Water Treatment Technologies for Global Unconventional Gas Plays

U.S. – China Industry Oil and Gas Forum

Fort Worth, TX
September 16, 2010

Overview of CDM

- Company Background
  - Founded in 1947
  - 4,500+ Employees in Over 85 U.S. Offices and 24 International Offices
  - Over $1 Billion in Revenues in 2009
  - Employee Owned / Operated
- Proven Reliability – We stand behind our work
- Our Core Business

Water and Wastewater Treatment

Air Quality

Remediation

Management Consulting

Design Build Operate

Introduction and Purpose

- The United States has experienced a significant transformation of our energy sector in the last 5 to 10 years due to the development of unconventional gas
- Development has posed significant challenges to engineering, consulting, construction, and operational professionals
- CDM has the opportunity to support the development of these resources utilizing our core service area strengths
- These value-added services are transferable throughout the world
- CDM is well positioned to use our strong client relationships and reputation with public, political, and regulatory agencies to develop significant business opportunities in the U.S., Poland, the Middle East and throughout Central Europe

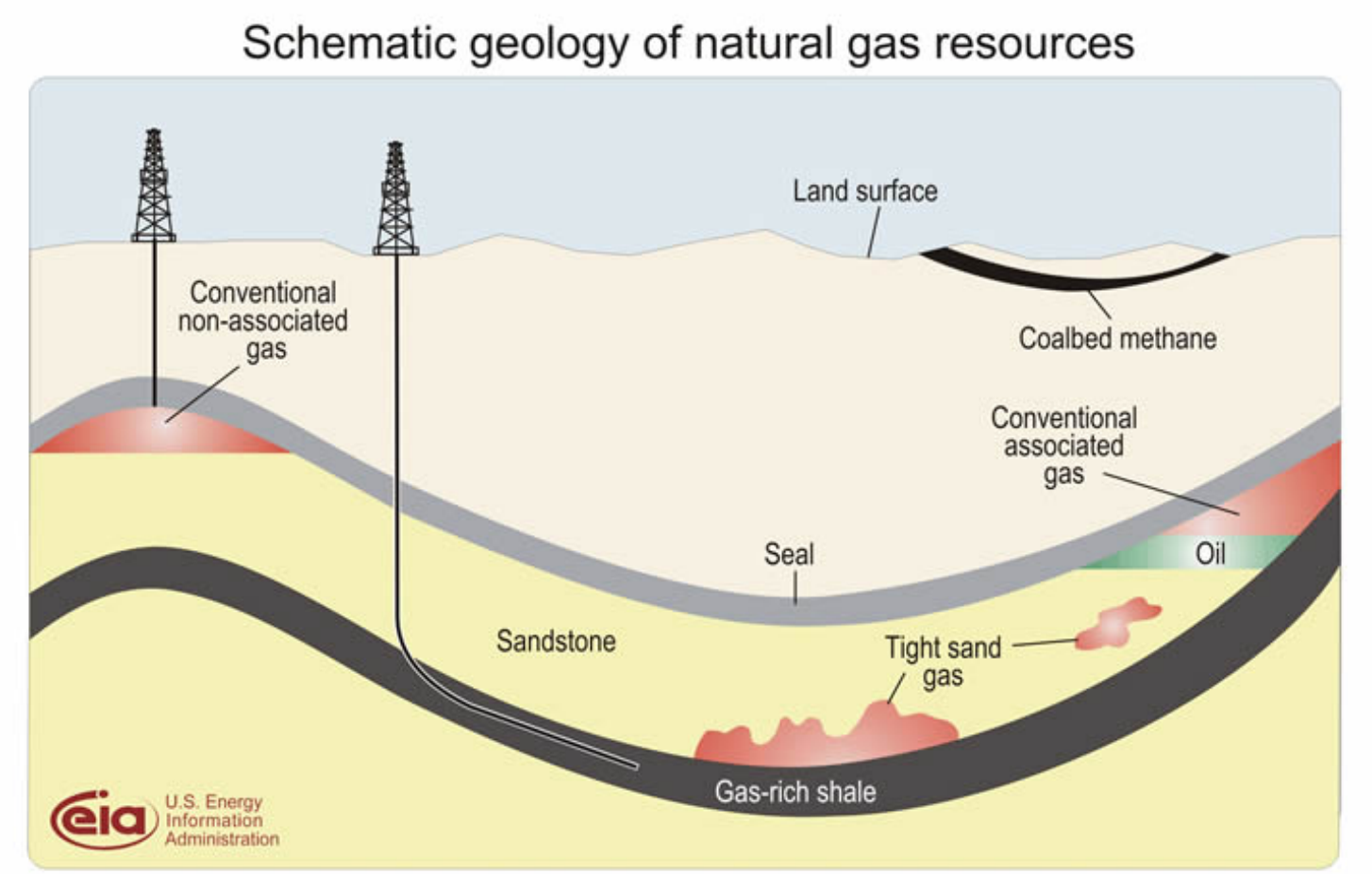
Agenda

- Overview of Shale Gas Development
  - Overview
  - Development Information
- Development Process and Challenges
- Flow and Water Chemistry
- Water Management and Treatment Alternatives

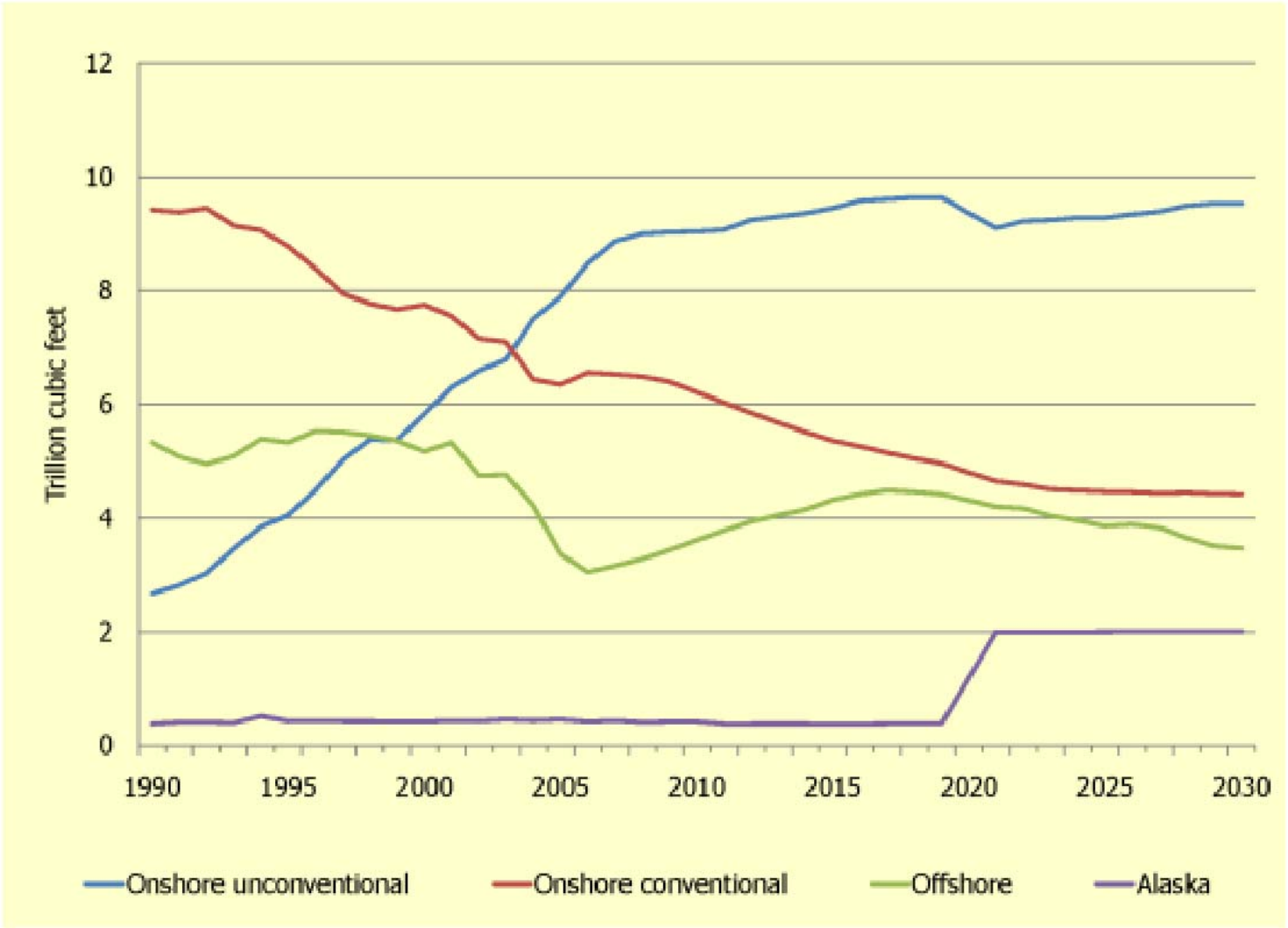
Natural Gas – Important Energy Source for U.S. and Abroad

- Cleanest burning fossil fuel emitting the fewest pollutants into the air
- Produces less CO_2 emissions than oil and coal
- Ideal "bridge" fuel to support alternative energy development
- Recent increase in national reserves as a result of the economical development of unconventional gas sources:
  - Coalbed Methane
  - Tight gas
  - Shale gas

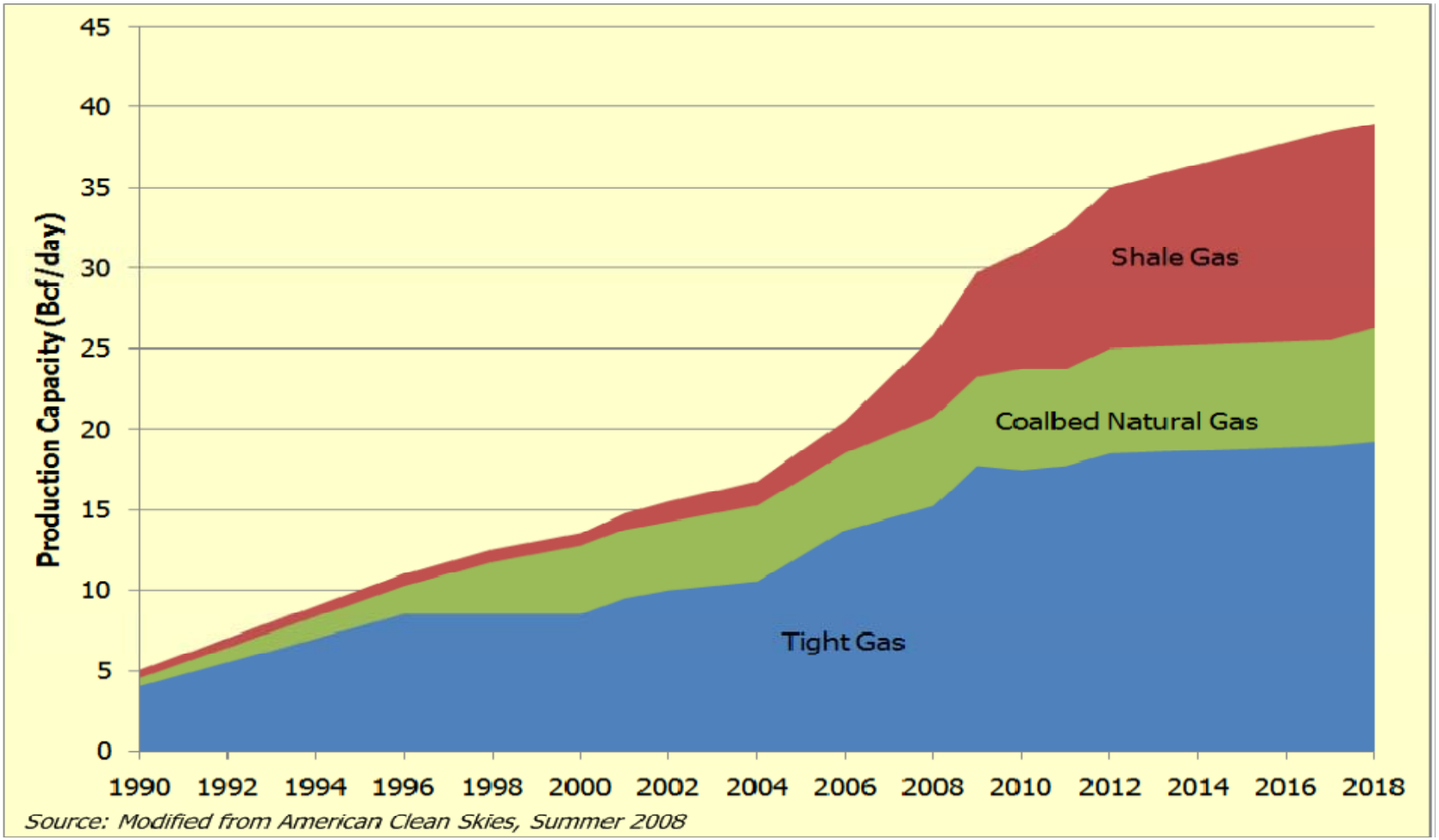
Gas Play Types



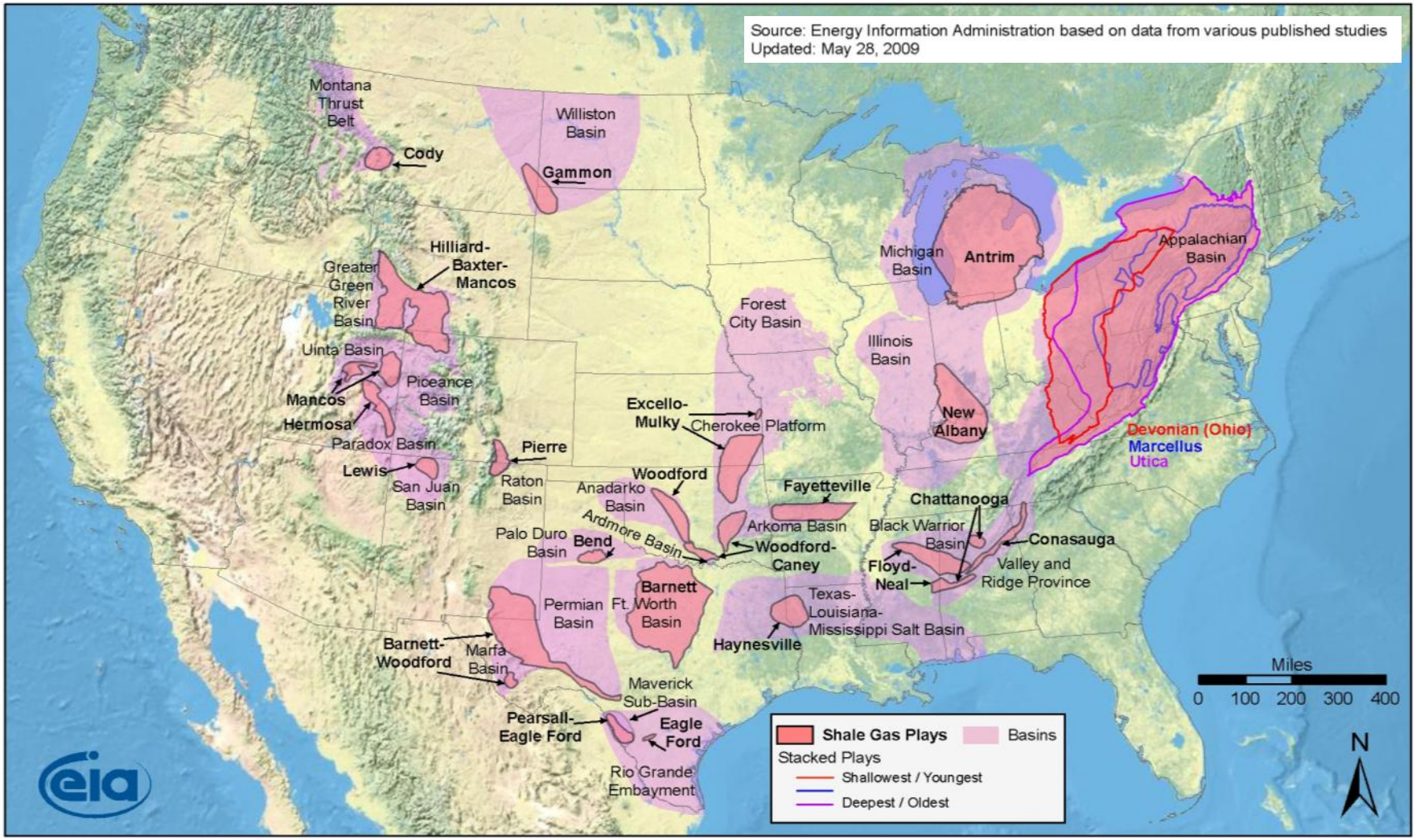
Natural Gas Production by Source



United States Unconventional Gas Outlook



U.S. Shale and Tight Gas Basins

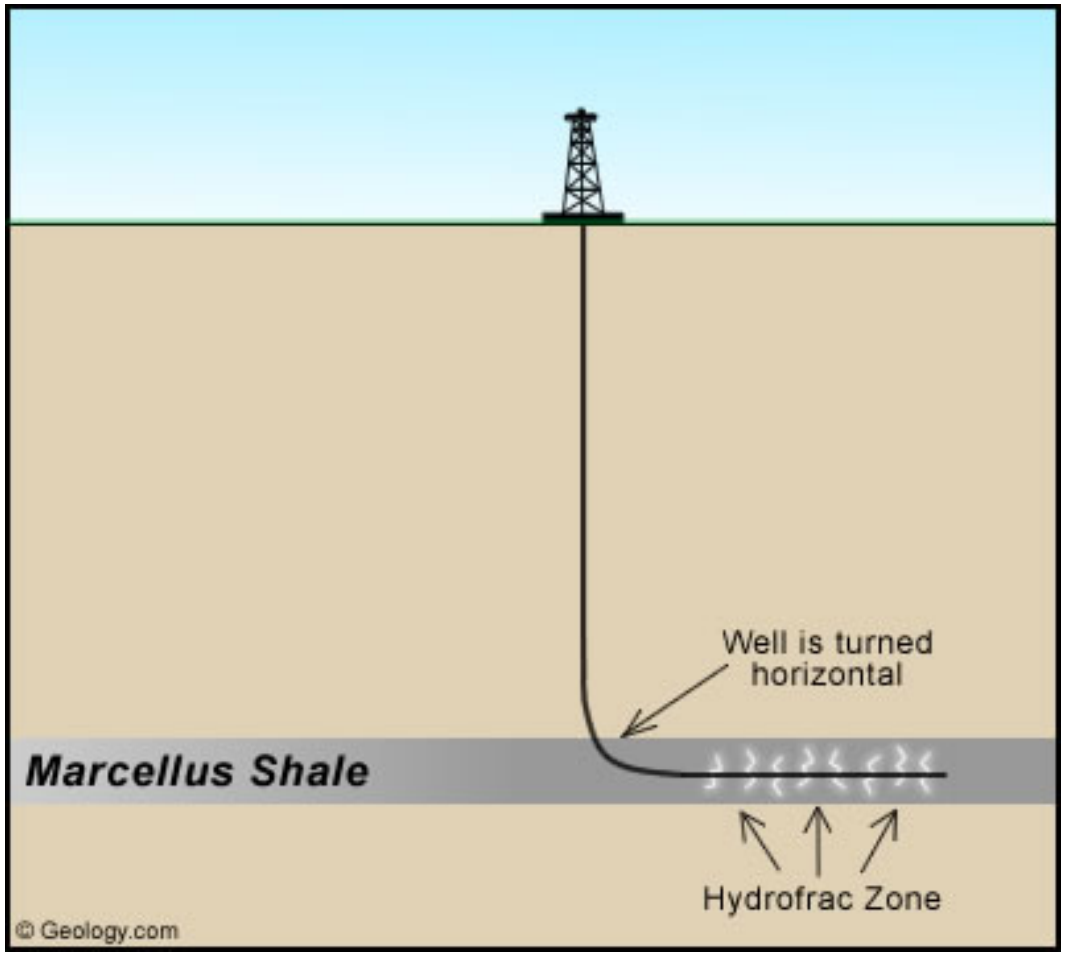


Horizontal Drilling

- 6 to 8 wells at a single site versus approximately 16 separate wells for typical vertical well spacing
- ~1/10 surface impact
- 2,000 – 6,000 feet of formation exposure per well versus only formation thickness (50 – 300 feet typical) for vertical wells

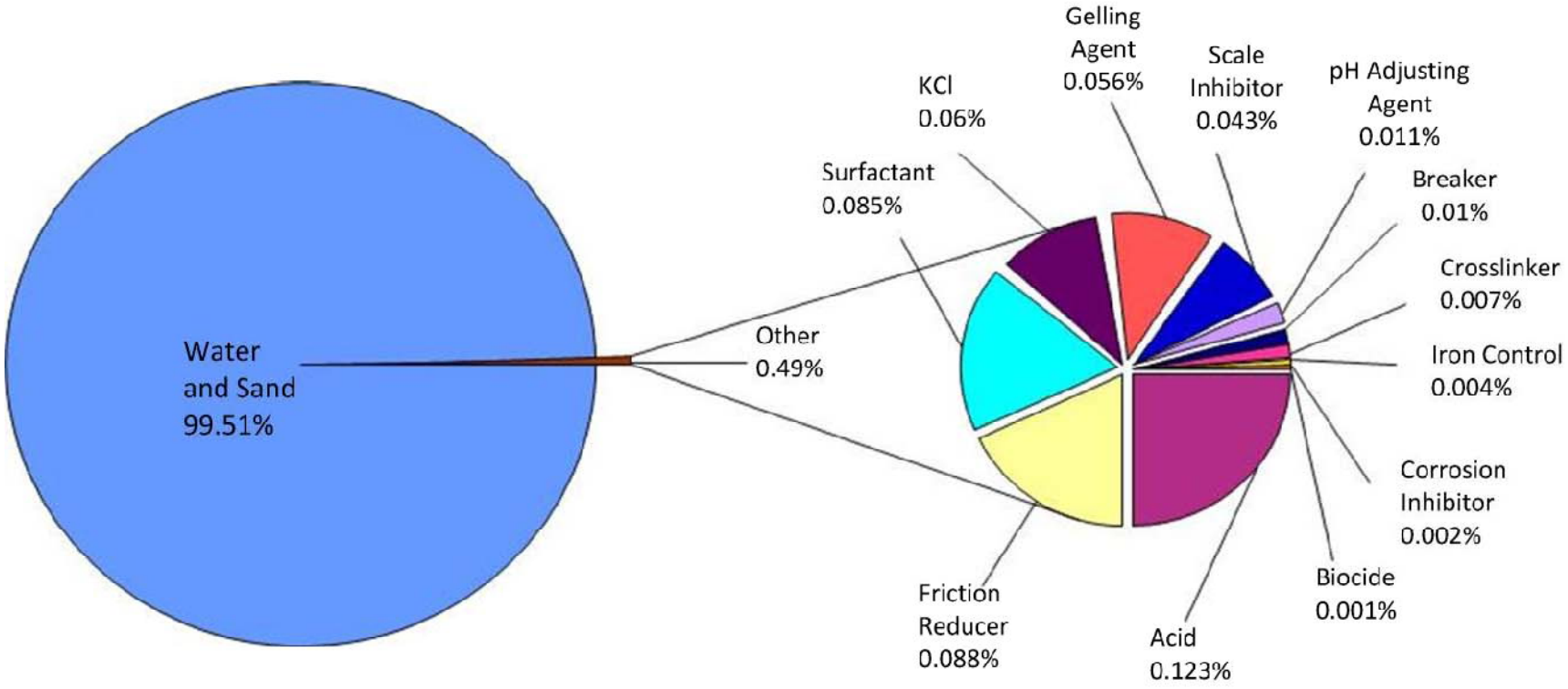
Hydraulic Fracturing Process – The Solution and the Controversy

- Frac Water Volume: 3 to 7 M gal
- Additional components include biocides, corrosion inhibitors, O_2 scavengers, proppant, etc.
- 20 -30% Frac "flowback" water recovery requires collection, handling, and disposal / treatment



Source: ALL Consulting. ***Handbook on Coal Bed Methane Produced Water: Management and Beneficial Use Alternatives,*** **July 2003.**

Composition of a Fracturing Fluid

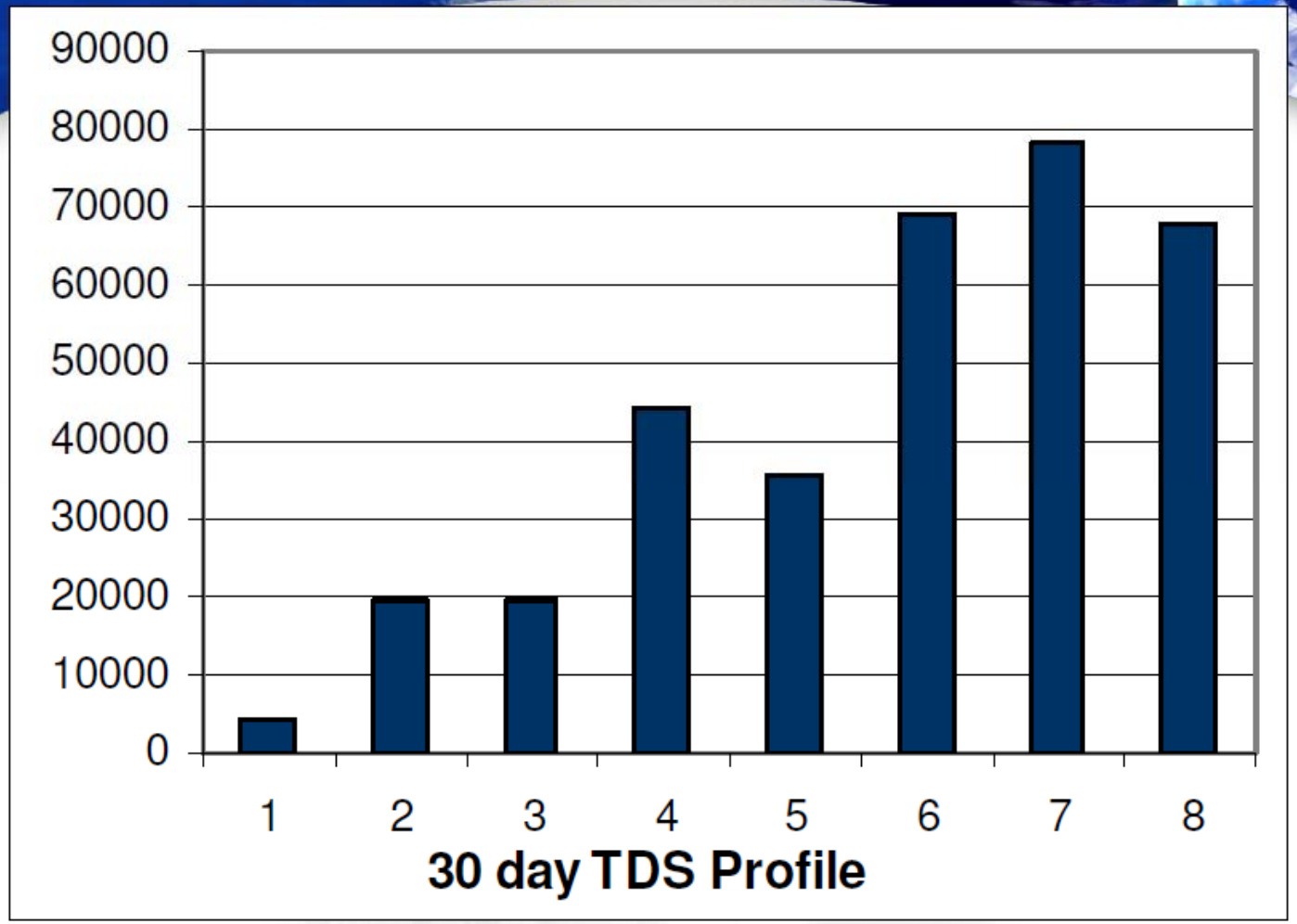


Reference: All Consulting 2009

Frac Flowback Water Quality
(mg/L)

Parameter	Feed Water	Flowback
pH	8.5	4.5 to 6.5
Calcium	22	22,200
Magnesium	6	1,940
Sodium	57	32,300
Iron	4	539
Barium	0.22	228
Strontium	0.45	4,030
Manganese	1	4
Sulfate	5	32
Chloride	20	121,000
Methanol	Neglible	2,280
TOC	Neglible	5,690
TSS	Neglible	1,211

TDS Profile Barnett Horizontal Well



STW Resources, Inc.

Water Reclamation using GE Innovation

Wide Variation in Frac Flowback Chemistry

Parameter	Frac 3	Frac 2	Frac 1	Frac 4
Barium	7.75	2,300	3,310	4,300
Calcium	683	5,140	14,100	31,300
Iron	211	11.2	52.5	134.1
Magnesium	31.2	438	938	1,630
Manganese	16.2	1.9	5.17	7.0
Strontium	4.96	1,390	6,830	2,000
TDS	6,220	69,640	175,268	248,428
TSS	490	48	416	330
COD	1,814	567	600	2,272

Ref: ProChemTech International, Inc.

Flowback Water Management Issues

- Limited disposal capacity
- Long haul distances
- Limited freshwater supplies for fracturing
- Water volumes and chemistry presents treatment challenges
- Increased regulatory scrutiny

Flowback Water Management Solutions

- Treatment for Reuse
  - Oil/Grease
  - Hardness
  - Bacteria
- Treat for Discharge
  - Same as Reuse, Plus:
  - TDS Removal

Treatment for Reuse

Treatment for Reuse Objectives

- Remove petroleum hydrocarbons
- Remove friction reducers and other polymer additives
- Remove inorganic scale forming compounds
- Kill bacteria
- Utilize mobile, on-site treatment technologies
- Cost-effective

Re-use Technologies

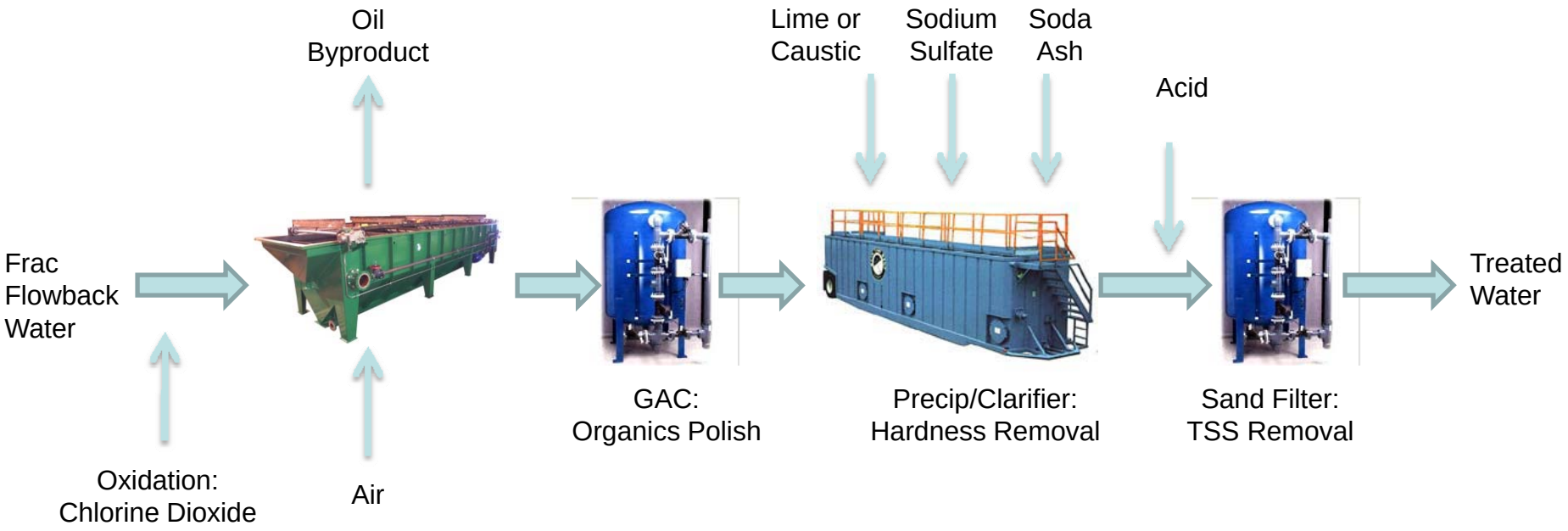
Organic Removal

- API Separators
- Dissolved Air Flotation
- Chemical Oxidation
- Biological Processes
- Activated Carbon
- Walnut Shell Filters
- Organo-Clay Adsorbants
- Air Stripper (VOC)

Inorganic Removal

- Chemical Precipitation
- Lime/Soda Softening
- Clarifiers
- Settling Ponds
- Ion Exchange
- Multi-Media Sand Filtration
- Greensand Filters
- Cartridge Filtration

Example of Reuse Treatment Solution



Step 1. Chlorine Dioxide Oxidation
Oxidation/Disinfection

- Chlorine dioxide is strong oxidant that provides selective chemical oxidation
- Breaks oil/grease emulsions
- Destroys friction reducers and other chemical additives
- Kills Bacteria
- Oxidizes reduced compounds, such as Fe, Mn, Sulfide, ammonia, etc.
- More efficient than bleach

Ref: Sabre Technologies

Step 2. Dissolved Air Flotation
Hydrocarbon Removal

- Fine bubble diffusion floats oil/grease and TSS to top
- Skimmer potentially recovers saleable oil
- Covered designs also available for VOC emission control
- Mobile skid-mounted design

Ref: Pan America Environmental Website

Step 3. Granular Activated Carbon
Organics Polish

- Liquid phase activated carbon removes most hydrocarbons and other organics
- Spent carbon is disposed of in approved facility
- Simple design and operation
- Mobile skid-mounted design
- Periodically backwashed to remove TSS.

Step 4. Chemical Precipitation/Clarification
Metals/Hardness Removal

- Chemical precipitation system removes inorganic scale-forming compounds (barium, strontium, metals, hardness, etc.)
- Custom design mobile frac tank design includes multiple mix tanks and built-in clarifier
- Sludge is removed and dewatered in separate system prior to off-site disposal
- High pH operation (9.5 to 11)
- Elevated pH helps minimize bacteria growth

Ref: Rain-for-Rent Website

Step 5. Multi-Media Sand Filtration
TSS Polish

- Conventional sand filter removes TSS before reuse
- Acid or carbon dioxide addition ahead of filter to reduce pH and eliminate calcium carbonate scaling
- Periodically backwashed with filtered water. BW returned to front of system.

Summary of Reuse Treatment System

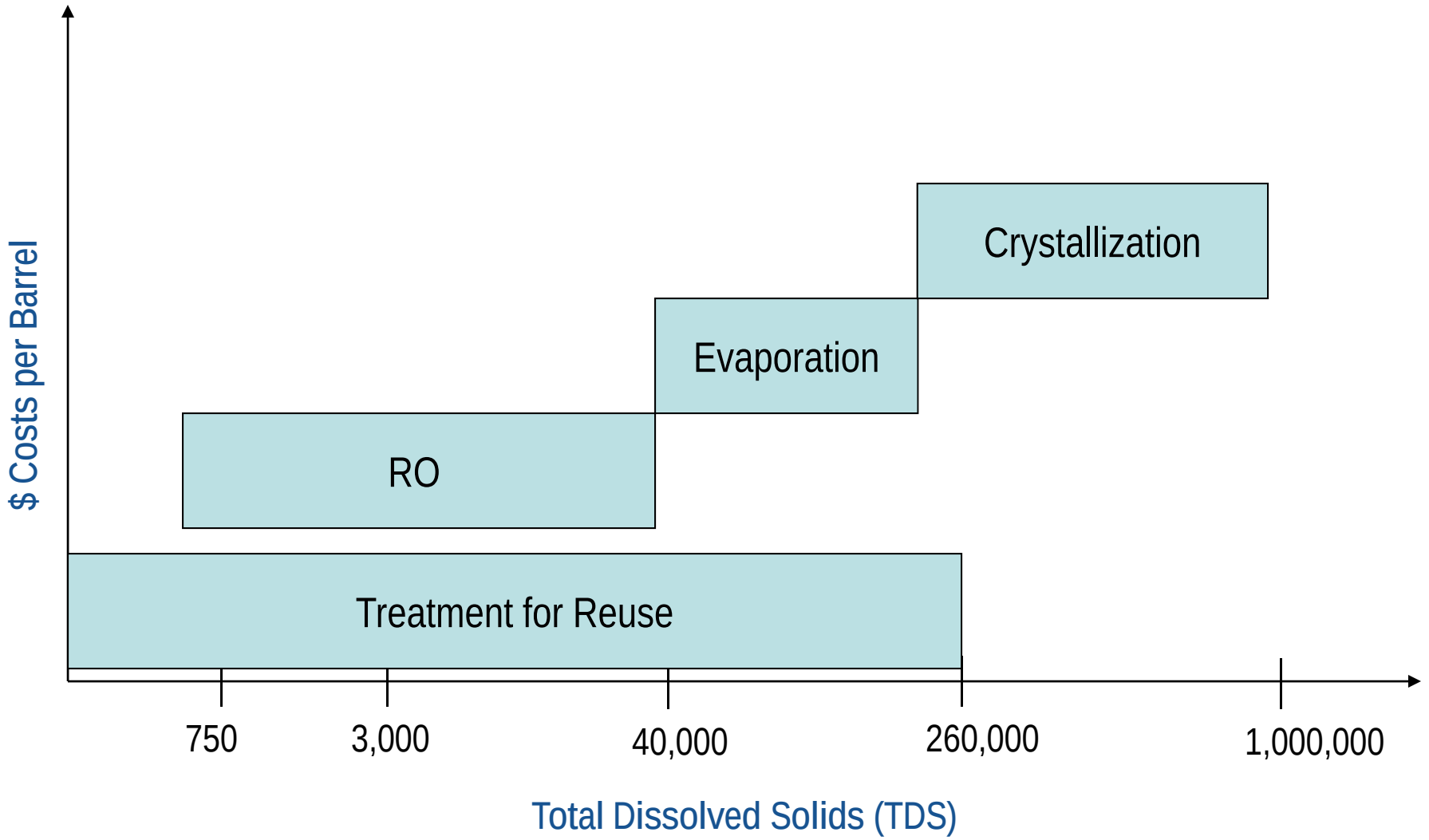
- Mobile treatment systems are available to remove organic and scale-forming compounds, allowing reuse without TDS removal
- On-site treatment reduces fresh water makeup requirements and off-site disposal costs
- Multiple design options are available
- Bench and pilot-scale testing recommended to select best treatment options and minimize cost

Removal of TDS

Viable TDS Removal Alternatives

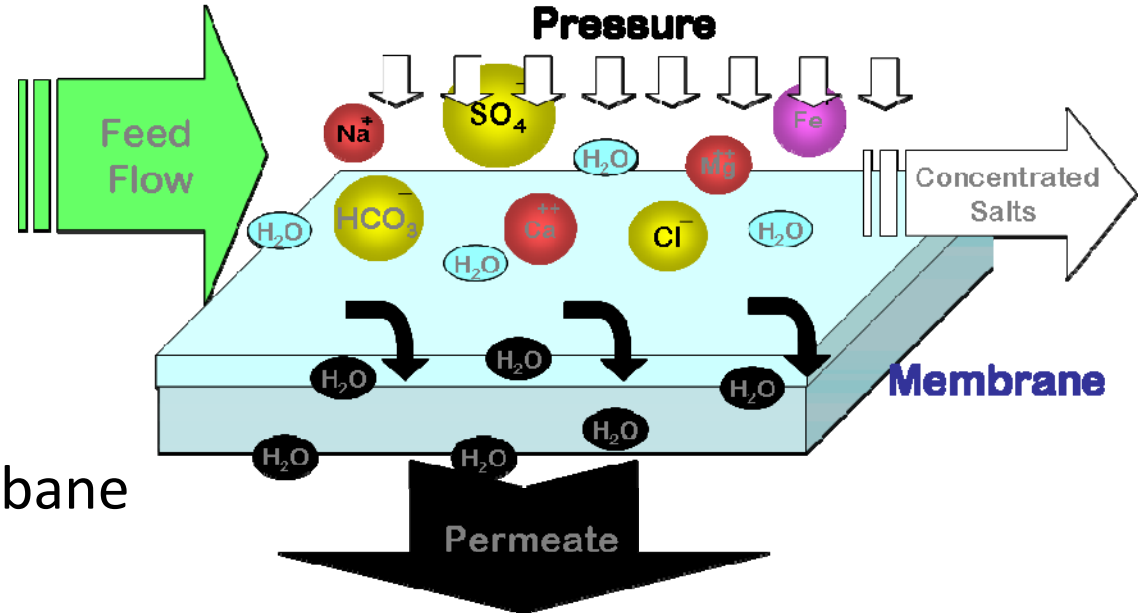
- Membrane Treatment
  - Reverse Osmosis
  - Nanofiltration
- Evaporation
  - Thermal Evaporators
  - Crystallization

Range of Applicability vs. Cost



Reverse Osmosis

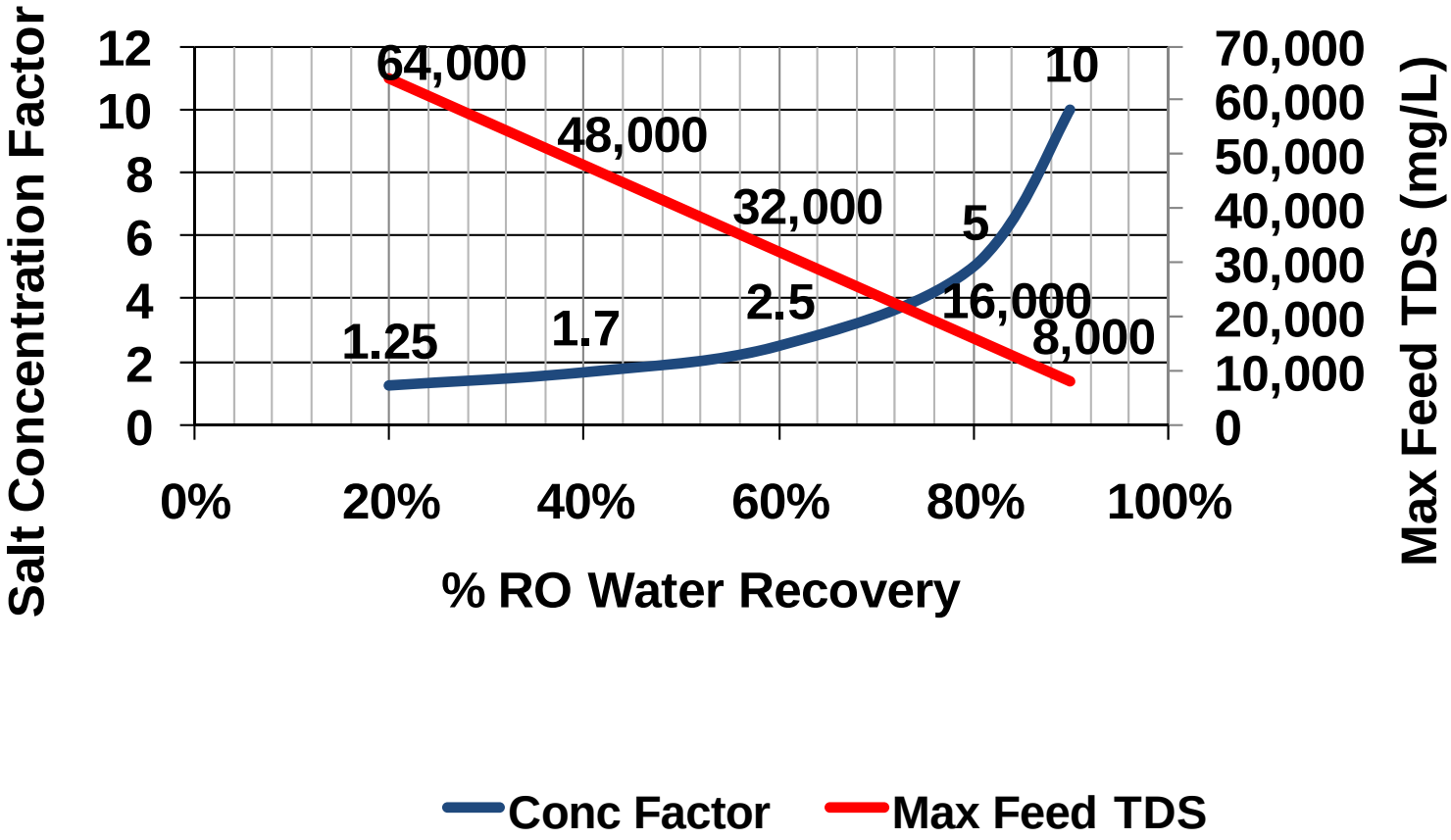
- Membrane separation technology that removes dissolved solids (TDS) from water
- Membrane is semi-impermeable - allowing only water to pass; 99%+ of all ionized species are rejected
- Non-selective treatment process
- Degree of all ion rejection is dictated by size and charge
- NF is a loose RO membane



Reverse Osmosis (cont)

- Maximum concentrate TDS is 80,000 mg/L
- Energy costs are 1/10th to 1/15th the cost of mechanical evaporation
- Skid-mounted, compact design suitable for trailer mounting
- Operating pressures up to 1200 psig
- Multiple membranes and manufacturers available

Salt Concentration vs. Recovery



Historical Problems with RO Treatment for Produced Water

Limited success due to inadequate pretreatment, resulting in fouling and scaling from:

- Calcium Hardness
- Iron
- Barium and Strontium
- Silica
- Microbiological Growth
- Organics
- Silt and Suspended Solids

Key to Success: Efficient Pretreatment

Pretreatment Steps:

- Organics removal (oil/grease, polymers, etc.)
- Efficient hardness and metals removal
- Particulate removal (coal fines, clay, etc.)
- Bacteria control

Result: High recoveries with much less fouling potential, resulting in a lower cost of operation and brine disposal

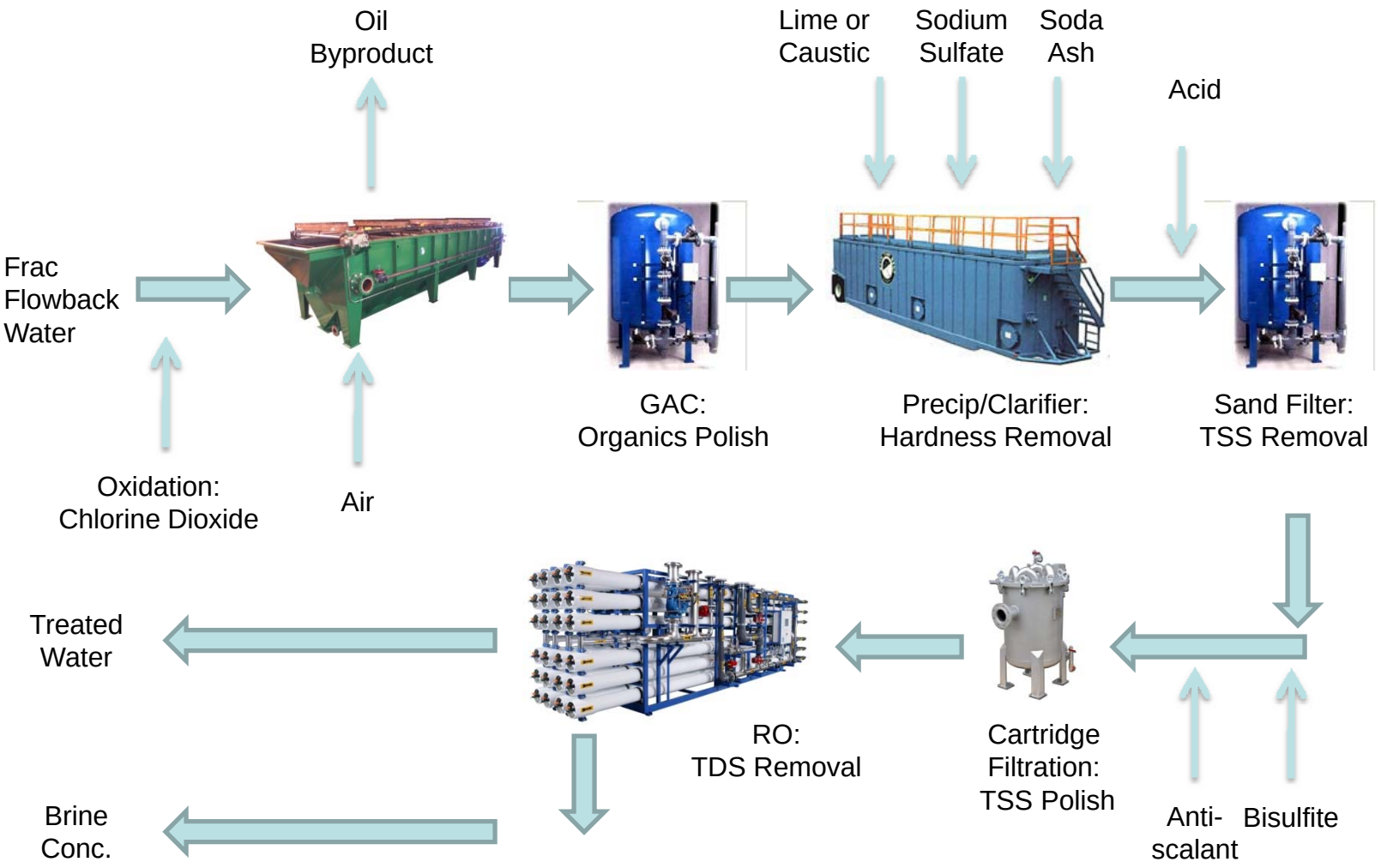
Scale Forming Salts

Salt	Saturation Concentration (mg/L)
Calcium Carbonate ($CaCO_3$)	8
Calcium Fluoride (CaF_2)	29
Calcium Orthophosphate ($CaHPO_4$)	68
Calcium Sulfate ($CaSO_4$)	680
Strontium Sulfate ($SrSO_4$)	146
Barium Sulfate ($BaSO_4$)	3
Silica, amorphous (SiO_2)	120

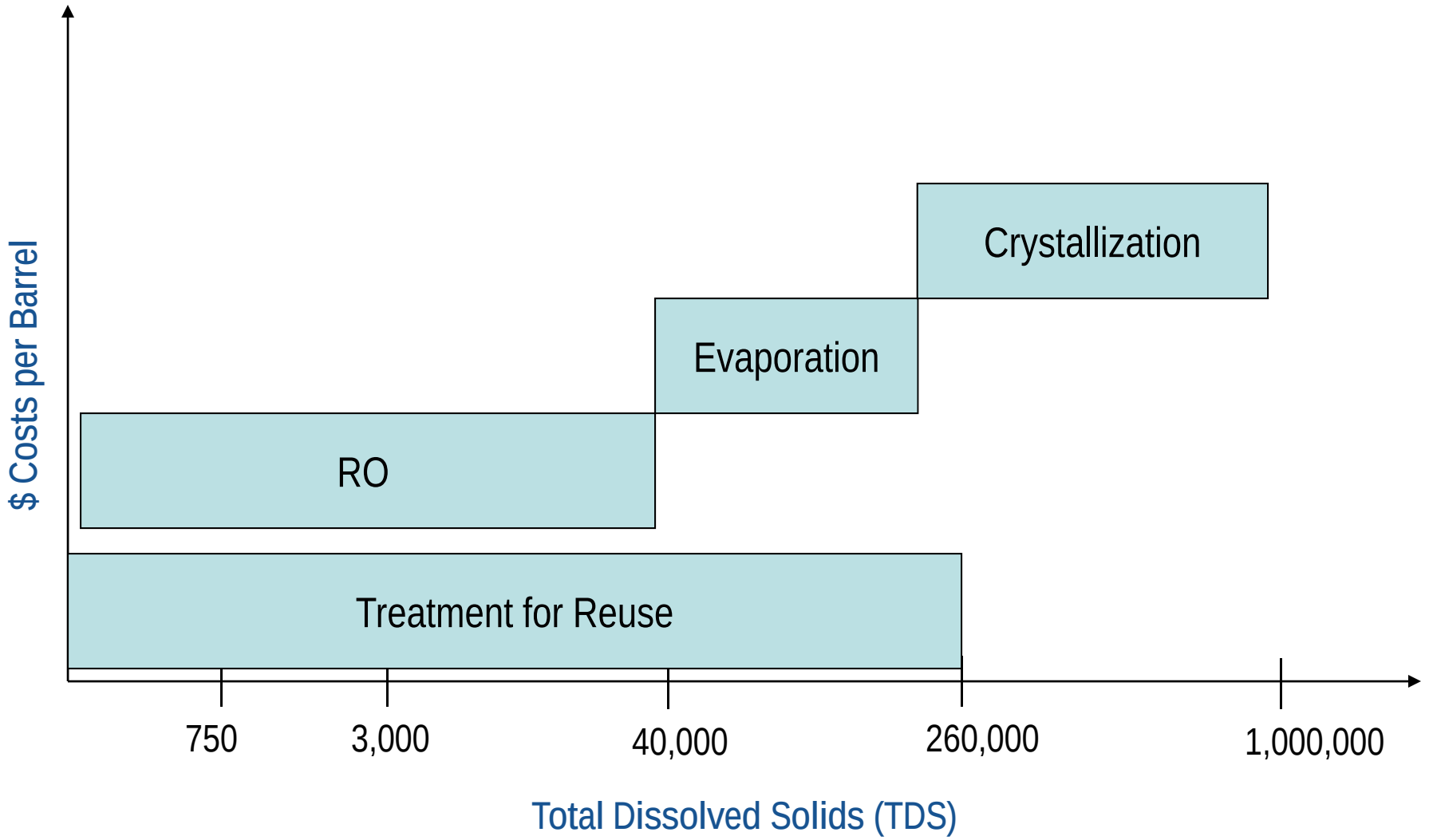
Recommended RO Design Limits for Scale Forming Salts in the Concentrate

Index	Typical	Aggressive
LSI	<1.8	<2.5
$CaSO_4$ (% Sat)	230	N/A
$BaSO_4$ (% Sat)	6,000	N/A
$SrSO_4$ (% Sat)	800	N/A
SiO_2 (% Sat)	100	150

Example Treatment Solution for TDS Removal Using RO Technology



Range of Applicability vs. Cost



Evaporation

- Ideal TDS Range of Feed Water is 40,000 to 120,000 mg/L
- Produces high quality distilate and liquid brine concentrate
- Brine concentrate requires further treatment or disposal (max TDS concentration is 260,000 mg/L)
- Evaporation systems more energy intensive than RO
- Most evaporation systems cannot handle any solids

Types of Evaporation Systems

- Forced Circulation
- Falling Film
- Rising Film
- Agitated Thin Film
- Plate and Frame

Selection Considerations

- Chemical Composition of Feed Stream
- Scaling/Fouling Potential
- Foaming Potential
- Materials of Construction
  - Based on Corrosion Potential of Feed Stream

Economization

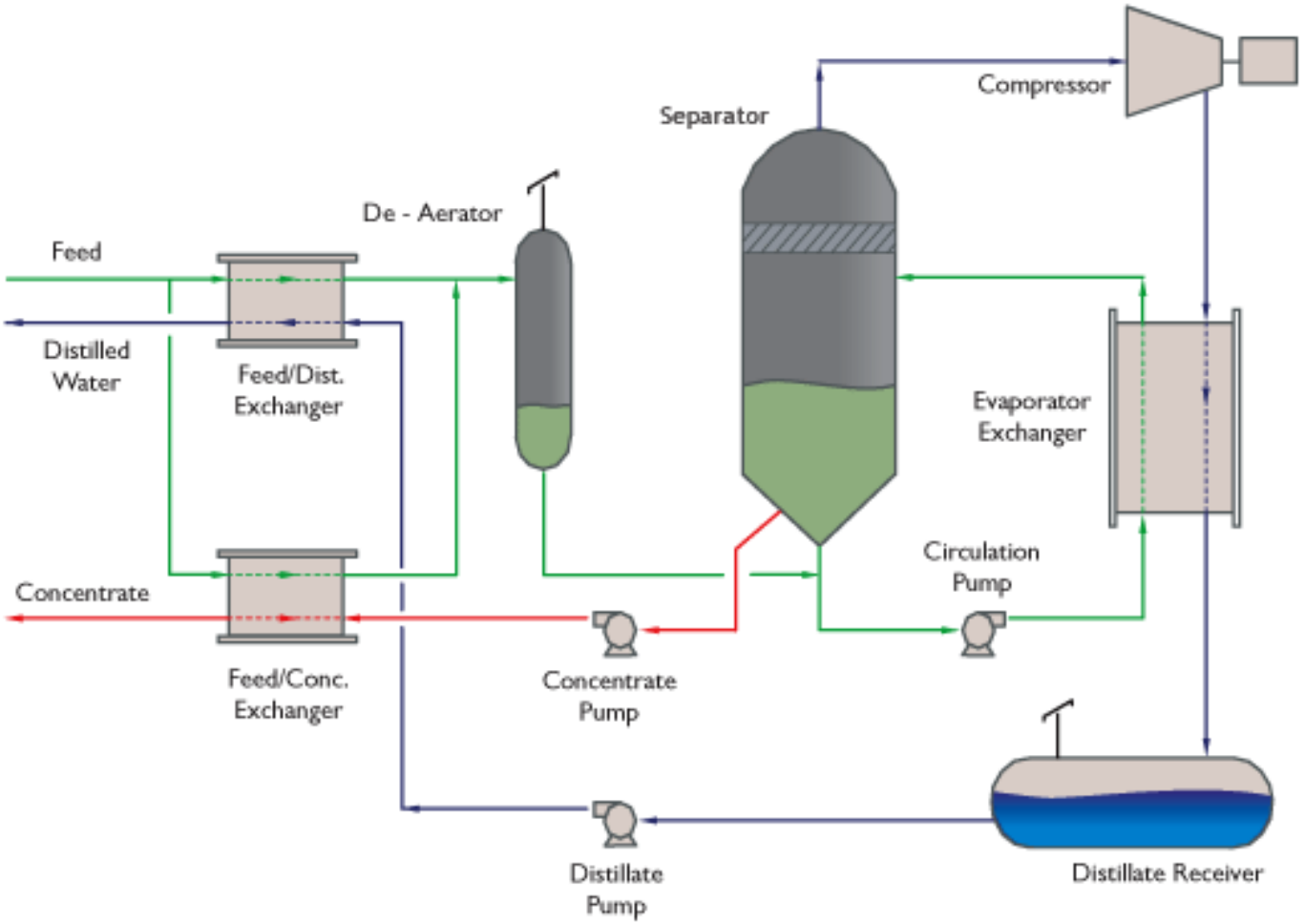
- Multiple Effects
  - Vapor From Each Effect is used in the Next/Previous Effect Depending on Set-up to Reduce Steam Use
- Vacuum
  - Reduces Boiling Point
  - Maximizes Efficiency When Used in Concert With Multiple Effects
- Mechanical Vapor Recompression
  - Recompresses the Vapor to Reduce Steam Use
  - Usually Uses Just One Effect

Pretreatment Equipment and Controls

- Particulate Removal via Filtration
- pH Control
- Scale Prevention
- Organic Removal
- Defoamer Addition
- Preheating via Heat Exchangers

MVR Evaporator

Most Economical



Brine Concentrate Treatment Options

- Crystallizer
- Drum Dryer
- Spray Dryer
- Haul to Disposal Well

Crystallizer

- Complex system designed to produced purified salt products
- Very large systems requiring central location
- Multiple Types of Crystallizers available
- For Marcellus flowback water, two products can be produced with proper pretreatment:
  - Sodium Chloride dry salt
  - Calcium Chloride liquid

Drum Dryer

- Capable of converting mixed salt liquids into dry solids
- Typically steam driven systems operating at atm or under vacuum
- Relatively compact footprint
- Multiple types of dryers available
- Results in dry product

Ref: Buflovak website

Spray Dryers

- Hot air produced from burning natural gas used to evaporate liquid sprayed in top of tall cylindrical vessel
- Dries solids quickly in a single pass
- Baghouse is used to collect salts and vent off gas
- Very tall systems require central treatment location
- In general, very effective for mixed salt streams

Ref: Swenson Technology Website

Evaporation Summary

- Most economical for high TDS/ low volume sources
- Pretreatment necessary to keep heat transfer surfaces clean
- Variety of manufacturers and designs available
- Most efficient design is Mechanical Vapor Recompression
- Evaporators are generally very large; some skid mounted units available
- Produced brine stream requires further treatment

Questions and Answers

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