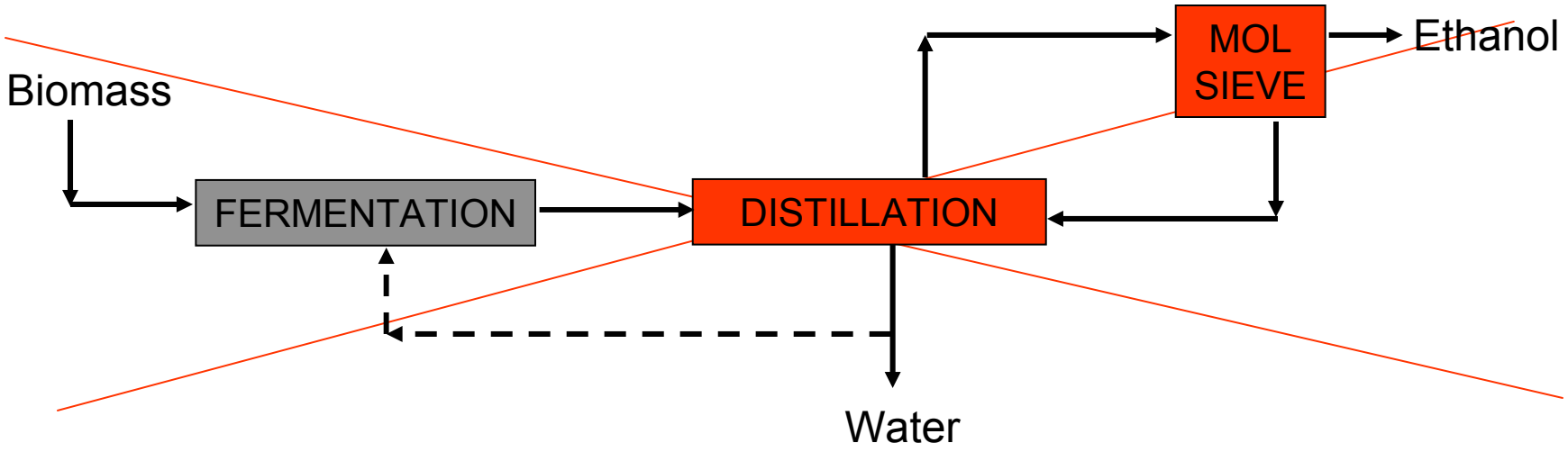
  → driver for distributed production in rural areas

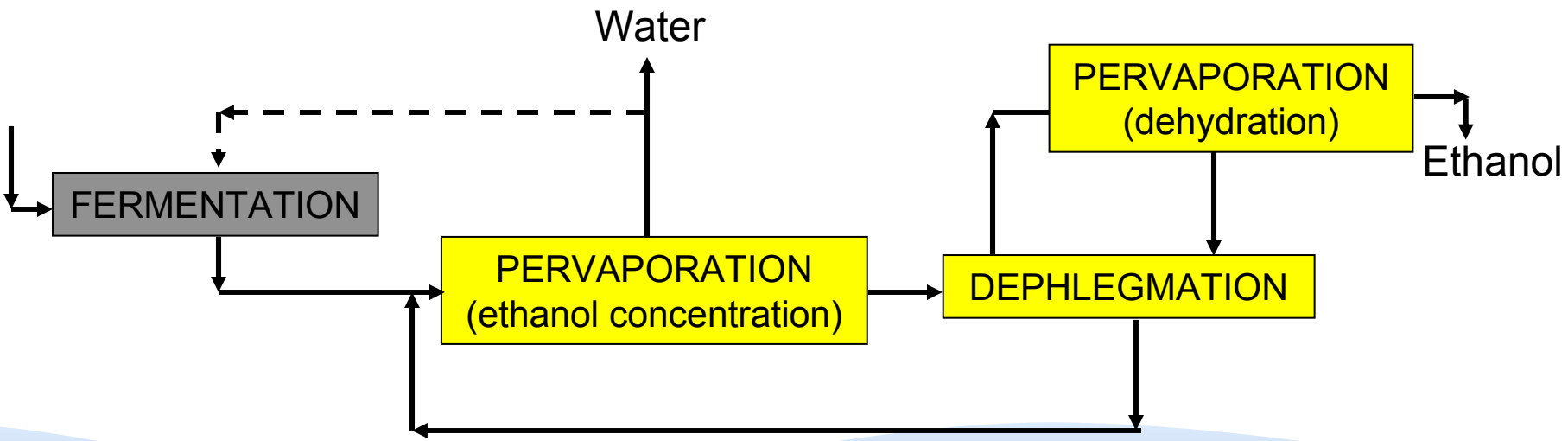
  (with added benefits for rural economies)

Can this problem be solved?

The solution is membranes (of course).

MTR BioSep Process



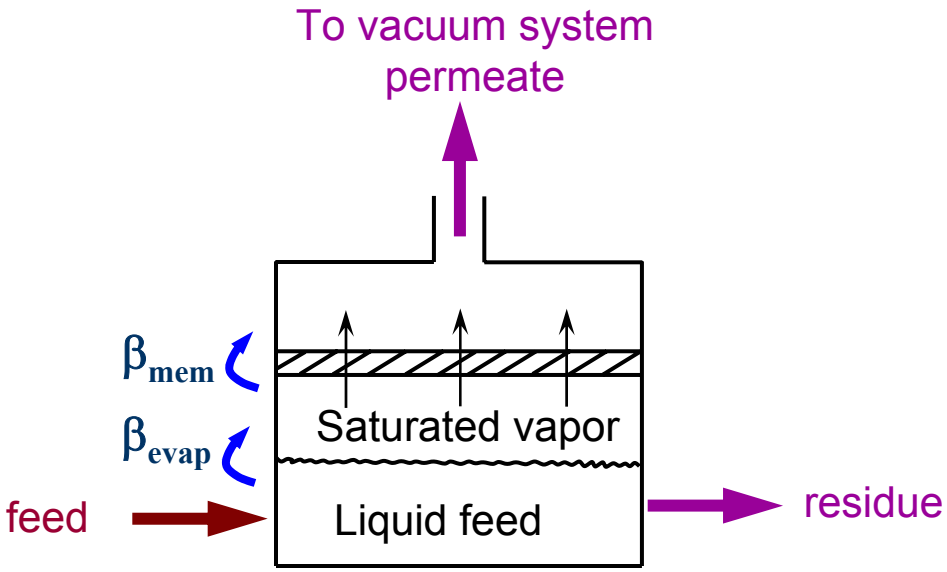


Applications of BioSep Process

- Small biomass waste streams generated in the production of
  - -- beer, wine, and juice
  - -- cane and beet sugar
  - -- potatoes, yams, and other root crops
  - -- cheese, soft drinks, confectionery and packaged foods
- Replace molecular sieve in conventional corn to ethanol plant
- Replace distillation in conventional corn to ethanol plant

What is pervaporation?

Pervaporation = Permeation + Evaporation



Separation factor $\beta = \beta_{evap} \cdot \beta_{mem} = \dfrac{y_1/(1-y_1)}{x_1/(1-x_1)}$

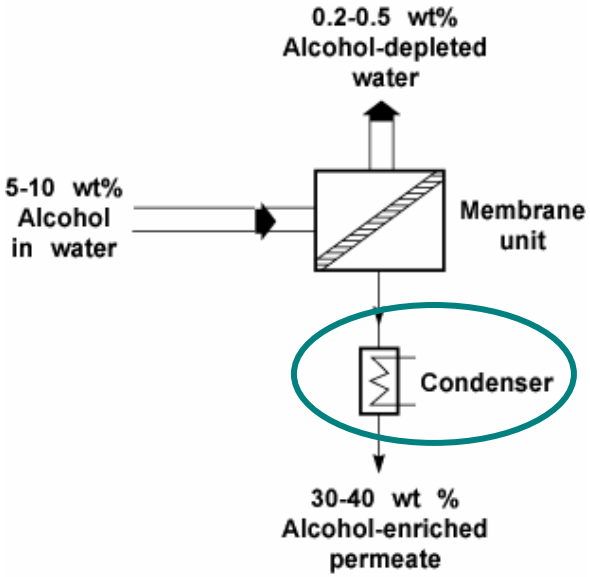
Not limited by thermodynamic vapor-liquid equilibrium (VLE)

Pervaporation Applications

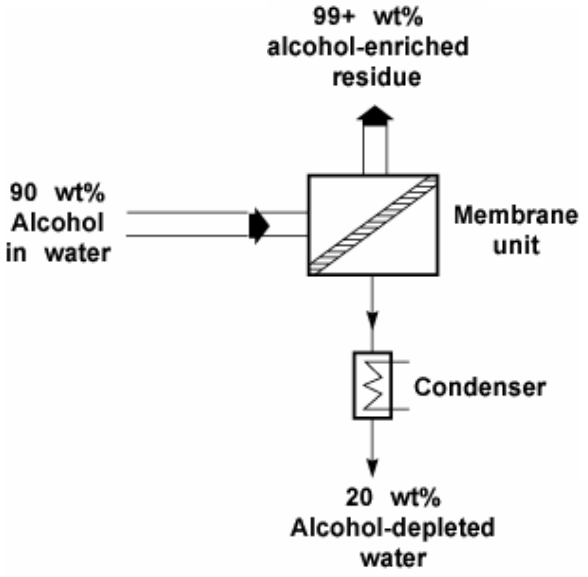
- Dehydration of organic solvents
  - Primarily dehydration of ethanol and iso-propanol
  - First commercial plant in the world was put into operation in Brazil in 1984.
  - Commercial application of inorganic membranes
  - Needs improvements to be competitive with molecular sieves in large scale applications
- Removal and recovery of organic solvents from water
  - Commercially successful applications are hard to find

Pervaporation using Ethanol-Permeable and Water-Permeable Membranes

Ethanol removal from 5-10 wt% ethanol/water mixture

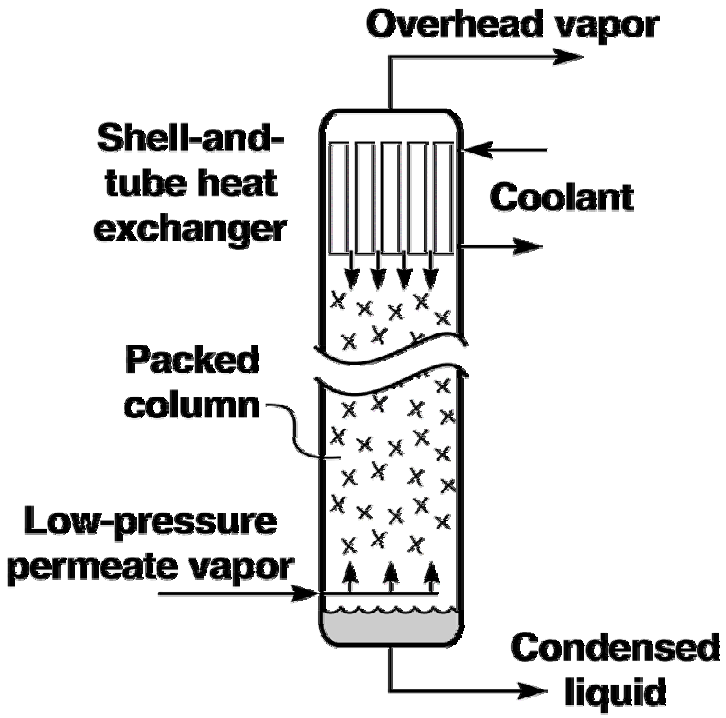


Water removal from 90 wt% ethanol/water mixture



Fractional condensation (dephlegmation) improves separation

Packed-column dephlegmator



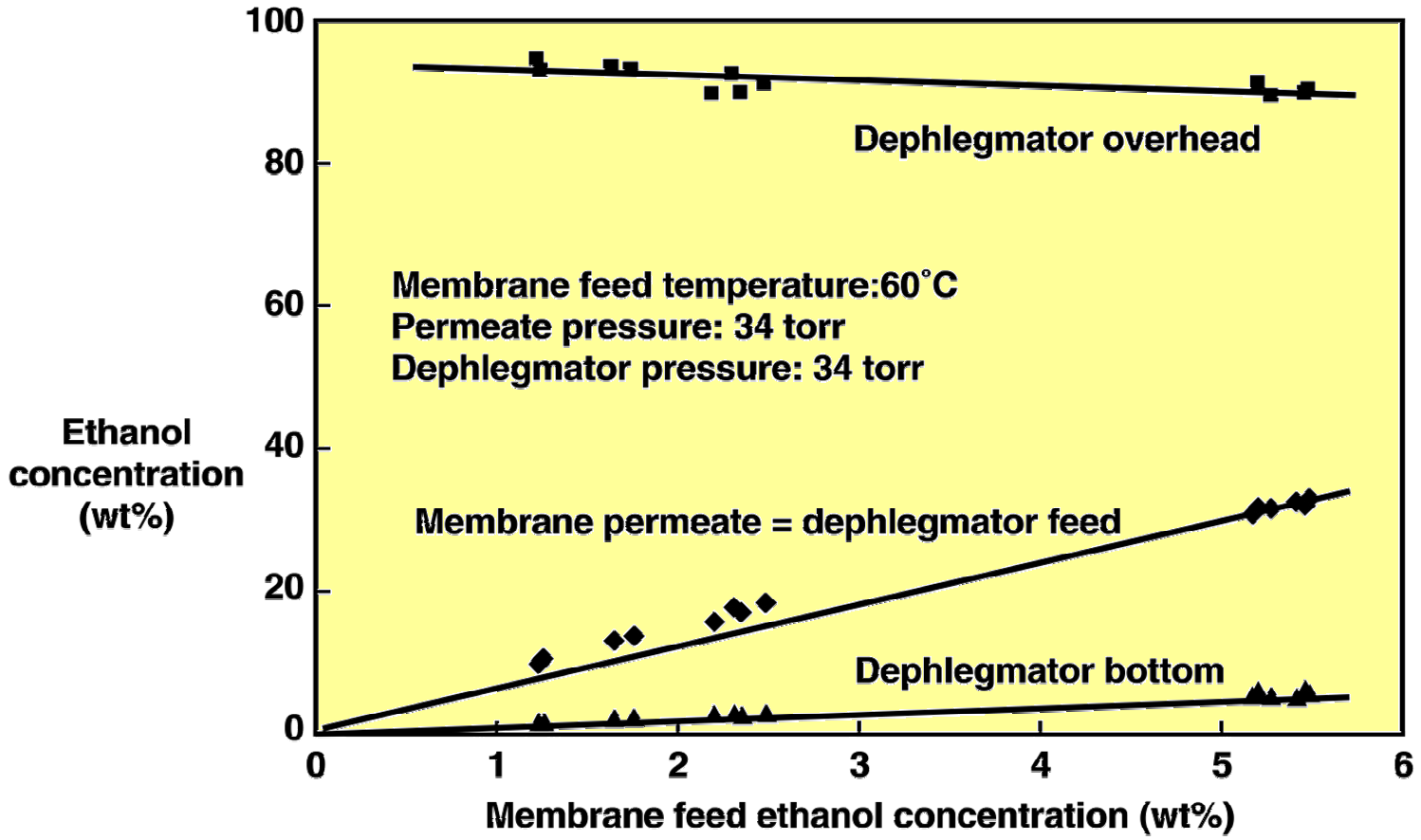
Vapor enters at the bottom

Vapor is partially condensed at the top

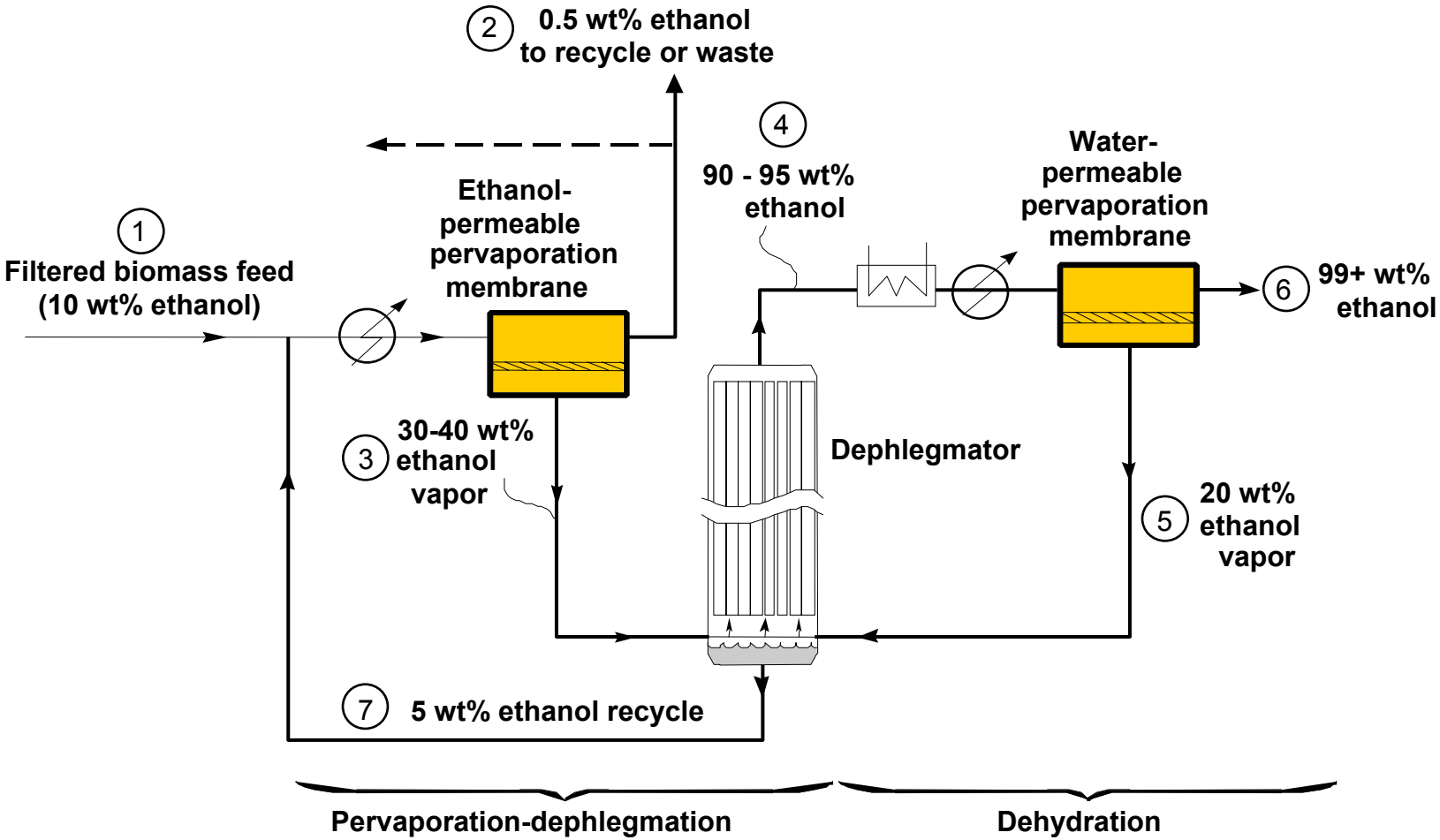
Condensate trickles down, creates a counter-current effect

Achieves 4 to 6 theoretical stages of separation

Significant increase in separation performance ….

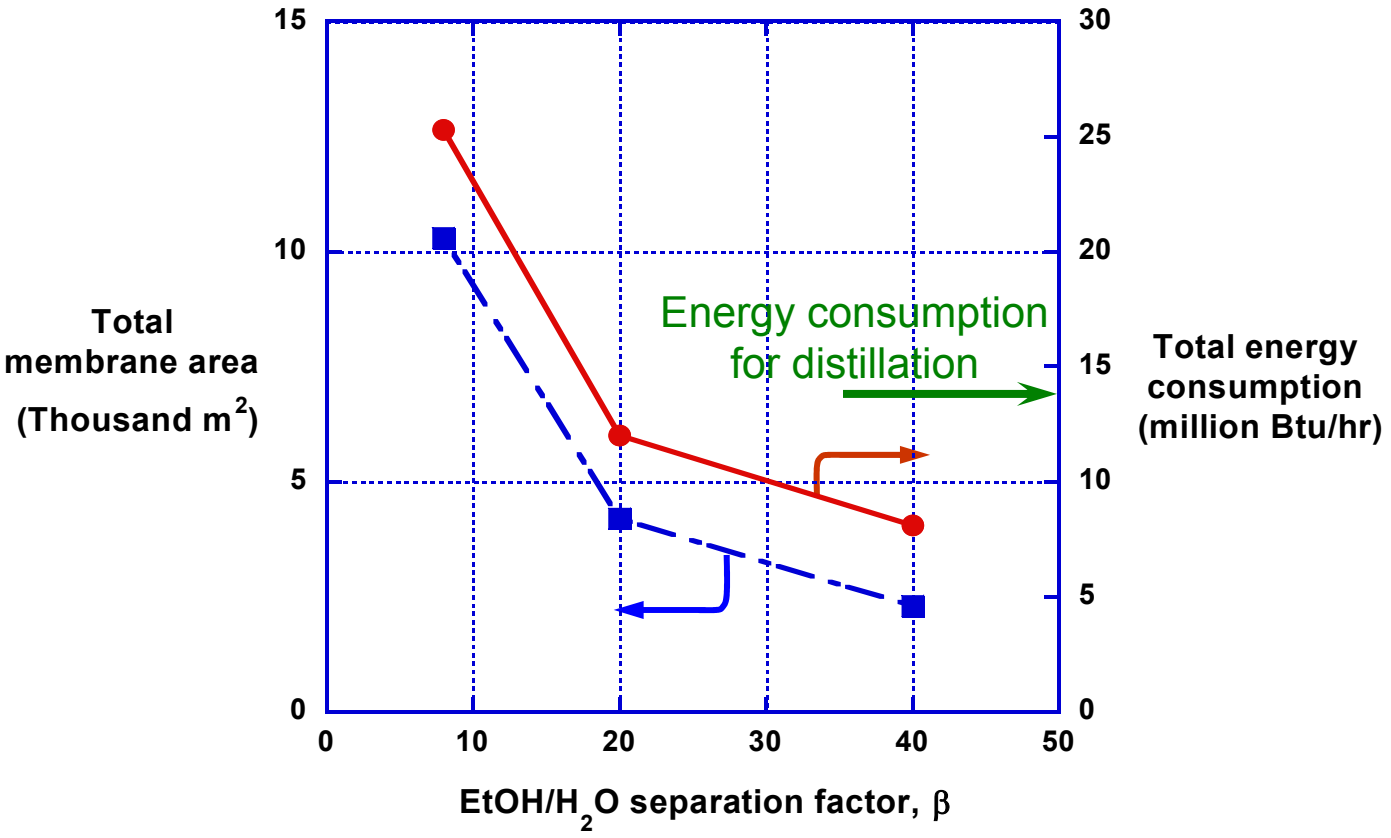


MTR BioSep Process



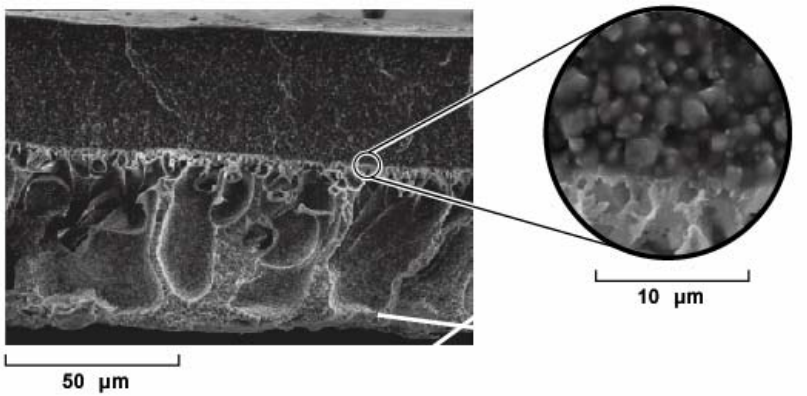
Ethanol Permeable Membranes

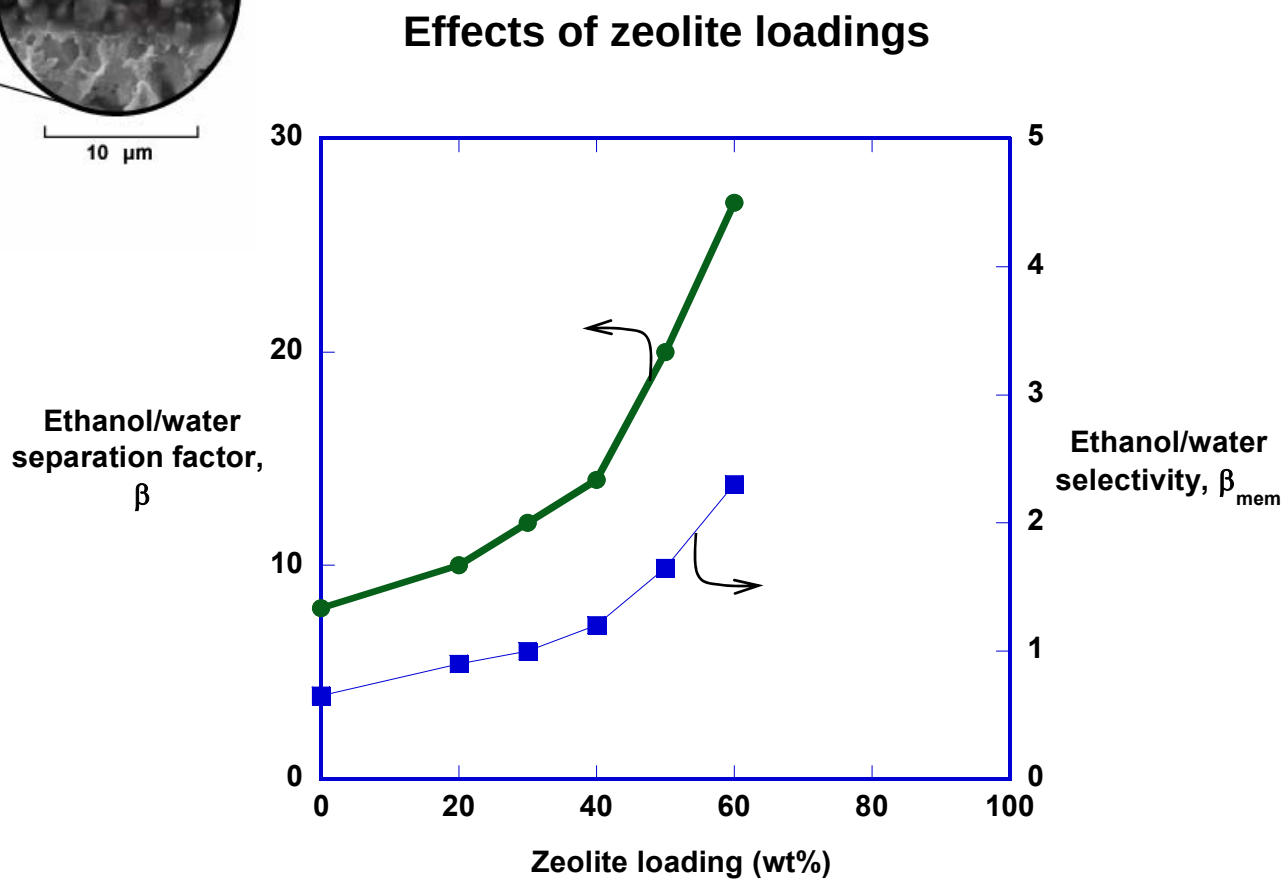
5 MM gal/year plant, feed ethanol concentration = 10wt%



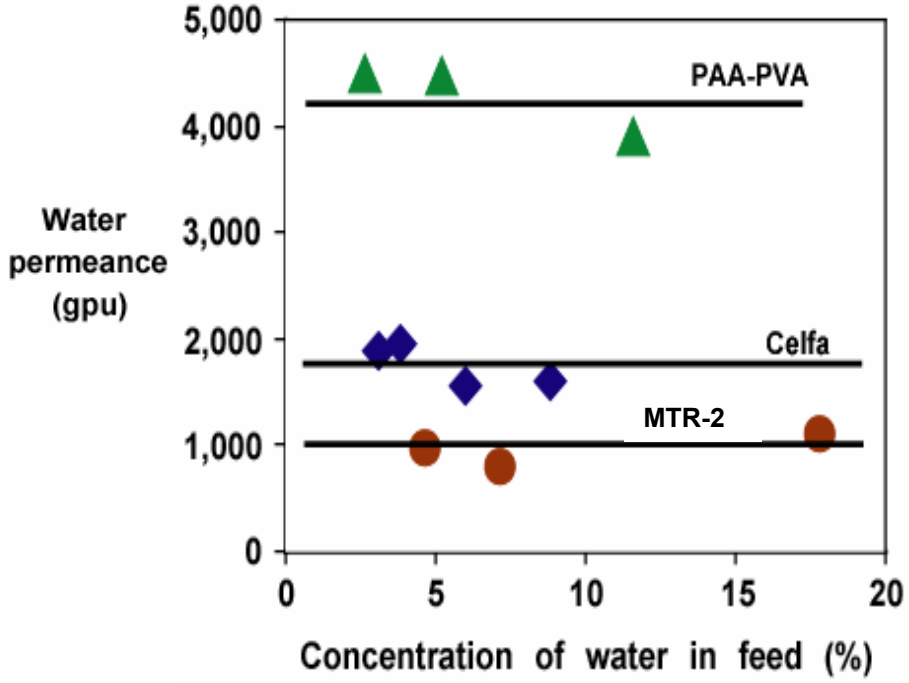
Solution: zeolite mixed-matrix membrane

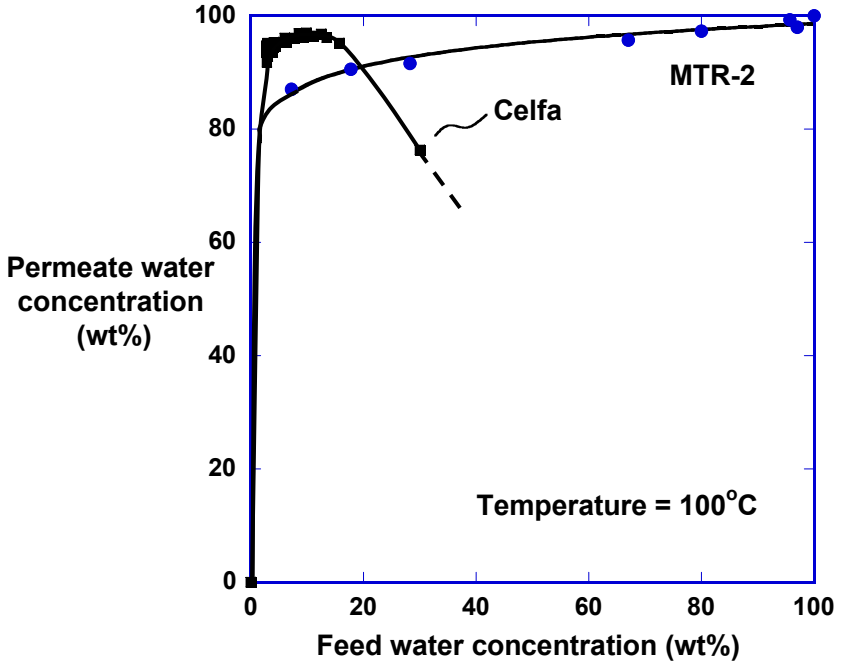
Mixed-matrix Membranes



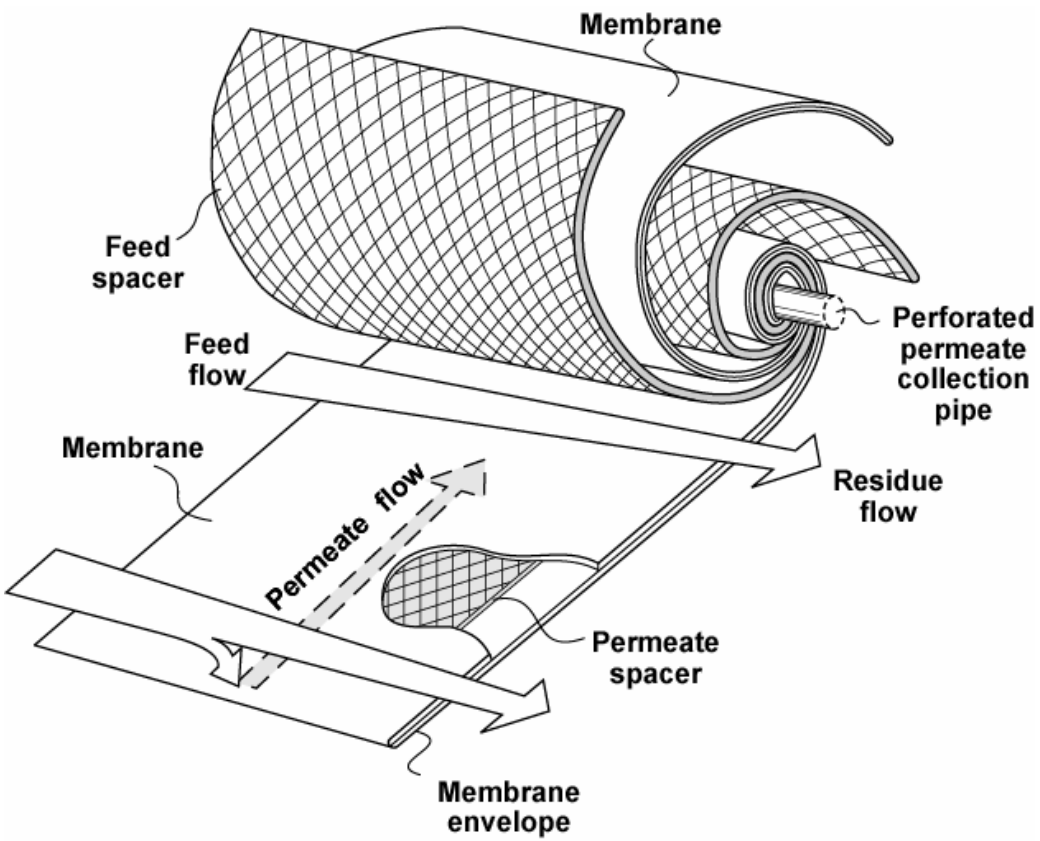


Ethanol Dehydration Membranes





Package membranes into spiral-wound modules



Conclusions

- Pervaporation offers alternative to distillation for ethanol recovery
  - Higher selectivity membranes will yield energy savings
  - Membranes scale down better than distillation
- Pervaporation offers alternative to molecular sieves for water removal
  - Chemical and thermal stable membranes developed
  - Systems commercially available
- Synergies achievable through use of pervaporation for both ethanol recovery and dehydration
  - Combined with dephlegmation condensation

Acknowledgments

- U.S. Department of Energy
- U.S. Department of Agriculture
- Jennifer Ly, Tiem Aldajani, Karl Amo of MTR
- Vasudevan Namboodiri, Travis Bowen of EPA

Questions?