Zero Water Discharge Management For Hydrofracturing Activities

A Brief Synopsis of the Concept

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March 13, 2013

Project Objectives & Goals

Major Objectives of Project

- Reduce trucking and acquisition costs of freshwater supplement
- Reduce off-site trucking and disposal costs of associated wastewaters (Flowback & Produced Waters)
- Reduce quantity of chemical additives into the fracturing fluids
- Organize and implement project along Industrial Wastewater Management methodology protocols

Implementation Goals

Final solution must encompass:

- 100% Performance and Reliability
- Environmentally Sound: No contact with Air, Surface Water, Ground Water and Soils
- Cost-Effective
- Flexibility For Any HF Site globally and Emerging and Near-Future Regulatory Issues

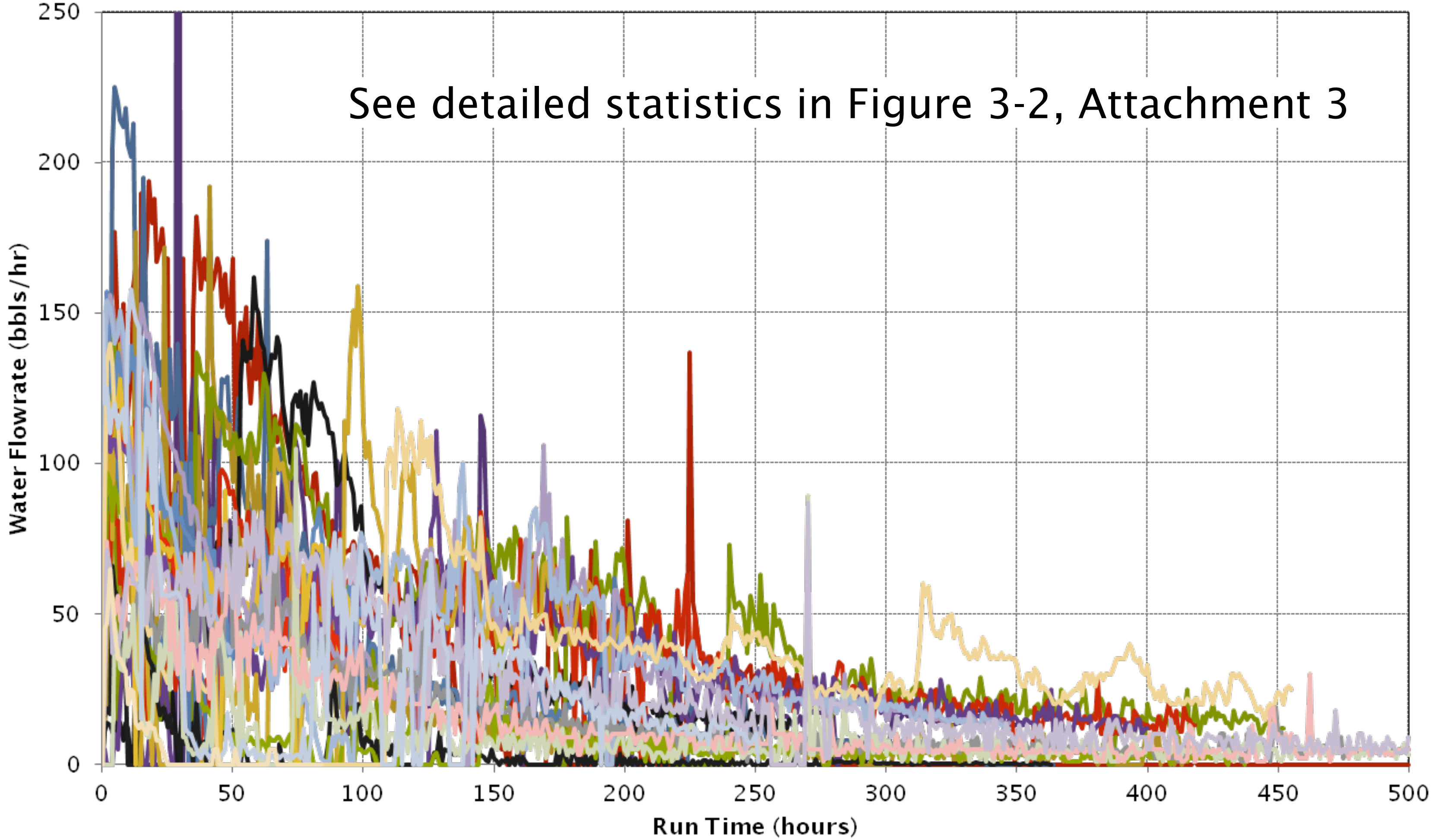
Awareness Goals

- Permitting is a big issue
  - Considerable public interest in local shale gas development activities
  - During project phases, should remain vigilant with respect to emerging permitting activities and addressing public concern
  - Will be sensitive to these obligations during the phases of the project
  - Will address Public Concern issues at appropriate crossroads in project

Development of an Industrial Wastewater Management Program

- Develop Comprehensive Wastewater Management Plan
  - Locate data sources of representative and reliable characteristics
  - Assimilate and correlate appropriate parameters
  - Define required treatment quality for recycle and discharge
- Discussions with experienced personnel
- Comprehensive technology evaluation & selection
- Develop process design, mass balance and economics for selected process train

Flowback Water Volumes (25 Wells)



Summary of Flowback and Produced Water Quantities: Marcellus Shale (Taken from Data Sources in Slides

Water Category	Average	Maximum	Typical
Fracturing Injection Water (gals)[1]	5,200,000	9,000,000	6,500,000
Flowback Water in First 1-3 Weeks			
% of Water Injected	8.9%	20.0%	10.0%
Flowback Cumulative Volume (gals)	360,000	780,000	650,000
Produced Water (gpd/days to 1 mil gal)[2]			
21 days to 50 days	3652 / 273	12,713	6300 / 158
50 days to 250 days	1001 / 1,000	1,990	3780 / 264
250 days to 1 year	452 / 2212	1,066	2630 / 380
1 year to end of well	96 / 10,416	1,315	1300 / 769

[1] Flowback statisitics based on 25 wells

[2] Produced Water satistics based on 64 wells

Summary: Typical Characteristics of Hydrofracturing Waters: Marcellus Shale

Parameter	Units	Flowback Water[1]					Produced Water[2]	
		Average	Minimum	Maximum	50th Percentile	95th Percentile	Average	Maximum
Total Hardness	mg/L	30,077	116.1	104,090	27,624	89,698	15,100	29,000
Total Alkalinity	mg/L	428	16.0	3,301	400	863	--	--
Total Dissolved Solids	mg/L	109,156	10,013	331,202	102,550	298,289	114,449	177,310
Chlorides	mg/L	69,315	5,999	196,956	65,985	187,158	70,400	104,000
Sulphate	mg/L	8.4	0.0	500	0.0	30	--	--
Calcium	mg/L	9,861	30.5	36,671	8,737	31,461	13,767	26,400
Magnesium	mg/L	1,330	5.8	17,014	1,118	3,160	1,333	2,600
Sodium	mg/L	27,617	1.0	96,975	24,700	83,695	27,500	40,500
Potassium	mg/L	174	1.0	500	200	300	690	1,600
Total Iron	mg/L	145	0.6	4,600	43	688	753	2,200
Barium	mg/L	6,506	95.0	96,000	2,300	55,800	6	10
Suspended Solids	mg/L	896	20.0	4,110	900	1,792	109	150
Ferrous Iron	mg/L	11.0	0.0	108	4.3	44	--	--
Biochemical Oxygen Demand	mg/L	--	--	--	--	--	1,100	1,400

Notes:

1.) Statistics based on all samples reported as "Flowback" in EXCO Pa Database.
2.) Statistics based on 3 samples representing 2 locations in Pennsylvania from September 1986 as reported by the American Petroleum Institute.
3.) Numbers in red are calculated.

Supporting Collaboration

ENVIRON requested technical exchange conferences at the research locations of two leading chemical companies involved extensively with hydrofracturing activities.

The companies were:

- NALCO, an Ecolab Company (Sugar Land, Texas) on November 13th
- Champion Technologies (Fresno, Texas) on January 31st
- The attendees and titles are given on the next two slides

The comments, presented herein on chemicals, were derived from these conferences, discussion with field operations in hydrofracturing, literature review and experience.

Other experienced personnel:

- Dr. Davis L. Ford, DLF & Associates, Inc.
- Dave Burnett, Director of Technology, Global Research Institute, Petroleum Engineering, Texas A&M
- Scott Wilson, Energy Coordinator, Industrial Branch / Water Permits Division, USEPA
- Ron Wagnon, President, Greenwell Energy Solutions, Specialty Chemicals
- Nicole Wilson, President, Pure Filter Solutions

Wastewater Treatment and Disposal Options

- Underground (deep well) injection
- Discharge into a receiving water: River, Stream, Estuary, Lake, etc.
- Pretreated discharge to municipal (POTW) facility
- Discharge to a commercial wastewater treatment facility, perhaps designed for HF wastewaters
- Pretreatment and recycle into subsequent HF wells or other industrial uses, instead of using “fresh water” from groundwater, surface waters, or treated wastewaters from municipal and industrial WWTPs

Major Technology Categories

- Adsorption/Exchange
- Chemical/Catalytic Conversion
- Chemical Oxidation
- Concentration/Volume Reduction
- Membrane Processes
- Physical Separation
- Thermal/Catalytic Destruction
- Biological Oxidation/Reduction/Conversion (presented at end)
- Miscellaneous

Comprehensive State-of-the-Art Technology List
(Considered Feasible based on Full-Scale or Reliable Pilot-Scale Application)

- Adsorption/Exchange
  - Activated Alumina
  - Activated Carbon
  - Ion Exchange
  - Macroreticular Resins
  - Bentonite
  - Natural Polymeric
  - Chitosan/Algal
  - Solvent Extraction
- Chemical/Catalytic Conversion
  - Catalytic Dechlorination
  - Hydrolysis
  - Photolysis
  - Reductive Degradation
  - Ozonation/chlorination
  - Fenton's Agent
- Concentration/Volume Reduction
  - Evaporation/Crystallization
  - Freeze Crystallization
  - Steam Stripping
  - Vacuum Distillation
  - Pervaporation
- Membrane Process
  - Electrodialysis
  - Reverse Osmosis
  - Nano Filtration
  - Ultrafiltration

Five Evaluation Categories (see Attachment 8 for subdivision of Evaluation Categories)

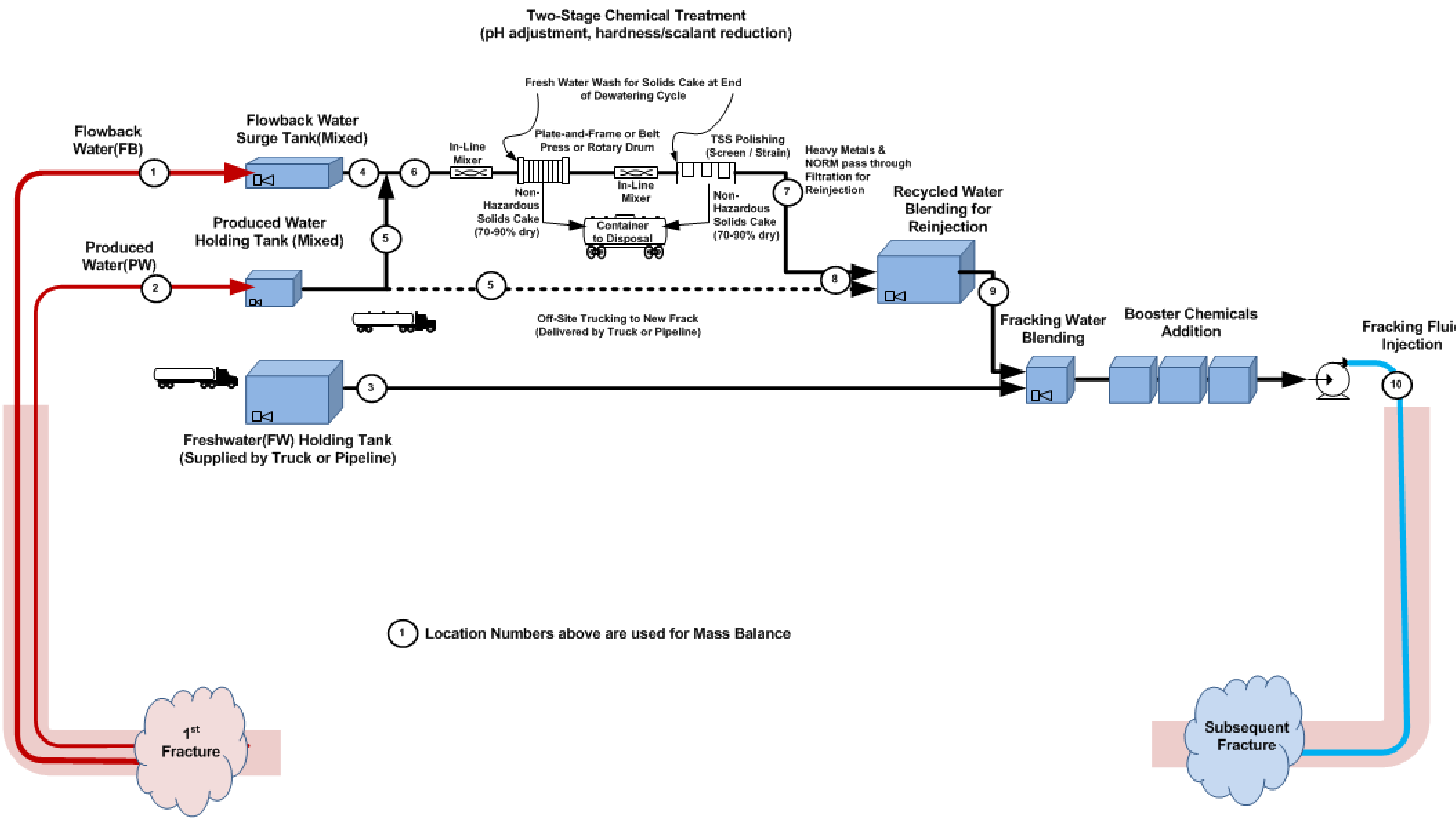
1. Technical Feasibility
2. Cost-Effectiveness
3. Operational Reliability
4. Environmental Issues
5. Aesthetic Considerations

Preliminary Screening of Water Treatment Technology Options

Technology	Target Treatment	Advantages	Disadvantages	Selection Results
Total Suspended Solids Removal, Including Precipitated Heavy Metals (including Radioactivity) and Free Oils				
pH Adjustment	Maintain pH; necessary for other treatments and/or discharge.	Improves certain chemical reactions; allows standard materials of construction. Can use organic rather than inorganic acid to minimize TDS input.	Adds salt (TDS), annual operating expense.	Selected for further evaluation. Opportunity for combined use of recycled wastestreams for pH control.
Coagulation / Precipitation of heavy metals with inorganic precipitation	Removal of heavy metals non-soluble hydroxide of co-precipitate in an inorganic sludge. May not be necessary for reuse of flowback.	Renders heavy metals into an insoluble form for gravity separation and concentration into a disposal sludge.	Will probably require pH adjustment and chemical addition. Can produce substantial quantities of solids for disposal. Care must be taken to maintain solids as a non-hazardous waste. Requires sludge handling system for dewatering. Chelating agents can inhibit specific constituent precipitation, if desired.	Selected for further evaluation.
Coagulation / Precipitation of heavy metals with high-affinity coagulant	Very efficient for low concentrations of heavy metals without substantial solids production. Tri-mercaptan / carbamates have been very successful.	Low sludge production, low heavy metals concentration in treated effluent. Minimal solids production and handling. Filter may be used instead of clarifiers.	Chemical precipitant is expensive. Chemical handling is sensitive and control is necessary to prevent accidental effluent aquatic toxicity.	Selected for further evaluation.
Ion Exchange Resins	Selective removal of salts and/or metals if recovery issues are prevalent.	Can effectively remove acid/base and metal ions.	Would require extensive pretreatment for oil, TSS and possibly TDS, Adds considerable TDS to system. Regenerant is liquid and can be hazardous.	Rejected for further evaluation.

RED SHADING INDICATES "REJECTED TECHNOLOGY" NOT DEEMED APPROPRIATE FOR FURTHER EVALUATION

Concept: Zero Water Discharge Water Lifecycle



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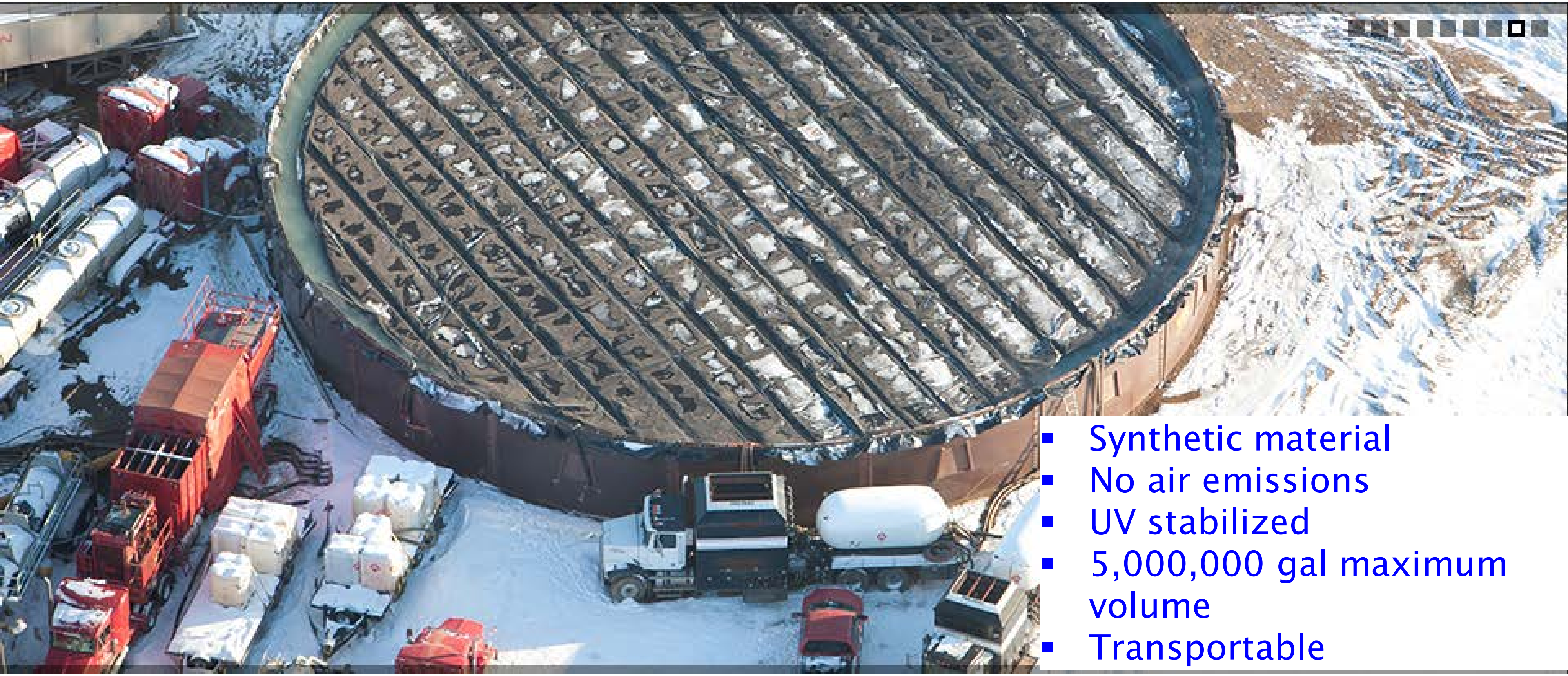
Bladders

- Synthetic material
- No air emissions
- UV stabilized
- 200,000 gal maximum volume
- Transportable

Swimming Pools-B: Circular



- Synthetic material
- No air emissions
- UV stabilized
- 5,000,000 gal maximum volume
- Transportable

Plate & Frame Filter Press Illustrations

Trailer-mounted
Conveyor for cake discharge to container for hauling to disposal

Positive displacement, air diaphragm pumps for pumping sludges.

Synopsis of Zero Water Discharge Concept

- Designed to Eliminate Exposure to the Environment: air, surface water, groundwater and solids residues
- Emphasizes Staged / Selective Treatment of Flowback Water to Minimize Chemicals in Reuse Cycle
- Optimizes Water Flow / Storage Management for Salt Blending
- Minimizes Chemical Treatment on Blended Recycle Stream
- Flexible for Near-Future Issues
  - Modularly expandable
  - Range of chemical additives, if required

Goals & Benefits

- Goals
  - 100% Performance and Reliability
  - Environmentally Sound
  - Cost-Effective
  - Flexibility For Emerging and Near-Future Anticipated Issues
- Benefits
  - Substantially Lower Operational Costs (trucking, chemicals, process management)
  - Less Sulfide
  - Less Trucking
  - True EHS Consequence: Less Harmful
  - Operator-Friendly Manageable Industrial Wastewater Process
  - More Reliable, Predictable, Economical Process and Environmentally-Sensitive Program That Results in a Much Improved Gas Completion

Path Forward:
Laboratory & Field Confirmations

Confirmation of Approach and Realistic Economics

- Task 1. Bench-Scale Laboratory Screening Investigation
  - Round 1
  - Round 2
- Task 2. Small-Scale Field Confirmation
- Task 3. Full-Scale Field Performance