Treatment, Recycling, and Reuse of Unconventional Oilfield Produced Water

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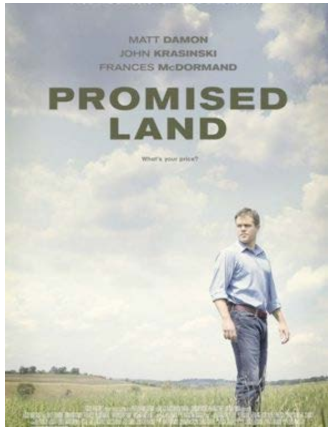

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What is unconventional oil and gas extraction?

Retrieval of gas and oil from
low permeability formations

Horizontal Drilling

Hydraulic Fracturing

Shale Acidization

Waste handling and disposal
(Underground injection wells and recycling)

Unconventional vs. Conventional

Unconventional…

- Higher volumes of water use
- Lower productivity of gas wells (e.g. 5 years vs 20 years)
- Greater concern over well integrity due to higher volumes of fluids
- Greater concern over spills because of high volume waste handling
- Higher transportation costs of large water/waste volumes

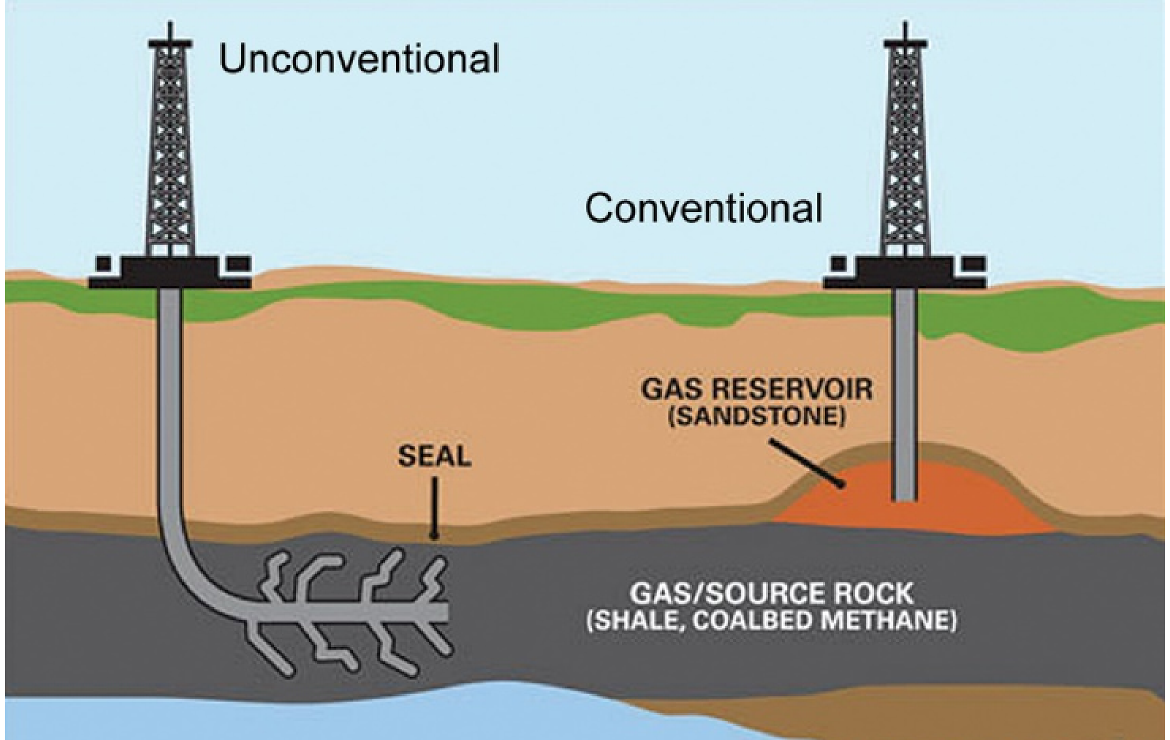
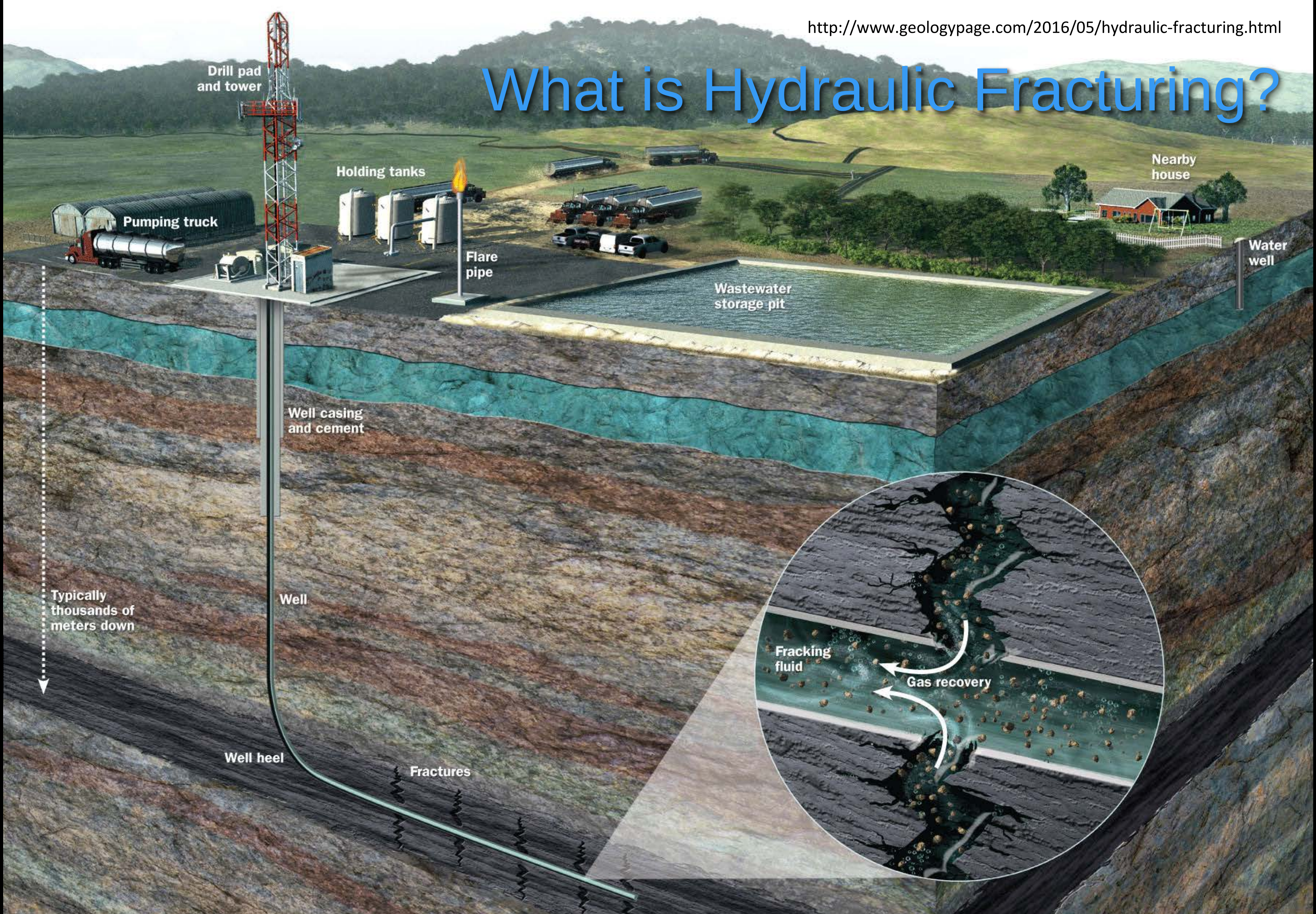


Photo: Croft Production Systems

http://www.geologypage.com/2016/05/hydraulic-fracturing.html

What is Hydraulic Fracturing?

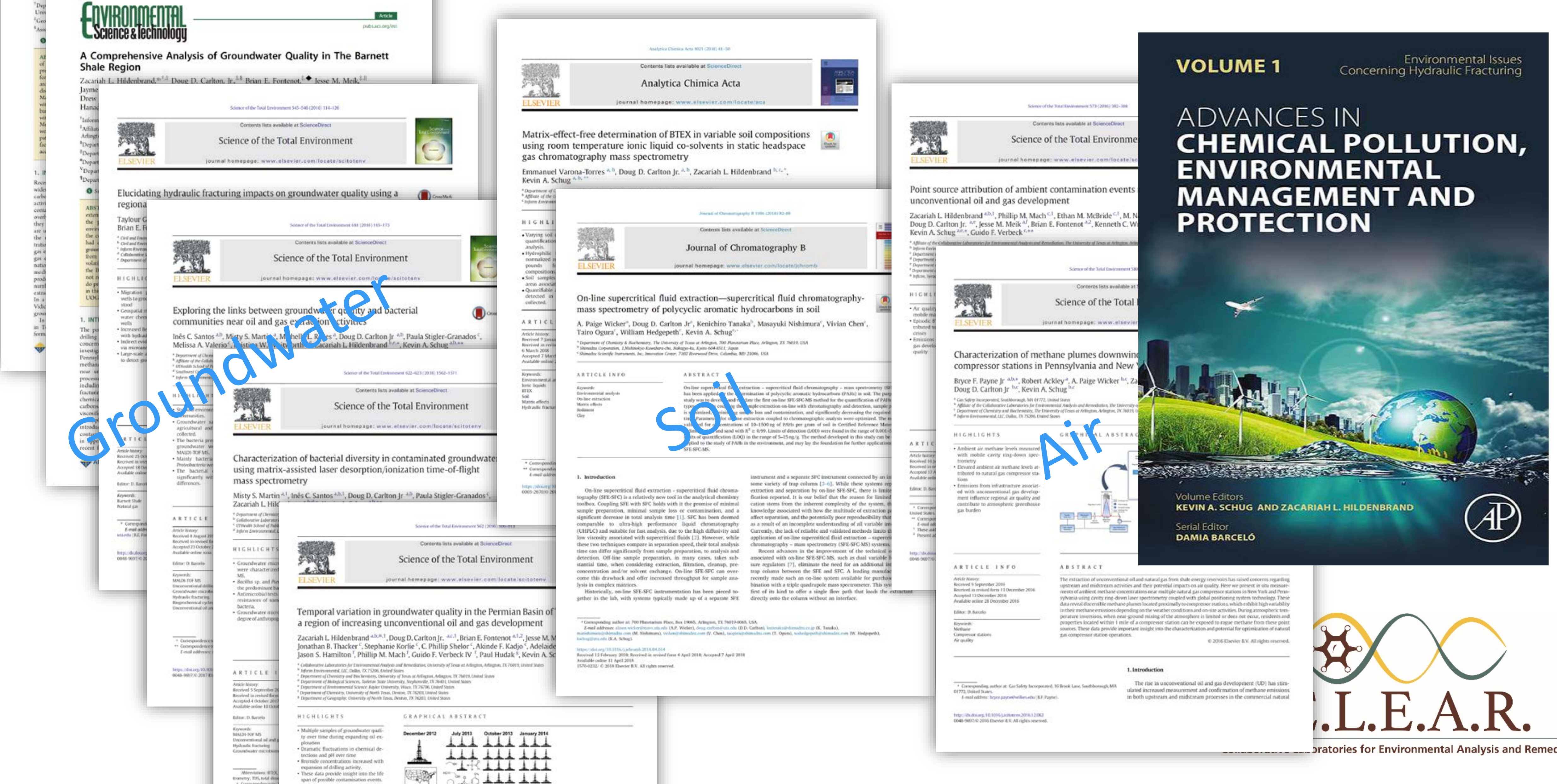


Where is this occurring?

Environmental Concerns

- Atmospheric pollution; greenhouse gases; climate change
- Emissions from waste storage, heavy equipment, processing and transport, and shale gas (leaks)
- Pollution of surface and groundwater; toxic substances; waste handling; water usage
- Withdrawal of land resources; industrial sites; changes in landscapes; soil quality
- Seismic activity; waste disposal/ recycling/ reuse

Environmental Monitoring



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Produced Water Analysis

Water **2015**, *7*, 1568-1579; doi:10.3390/w7041568

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Article

Chemical Analysis of Wastewater from Unconventional Drilling Operations

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Abstract: Trillions of liters of wastewater from oil and gas extraction are generated annually in the US. The contribution from unconventional drilling operations (UDO), such as hydraulic fracturing, to this volume will likely continue to increase in the foreseeable future. The chemical content of wastewater from UDO varies with region, operator, and elapsed time after production begins. Detailed chemical analyses may be used to determine its content, select appropriate treatment options, and identify its source in cases of environmental contamination. In this study, one wastewater sample each from direct effluent, a disposal well, and a waste pit, all in West Texas, were analyzed by gas chromatography-mass spectrometry, inductively coupled plasma-optical emission spectroscopy, high performance liquid chromatography-high resolution mass spectrometry, high performance ion chromatography, total organic carbon/total nitrogen analysis, and pH and conductivity analysis. Several compounds known to compose hydraulic fracturing fluid were detected among two of the wastewater samples including 2-butoxyethanol, alkyl amines, and cocamide

Water **2015**, *7*, 1568-1579.

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Analytical Instruments for the Hydraulic Fracturing Industry

Analytical Tools for the Analysis of Hydraulic Fracturing Produced Water

Science of the Total Environment 634 (2018) 1519–1529

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Characterizing variable biogeochemical changes during the treatment of produced oilfield waste

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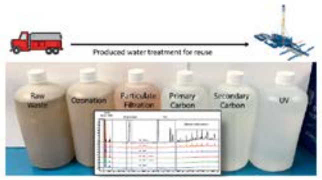
HIGHLIGHTS

- The biogeochemistry of waste from the Eagle Ford Shale was assessed.
- The efficacies of different water treatment technologies were evaluated.
- Resilient bacteria were found to survive different disinfection modalities.
- Multiple treatment processes are required for potential reuse.

GRAPHICAL ABSTRACT



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ABSTRACT

At the forefront of the discussions about climate change and energy independence has been the process of hydraulic fracturing, which utilizes large amounts of water, proppants, and chemical additives to stimulate sequestered hydrocarbons from impermeable subsurface strata. This process also produces large amounts of heterogeneous flowback and formation waters, the subsurface disposal of which has most recently been linked to the induction of anthropogenic earthquakes. As such, the management of these waste streams has provided a newfound impetus to explore recycling alternatives to reduce the reliance on subsurface disposal and fresh water resources. However, the biogeochemical characteristics of produced oilfield waste render its recycling and reutilization for production well stimulation a substantial challenge. Here we present a comprehensive analysis of produced waste from the Eagle Ford shale region before, during, and after treatment through adjustable separation, flocculation, and disinfection technologies. The collection of bulk measurements revealed significant reductions in suspended and dissolved constituents that could otherwise preclude untreated produced water from being utilized for production well stimulation. Additionally, a significant step-wise reduction in pertinent scaling and well-fouling elements was observed, in conjunction with notable fluctuations in the microbiomes of highly variable produced waters. Collectively, these data provide insight into the efficacies of available water

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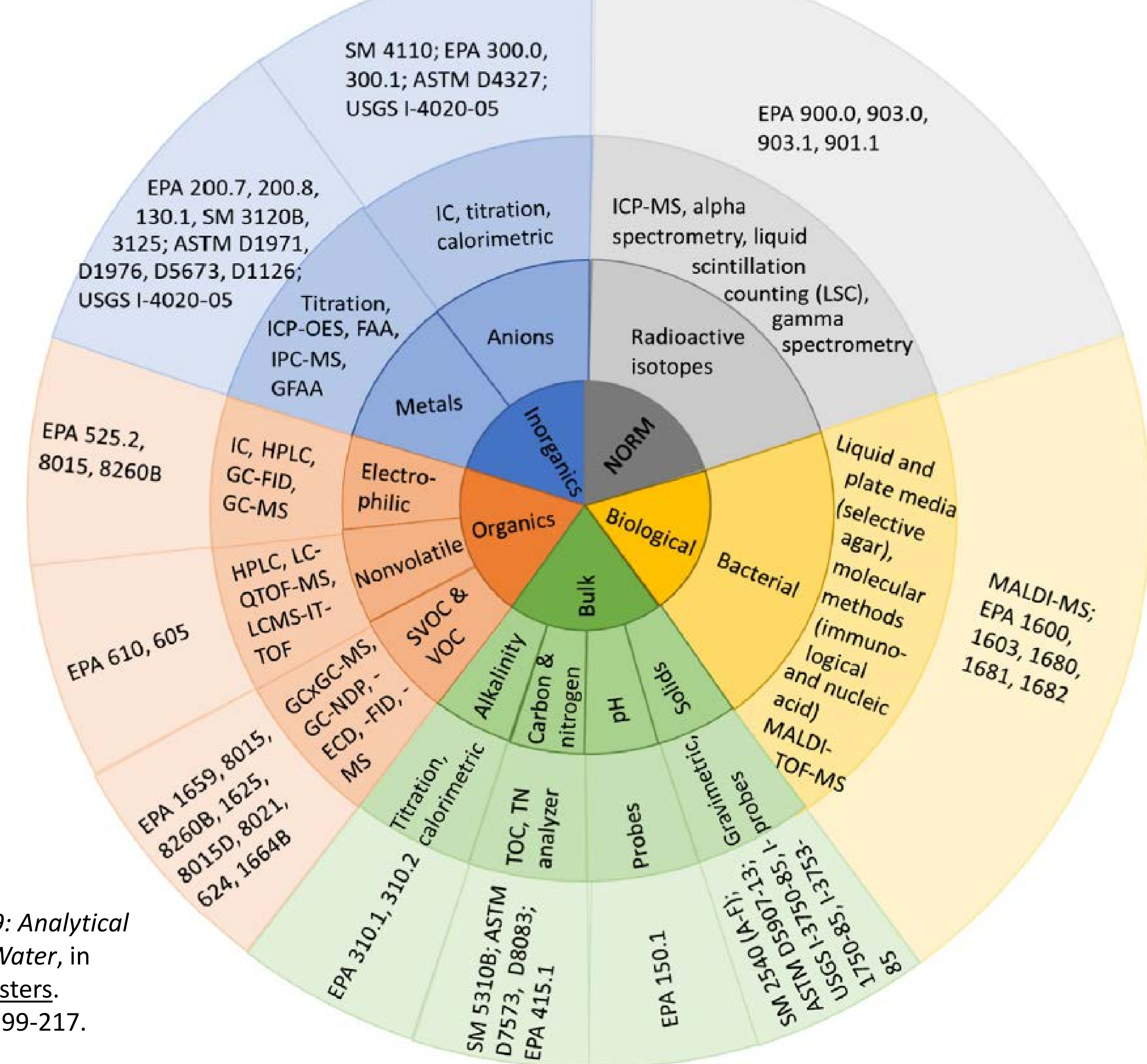
Produced Water Analysis

1. Bulk properties
2. Organics
3. Inorganics
4. NORM
5. Biological



Liden, T.; Santos, I.C.; Hildenbrand, Z.L.;* Schug, K.A.* *Chapter 9: Analytical Methods for the Comprehensive Characterization of Produced Water*, in Ahuja, A. (Ed.), Evaluating Water Quality to Prevent Future Disasters. Separation Science and Technology, Vol. 11. Elsevier. **2019**. Pp 199-217.

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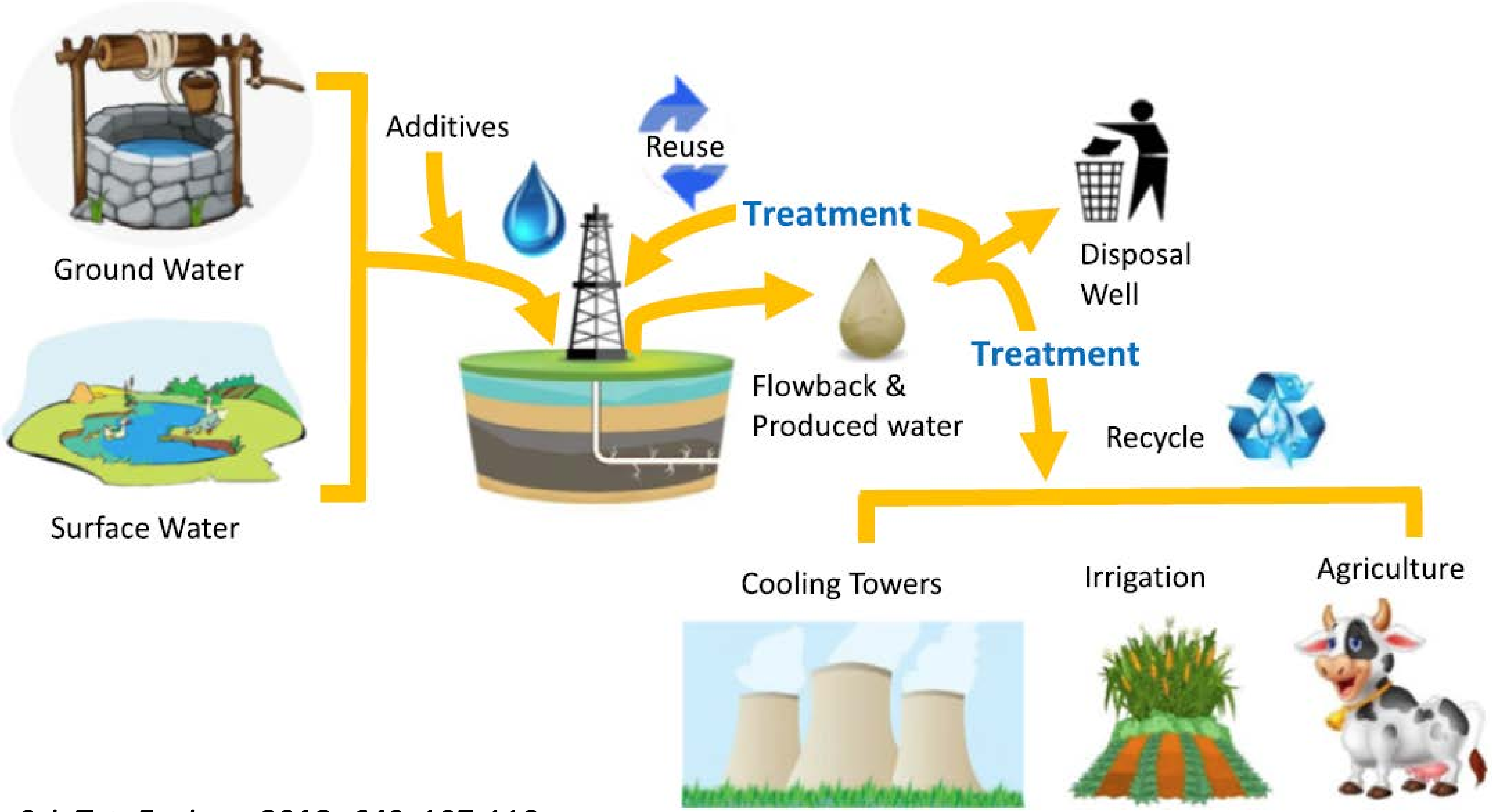
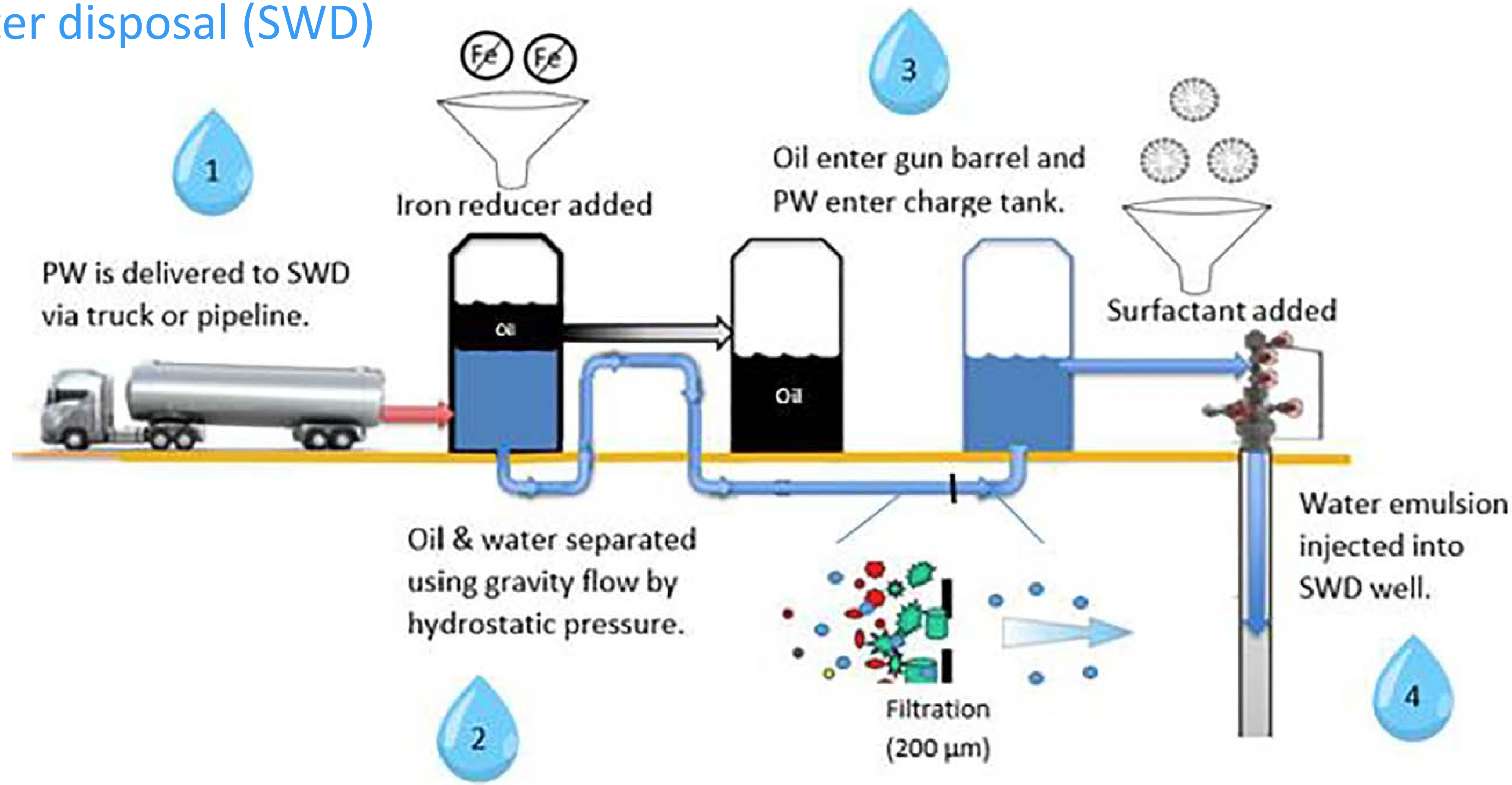
PW Treatment Options



Liden et al. *Sci. Tot. Environ*. **2018**, *643*, 107-118.

PW Treatment Options

Saltwater disposal (SWD)

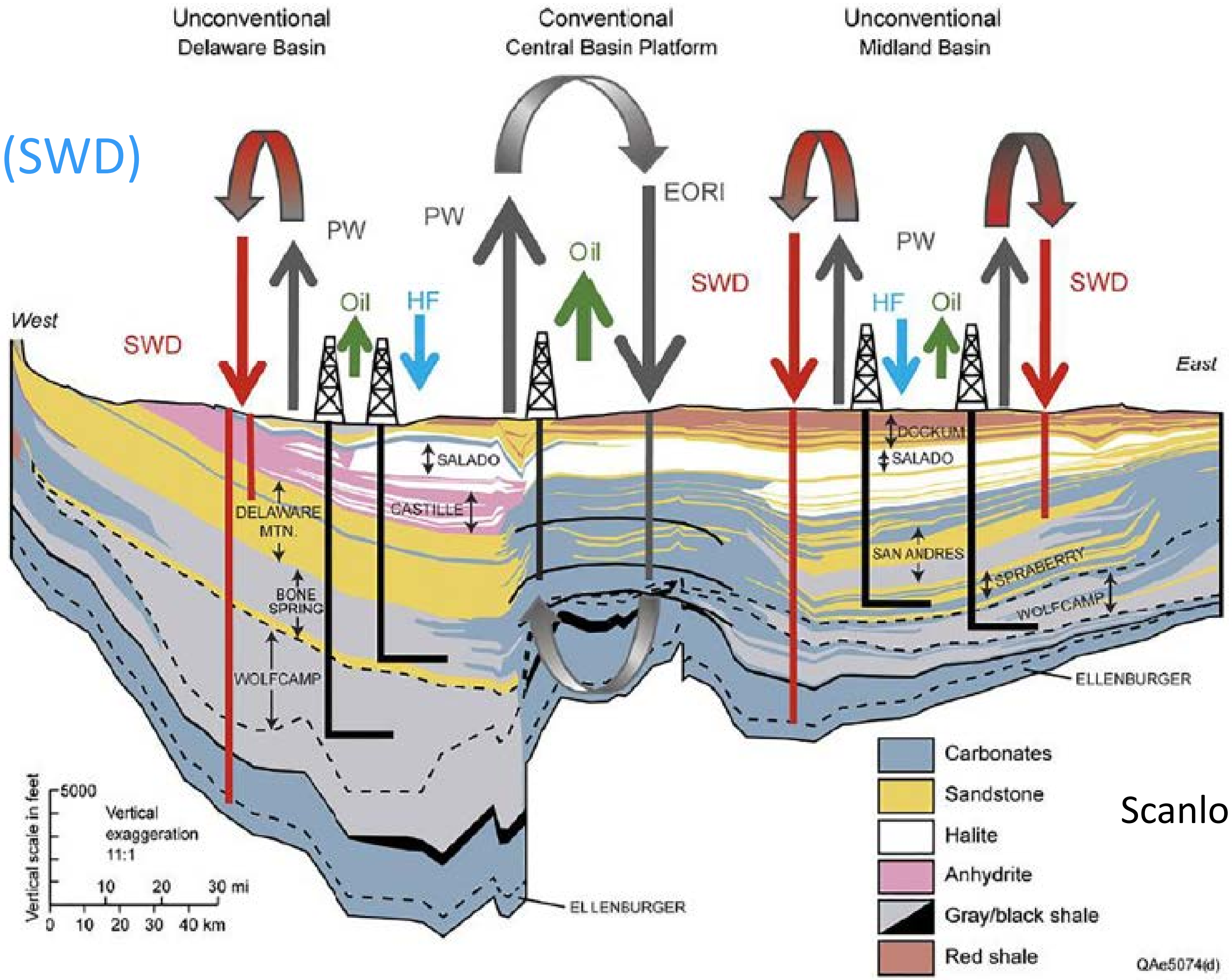


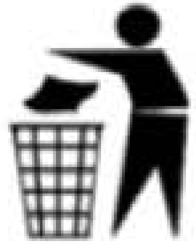
Disposal Well

Liden, T., Clark, B.G., Hildenbrand, Z.L., Schug, K.A., 2017. Unconventional oil and gas production: waste management and the water cycle. In: Schug, K.A., Hildenbrand, Z.L. (Eds.), Environmental Issues Concerning Hydraulic Fracturing. vol. 1. APMP. Academic Press, UK: pp. 17–45.

PW Treatment Options

Saltwater disposal (SWD)





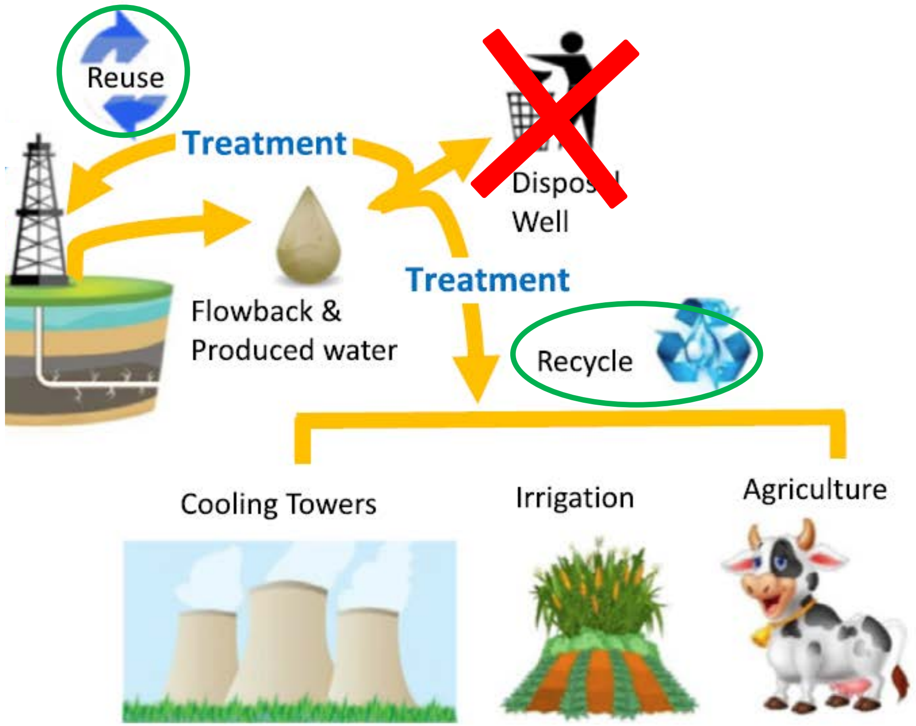
Disposal Well

Scanlon et al. *Environ. Sci. Technol.* **2017**, *51*, 10903-10912

PW Treatment Options

1. Removal of organics, incl. oil and grease
2. Solids removal; suspended particles and sand
3. Disinfection
4. Dissolved gas removal, if needed (H_2S)
5. Softening; reduce hardness/scaling
6. Removal of NORM
7. Desalination

- Cost, Throughput, Performance
- Beware of industry stigma!



Liden et al. *Sci. Tot. Environ*. **2018**, *643*, 107-118.

Treatment Performance for Reuse

	Drinking water (mg/L) (EPA SDWA)	Agricultural irrigation (mg/L) (EPA)	Livestock (mg/L) (FAO)	Production well stimulation (mg/L) (Hildenbrand et al., 2018; Wasylishen and Fulton, 2012)
TDS	500	450		
PH	6.5–8.5	6.5–8.4		6.0–8.0
TSS				500
Total nitrogen	44.3			
Fluoride	4	1	2	
Chloride	250	92		30,000–50,000
Bromide				
Nitrate	44.3	5	90	
Nitrite			10	
Nitrate + nitrite			100	
Sulfate	250		1000	500
Bicarbonate		91.5		300
Silica				35
Silver (Ag)	0.1			
Aluminum (Al)	0.05–0.2	5	5	
Arsenic (As)	0.01	0.1	0.2	
Boron (B)		0.7	5	10
Barium (Ba)	2			20
Beryllium (Be)	0.004	0.1	0.1	
Calcium (Ca)				2000
Cadmium (Cd)	0.005	0.01	0.05	
Cobalt (Co)		0.05	1	
Chromium (Cr)	0.1	0.1	1	
Copper (Cu)	1.3	0.2	0.5	
Iron (Fe)	0.3	5		10
Mercury (Hg)	0.002		0.01	
Lithium (Li)		2.5		
Magnesium (Mg)				2000
Manganese (Mn)	0.05	0.2	0.05	
Molybdenum (Mo)	0.04	0.01	0.3	
Sodium (Na)	20	69	1000	
Nickel (Ni)	0.1	0.2		
Lead (Pb)		5	1	
Antimony (Sb)	0.006			
Selenium (Se)	0.05	0.02	0.05	
Strontium (Sr)	4			
Thallium (Tl)	0.002			
Uranium (U)	0.03			
Valadium (V)		0.1	0.1	
Zinc (Zn)	5	2	24	
Benzene	0.005			
Dichloromethane	0.005			
Ethylbenzene	0.7			
Toluene	1			
Total xylenes	10			

PW Treatment Options

1. Removal of organics, incl. oil and grease
2. Solids removal; suspended particles and sand
3. Disinfection
4. Dissolved gas removal, if needed (H_2S)
5. Softening; reduce hardness/scaling
6. Removal of NORM
7. Desalination

- Gravity
- Holding tanks
- Hydrocyclones
- Floatation tanks
- Activated carbon and other media
- Bioremediation

Liden et al. *Sci. Tot. Environ*. **2018**, *643*, 107-118.

PW Treatment Options

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- TSS vs. TDS
- TSS, filter @ 1 – 2 µm
- Coagulation
- Flocculation
- Gravity separation
- Filtration

Liden et al. *Sci. Tot. Environ*. **2018**, *643*, 107-118.

PW Treatment Options

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2. Solids removal; suspended particles and sand
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4. Dissolved gas removal, if needed (H_2S)
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6. Removal of NORM
7. Desalination

- Aeration
- Biocides
- Chlorination
- Filtration
- Ozonation/UV

Liden et al. *Sci. Tot. Environ*. **2018**, *643*, 107-118.

PW Treatment Options

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3. Disinfection
4. Dissolved gas removal, if needed (H_2S)
5. Softening; reduce hardness/scaling
6. Removal of NORM
7. Desalination

- Chemical scavengers
- Flaring
- Venting

Liden et al. *Sci. Tot. Environ*. **2018**, *643*, 107-118.

PW Treatment Options

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2. Solids removal; suspended particles and sand
3. Disinfection
4. Dissolved gas removal, if needed (H_2S)
5. Softening; reduce hardness/scaling
6. Removal of NORM
7. Desalination

- Precipitation
- Zeolite and bentonite media

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PW Treatment Options

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- Distillation (many)
- Membrane processing (many)

Liden et al. *Sci. Tot. Environ*. **2018**, *643*, 107-118.

A Case Study

Modular Portable Multi-modal Treatment Process (15,000 bbls/d)

1. Oil and Waste Water Separation
2. Ozone Pre-Treatment
3. Solids Filtration
4. Media Filtration
5. UV Treatment

10# brine

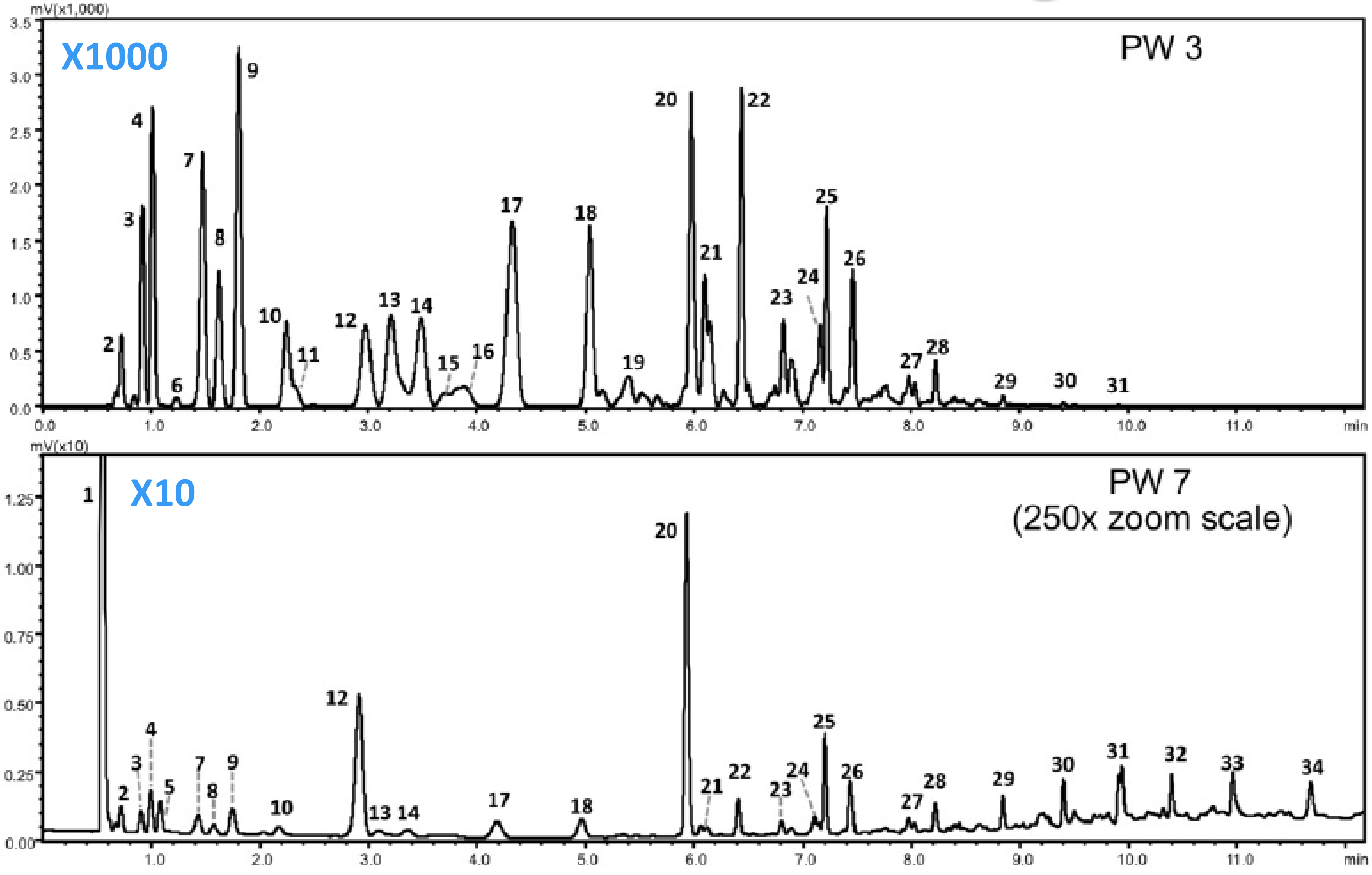
CHALLENGER WATER SOLUTIONS

Hildenbrand et al. *Sci. Tot. Environ*. **2018**, *634*, 1519-1529.

Sample ID	Sample notes
PW1	100 bbl of gel + breaker from waste pit. Only raw sample was collected as this fluid could not be run through water treatment system
PW2	Oilfield waste from gun barrel tanks of salt water disposal well site
PW2B	Oilfield waste from a second gun barrel tank from the same salt water disposal site as PW2
PW3	Oilfield waste from settling tanks of salt water disposal well site
PW3B	Oilfield waste from a second set of settling tanks from the same salt water disposal site as PW3
PW4	Oilfield waste from frac tanks of salt water disposal well site
PW4B	Oilfield waste from a second set of frac tanks from the same salt water disposal site as PW4
PW5	Flowback water
PW6	Produced water A
PW7	Produced water B (Gilette, TX)
PW8	Produced water C (Gonzales, TX)
PW9	Oilfield waste from waste water pipeline A
PW10	Oilfield waste from waste water pipeline B
PW11	Blend of PWs 8–10

Hildenbrand et al. *Sci. Tot. Environ*. **2018**, *634*, 1519-1529.

Variations in Organic Composition

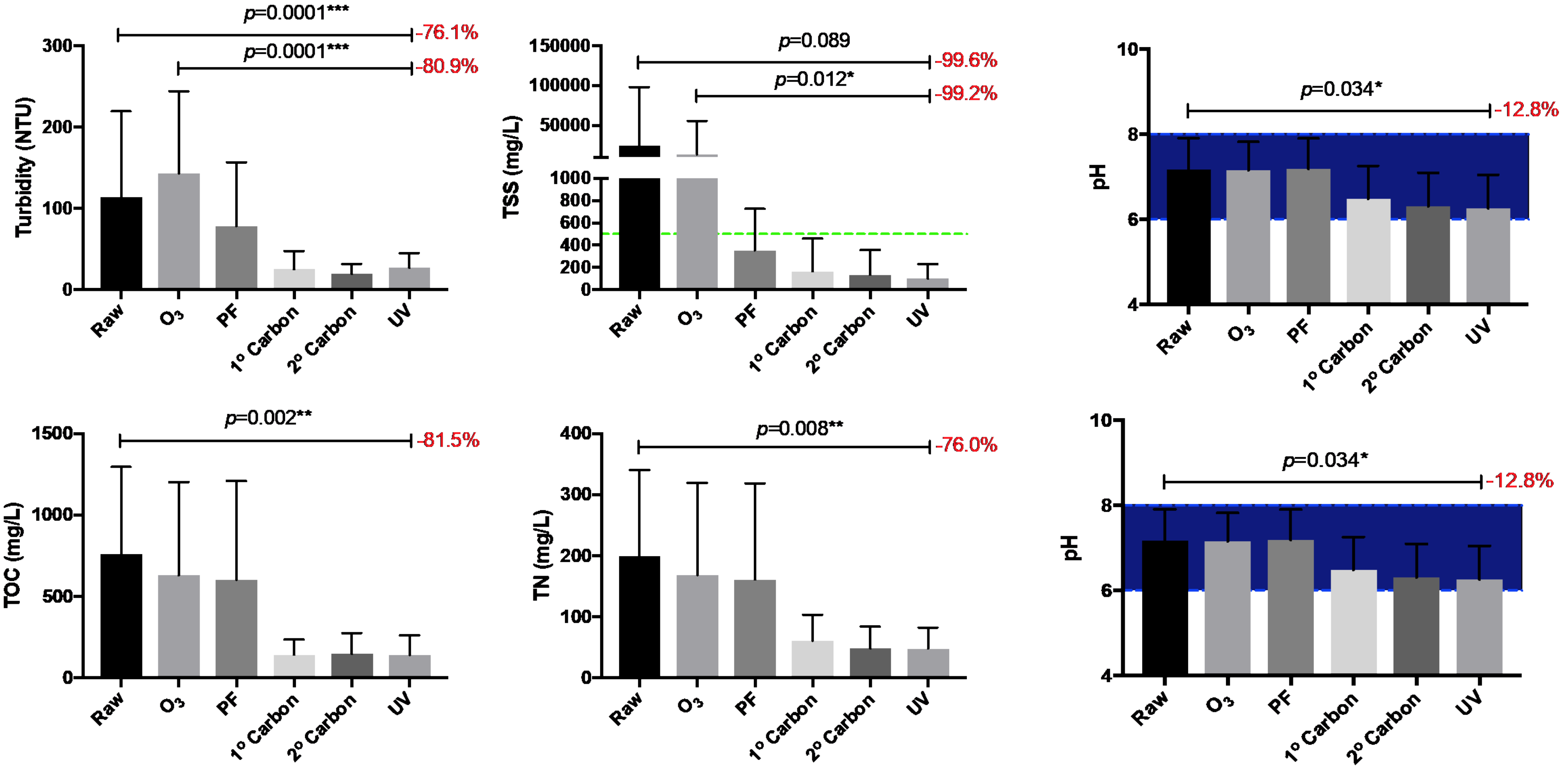


Raw produced water by GC-MS

#	Compound	#	Compound	#	Compound
1	Unretained Hydrocarbons	13	Ethylene chloride	25	m- + p-Xylene
2	Methanol	14	3-Hexanol	26	Nonane + o-Xylene
3	Methanethiol	15	Cyclo-hexane	27	Alkyl aromatics
4	Ethanol	16	Benzene	28	Decane
5	iso-Pentane	17	3-methyl hexane	29	Undecane
6	Pentane	18	Heptane	30	Dodecane
7	Methylene chloride	19	Methyl-cyclohexane	31	Tridecane
8	Methyl acetate	20	Toluene	32	Tetradecane
9	n-Propanol	21	C8 aliphatic + C8 cyclic HC	33	Pentadecane
10	Hexane	22	Octane	34	Hexadecane
11	2-butanol	23	C9 aliphatic HC		
12	Ethyl acetate	24	Cyclohexanone + Ethyl Benzene		

Hildenbrand et al. *Sci. Tot. Environ*. **2018**, *634*, 1519-1529.

Bulk Properties



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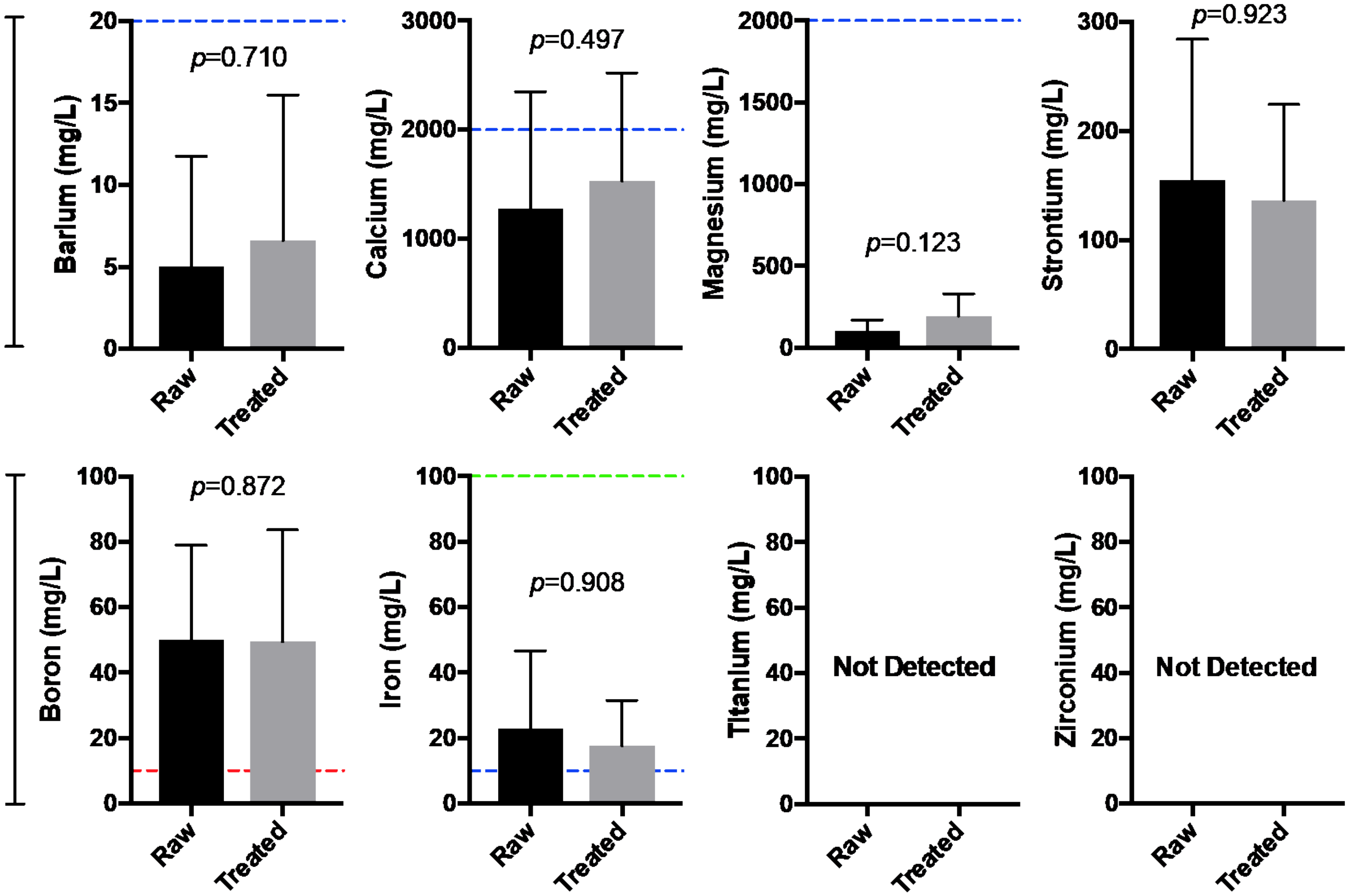
Metals of Concern

Scale

Crosslinker efficiency



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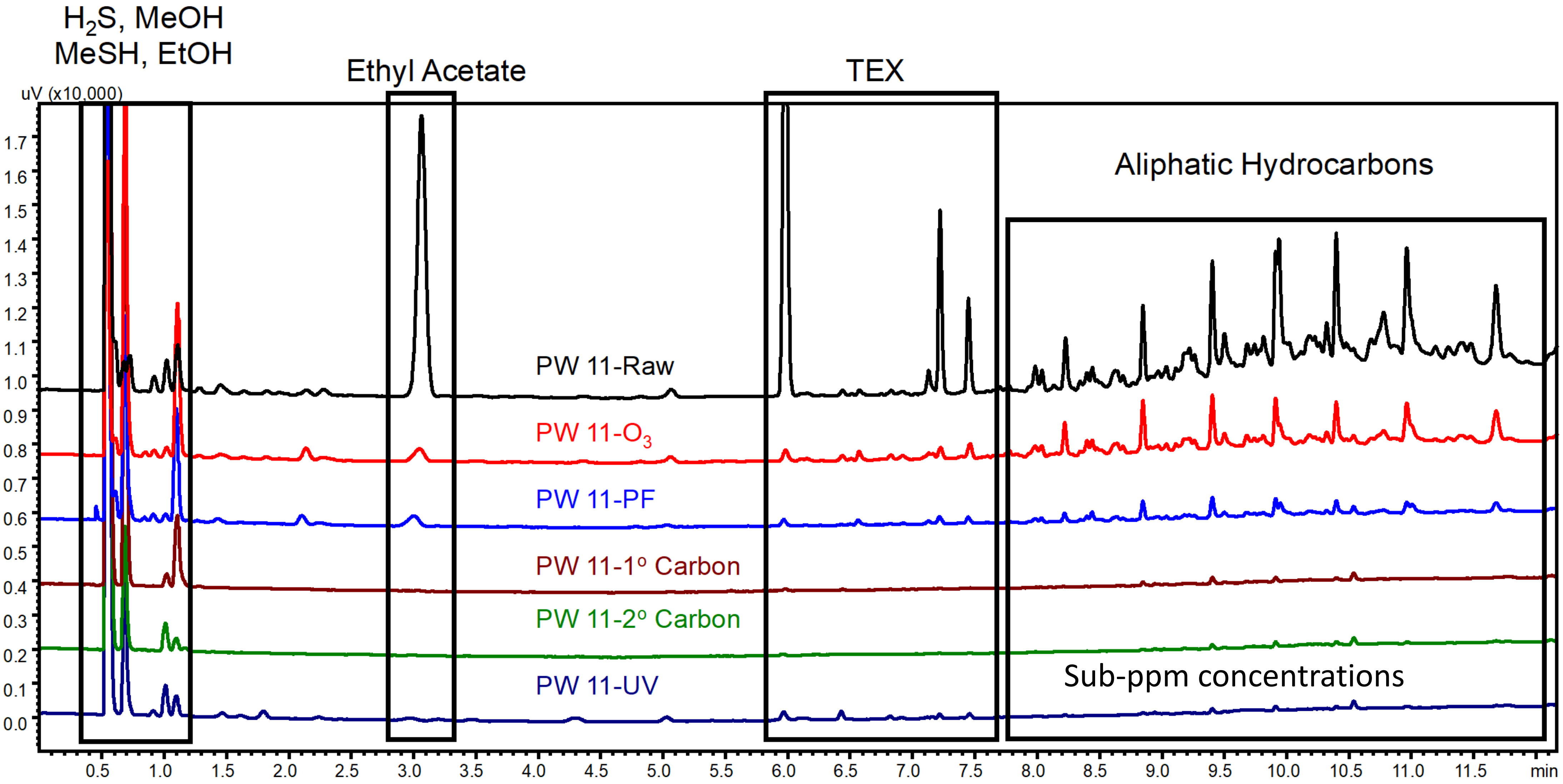
Organics



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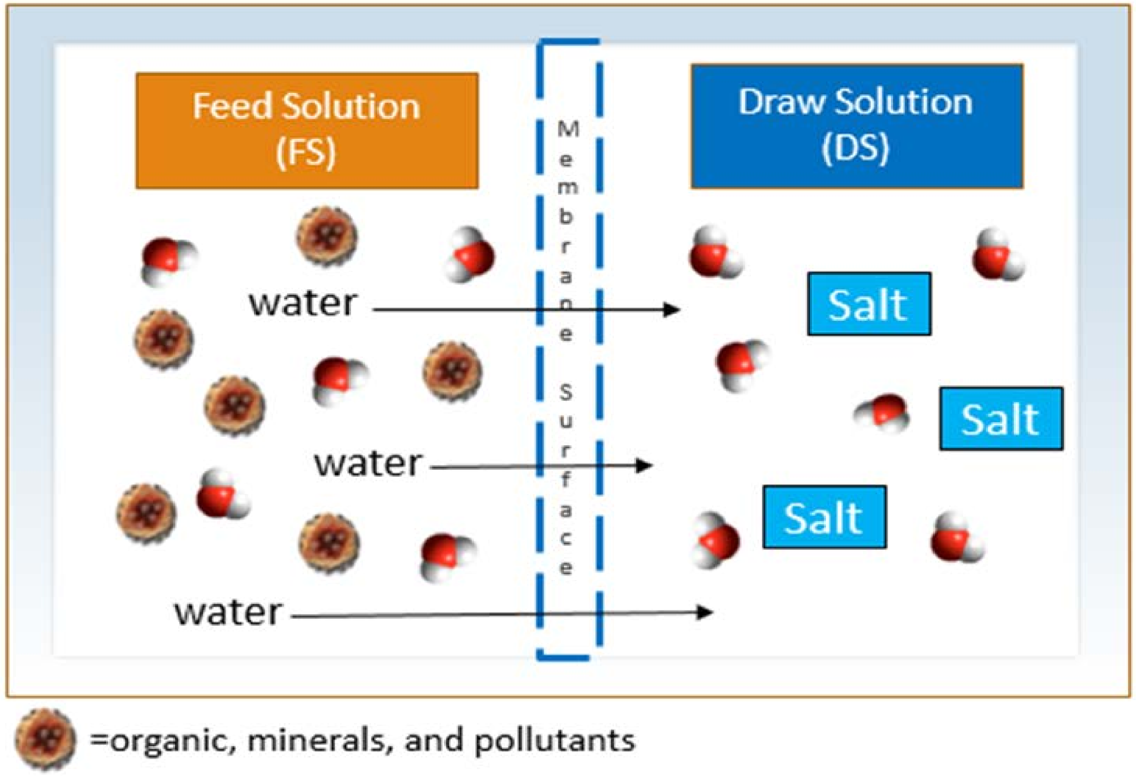
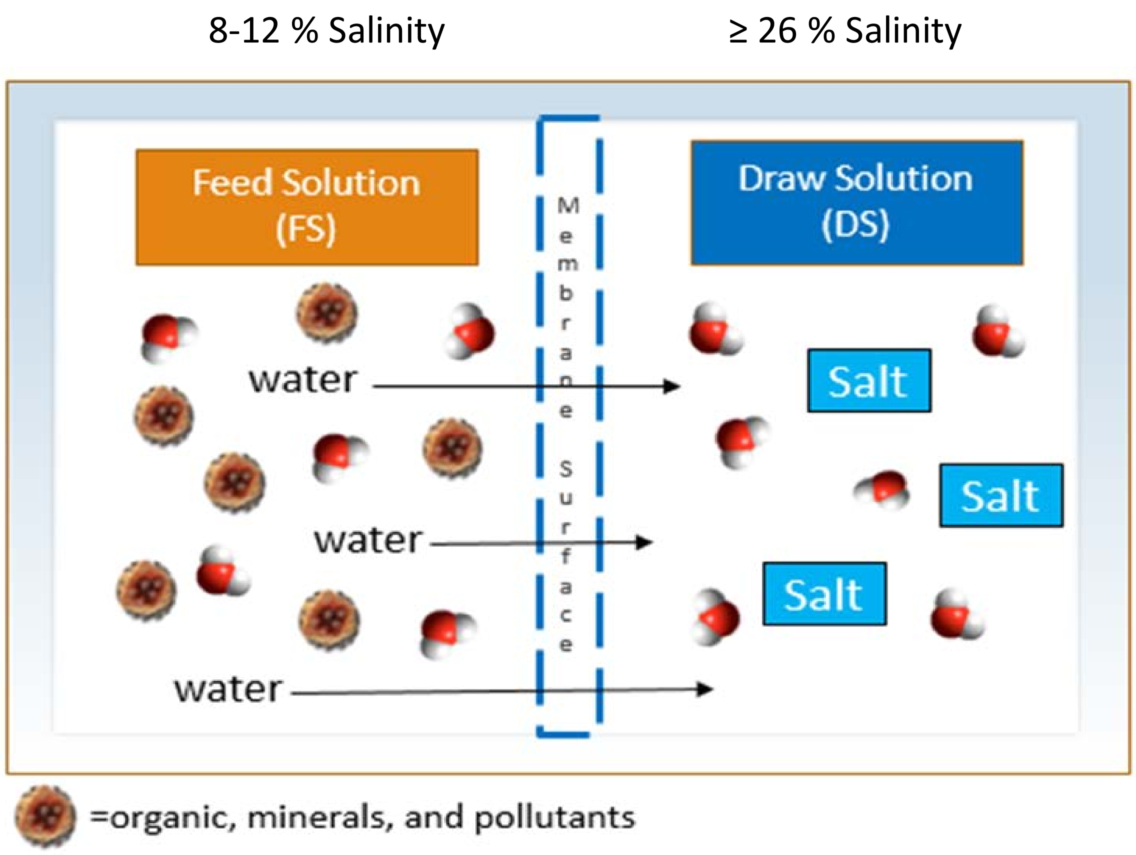
Forward Osmosis (FO)

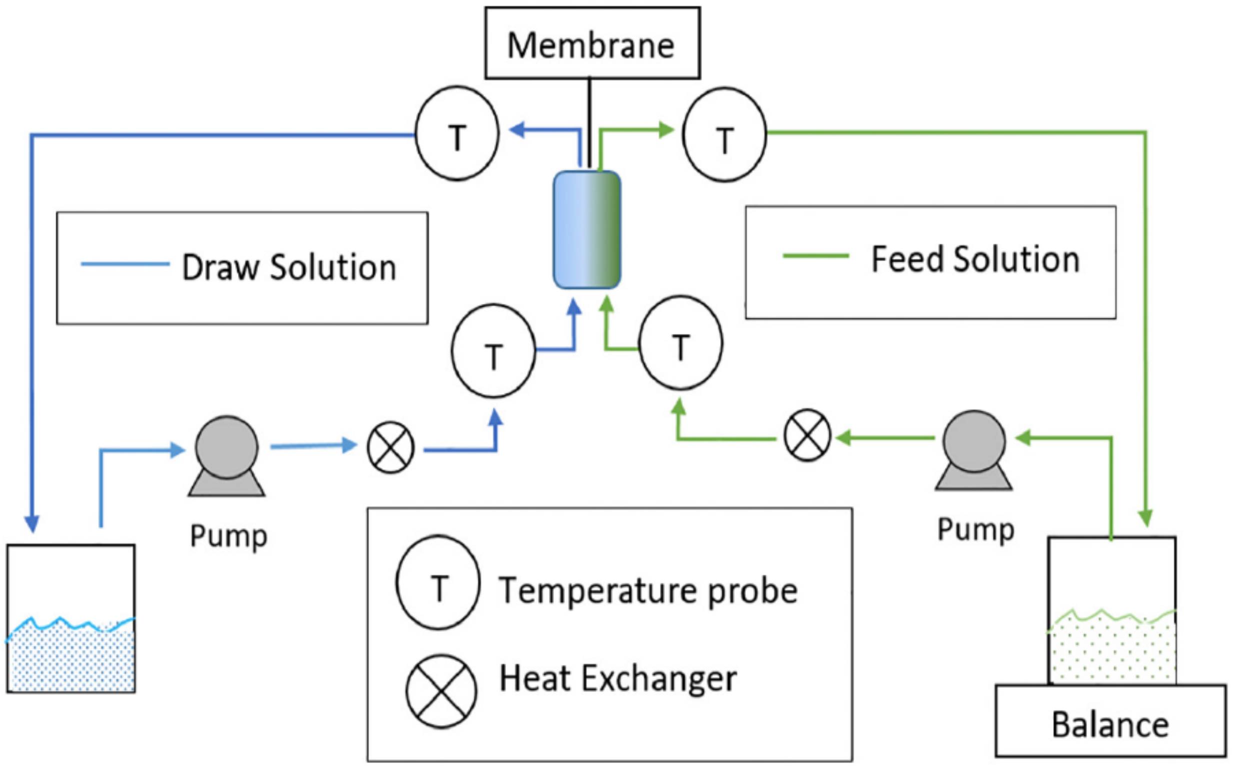
8-12 % Salinity ≥ 26 % Salinity



- Osmotic pressure is primary driving force
- Recover water and decrease waste volume
- Requires further desalination
- Less energy intensive than:
  - Membrane distillation
  - Mechanical vapor compression
  - Reverse osmosis (RO)
- RO limited to <40,000 mg/L (~seawater) TDS
  - Permian PW is 2 – 3.5x higher

Forward Osmosis (FO)





Liden et al. *Sci. Tot. Environ.* **2019**, 653, 82-90.
Liden et al. *Sci. Tot. Environ.* **2019**, 675, 73-80.
Liden et al. *Water* **2019**, 11, 1437.

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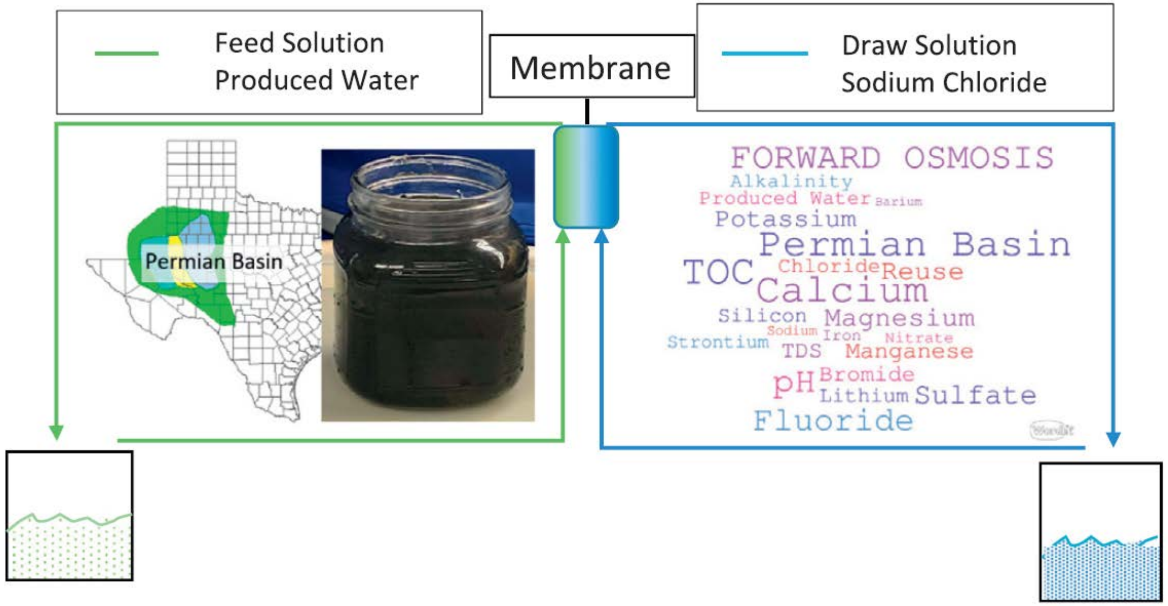
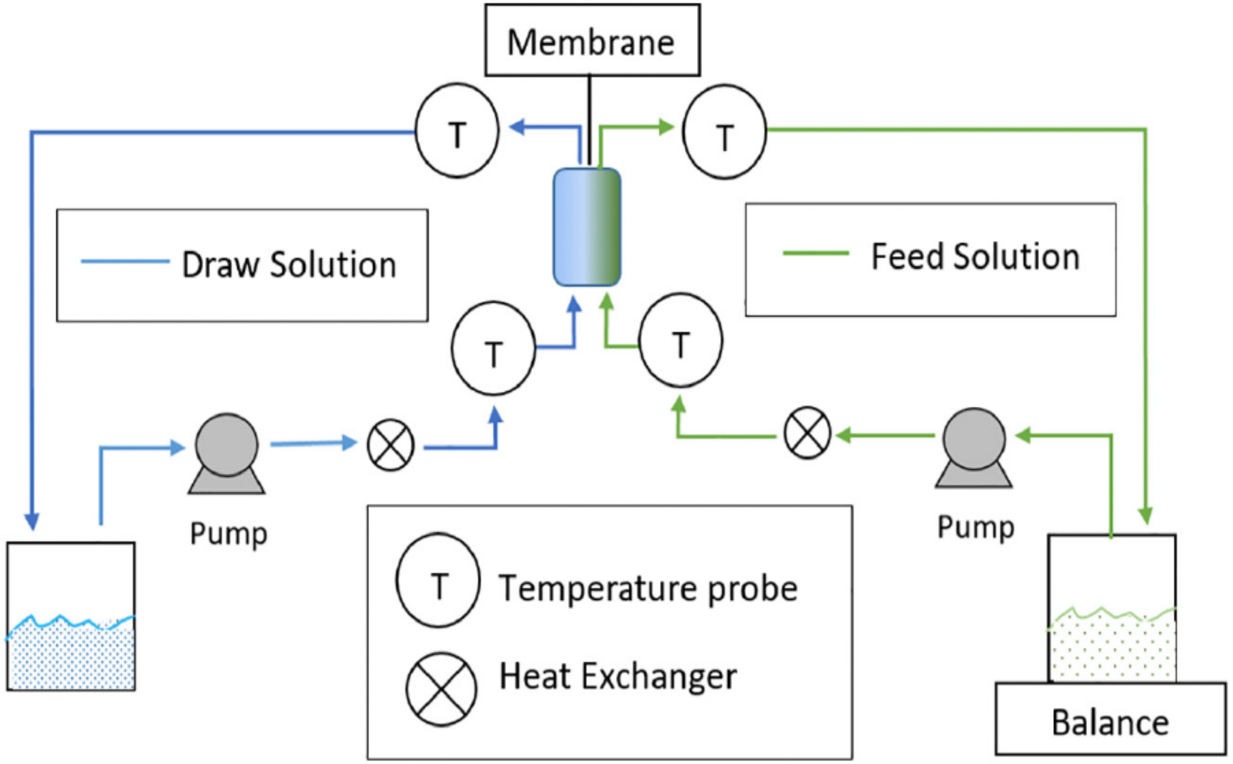
Forward Osmosis (FO)





Demonstrated use for treatment of Permian Basin PW for short periods

Liden et al. *Sci. Tot. Environ.* **2019**, 653, 82-90.

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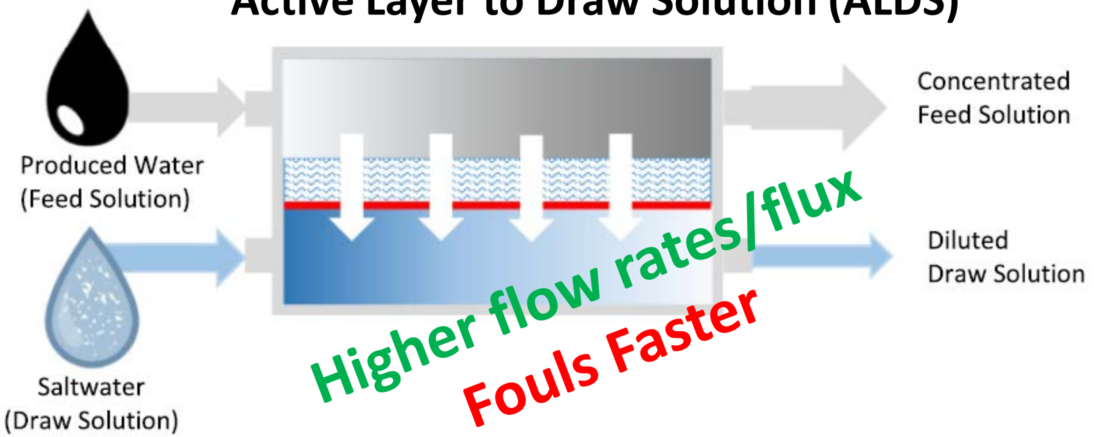
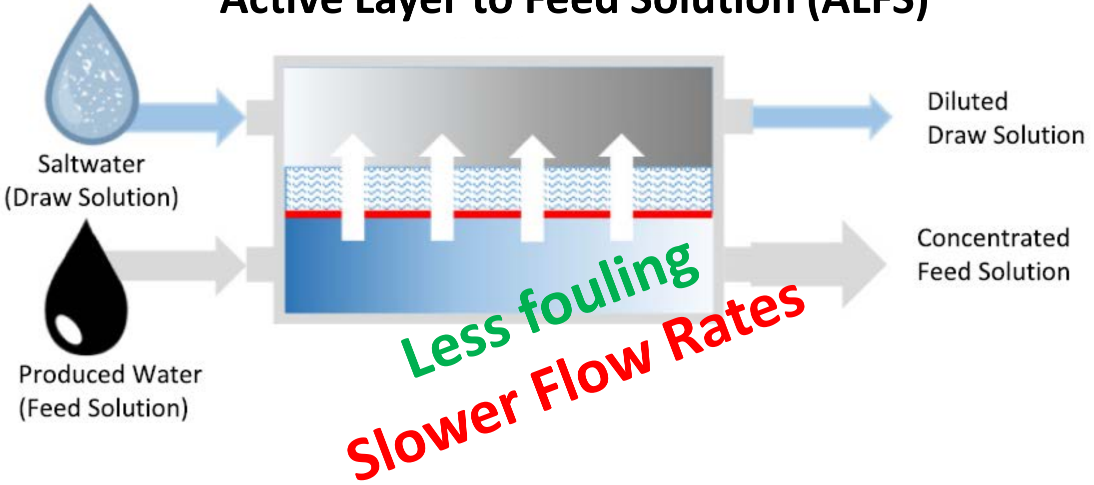
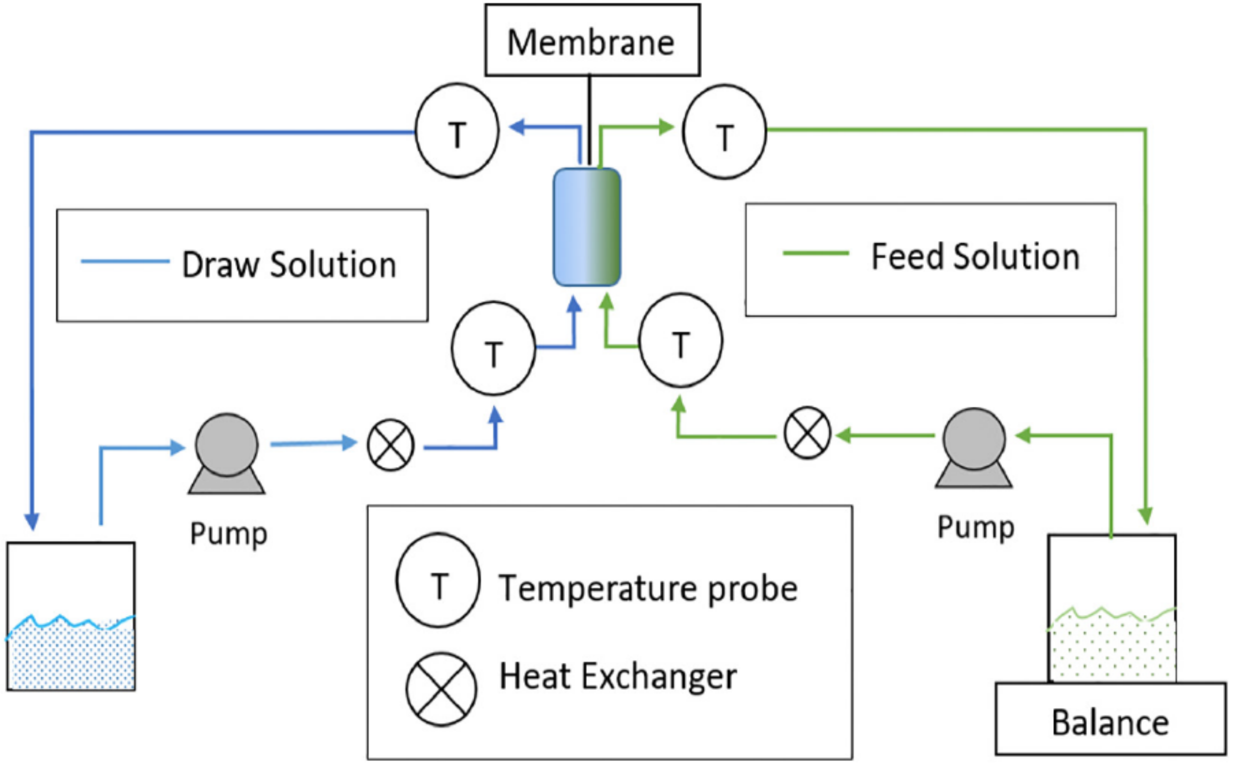
Forward Osmosis (FO)

Active Layer to Draw Solution (ALDS)



Active Layer to Feed Solution (ALFS)





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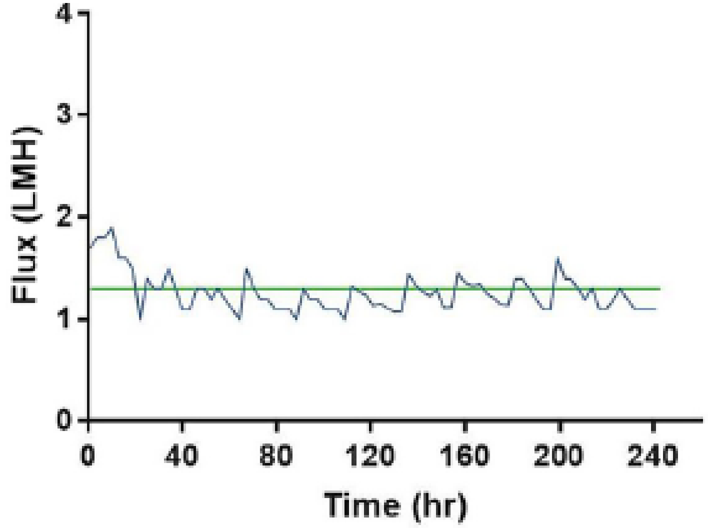
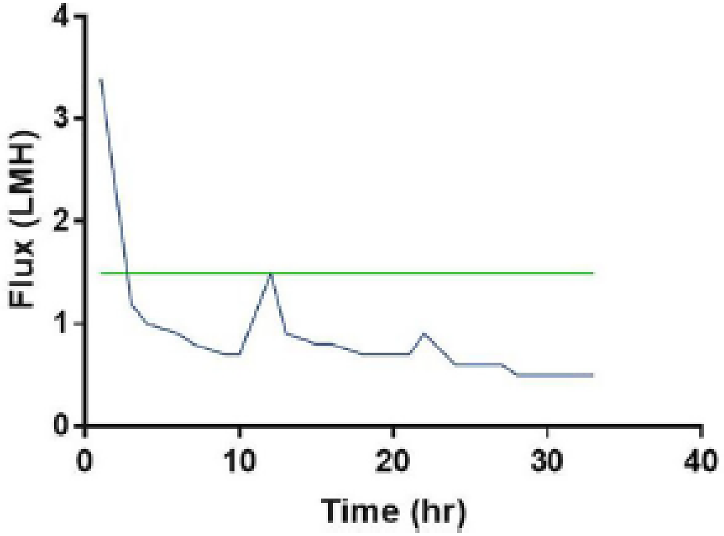
Flux, Fouling/Scaling

— Average Flux/hr — Target

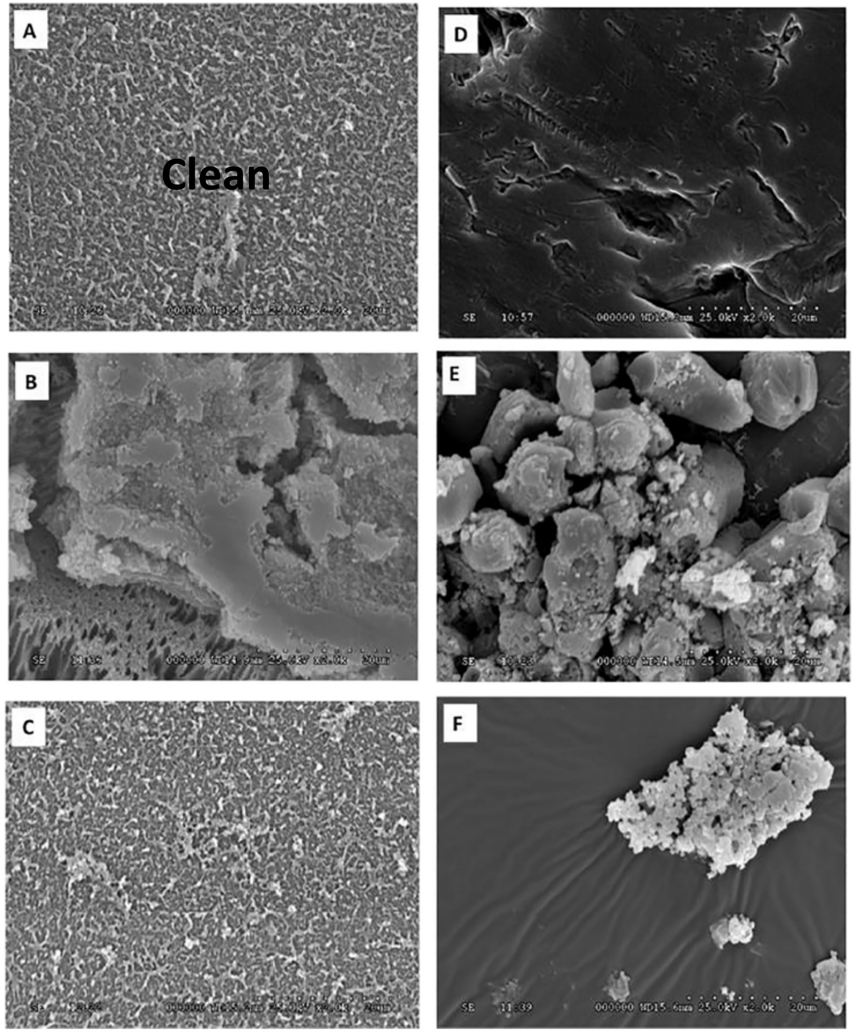
Active Layer to Feed Solution (ALFS)



Active Layer to Draw Solution (ALDS)



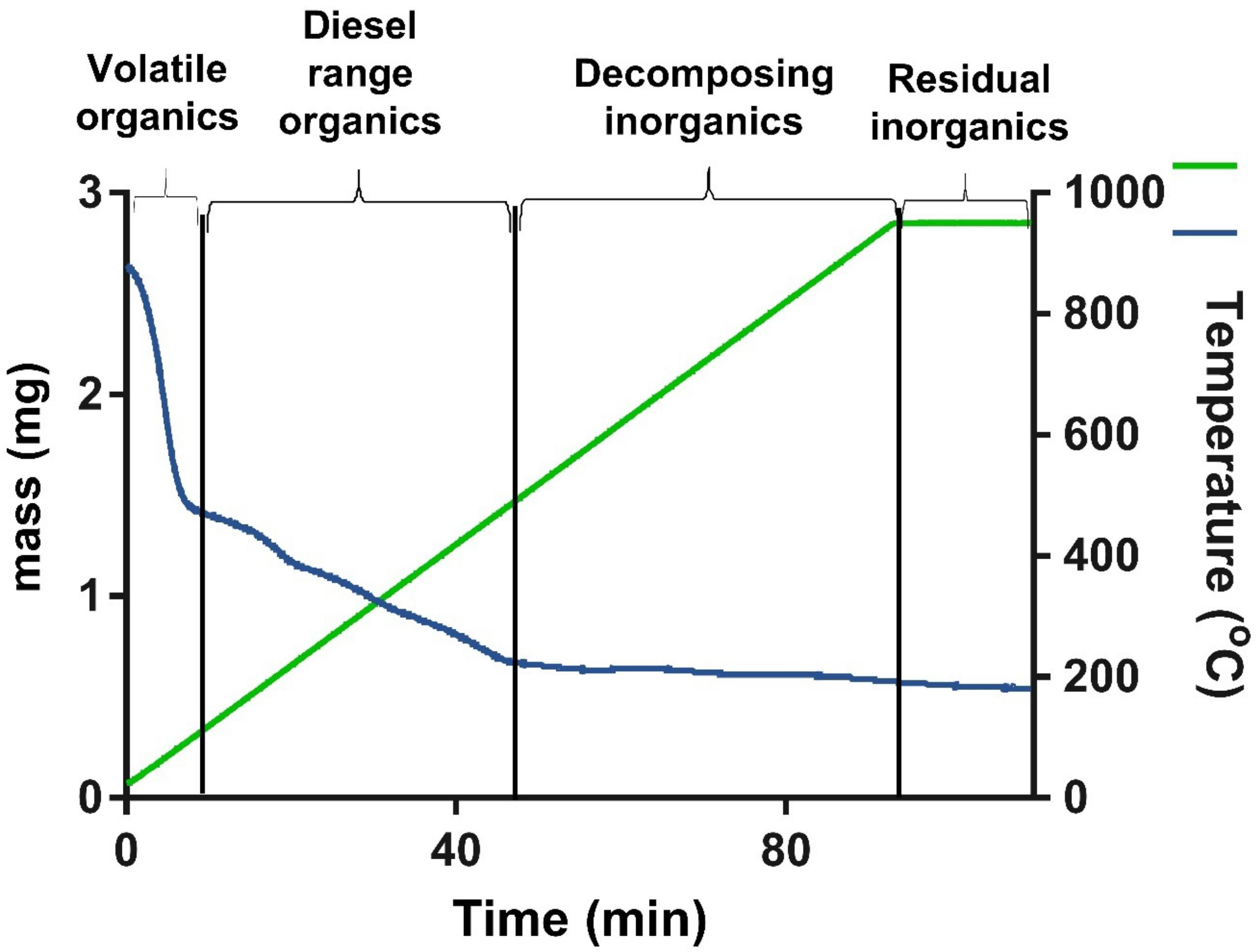
Consistent recovery of 0.5 initial flux with daily membrane washing for ~10 d using ALFS



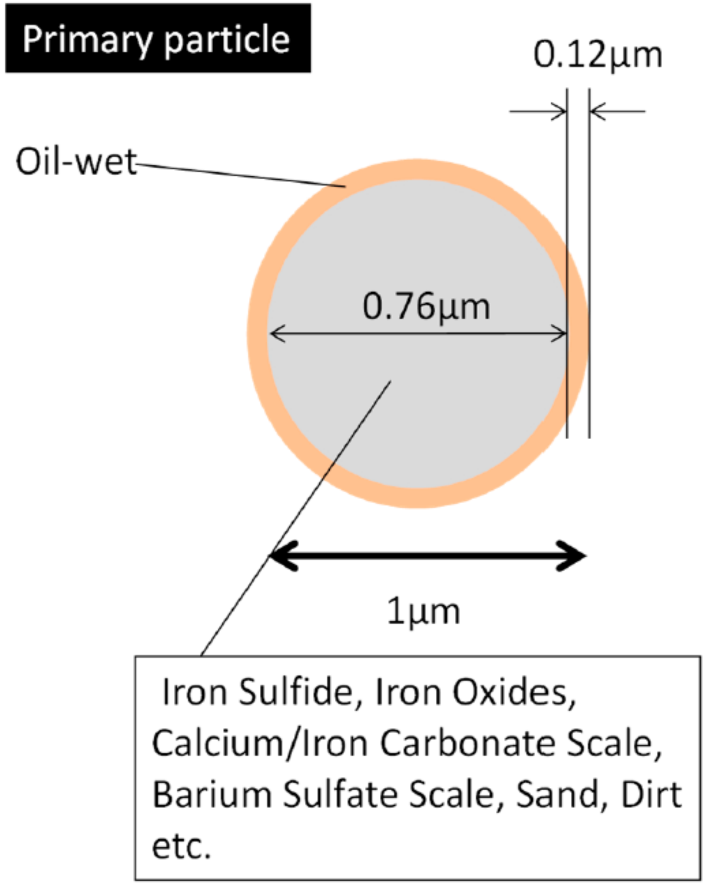
SEM of membrane surfaces

Liden et al. *Water* **2019**, 11, 1437.

Oil-Wetted Solids

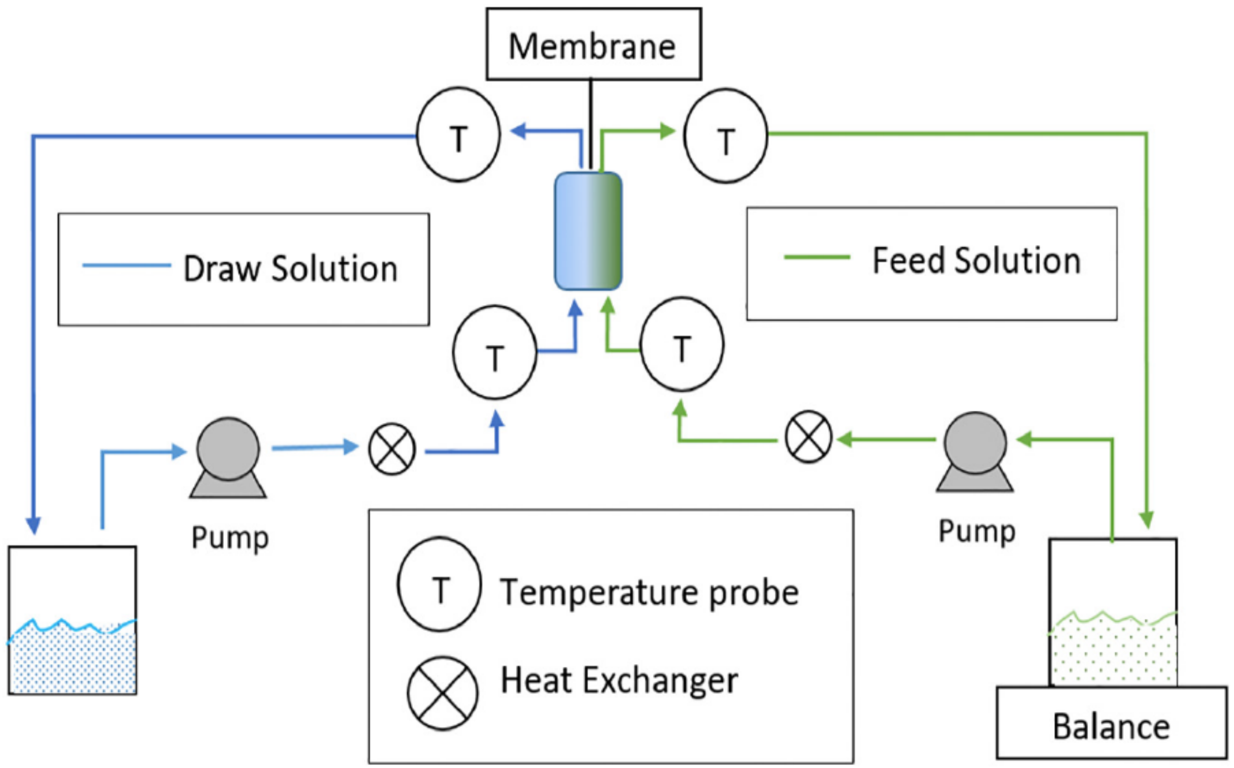


TGA of oil-wetted solids



Liden et al. *Water* **2019**, 11, 1437.

Forward Osmosis (FO)



- Low energy consumption
- Effective for concentrating high TDS PW
- Susceptible to scaling and fouling
- Scaling solved with periodic washing
- Fouling still a problem
- Pre-treatment needed for long-term field use
- Optimized washing protocol for long-term field use
- Ultimately, borders on too $$$ with need for pre-treatment

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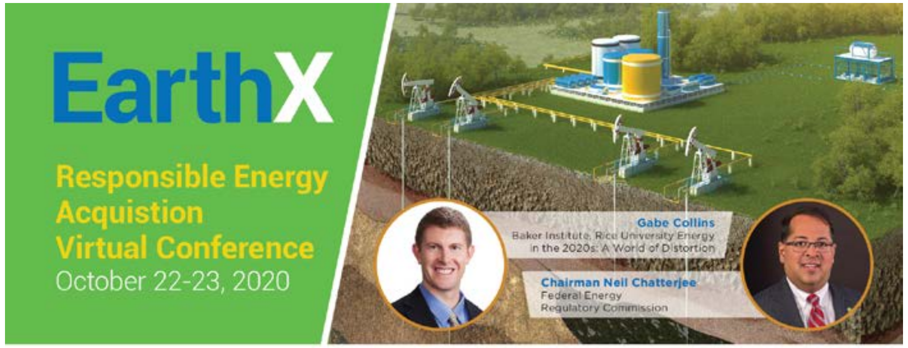
Future Directions

Develop and test new technologies and best management practices for unconventional oil and gas extraction

- Waste handling/processing
- Gas flaring

Expand methodologies for evaluating water, soil, air, and wastewater quality

Outreach, building awareness, and promoting environmental sustainability in the energy sector.



The EarthxEnergy: Responsible Energy Acquisition Virtual Conference
October 22-23, 2020

Day 1: October 22, 2020
Opening and Introductions
Zac Hildenbrand, *CLEAR, UT-El Paso*

Keynote Speaker
Chairman Neil Chatterjee,
Federal Energy Regulatory Commission

Conference Sessions
Flaring and Air Quality Issues
- ***Wiley Rhodes***, *Newpoint Gas, LLC*
- ***Cully Cavness***, *Crusoe Energy Systems*
- ***Thomas Slocum***, *Trifecta Solutions*

Produced Water Reuse and Recycling
- ***Brian Bohm***, *Apache*
- ***Fredrik Klaveness***, *NLB H20*
- ***Mark Patton***, *Hydrozonix*
- ***Karr Ingham***, *Texas Alliance of Energy Producers*
- ***Dan Mueller***, *Environmental Defense Fund*

Produced Water Desalination
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- ***Tiffany Liden***, *CLEAR, UT-Arlington*
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Ethically-Sourced Precious Metals
- ***Ashley Zumwalt-Forbes***, *Black Mountain Metals*

Responsible Energy Partnerships
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- ***Peter Schriber***, *Xpansiv*
- ***Soledad Mills***, *Equitable Origin*
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Day 2: October 23, 2020
Keynote Speaker
Gabe Collins, *Baker Institute, Rice University*
Energy in the 2020s: A World of Distortion

Conference Sessions
Latest Developments in the Permian and Delaware Basins
- ***Melinda Taylor***, *Mitchell Foundation*
- ***Ben Shepperd***, *Permian Basin Petroleum Association*
- ***Coyne Gibson***, *Big Bend Conservation Alliance*
- Moderator: ***David Schechter***, *WFAA*

Data Science in the Energy Sector
- ***Allen Gilmer***, *Enverus*
- ***Josh Adler***, *Sourcewater*
- ***Joel Warner***, *Karve IoT*
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Nuclear Energy: Challenges, Solutions & Opportunities
Fireside Chat
- ***Rod Baltzer***, *Deep Isolation*

Closing Remarks
Kevin Schug, *CLEAR, UT-Arlington*

***SWITCHON* Screening**
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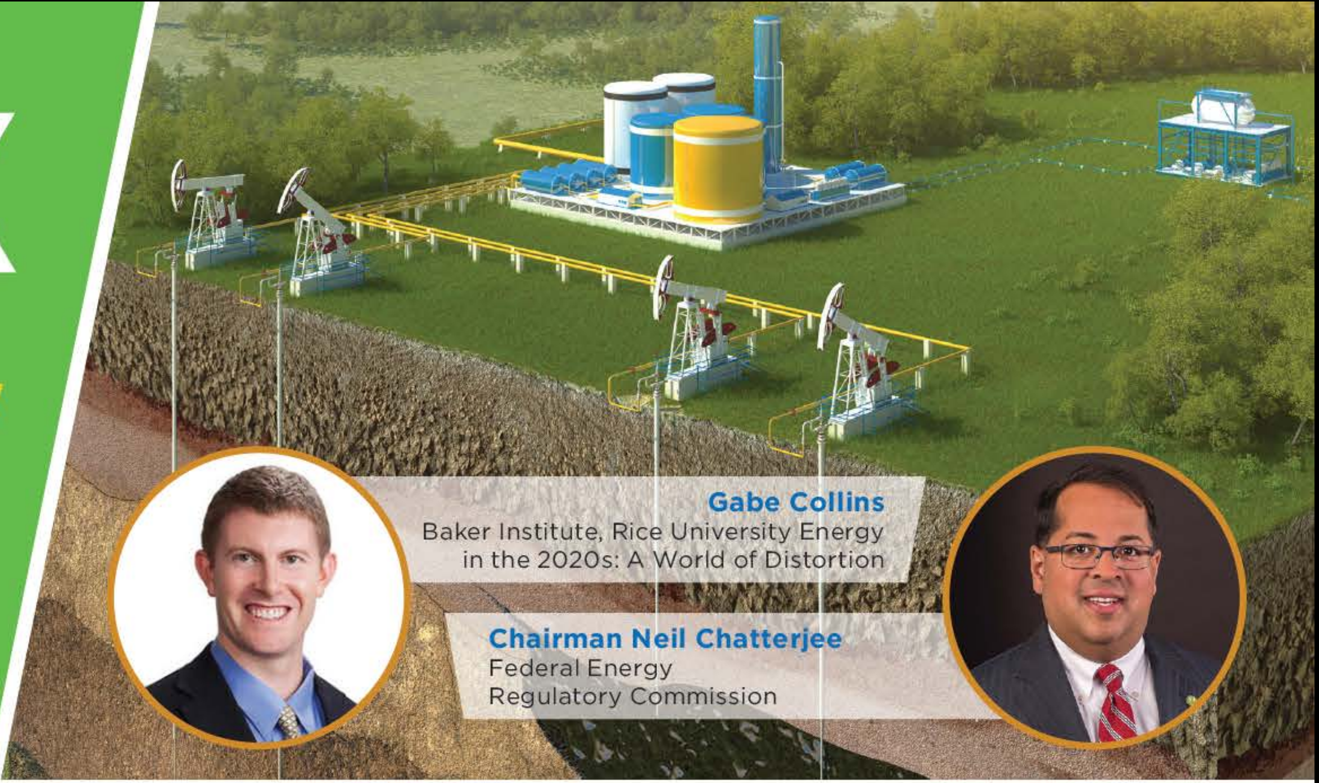

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Thank You!

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