المؤتمر العالمي لتحلية المياه 2024
معالجة ندرة المياه
ديسمبر 8 - 12
أبوظبي - الإمارات العربية المتحدة

IDRA WORLD CONGRESS 2024
ADDRESSING WATER SCARCITY
8 - 12 DECEMBER
ABU DHABI - UNITED ARAB EMIRATES

IDRA
Desalination and Reuse

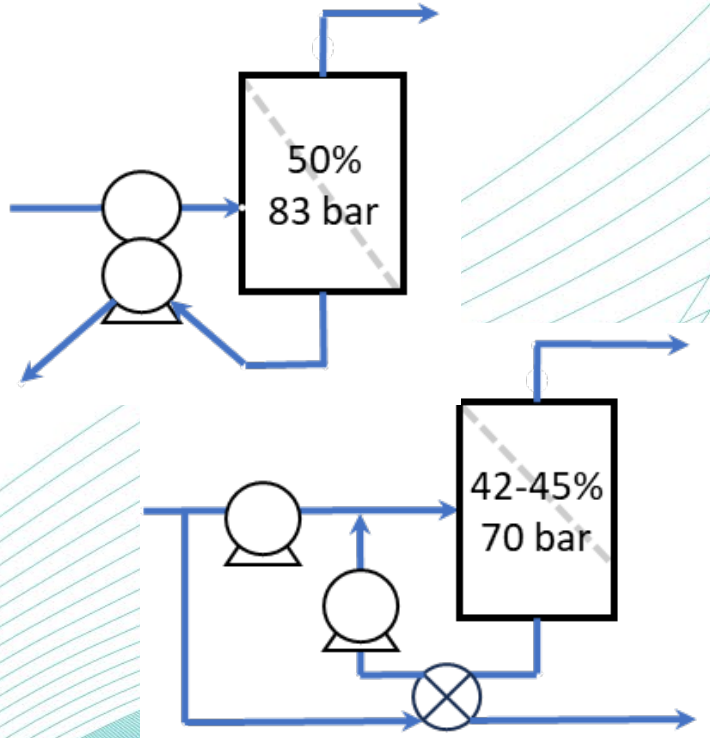
دائرة الطاقة
DEPARTMENT OF ENERGY

High Recovery Reverse Osmosis

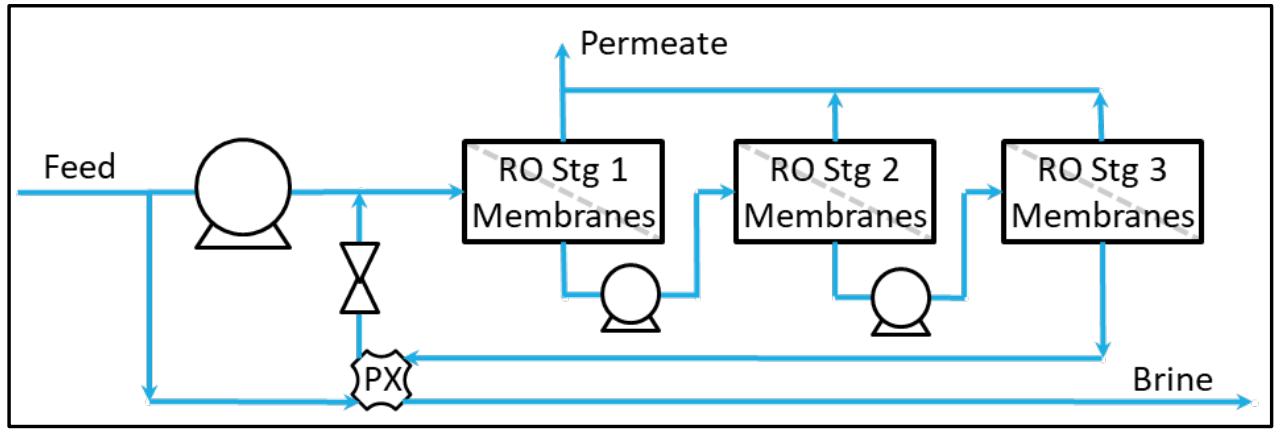
Richard L. Stover, Ph.D

What is the optimum recovery rate for SWRO?

- Optimum recovery rate balances capital cost (high recovery) and operating cost (low recovery) for lowest total cost.
- Optimum with HF CA & Pelton turbines (before ~2004) was max possible = ~50% = 83 bar.
- Spiral TFC & isobaric energy recovery devices reduced optimum to 42-45% because brine energy became almost free.
- Higher cost of capital, lower energy costs and new technology have made high recovery cheaper.

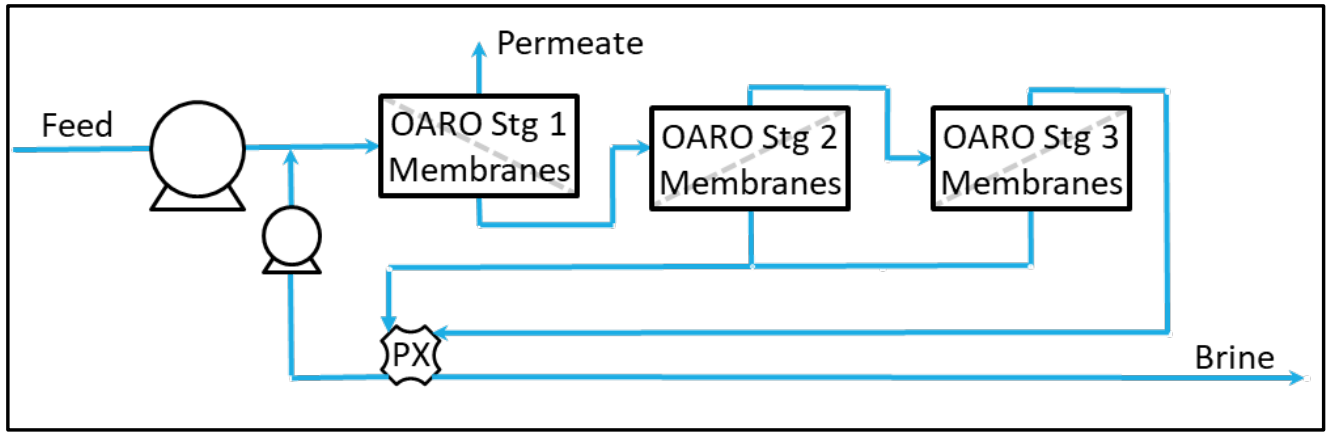


Higher Recovery in SWRO = Multiple Stages



Traditional multi-stage RO

- Hydraulic pressure increased as osmotic pressure increases
- Interstage pumps ☹
- Brine throttling or turbine ERD ☹

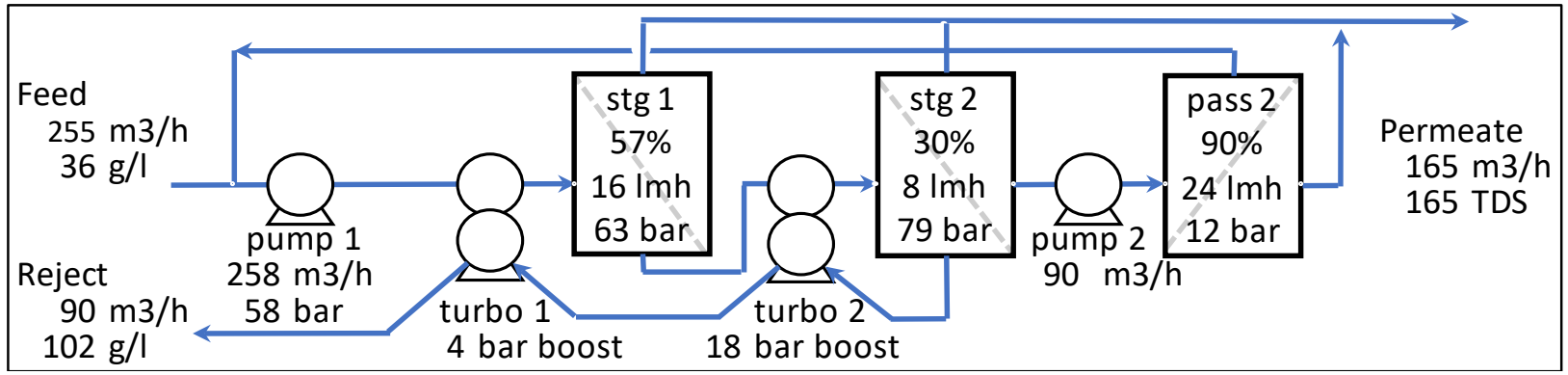


Osmotically Assisted RO (OARO)

- No interstage boosting
- Brine membranes are “loose”
- Permeance ramp
- Brine stage permeate recycled

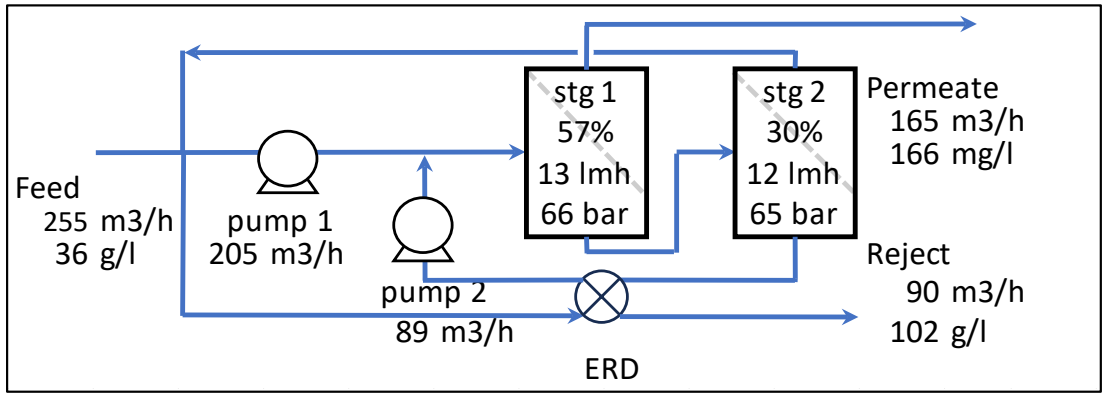
OARO provides a new way to balancing flux in multi-stage RO

Two-Stage SWRO: Two Turbos or OARO+PX



Two turbos
- Interstage boosting
- Second pass needed
- Turbo 1 contributes little

65% recovery



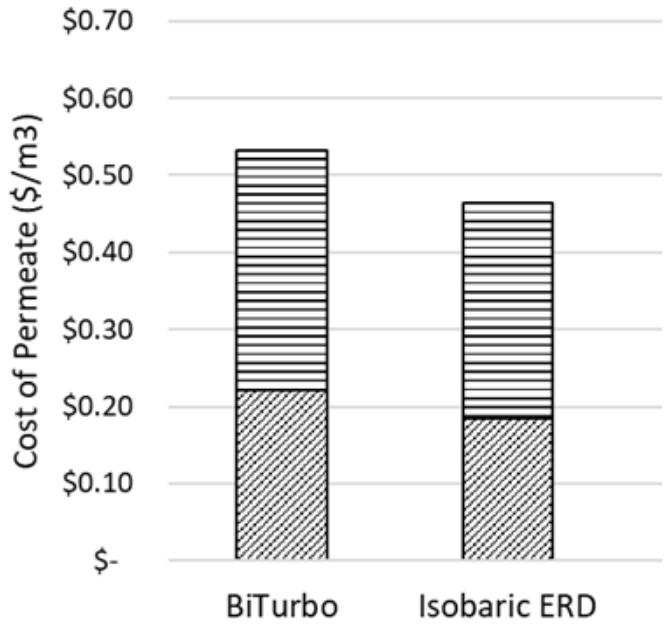
OARO + Isobaric ERD
- Built-in second pass
- Isobaric ERD

A simpler, more efficient process with OARO

Two-Stage SWRO with Two Turbos or PX+OARO

	BiTurbo	Isobaric ERD
Feed m^3/d	**6,116**	**6,098**
Permeate m^3/d	**3,960**	**3,960**
Recovery Rate	**65%**	**65%**
CAPEX ($)	3,175,238	2,668,216
OPEX ($/y)		
Membranes, 5 yr life	50,960	41,160
Spares, 5% of equip cost	29,739	23,770
Cartridge filters, 1 mo life	12,480	12,288
Chemicals	42,308	42,192
Specific Energy, kWh/m^3	3.62	3.26
Power @ $0.06/kWh	313,799	282,391
Total OPEX	449,285	401,801
COST ($/$m^3$ permeate)		
CAPEX (8% int, 20 years)	$ 0.22	$ 0.19
OPEX (power, spares, chems)	$ 0.31	$ 0.28
Total /m^3 permeate	**$ 0.53**	**$ 0.46**

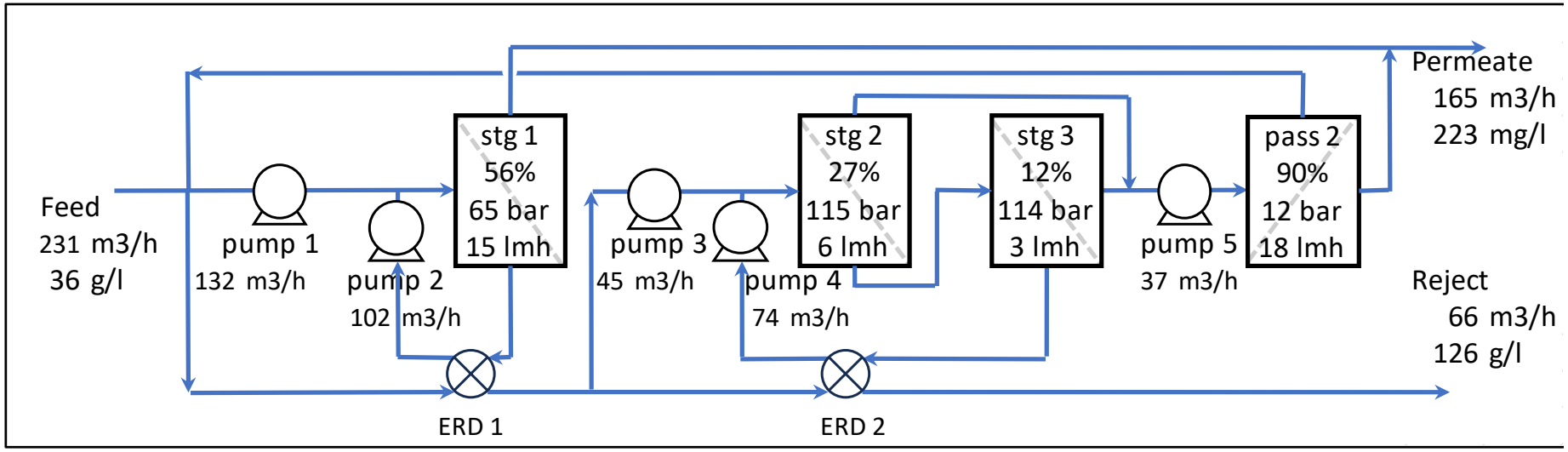
process cost / m3 perm



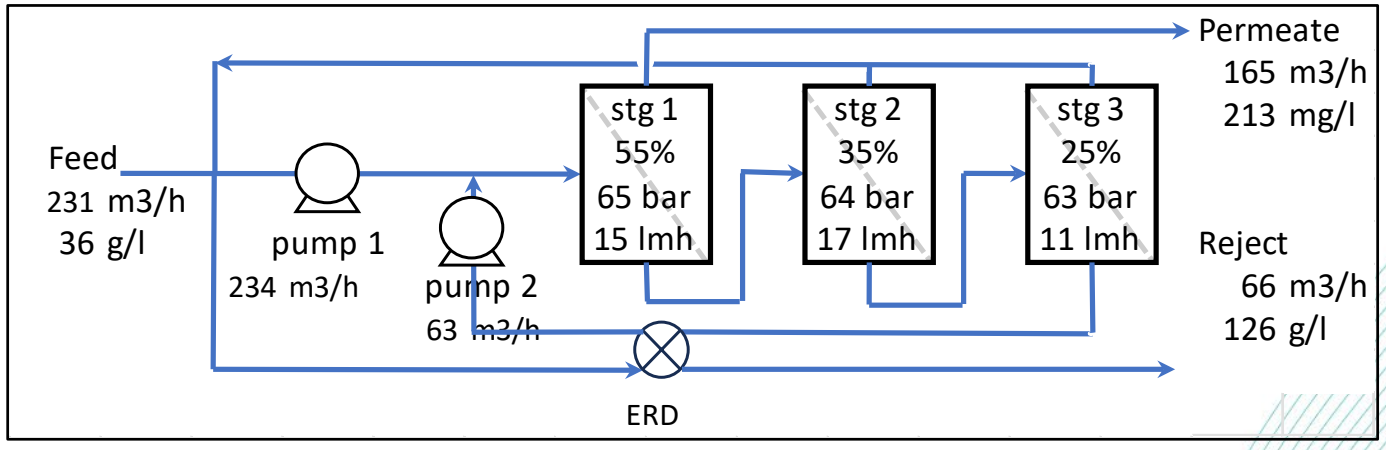
- **16% lower CAPEX**
- **10% lower energy**
- **13% lower total cost**

…. with PX+OARO

Three-Stage SWRO with UHPRO vs OARO



71% recovery



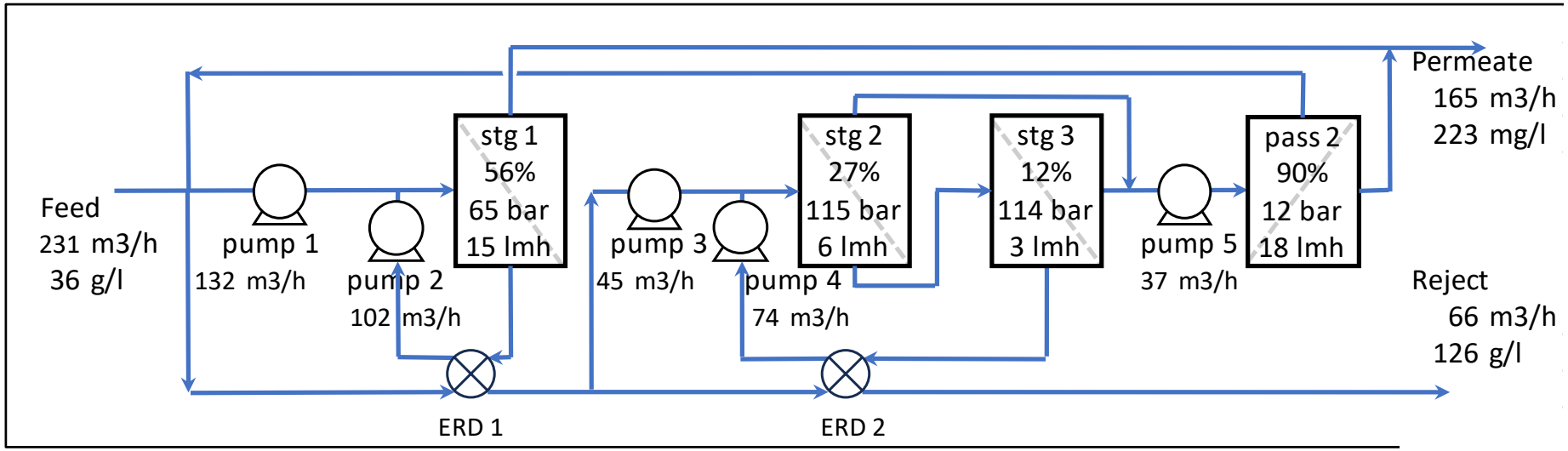
UHPRO

- Break 1st stg press for UHP pump
- Conv & UHP ERDs
- Low UHPRO flux
- 2nd pass needed

OARO

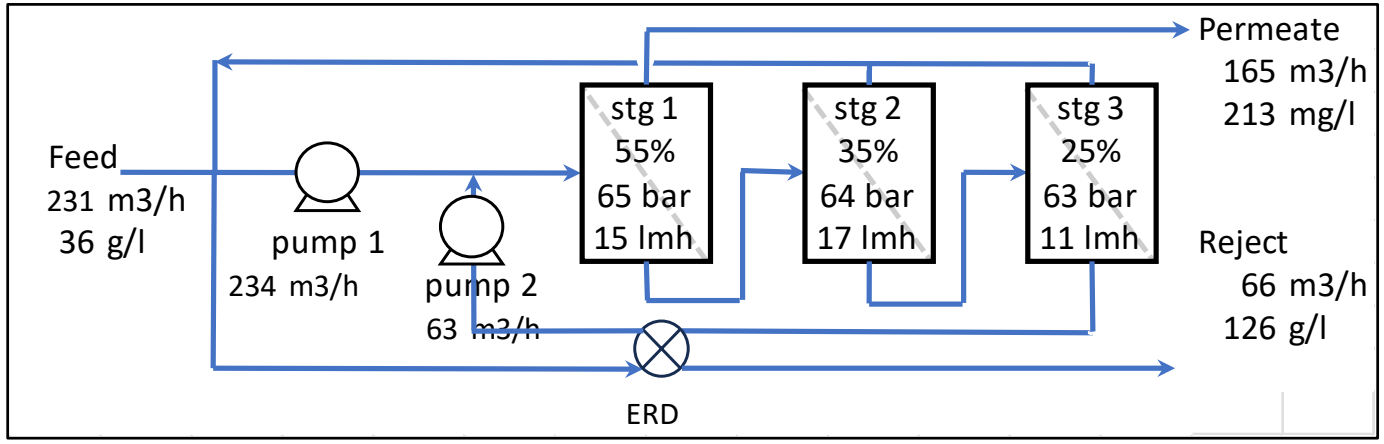
- Add a brine stage to previous design
- No interstage boost
- Built-in second pass

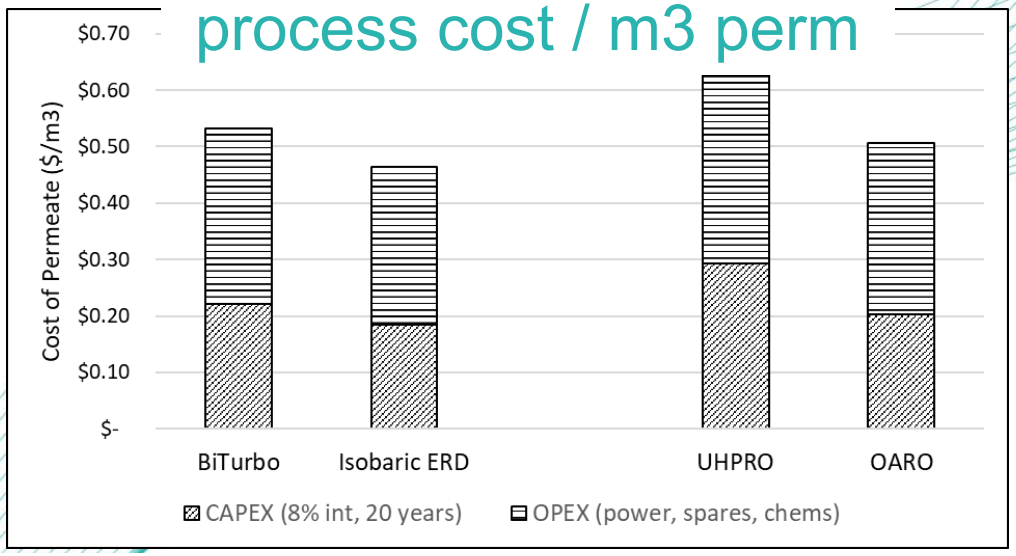
Three-Stage SWRO with UHPRO vs OARO



- 3% HIGHER energy
- 9% lower OPEX
- 31% lower CAPEX
- 19% lower total cost

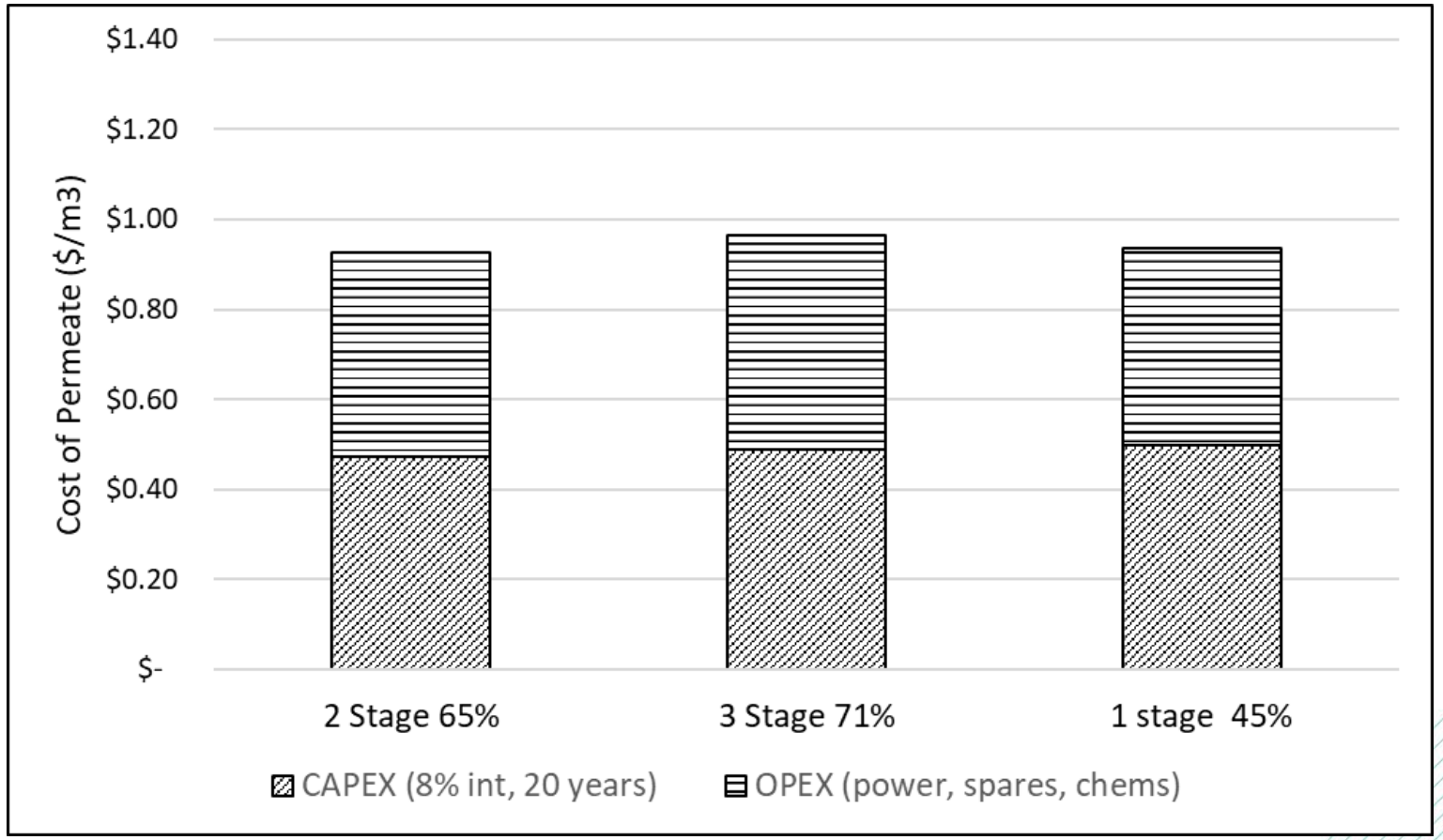
…. with OARO





OARO + isobaric energy recovery → lowest total cost

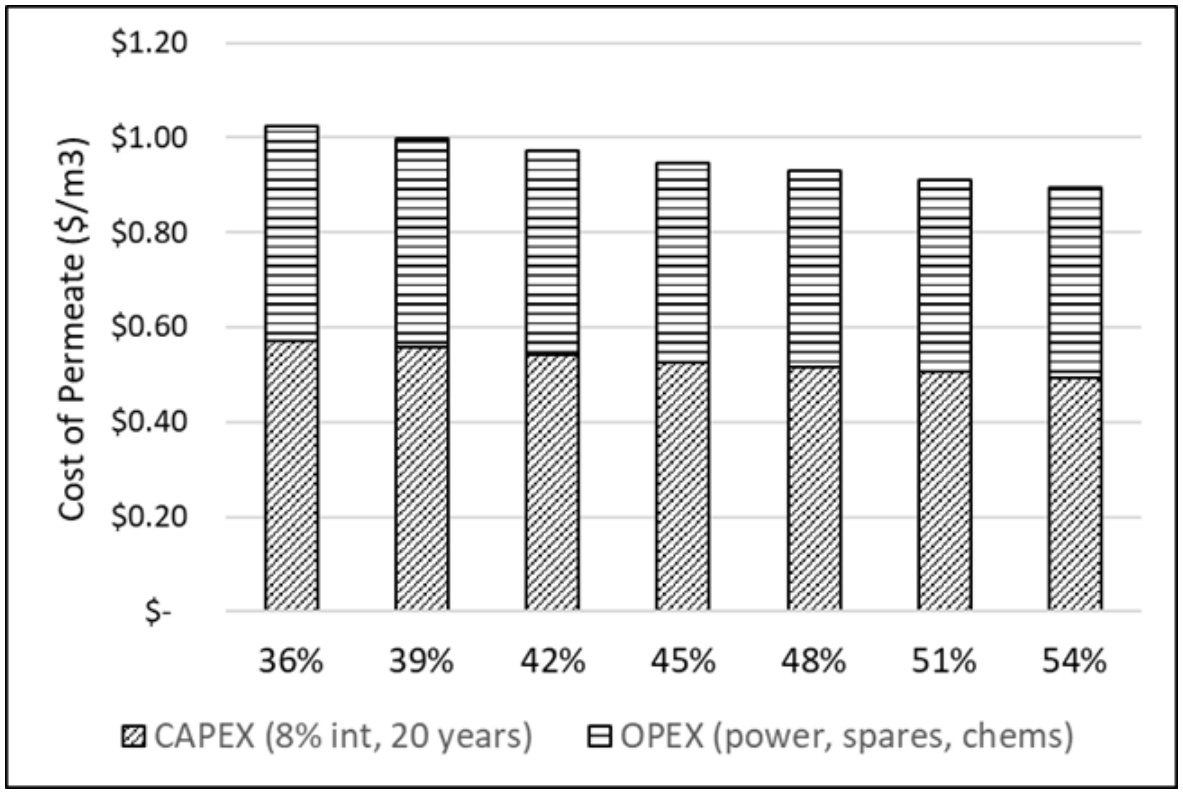
Full Installation Costs 45% vs 65% vs 71% Recovery

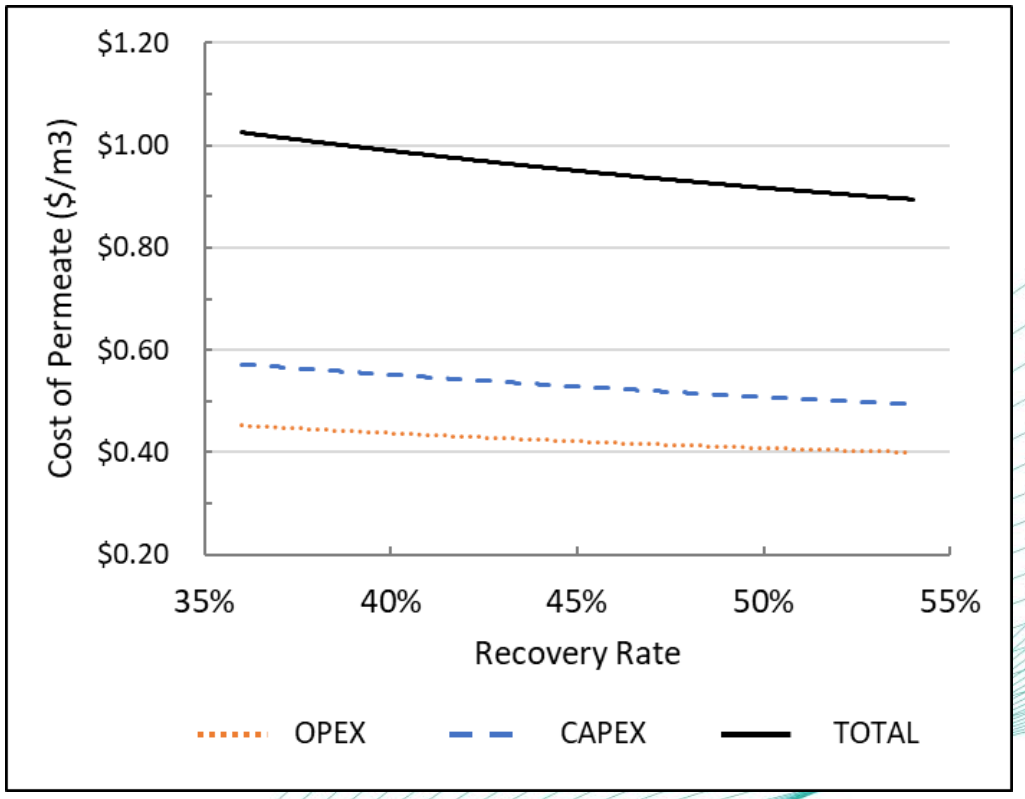


- Includes pretreatment, intake, outfall
- Conventional single stg vs OARO multi stg+IERD
- Higher civil costs and more pretreatment chems at 45% recovery
- Higher energy at 71%
- **65% recovery = lowest total cost**

Stover: are you crazy? 65% recovery SWRO lower cost than 45%??

Optimum Recovery Rate – Single Stage





- Equal permeate flow for each recovery rate
- Internal staging and split partial 2nd pass for equal permeate quality
- Maximum recovery 54% corresponding to flux distribution limit

Lowest total cost favors maximum recovery

Conclusions

- **Optimum recovery SWRO >54%**
  with current technology, typical power cost, current interest rates
- **High recovery SWRO should be considered for**
  - **High capital costs or interest rates**
  - **Cumbersome or expensive intake, outfall, pretreatment**
  - **Low power cost**
- **65% recovery SWRO: OARO + isobaric ERDs cheaper than two turbos.**
- **71% recovery SWRO: OARO significantly cheaper than UHPRO.**