Improving the Water Efficiency of Unconventional Development

Joe Lima
Director, Environmental Sustainability

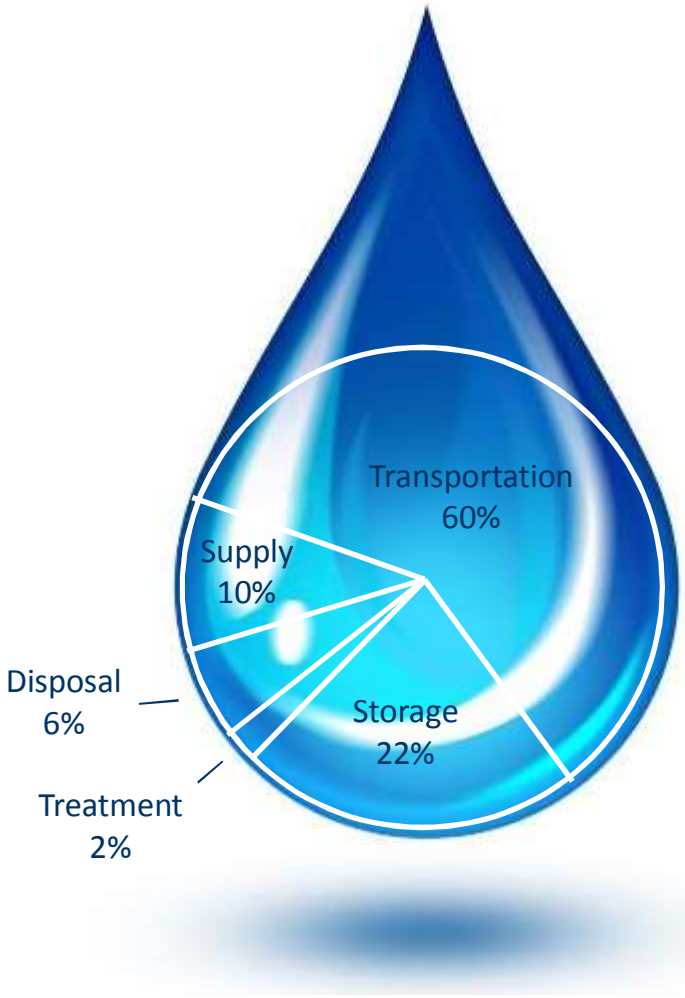
Schlumberger

Water Requirements by Energy Resource

Energy Resource	Range of Gallons of Water Used per MMBTU of Energy Produced
Marcellus Gas Well	1.30
Coal with No Slurry Transport	2 to 8
Coal with Slurry Transport	13 to 32
Nuclear (Uranium Ready to Use in a Power Plant)	8 to 14
Conventional Oil	8 to 20
Synfuel – Coal Gasification	11 to 26
Oil Shale	22 to 56
Tar Sands	27 to 68
Synfuel – Fischer Tropsch Synthesis (from Coal)	41 to 60
Enhanced Oil Recovery	21 to 2,500
Biofuels (Irrigated Corn Ethanol, Irrigated Soy Biodiesel)	>2,500

Source: From Chesapeake Fact Sheet with Data from GWPC, DOE

How About the Water…



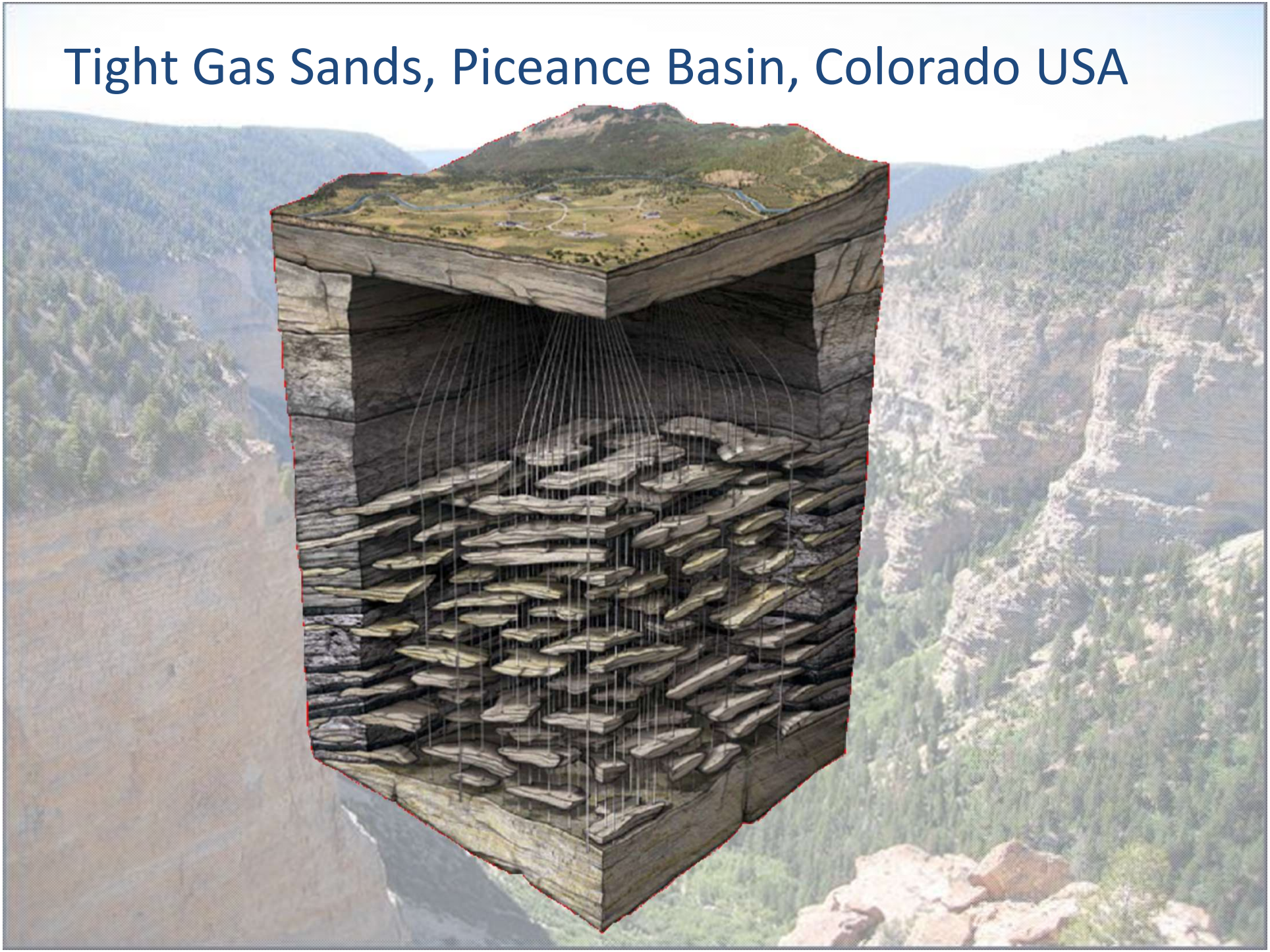
Direct Annual Use for Hydraulic Fracturing

- Over 90 Billion Gallons in United States
- Average of 2.6 Million Gallons per Well
- Total Associated Costs over $6.4B

Best Practices Include

- Recycling of Flowback
- Alternate Sources of Water

Tight Gas Sands, Piceance Basin, Colorado USA



Surface Management with Direction Drilling

0 0.5 1

kilometers

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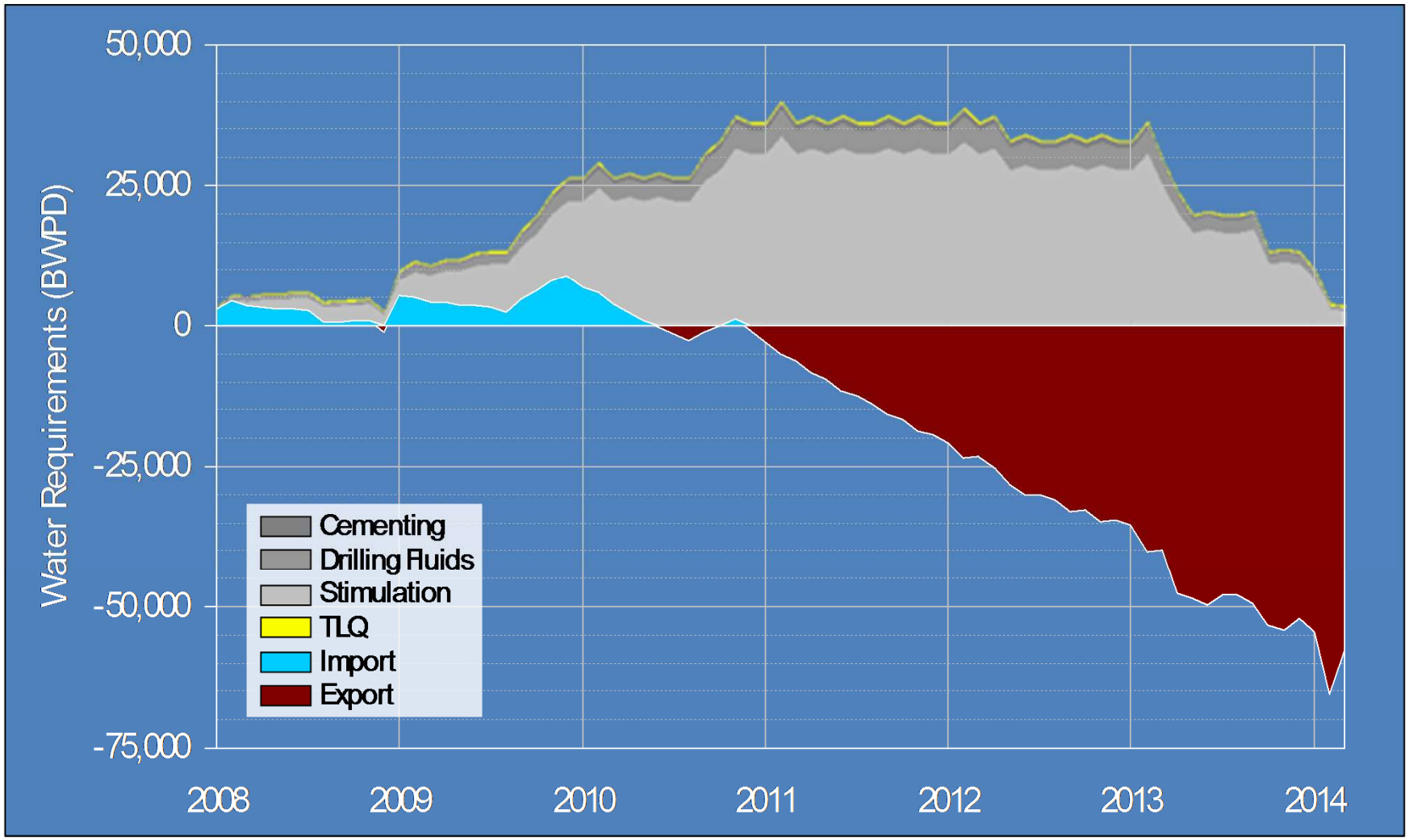
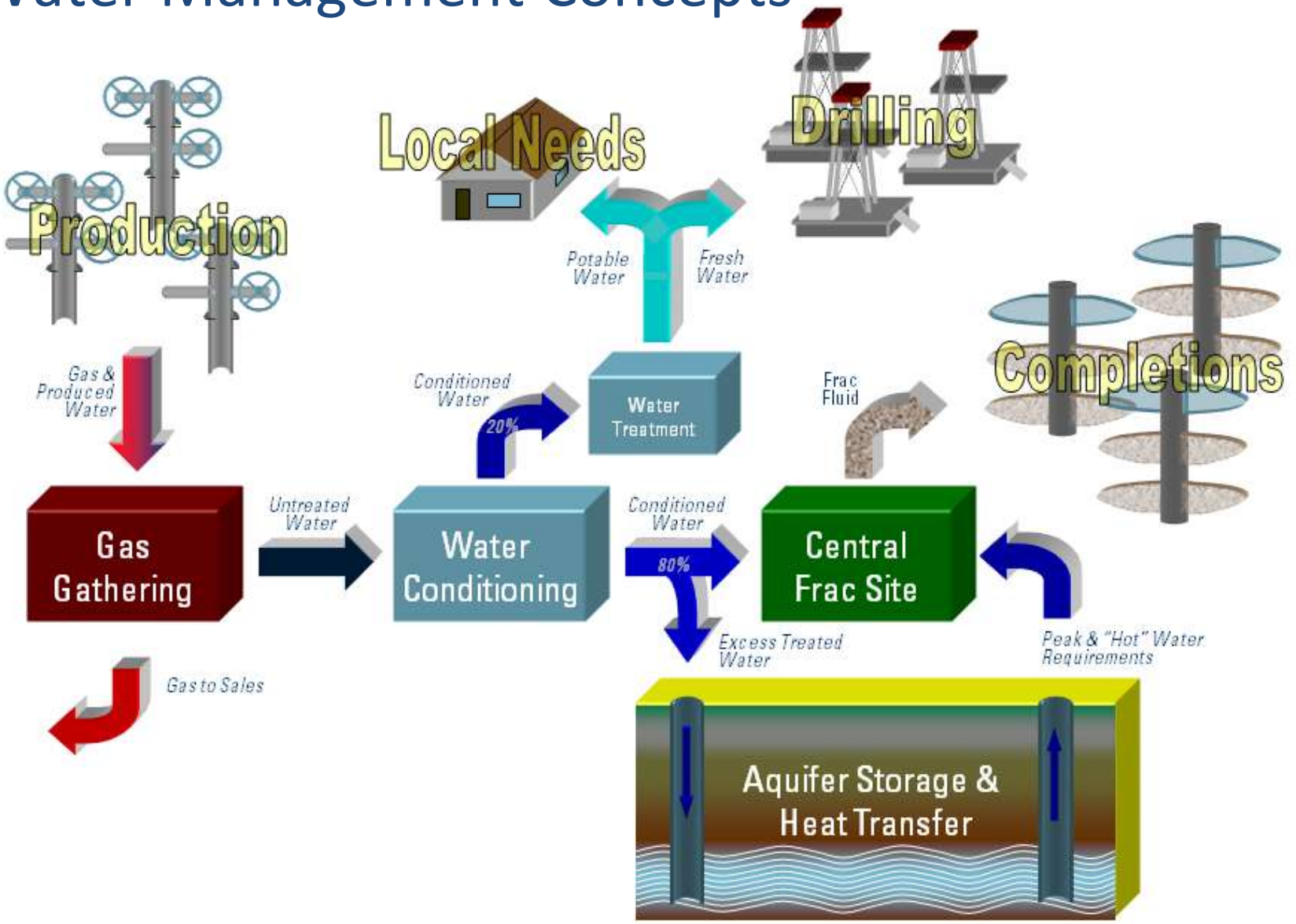
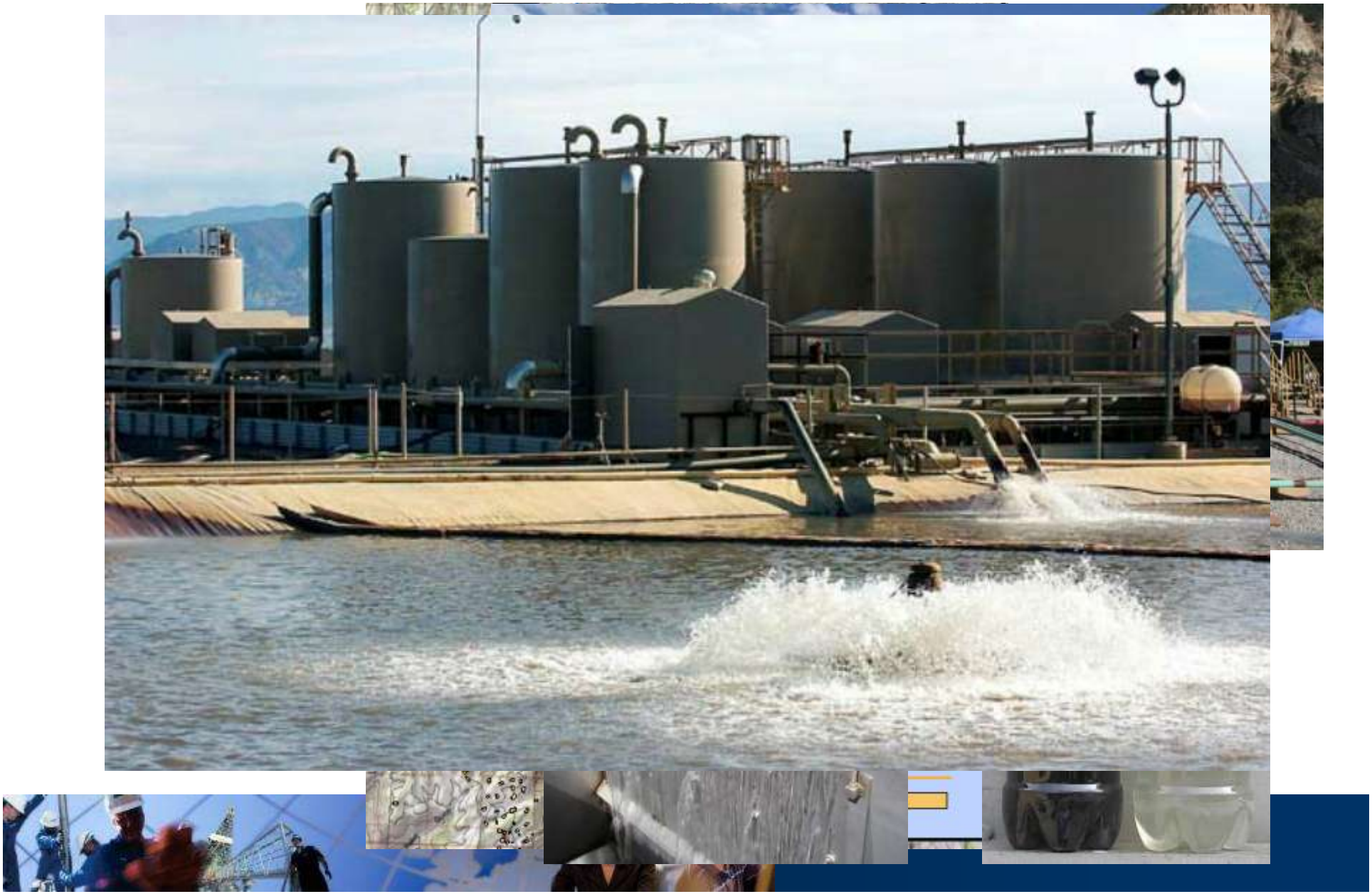
Water Requirements



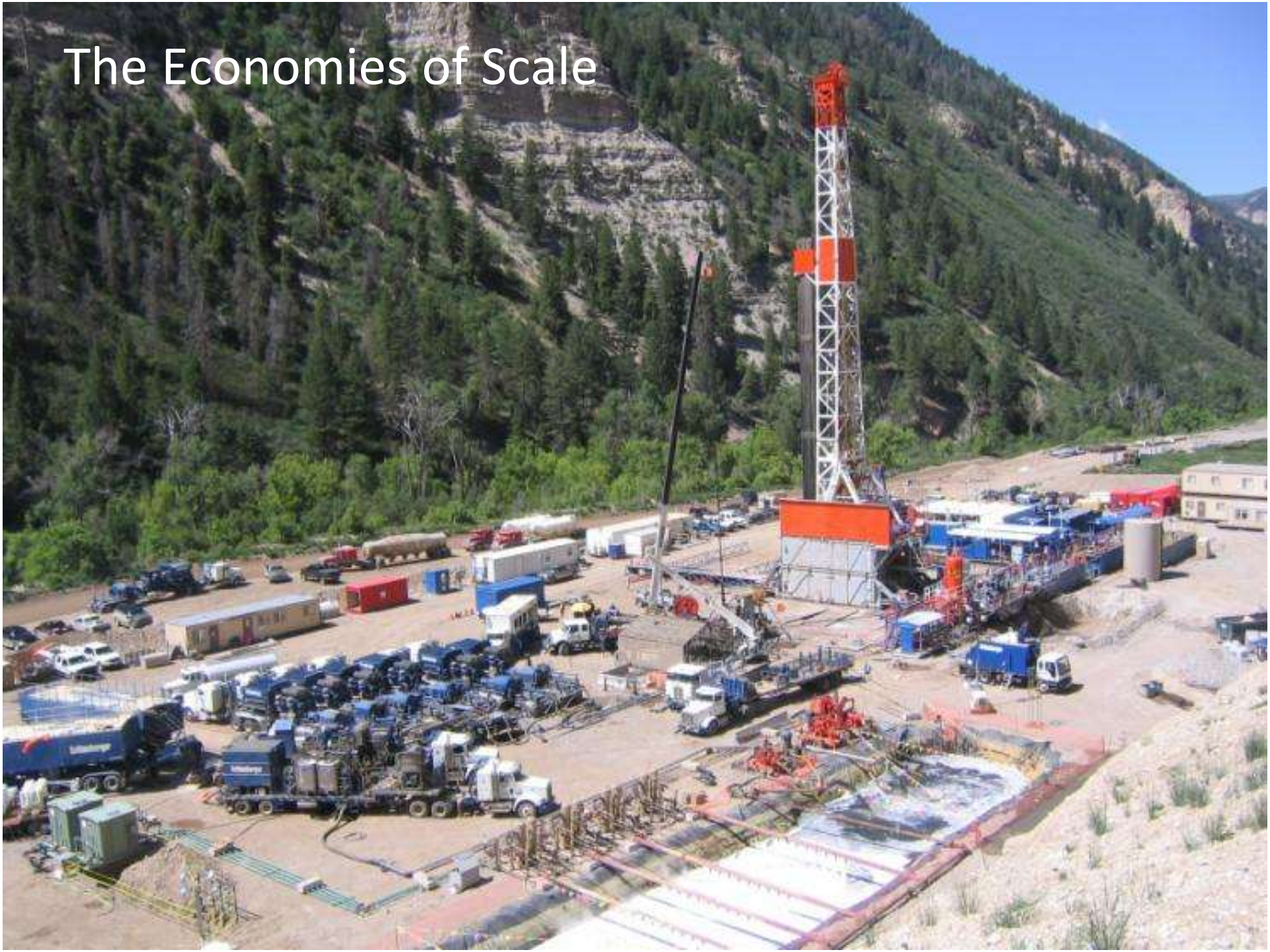
Water Management Concepts



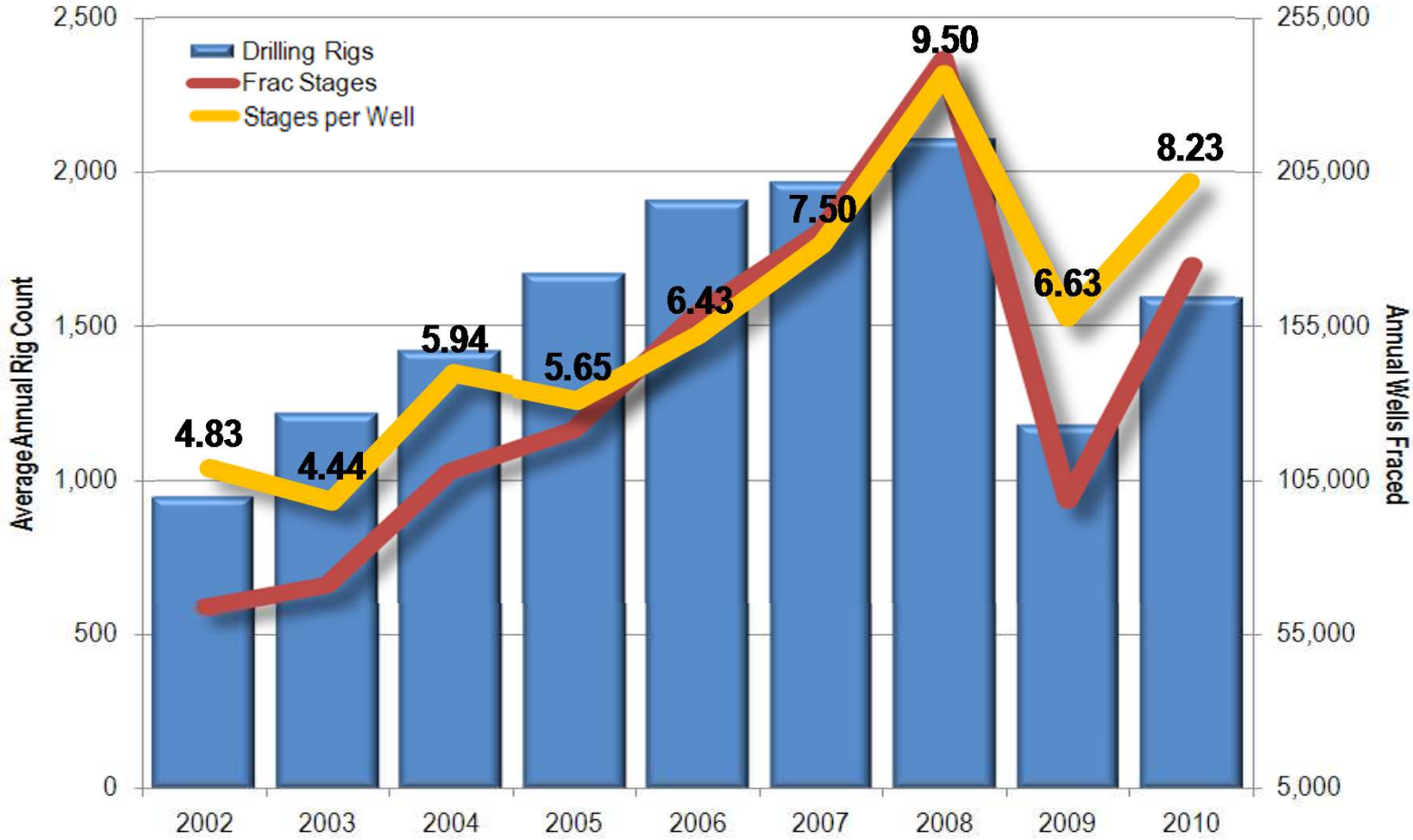
Water Management



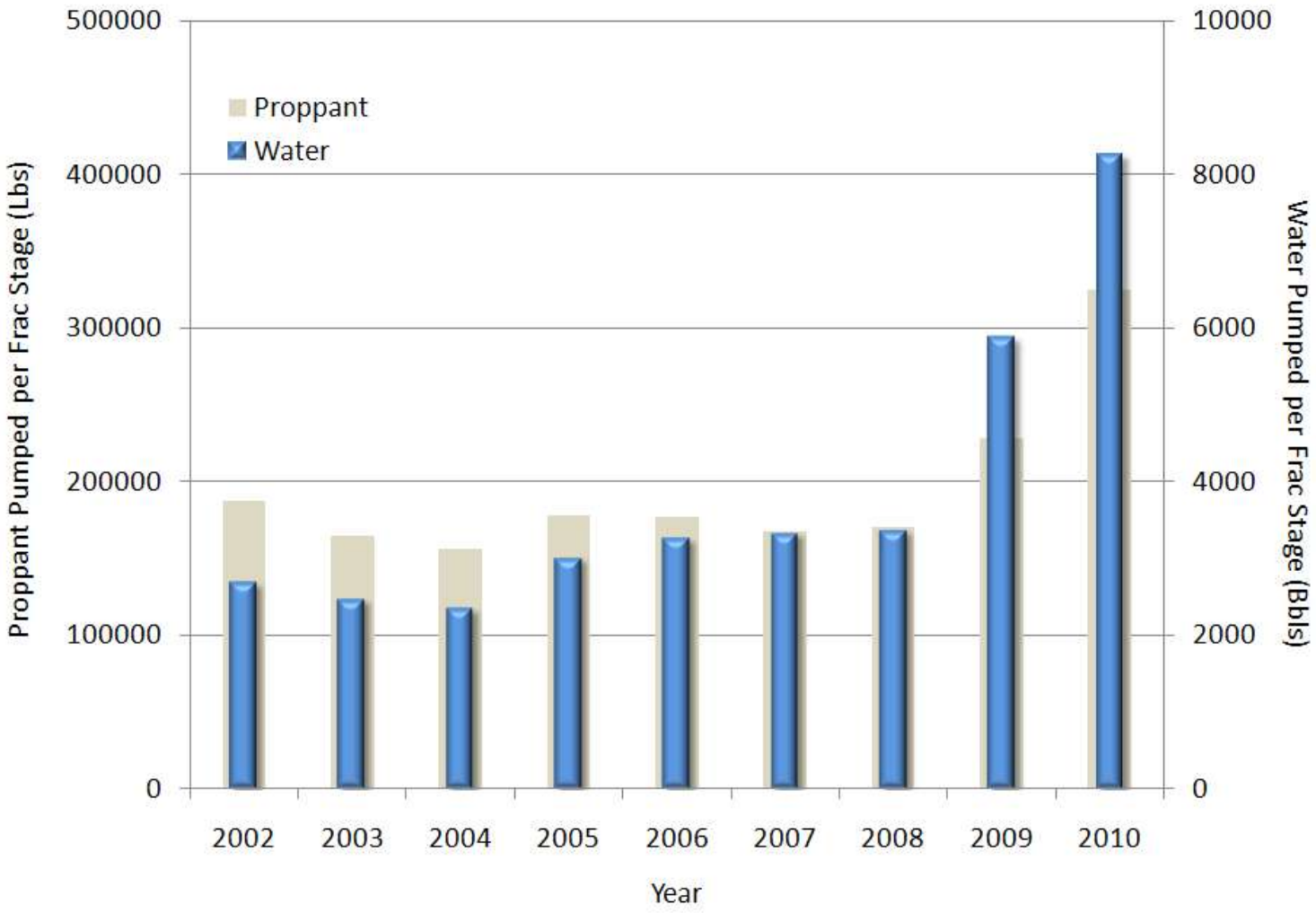
The Economies of Scale



US Land Drilling & Completion Intensity

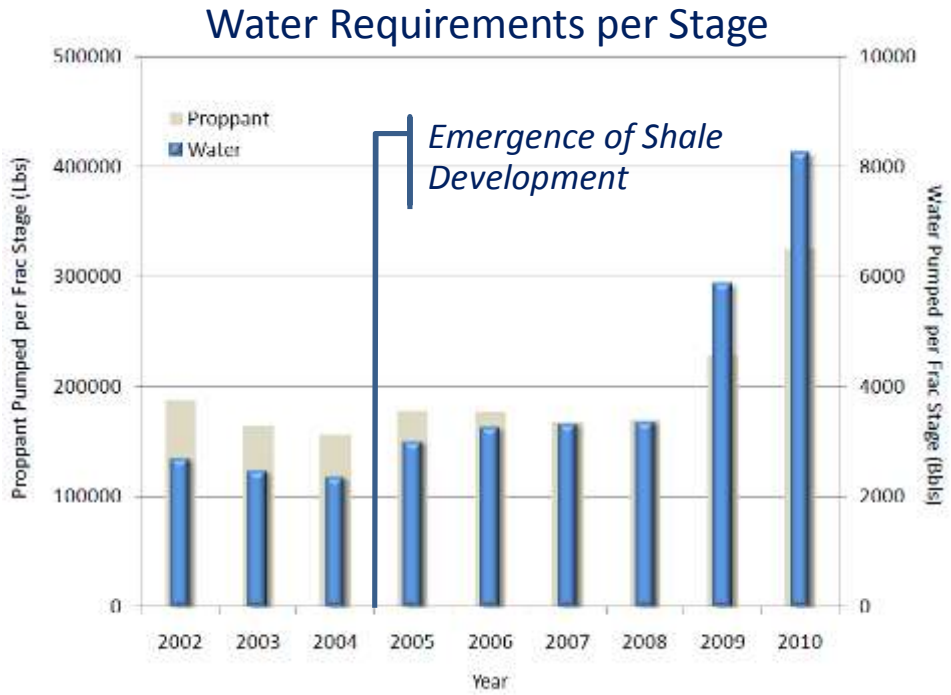


US Land Fracturing… Prop & Water by Stage



Frac Water Quality Drivers

- Historically, Fresh Water Availability Not an Issue
  - Chemical Compatibility Based off Ample Availability of High Quality Water
  - Usually Concerned with Salt, pH & Iron
- Shale Development & Corresponding Political Pressures on Place Focus on Water Usage
  - Poor Quality Water OK with Slickwater Type Treatments
  - Reuse Dictated by Flowback
- Shale Oil Development Requires High Viscosity Fluids
  - Large Quantity of Produced Water Available
  - Water Quality an Issue Again



Hydraulic Fracturing Water Requirements

1994 – Arkoma

Tight Gas Sands

Single Stage, Vertical Well
Crosslinked Fracs
45 to 60 BPM
250,000 Lbs of Prop
600,000 Gal of Water

- Fresh Water with No Recycling / Reuse
- High Quality / Low TDS, Iron, etc for Frac Chemistry

2004 – Barnett

Shale Gas

15-30 Stage, Horizontal Well
Slickwater Fracs
100 to 120 BPM
4,000,000 Lbs of Prop
4,000,000 Gal of Water

- Fresh Water with > 10% Recycling / Reuse
- Low Quality Due to Simplicity of Chemistry

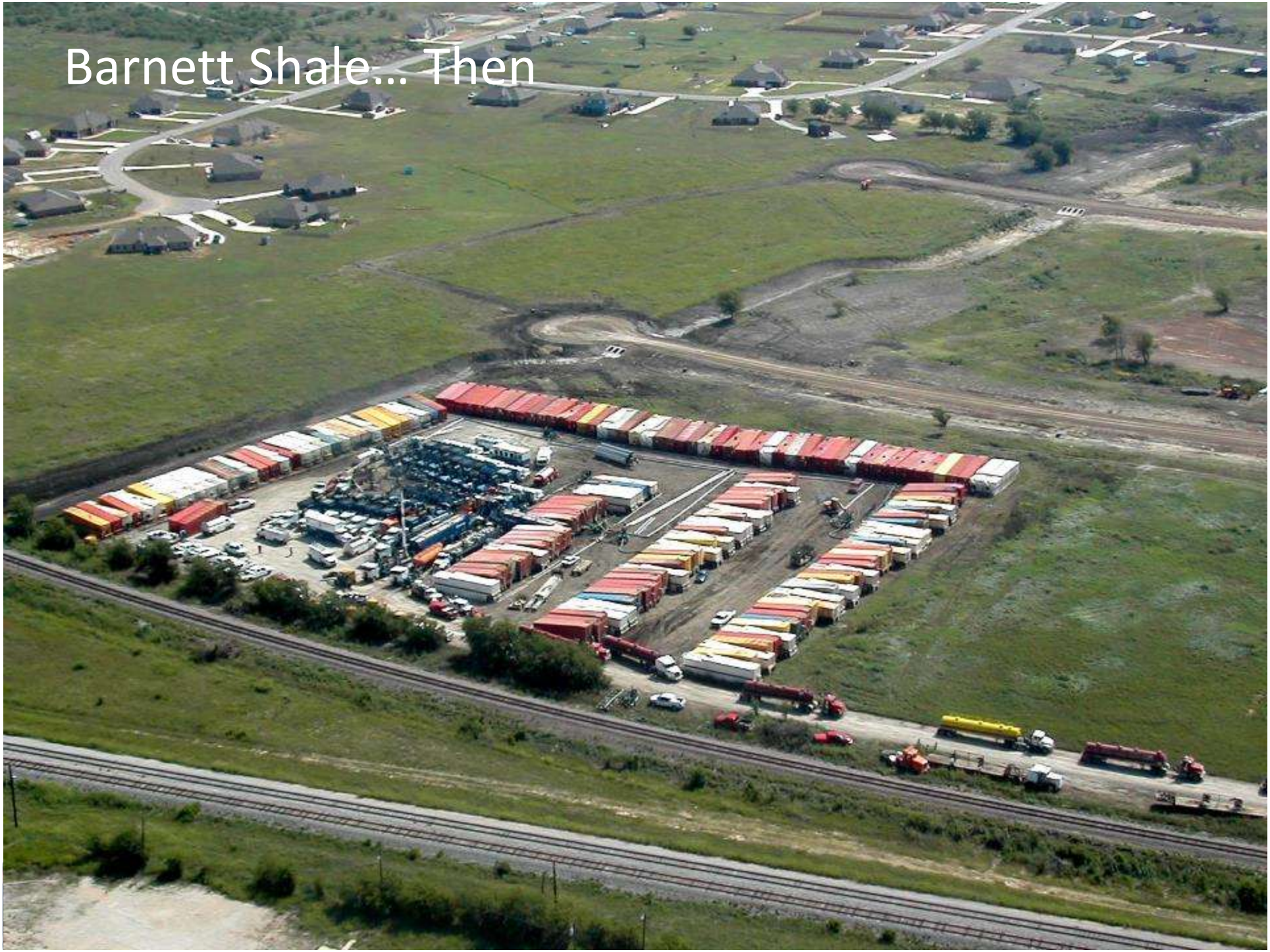
2014 – Bakken

Shale Oil

30-40 Stage, Horizontal Well
Crosslinked Fracs
30 to 40 BPM
2,500,000 Lbs of Prop
2,500,000 Gal of Water

- Fresh Water with > 10% Recycling / Reuse
- New Chemistry Allows for Use of Low Quality Water

Barnett Shale… Then



Barnett Shale… Now

Water Consumption & Reuse by Key Basins

	Frac Water (MM Gallons)	Annual Wells	% Recycled
Bakken	2.5	2281	5%
Barnett	2.8	660	7%
Central Rockies	3.0	1743	50%
Eagle Ford	5.1	4257	10%
Fayetteville	4.9	674	7%
Granite Wash	5.5	896	20%
Haynesville	5.6	368	6%
Marcellus	5.6	1485	85%
Mississippi Lime	2.2	1046	2%
Niobrara	3.3	909	6%
Permian	4.0	2073	2%
Woodford	5.5	619	20%
OVERALL		17011	**11%**

And Flowback Water Quality Varies by Play

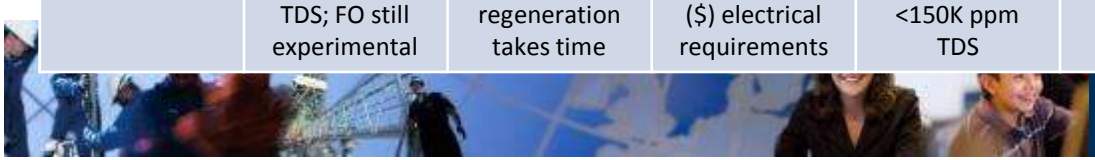
Constituent	Units	Marcellus	Bakken	Haynesville	Piceance	Eagle Ford
Alkalinity as CaCO3	mg/L	260	270	320	930	335
Chlorides	mg/L	51,870	58,680	48,400	19,880	11,000
Calcium	mg/L	5,780	4,340	8,180	1,570	255
Magnesium	mg/L	410	720	640	190	50
Sodium	mg/L	24,350	26,200	23,770	10,550	7,515
Potassium	mg/L	195	1,720	635	280	0
Iron	mg/L	30	50	70	30	15
Barium	mg/L	2,900	10	920	220	1
Strontium	mg/L	2,160	710	1,600	40	50
Total Suspended Solids	mg/L	3,070	510	530	840	770
Total Dissolved Solids	mg/L	87,020	89,120	95,770	38,960	19,150

Water Treatment Considerations

- Total Suspended Solids (TDS) Removal & Disinfection
- Hardness Removal… Ca, Mg, Ba, Sr, Fe, etc
- Oil & Grease Removal
- Total Dissolved Solids (TSS) Removal… Desalination
- Management of Mass Quantities of Water…
  - Water Collection (Piping, Trucking, Pre Treatment Storage, etc)
  - Waste Disposal (Post Treatment)
  - Finished Water Storage
  - Delivery to Wellsite
  - …

No Single Treatment Technology…

	Reverse / Forward Osmosis	Biological	Electro-Coagulation	Evaporation/ Distillation (MVR)	Filtration / Advanced Filtration (UF, MMF, NF)	Ozone / Ultra-Violet / Chlorine Dioxide	Chemical Precipitation / Ion Exchange	Dissolved Air Flotation (DAF)
Total Dissolved Solids (TDS)	✓			✓			Partial Removal	
Total Suspended Solids (TSS)		Partial Removal	✓		✓	Ozone Aids Removal	Partial Removal	✓
Total Organic Carbon (TOC)	✓	✓	Partial Removal		Partial Removal	Partial Removal		Partial Removal
Multivalent cations (Ca, Mg, Fe)			Minimal Removal		Partial Removal		✓	Partial Removal
VOCs / HAPs	Partial Removal	✓	Minimal Removal		✓	Ozone Aids Removal		Partial Removal
Bacteria	✓	✓		✓	Partial Removal	✓		
Limitations	Rigorous Pre-Treatment Required. RO<40K, FO <120K ppm TDS; FO still experimental	Not suitable for high TDS; susceptible to upsets & colony regeneration takes time	Requires very consistent / stable influent water quality ; Can have high ($) electrical requirements	High Energy Required, Cost, Rigorous Pre-Treatment. Can handle <150K ppm TDS	Pretreatment required; backwash water to reprocess	UV not applicable in turbid waters; high demand for O3; neither provide residual	Can have large chemical demand and solids processing / landfilling $	Requires consistent / stable influent water quality; Provides good first cut

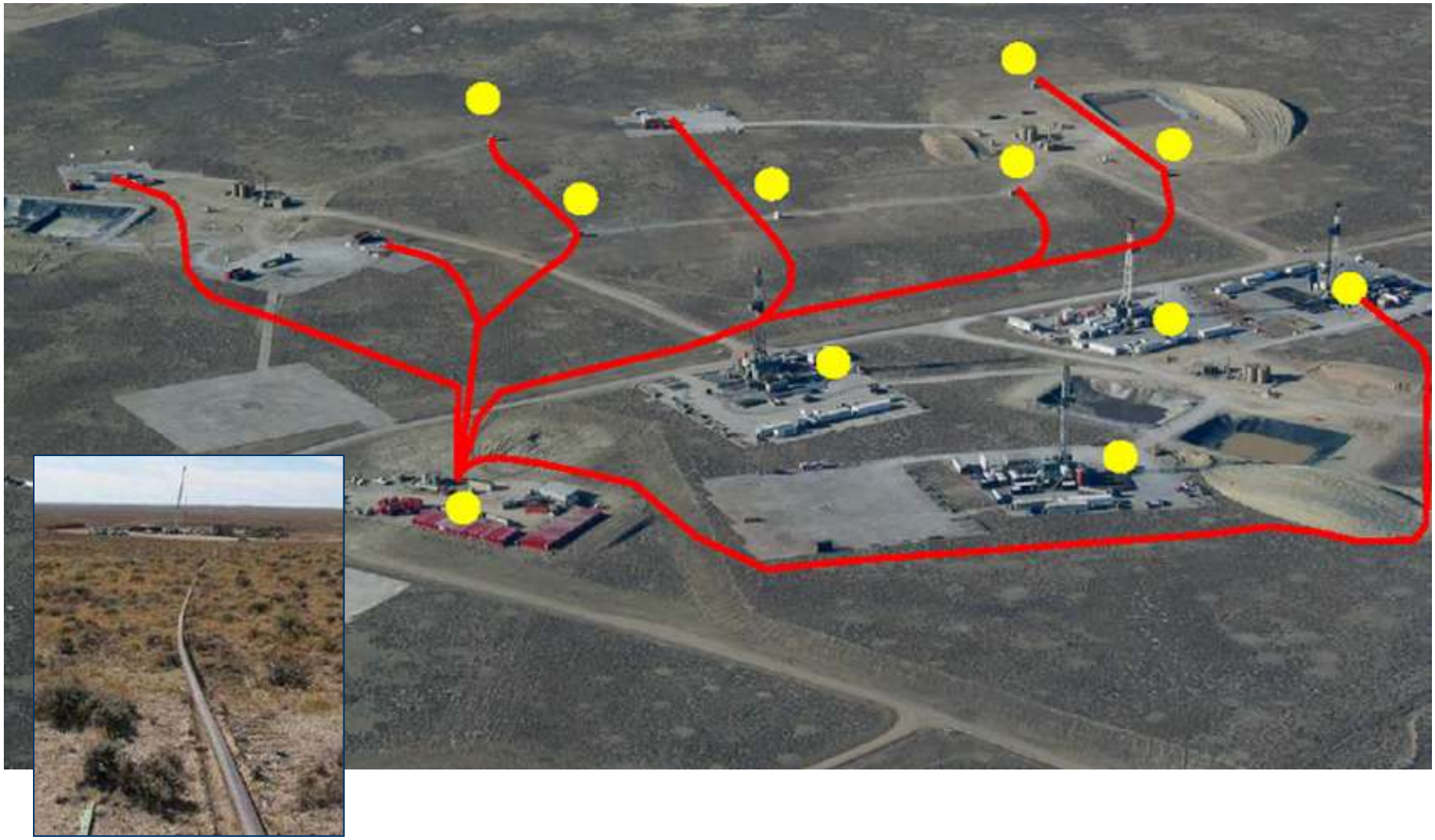


… But Ask Yourself… What's My Goal

Before Treatment

After Treatment

… What Logistics Are Involved



… And What Are Your Sources for Makeup Water

Water Sourcing:

- Municipal
- Water Wells: Shallow and Deep
- Ponds, Streams and Rivers
- AMD, Waste Waters
- Re-use / Treatment
- Sea Water

Environment:

- Concern about Depletion of Reservoirs
- Impacts the Aquatic Life
- Footprint

Transportation:

- Number of Trucks: 12,000 Bbls = 100 Trucks
- Piping the System

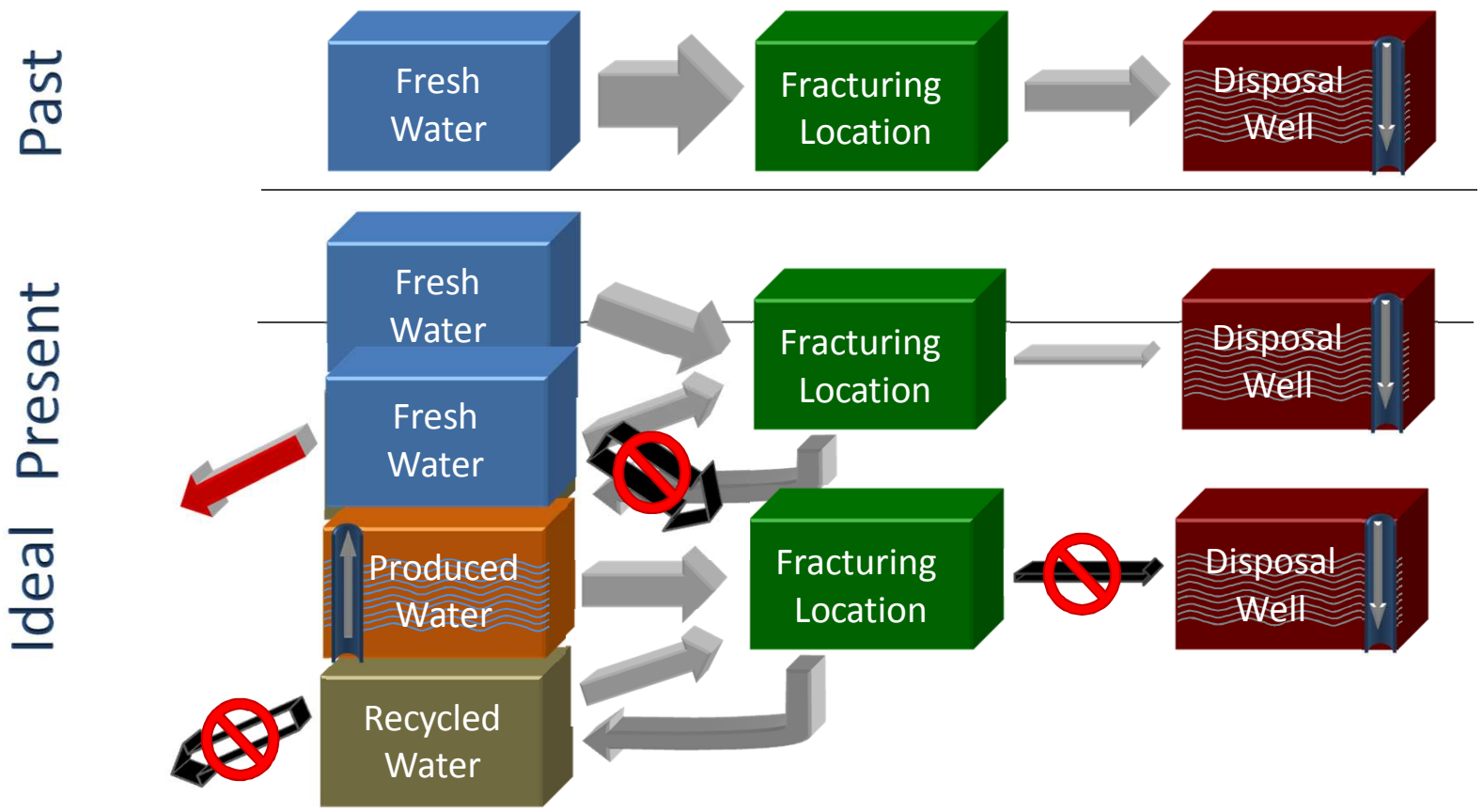
Water Storage

- Use of Ponds, Impoundments, Frac Tanks
- Temporary and Re-usable above Ground Tanks

Regulations

- Ultimate Drivers for Permits of Water Sourcing
- Dictate Discharge Criteria

Water Sourcing for Hydraulic Fracturing



Today's Approach

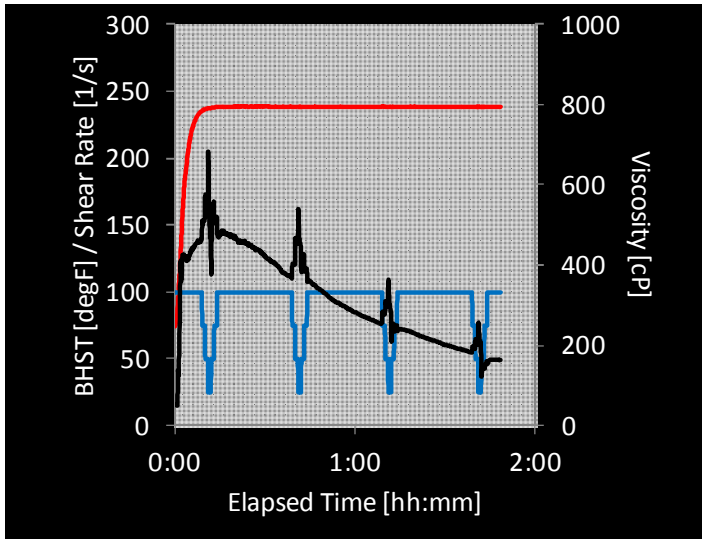
- Reduced Water Requirements & Intelligent Treatment Design
- Alternative Crosslinking Mechanisms for Oil Plays
- Tolerance Built into Chemistry for High TDS
- Still Required:
  - Treat for Bacteria as Needed
  - Determine Scaling Tendencies

Recent Example:

- Fraced Bakken Wells with 100% Connate Water from Offset Producers
- 28% to 32% Salinity
- Inherent Variation in Water Quality
- No Water Treatment
- Fracs Placed without Incident

Water Sourcing for Hydraulic Fracturing

Cation	Sample 1
Sodium	80423
Calcium	18938
Potassium	6800
Magnesium	889
Iron	82.29
Boron	364
pH	5.68
SG	1.187
TDS	275000



Final Thoughts…