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An Innovative Approach to Managing Produced Water and Frac Flowback in the Marcellus Shale

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BUILDING A BETTER WORLD

Somerset Regional Water Resources

- Building several commercial frac flowback and produced water management facilities
- First is in Somerset County, PA
- MWH was retained for permitting, engineering, and construction services
- Awaiting construction permit

- Unique approach to water management

Lack of Sufficient Water Supply is Limiting O&G Production

- Need 1 to 8 Millions gallons of water per well for hydrofracturing
- Surface Water Withdrawals
  - Concerns about depletion of water resources, especially in drought years
  - Impacts to aquatic life
  - Negative publicity
  - Ability to get withdrawals approved
  - Cost can be significant ($0.1/bbl to $2/bbl)
  - Don't really need high quality water, but consistent quality is important

Required Water Quality for Fracing

- Largest water use for production
- Desired water quality varies
- General guidelines

Frac Water Quality Requirements	
Chlorides	<30,000 typical but up to 90,000 mg/L
Hardness	<2,500 mg/L
Calcium	<350 mg/L
TSS	<50 mg/L
TDS	<50,000 mg/L typical
Iron	<20 mg/L
Bacteria	<100 cells/100mL
Oil	<25 mg/L

Acid Mine Drainage
An Alternative Water Source

- Pennsylvania's single greatest source of water pollution
  - Contaminated 3,000 miles of streams
- Often has low pH (<5) and elevated levels of iron and sulfate
- Can have elevated hardness
- TDS typically around 1,000 mg/L

- Treatment is required prior to surface discharge
- But suitable as frac water with little or no treatment

Wastewater Management is also a Limiting Factor in O&G Production

- Frac Flowback
  - High flows for short duration
  - 10 to 40% of frac fluid recovered
  - Most recovered in first 1 to 2 weeks
  - TDS quickly climbs to 30,000 mg/L up to 200,000 mg/L
  - Contains numerous chemical additives and naturally occurring constituents
- Produced Water
  - Lower flows (2 to 30 bpd per well)
  - Potentially very high TDS (100,000 to 300,000 mg/L)
  - Continues to flow for the life of the well

Frac Flowback & Produced Water Management Strategies

- Evaporation in pits/ponds w/enhancements
- Injection/disposal wells
- Discharge to POTW
- Direct reuse for drilling and fracing
- Treatment for reuse or surface discharge
- Thermal/mechanical evaporation
- Evaporation/distillation for reuse or surface discharge

Evaporation (from ponds)

- Natural pond evaporation not practical
  - >40 in/yr precip & < 30 in/yr evap
  - Poor evaporation at high salinity
  - Crusting over

Evaporation (from ponds)

- Use of sprayers can enhance evaporation
- Potential Issues
  - Regulatory hurdles
  - Salt deposition ➪ environmental impacts
  - Odors and VOC emissions
- Ponds may still be part of management strategy

Injection or Disposal Wells

- Significant regulatory hurdles
  - Impacts to water supply aquifers
  - Potential for injected water to migrate to streams
- Limited capacities (1200 to 3000 bpd)
- Substantial capital investment with uncertain life span ($1M to $2M)
- Probably will only play a limited role
- No new injection wells have been permitted!

Discharge to POTW

- POTWs are biological processes such as lagoons, trickling filters, or activated sludge plants
- Biological systems cannot handle high salinity

  -few case studies above 35,000 mg/l
- Need to understand POTW discharge limits and the treatment processes used, flow variability
- Potential for VOC emissions issues at POTW
- If high TDS + flow is significant portion of POTW influent, this is not an option
- Regulatory limitations on acceptance

Direct Reuse for Drilling and Fracing

- Not a viable option for Marcellus
- TDS is too high
- Chlorides, in particular
  - Corrosion concerns
  - Impacts on fracing
- Solids,hardness, and bacteria removal
  - Chemical conditioning, separation, filtration
- Sulfides control
  - Safety, corrosion, SRB downhole concerns
- Recycling of chemical additives

Typical Water Quality

Samples of Frac Flowback and Produced Water Quality				
(All in mg/L)	FFB Grab	FFB Pit	Produced Water	SRWR Data Sum*
TDS	64,800	44,627	222,000	38,000
Chloride	35,900	27,096	145,000	31,000
TSS	1,910		765	398
Hardness	11,800	9,197	67,300	3,700
Calcium	4,130	3,236	23,200	770
Iron	40	12	99	80
Barium	802	1,450	15,700	1,030

*Includes some pit waters and drilling mud waste

Treatment & Evaporation are the Only Viable Management Strategies

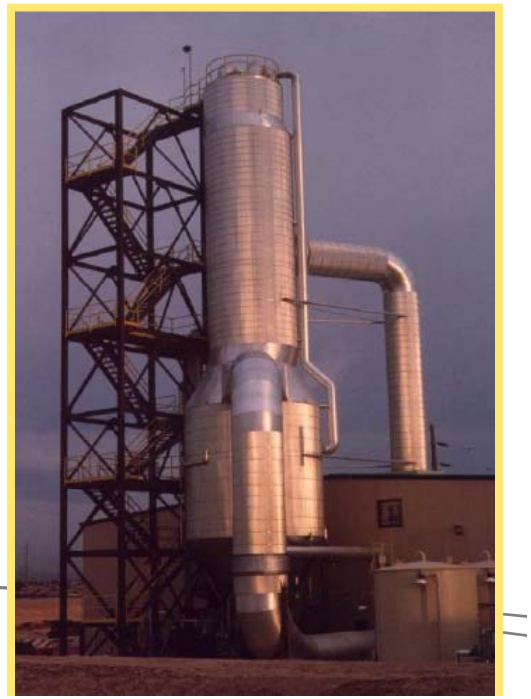
- Evaporation in pits/ponds w/enhancements
- Injection/disposal wells
- Discharge to POTW
- Direct reuse for drilling and fracing
- Treatment for reuse or surface discharge
- Thermal/mechanical evaporation
- Evaporation/distillation for reuse or surface discharge

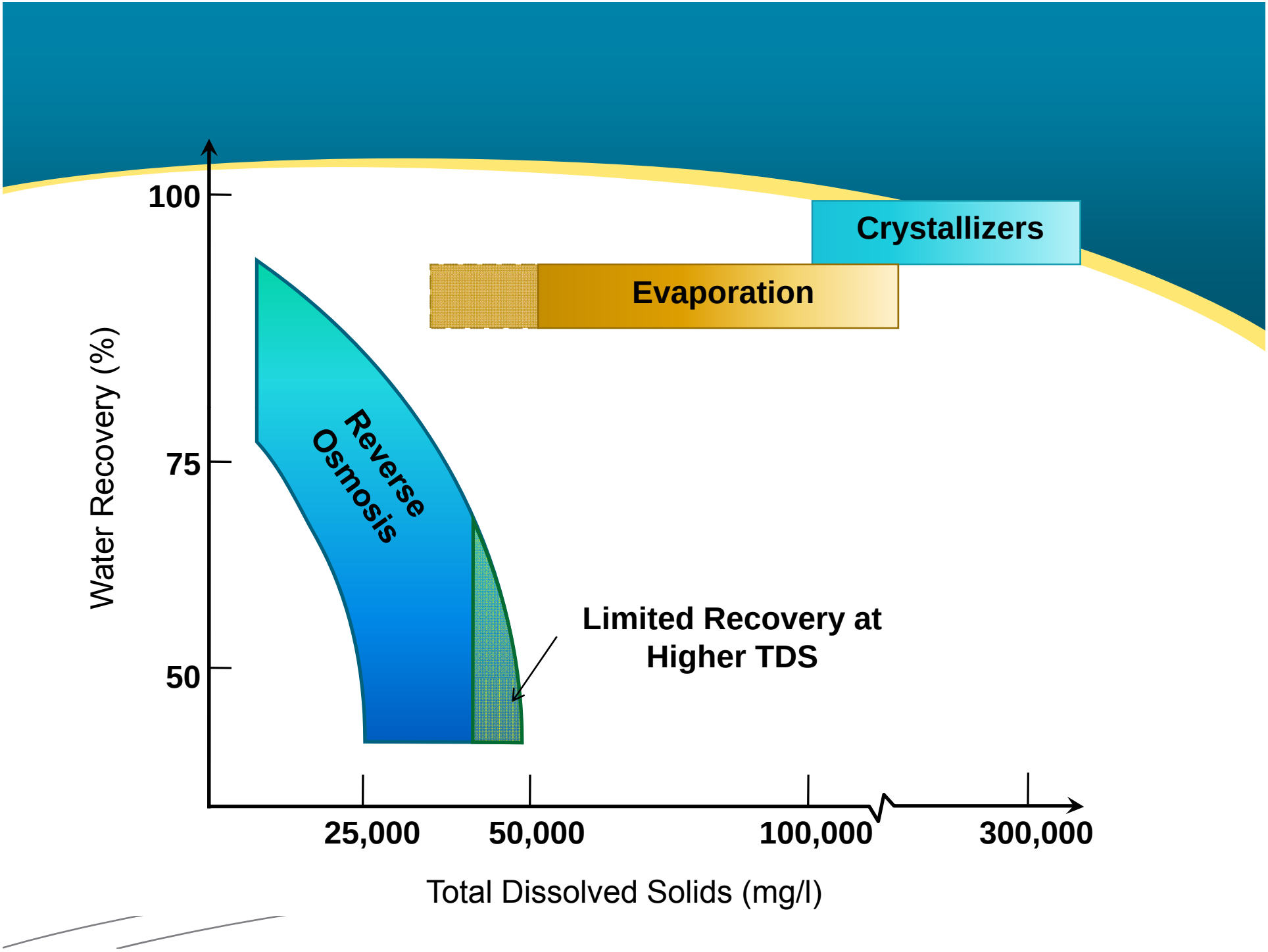
Treatment and Evaporation Technologies

Salinity Reduction Technologies	Maximum Feed TDS mg/l	Energy kWh/100 barrel-treated
Capacitive Deionization	5,000	20
Electrodialysis Reversal (EDR)	7,000	60
Electrodialysis (ED)	42,000	-
Reverse Osmosis	50,000	15-30
VSEP	35,000	15-30
Dewvaporation	100,000 to 150,000	150-400
Membrane Distillation	250,000	600-700
Evaporator/Concentrator	100,000	400
Crystallizer	250,000 to 350,000	1000-1300

Treatment versus Evaporation/Distillation

- Membranes are generally less expensive than evaporators, even though significant pretreatment is required
- Therefore, Salinity (NaCl) level controls decision
- TDS > 50,000 mg/l is not practical to treat with membranes (prefer 35,000 mg/l)




Crystallizers
Evaporation
Reverse Osmosis
Limited Recovery at Higher TDS
100
75
50
Water Recovery (%)
25,000
50,000
100,000
300,000
Total Dissolved Solids (mg/l)

Treatment versus Evaporation/Distillation

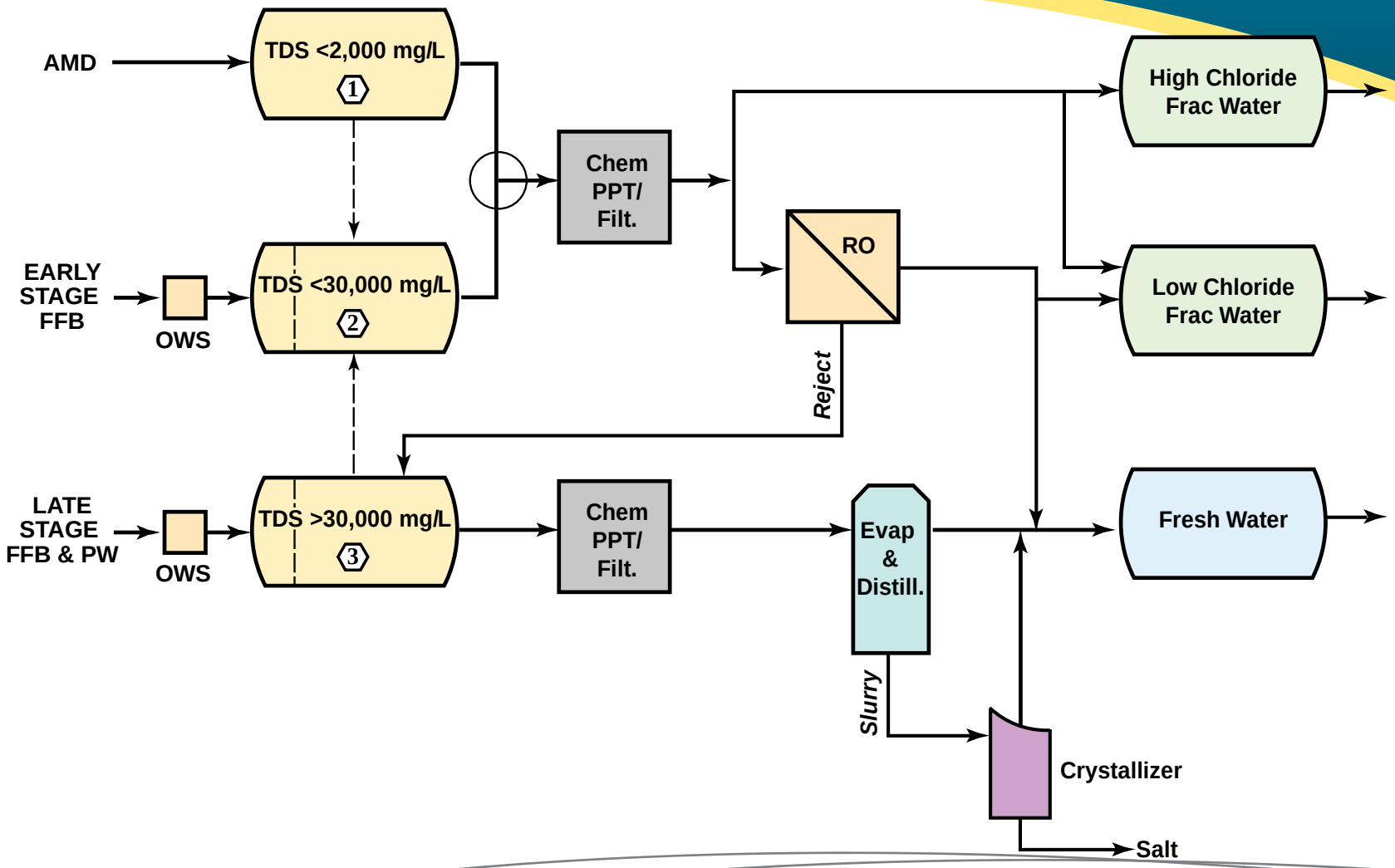
- High TDS (>35,000 mg/L) water needs to be blended if membranes are to be used
- Could capture first few days of flowback for treatment, but this creates logistical issues
- Membranes generate a reject stream to manage and will need an evaporator and crystallizer anyway

SRWR Approach

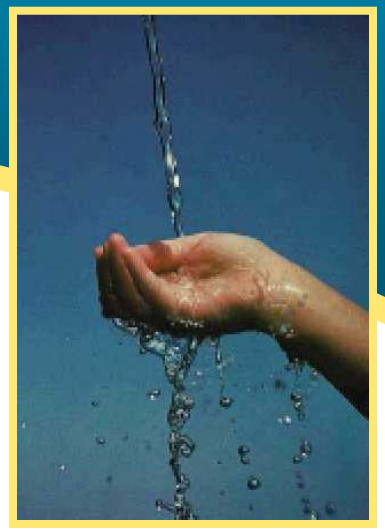
- Segregate trucks based on conductivity
- Storage in separate ponds
- Purchased property with AMD as low TDS water source

- Blend as needed to provide:
  - High chloride frac water(15,000 to 30,000 mg/L)
  - Low chloride frac water (<2,000 mg/L)
  - Surface discharge quality water

Conceptual Process Flow Diagram



SRWR Approach (cont'd)



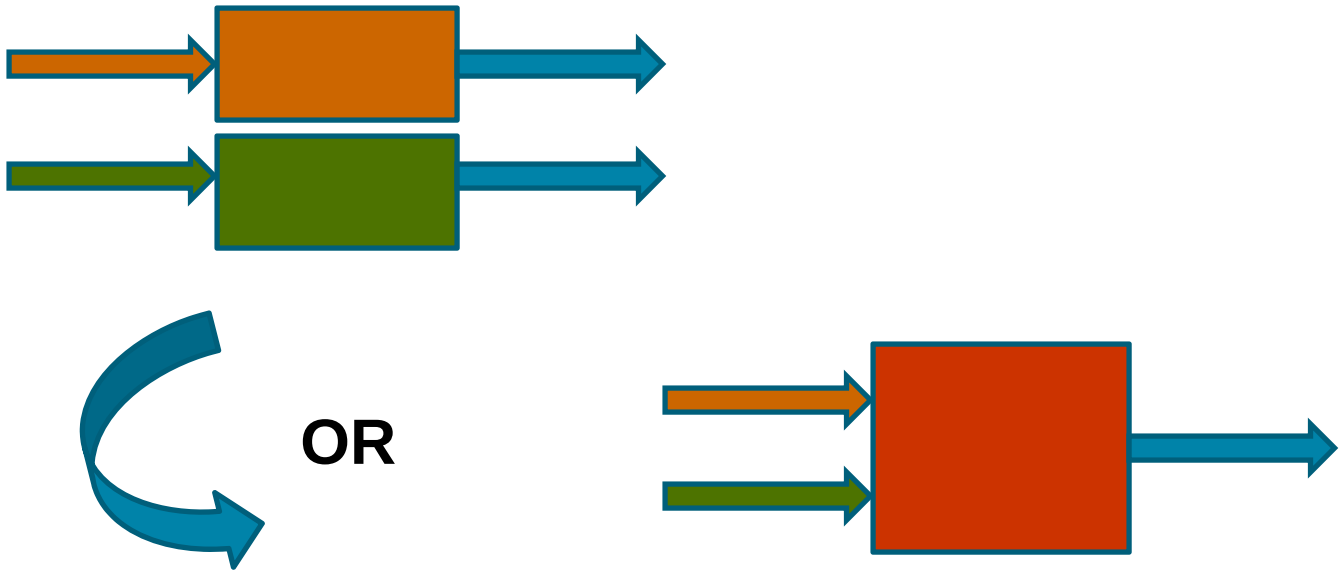
- Focus on consistent water quality
- Require operators to take water back
- Minimize surface discharge
  - Wasting a resource
  - Very stringent discharge limits

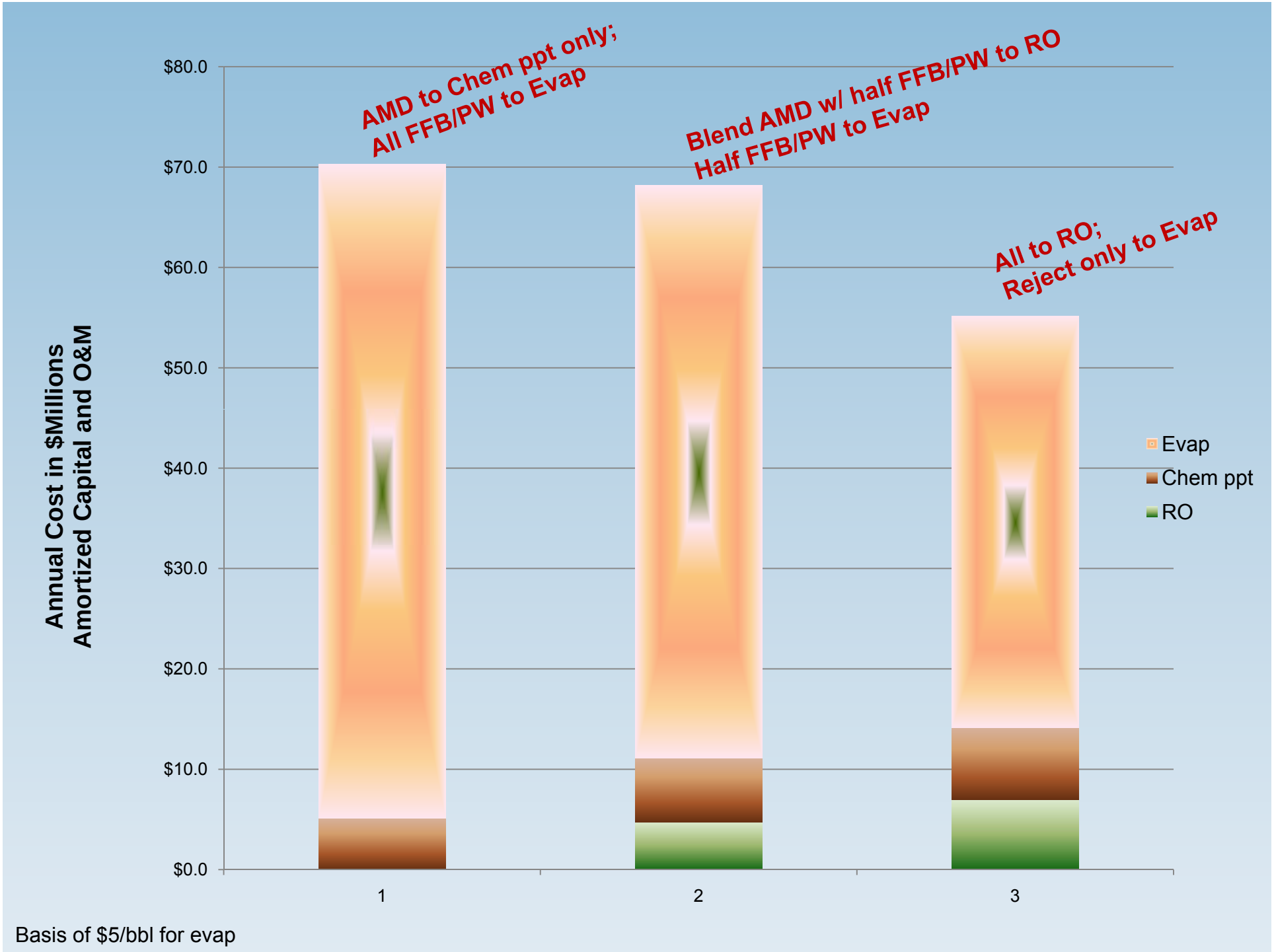
SRWR Discharge Limits

Parameter	Effluent Limit	Detection Limit	Units
TDS	500		mg/L
Chloride	250		mg/L
TSS	ND	4	mg/L
BOD (methanol concern)	8.35		mg/L
O&G	ND	1.4	mg/L
Phenols	ND	0.002	mg/L
Naphthalene	0.053		mg/L
Aluminum	ND	0.003	mg/L
Strontium	ND	0.0003	mg/L
Boron	1.99		mg/L
Benzene	0.001		mg/L
Iron	ND	0.001	mg/L

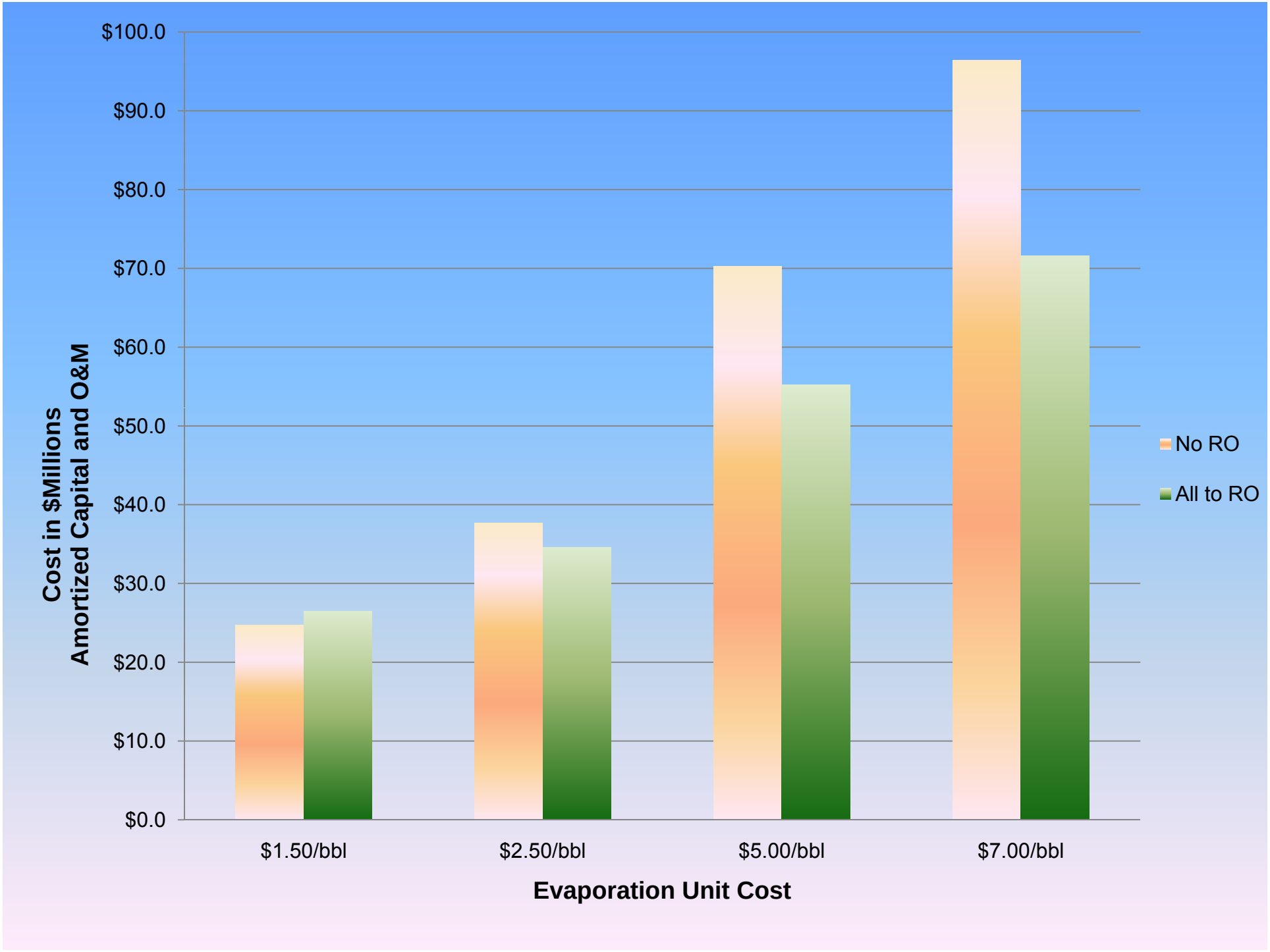
Does Blending Make $ense?

- Is it less expensive to treat AMD separately from FFB and PW?





Basis of $5/bbl for evap


$100.0
$90.0
$80.0
$70.0
$60.0
$50.0
$40.0
$30.0
$20.0
$10.0
$0.0
Cost in $Millions
Amortized Capital and O&M
$1.50/bbl
$2.50/bbl
$5.00/bbl
$7.00/bbl
Evaporation Unit Cost
No RO
All to RO

FFB and PW Have High Fouling Potential

- Reversible fouling
  - Particulate, scale, or slime
  - Temperature, pH adjustment, surfactants
- Inorganic
  - Calcium, barium, iron, silica, strontium
  - Low pH, temperature
- Organic
  - Dissolved organic carbon
  - High pH, temperature
- Biofouling
  - Slime
  - Biocide/high pH, temperature
- Irreversible fouling
  - Cleaning study
- Temperature drop in process
  - Reduces solubility
  - Solidification of paraffin
  - Particulate and paraffin fouling

Operational Parameters and Conditions for Desalination Membranes

Parameter	Nanofiltration	Reverse Osmosis
Max. Feed Pressure	600 psi	1,500 psi
Max. TDS	-	50,000 mg/l
Water Recovery	75-90%	40-80%

Solid Phase	Mitigation Strategy and Operating Limitations
Calcium Carbonate	Depress pH, LSI <2.5- 3.2
Calcium Sulfate	Antiscalant, Ω < 2-400
Strontium Sulfate	Antiscalant, Ω < 43-50
Barium Sulfate	Antiscalant, Ω < 50
Calcium Fluoride	Antiscalant, Ω < 16,000
Iron	Antiscalant, <8 ppm Fe
Silica: Reactive Non-reactive	Antiscalant, < 120 ppm

Multi-Stage Pretreatment Required

- Gross oil and solids removal
- Softening
- Particulate removal
  - Coagulation, sedimentation, media filters, MF/UF
- Ion exchange
- Organics reduction vs control of fouling
- Degasification for CO_2 reduction
- Acid addition
- Antiscalants

Ongoing Issues

- Pretreatment to control fouling/scaling
- Radionuclides
- VOCs
- Residuals management
- Economics over time as influent becomes primarily produced water

Somerset in Summary

- Filling a need for centralized water management facilities for O&G industry
- Treating two sources of pollution
- Reduce overall treatment costs by blending
- Generating an alternative fresh water source
- Reduce O&G industry's need to use surface water
- Can recover some minerals
- Minimize amount of wastes for disposal

Thank You!

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