



Shale Development: Understanding and Mitigating Risks Associated with Well Construction and Hydraulic Fracturing

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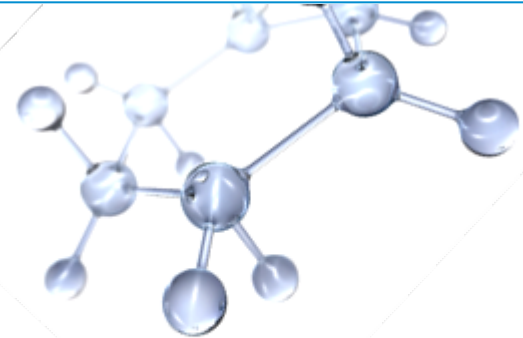
May 30, 2013

National Academy of Engineering / National Research Council Workshop
on Risks of Unconventional Shale Gas Development

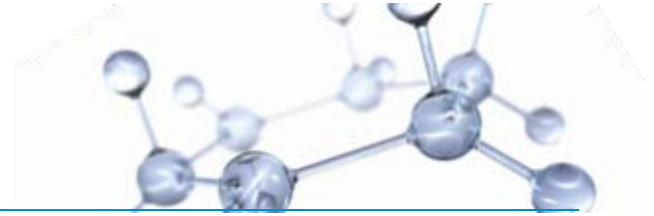
Washington, D.C.

This presentation includes forward-looking statements. Actual future conditions (including economic conditions, energy demand, and energy supply) could differ materially due to changes in technology, the development of new supply sources, political events, demographic changes, and other factors discussed herein (and in Item 1 of ExxonMobil's latest report on Form 10-K). This material is not to be reproduced without the permission of Exxon Mobil Corporation.

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This Presentation Will Discuss



- **Core Principles Enabling Safe and Responsible Well Construction**
- **Well Construction & Hydraulic Fracturing Design Considerations**
- **Operations Integrity Monitoring & Assurance**
- **Risk Assessment & Mitigation**
 - The potential for subsurface communication between hydrocarbon bearing zones & drinking water aquifers
 - The potential for hydraulic fracturing fluid chemicals contacting drinking water aquifers
 - The potential for unplanned surface release of chemicals or well fluids
 - The potential for fluid injection inducing negative consequence seismicity resulting in damaging levels of surface ground shaking



Enabling Responsible & Sound Well Construction

The Development Stages

Establishing Common Terminology



- Well Construction** {
- 1. Drilling**
 - 2. Completion & hydraulic fracturing**
 3. Production
 4. Gas treatment and transportation



Video of process available at: <http://www.youtube.com/watch?v=WP5wSfD0fk4>

Shale Development

Keys To Success



Managing Risks

- Responsible operations philosophy
- Effective risk management framework

Managing Uncertainties

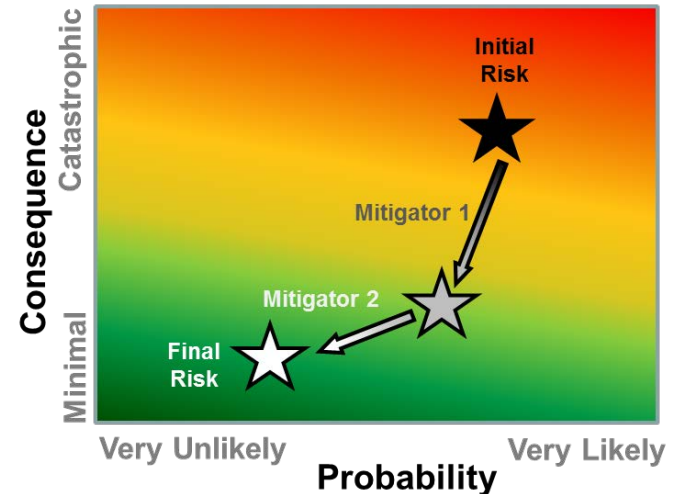
- Accounting for subsurface complexity
- Calibrating models with appropriate data
- Evaluating results based on risk mitigation, and the probabilities & consequences

Collaborating with Stakeholders & Regulators

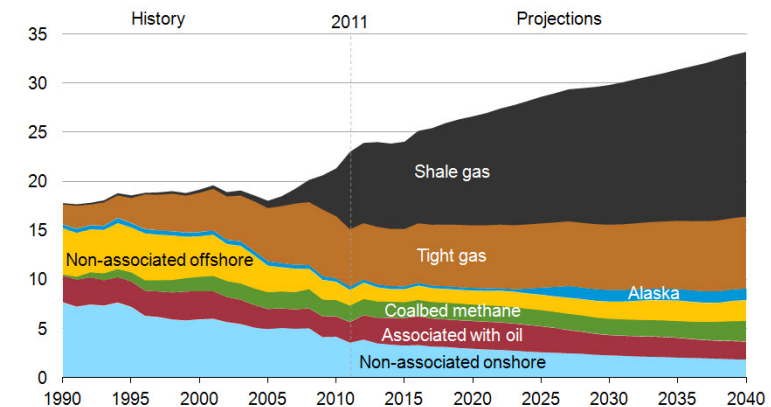
- Working with local communities to manage impacts
- Transparency and reasonable regulations to enable safe and sound development

Generating Opportunities

- Meeting energy demand
- Job and revenue growth
- Emissions reduction



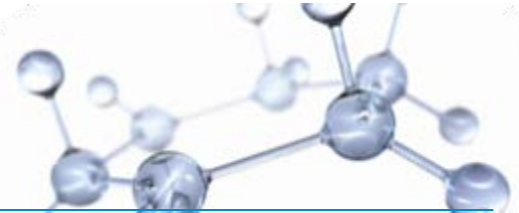
U.S. dry natural gas production
trillion cubic feet



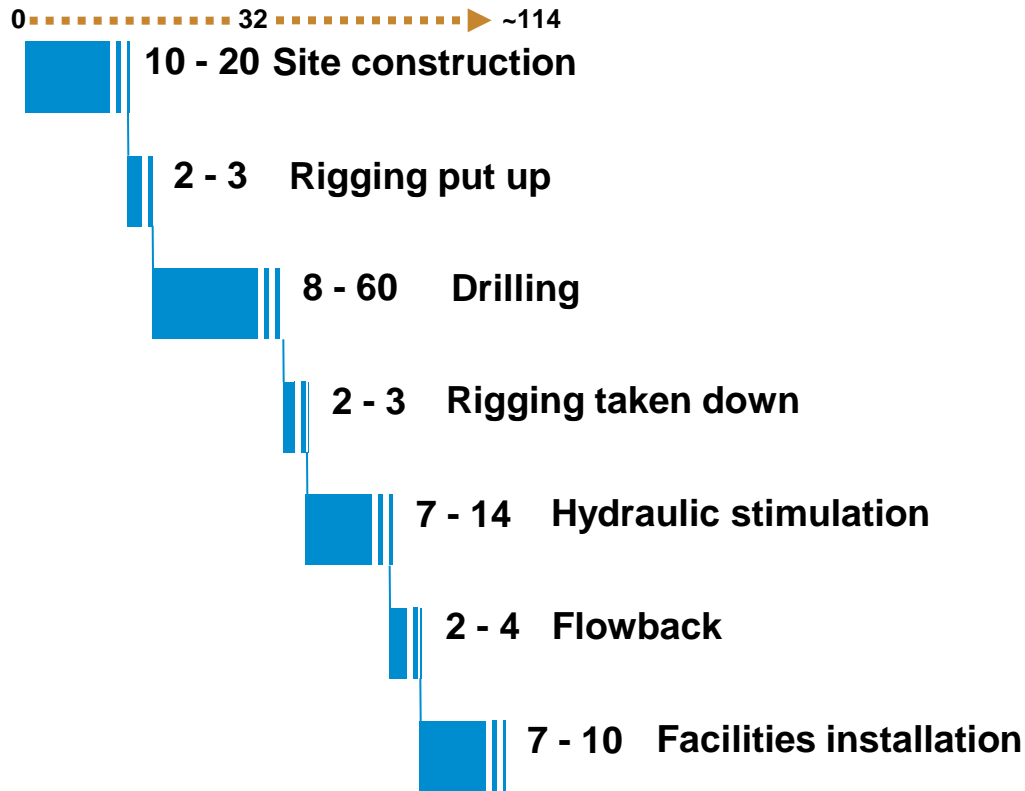
Source: U.S. Energy Information Administration, *Annual Energy Outlook 2013 Early Release*

Well Construction Occurs In Very Short Time

Example Timeline



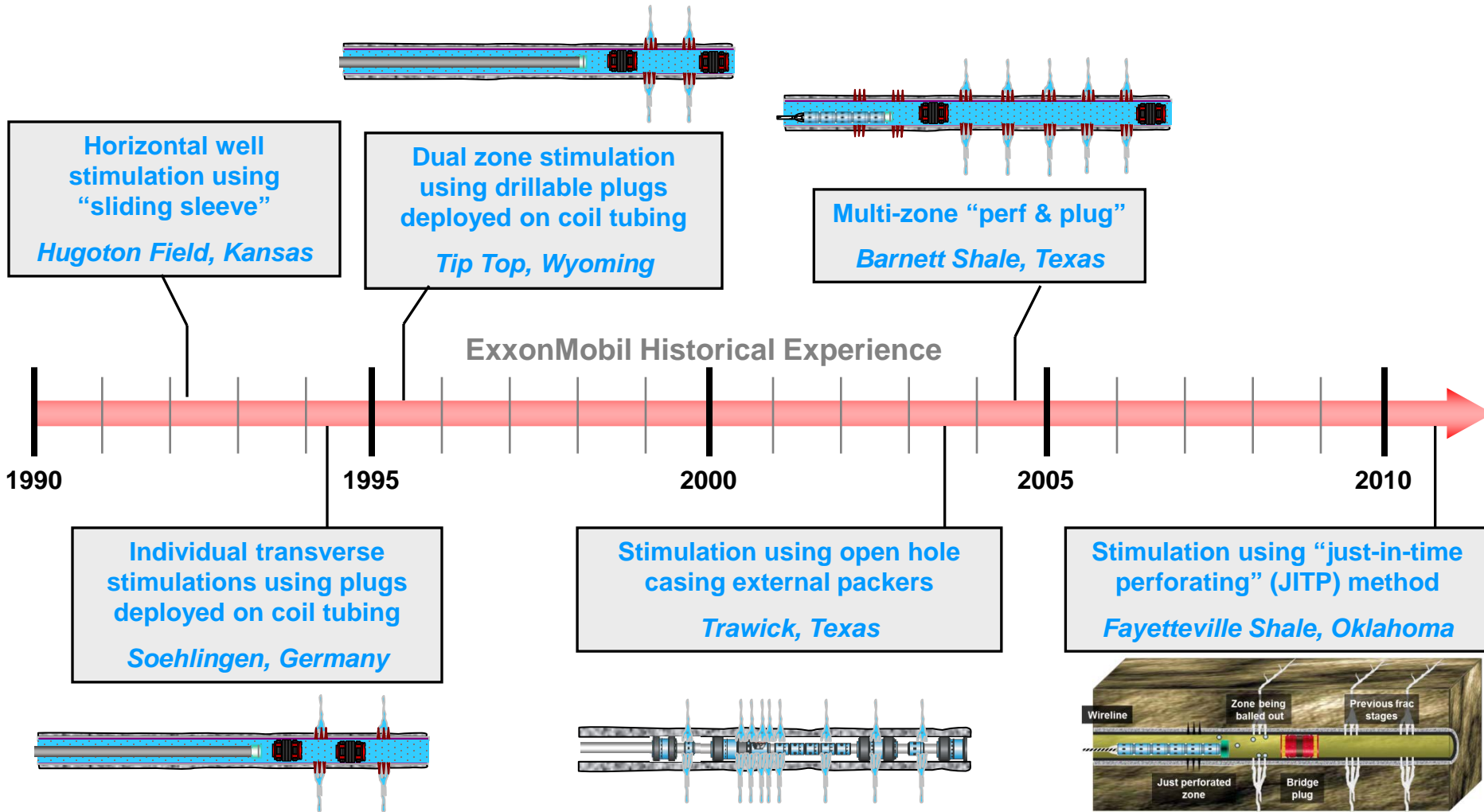
Days to Construct One Well



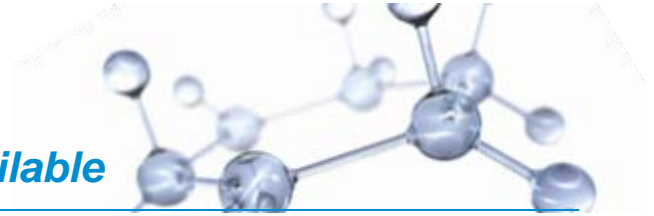
Years of Production



Horizontal Well Construction is Not “New” Industry has Significant Experience



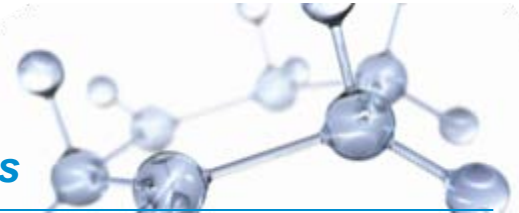
Sound Well Construction Practices Exist *Extensive Guidelines and Standards are Widely Available*



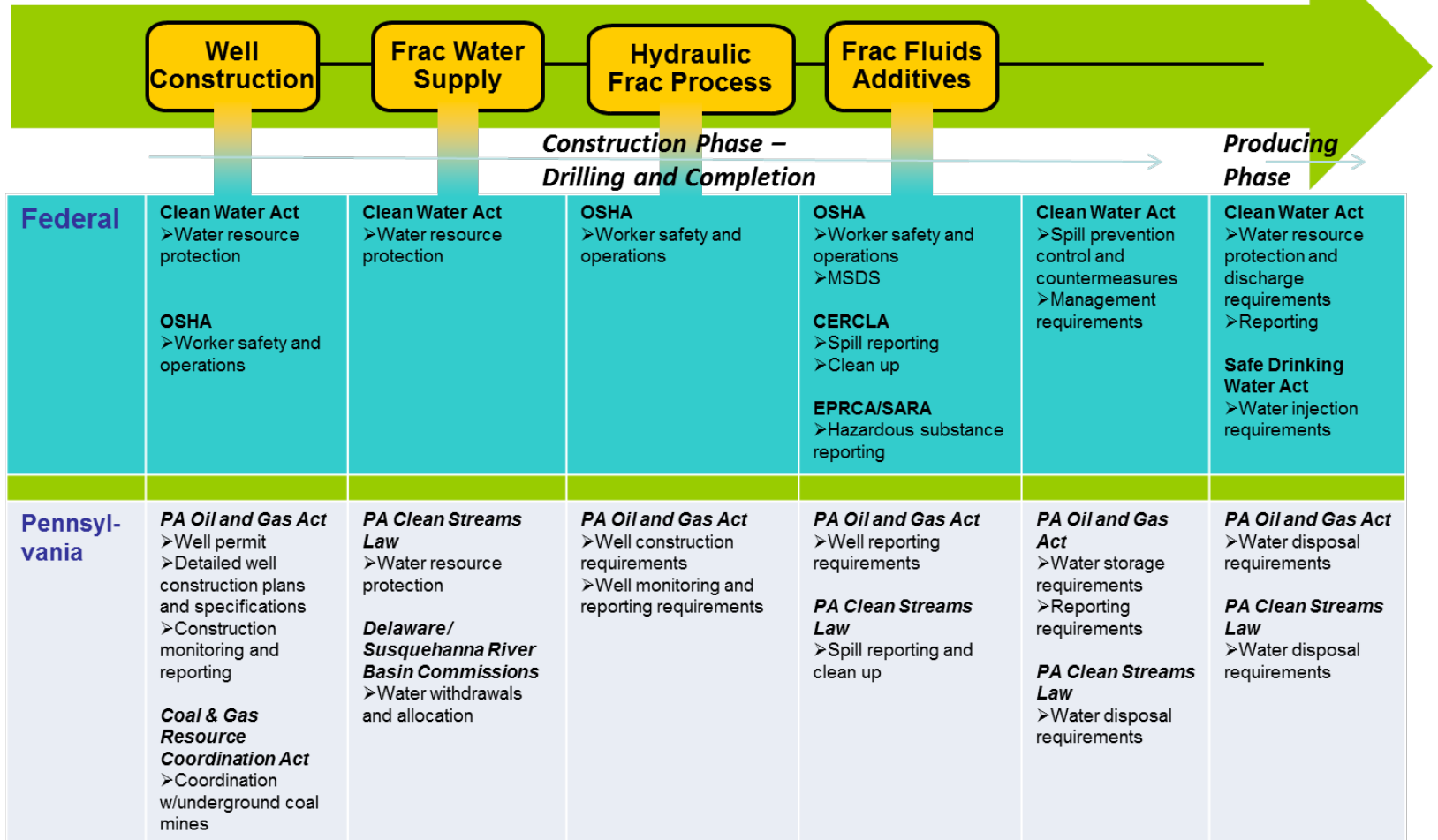
Selected examples from American Petroleum Institute of significant technical resources that exist and are readily available, considering local conditions

- ***API HF1 “Hydraulic Fracturing Operations – Well Construction & Integrity Guidelines, First Edition”***
- ***API HF2 “Water Management Associated with Hydraulic Fracturing, First Edition”***
- ***API HF3 “Practices for Mitigating Surface Impacts Associated with Hydraulic Fracturing, First Edition”***
- ***API Recommended Practice 51R “Environmental Protection for Onshore Oil and Gas Production Operations and Leases, First Edition”***
- ***API Standard 65 – Part 2 “Isolating Potential Flow Zones During Well Construction, Second Edition”***

An Effective Regulatory Framework is Critical Driven and Led by the Unique State and Local Conditions



Examples of Federal & Pennsylvania State regulations driving reliable well construction & operation



Risk Management is Fundamental *Enabled by Company Policies, Procedures, & Systems*



Well-developed and clearly defined policies and procedures

- **Management accountability**
- **High standards**
- **Employee and contractor training**

Rigorously applied systems

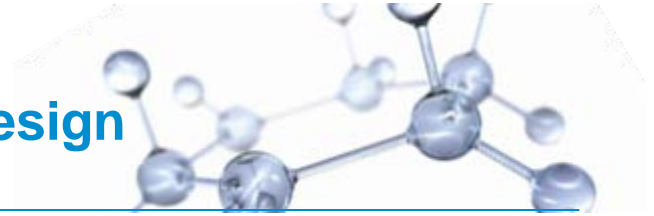
- **Operational Integrity Management Systems (OIMS)**



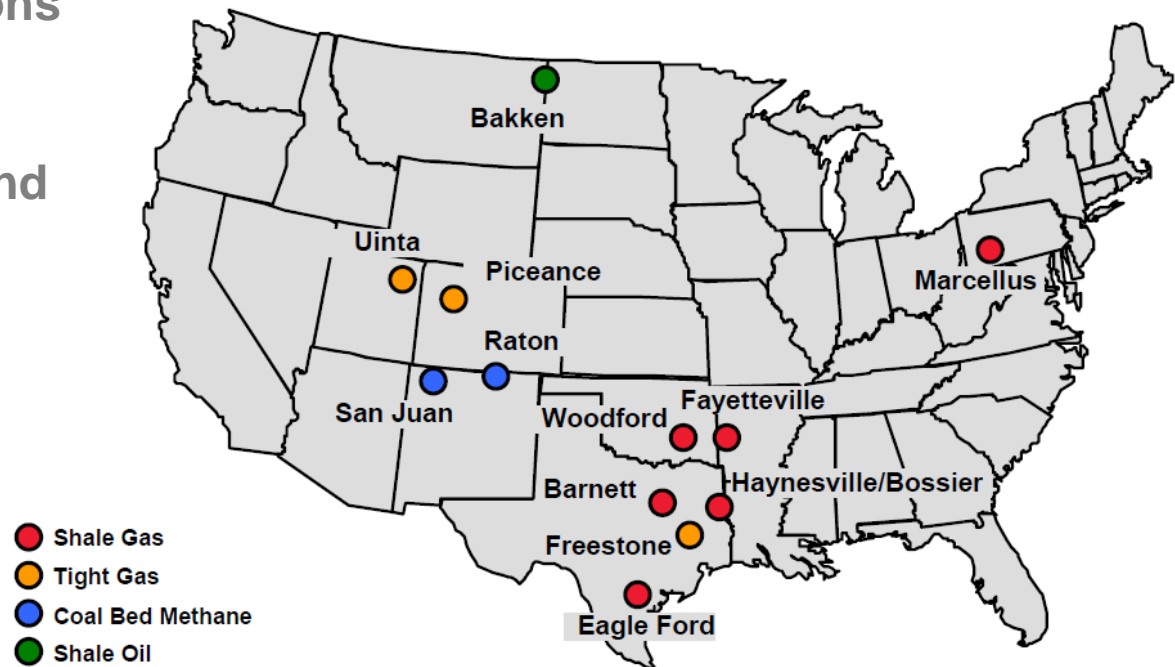
Well Construction & Hydraulic Fracture Design

Well Construction & Hydraulic Fracture Design

Local Geology Drives the Design

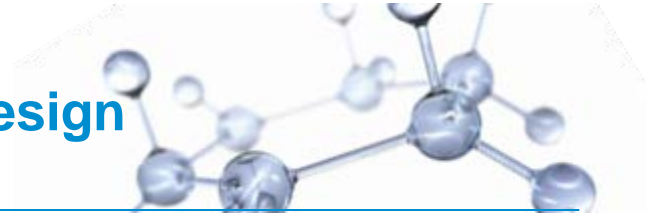


- Local surface environment
- Protection of freshwater aquifers
- Isolation of hydrocarbons
- Reservoir depth
- Formation pressures and temperatures
- Earth stresses



Well Construction & Hydraulic Fracture Design

Site Requirements Depend On Many Factors



- Location (terrain / topography), number of wells
- May typically be ~3-8 acres depending on number / type of wells
- May typically access over ~100's to > ~2000 acres of underground reservoir
- Wells may occupy < ~0.3 acres when operations done



Pad locations carefully designed to minimize surface footprint and community impact

Well Construction & Hydraulic Fracture Design

Material & Logistics Considerations (Generic Example)



Water (per well)

~5,000,000 gallons

~8 swimming pools – Olympic size (substantially less with recycling of flowback waters in development phase)

Proppant (per well)

~2,500 tons

~20 railcars and ~120 trucks

Chemical Additives (per well)

~25,000 gallons (~0.5% of stimulation treatment of water)

~6 trucks (can be less depending on specific situation and dry vs. liquid form)

Stimulation Equipment

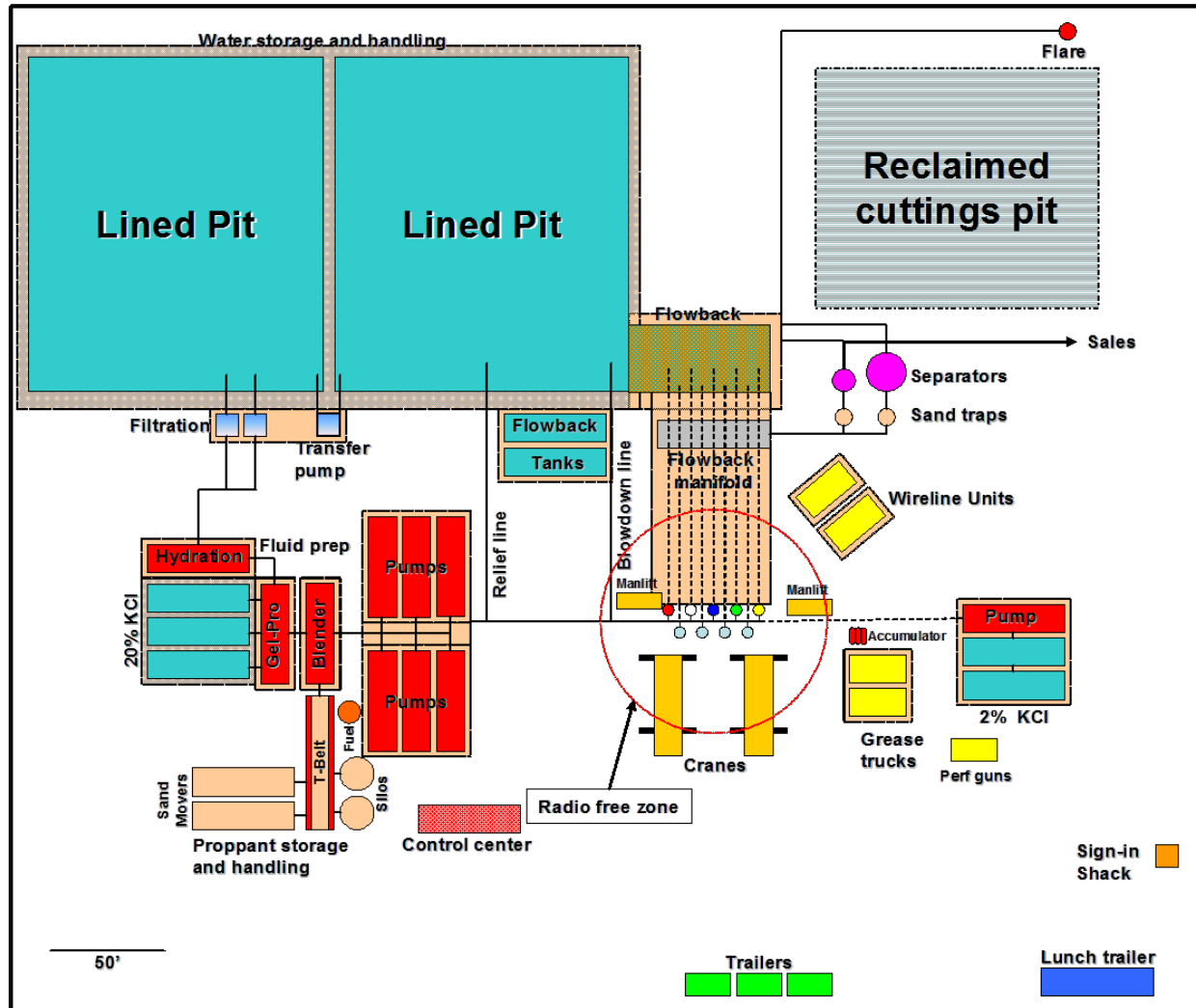
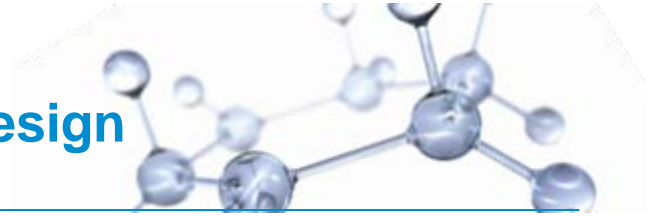
~20-30 trucks on location

Surface Site Size

~3 – ~8 acres depending on local conditions and number of wells on pad (if lined water storage pits used, slightly larger pending specific design of pits)

Well Construction & Hydraulic Fracture Design

Site Design for Fracturing Operations



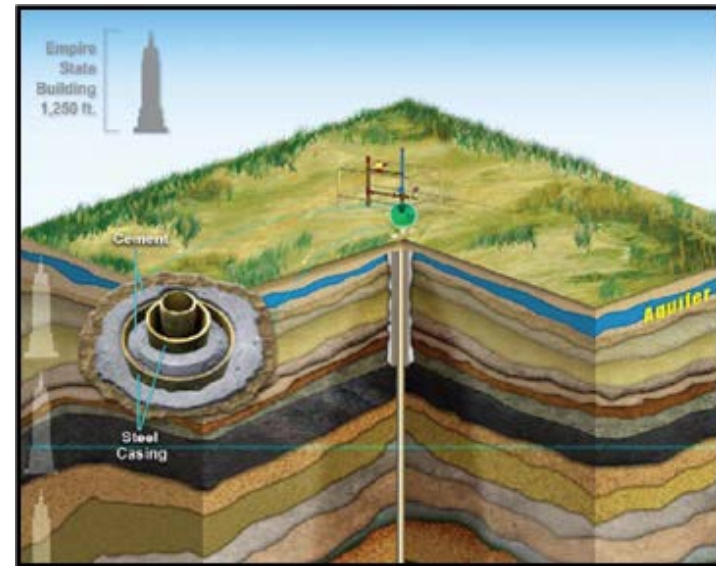
Well Construction & Hydraulic Fracture Design

Protecting Water Aquifers



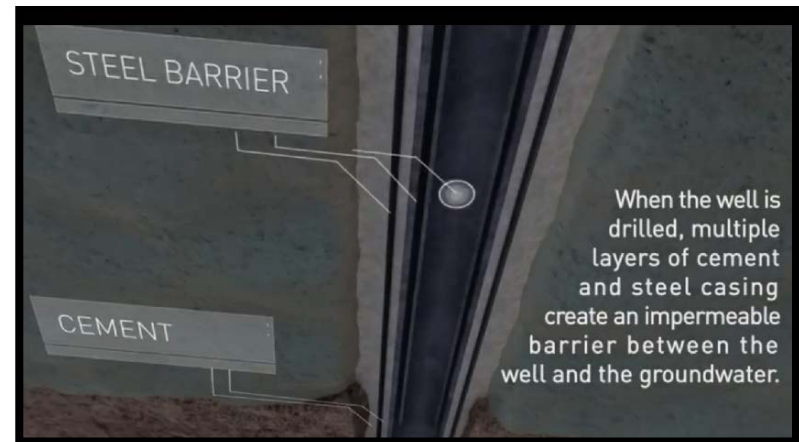
Protective measures in place

- Aquifers isolated by multiple well barriers
- Aquifers isolated by impermeable formation(s) over large distances from reservoir gas zone
- Frac operations closely monitored and of short duration



Enabled by sound well construction procedures

- Engineered designs
- Integrity practices
- Execution & verification



Well Construction & Hydraulic Fracture Design

Steel Casing Design Practices



Casing Designs:

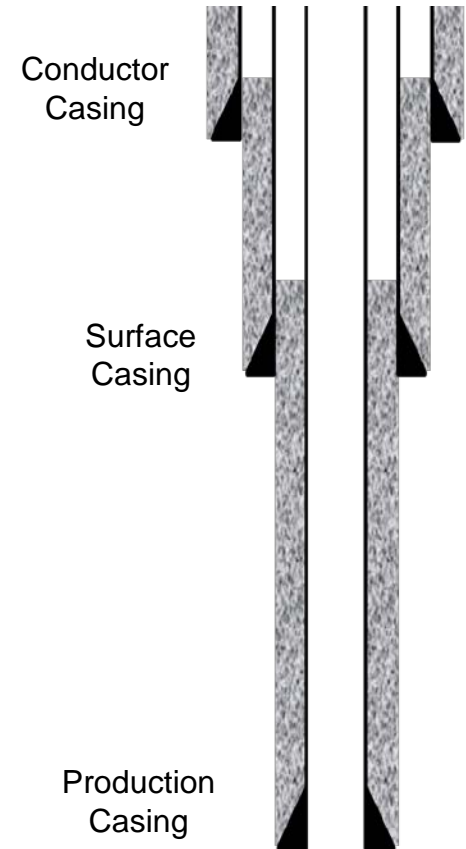
- Safety factors are applied with respect to pressure containment through an engineering design process.
- The Design process takes into account current and future well activities.

Casing Placement:

- Takes into account the location of fresh water zones, formation barriers, as well as future well operations, and regulatory requirements.
- Isolating fresh water formations, as well as primary and secondary production formations is key to the selection of casing locations.

Custom Designs

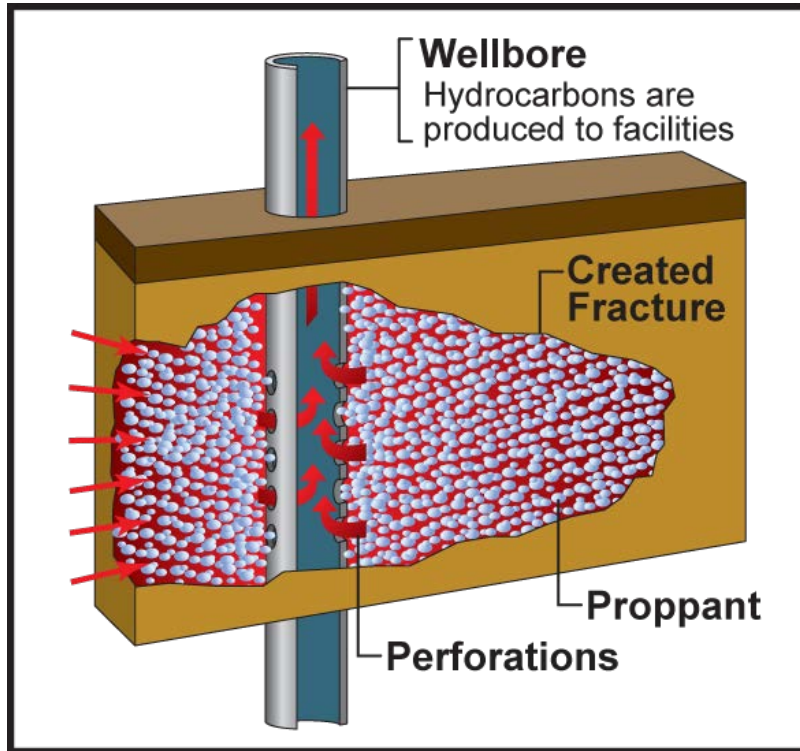
- Take into account variations in regulatory requirements, local geology, well location, specific well parameters, and production needs.



It is clear general recommendations are not a substitute for the application of sound engineering practices to each specific situation.

Well Construction & Hydraulic Fracture Design

Fracture Treatment Design - Materials



Note: Proppant are tiny grains of sand, or man-made ceramic beads, needed to hold the hairline cracks open

Proppant Selection:

- Must be of sufficient quantity, diameter, and strength to achieve & maintain a conductive fracture for expected production life of the well, considering the reservoir conditions

Chemical Additives:

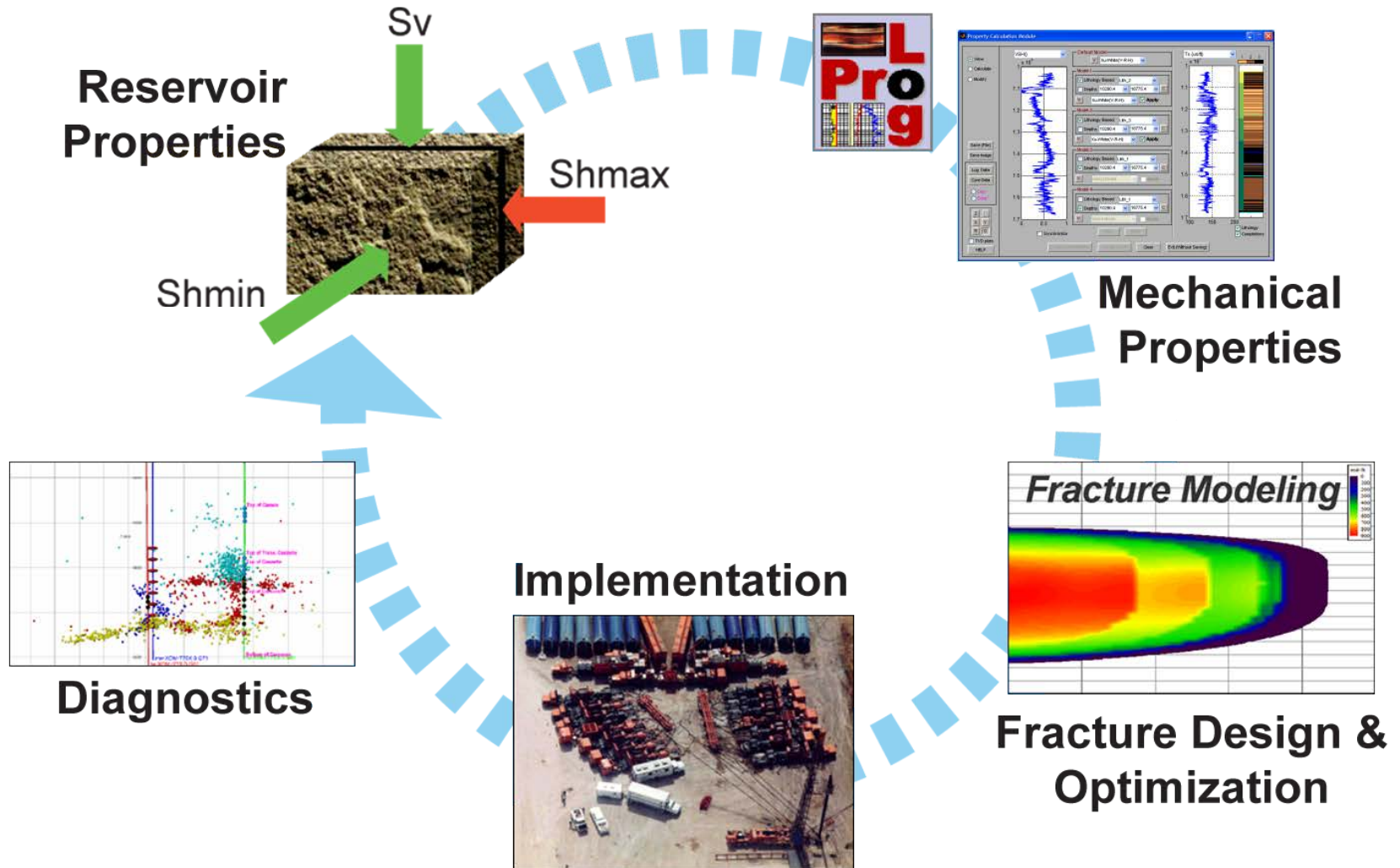
- Provides sufficient fluid viscosity to suspend small diameter proppant
- Ensure bacteria growth, scale formation, corrosion, and adverse chemical reactions do not occur under the specific reservoir conditions
- Minimize the amount and volume of fracture fluid chemical additives

Water:

- Maximize use of produced water and water recycling when possible
- Minimize use of freshwater when possible

Well Construction & Hydraulic Fracture Design

Fracture Treatment Design – Size of the Job



Well Construction & Hydraulic Fracture Design

Site Flowback Systems



Flowback systems and procedures are also “custom” designed based on a range of technical and operational considerations:

- Expected flow rate, pressure, and temperature conditions
- Produced fluid composition
- Wellbore hydraulics
- Available surface facility and flowline/pipeline infrastructure (exploration phase vs. development)
- Short-term flaring vs. venting (e.g. low heating value gas or in areas of “burn bans”)

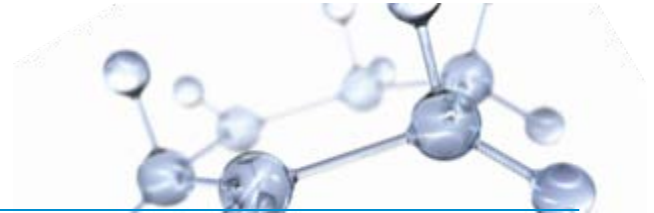




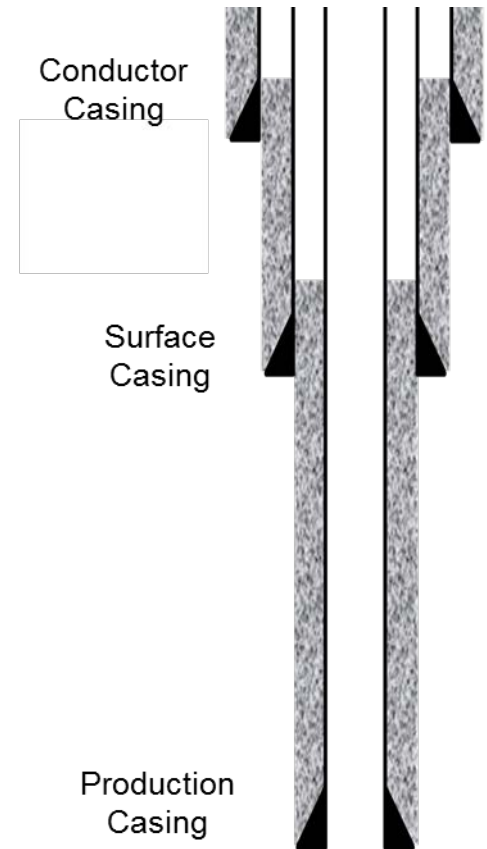
Operations Integrity Monitoring & Assurance

Integrity Monitoring & Assurance

Example Casing & Cement Placement

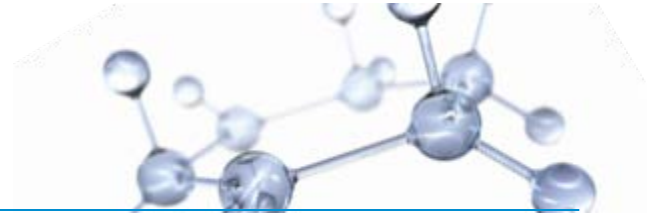


- Collect information regarding produced fluids (e.g., fluid composition, temperature, pressure)
- Select the right casing grades to withstand the effect of produced fluids for the life of the well
- Select the right casing size and strength in that particular grade to withstand fracturing pressure including safety factor
- Design and monitor cement jobs to confirm cement placed as planned
- Confirm casing integrity with pressure tests
- If cement monitoring or pressure tests identify potential concerns, perform additional diagnostic measurements (e.g., cement evaluation logging); and if any concerns identified from diagnostics, implement remedial operations (e.g., squeeze cementing)
- Obtain regulatory approval(s) on well construction as appropriate
- Pressure test the well before pumping fracture treatment
- Set safety pop-off valves in the frac line to vent pressure if pressure exceeded the approved limit
- Conduct a preliminary pressure test to check for surface leaks



Integrity Monitoring & Assurance

Integrity via Engineered Equipment Designs

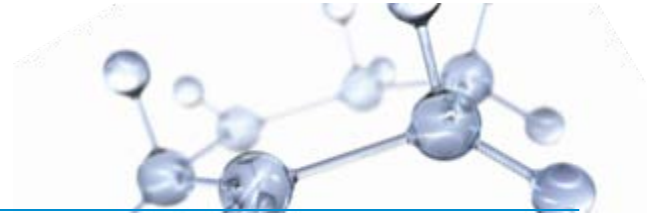


Example: Pressure control equipment enables reliable installation & running of well tools



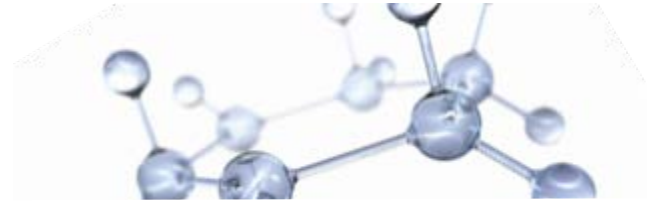
Integrity Monitoring & Assurance

Real-time Extensive Monitoring During Fracturing



Monitored & controlled with multiple pressure gauges and electronic instrumentation





Risk Assessment & Mitigation

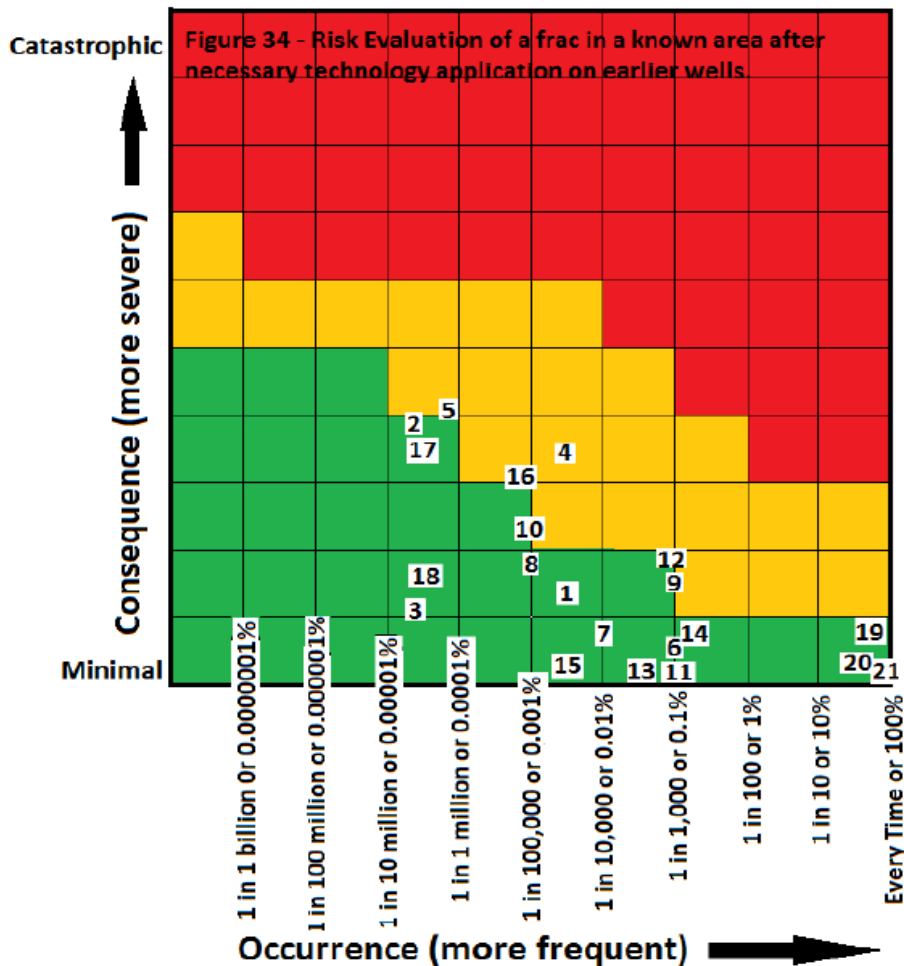
Water aquifer exposures

Surface releases

Induced seismicity

Risk Assessment & Mitigation

Characterizing Risk with Data



A recent SPE publication presents a assessment of publicly available data

- Risks can be effectively mitigated and most activities are generally lower risk
- A reasonable and prudent regulatory framework is required to foster responsible operations by all

1. Spill of 130-bbl transport load
2. Spill of 500-gallons of liquid concentrated biocide or inhibitor
3. Spill of 500-lbs of dry frac chemical additives
4. Spill of 300-gallons diesel from diesel-fueled truck accident
5. Spill of 3500-gallons fuel from truck accident
6. Spill / leak from 500-bbl well site fluid storage tank
7. Spill of water treated for bacteria control
8. Spill of diesel while refueling pump trucks
9. Spill of 500-bbl stored flowback water from frac
10. Frac pressures ruptures surface casing at exact depth of fresh water sand
11. Frac fluid tubular cooling causes wellhead leak
12. Frac opens mud channel in cement in wells < 2000-ft deep
13. Frac opens mud channel in cement in wells > 2000-ft deep
14. Frac intersects another frac or well within a 1000-ft
15. Frac intersects an abandoned wellbore
16. Frac to surface through rock strata – shallow well < 2000-ft
17. Frac to surface through rock strata – deep well > 2000-ft
18. “Felt” earthquake from hydraulic fracturing of magnitude > 5
19. Frac changes output of natural seep at surface
20. Emissions
21. Normal frac operations without significant (reportable) spills, ruptures, leaks

Image from King, G.E. (2012) SPE Paper No. 152596, Copyright 2012 Society of Petroleum Engineers, Reproduced with permission of SPE. Further reproduction prohibited without permission.

Risk Assessment & Mitigation

Characterizing Risk with Data

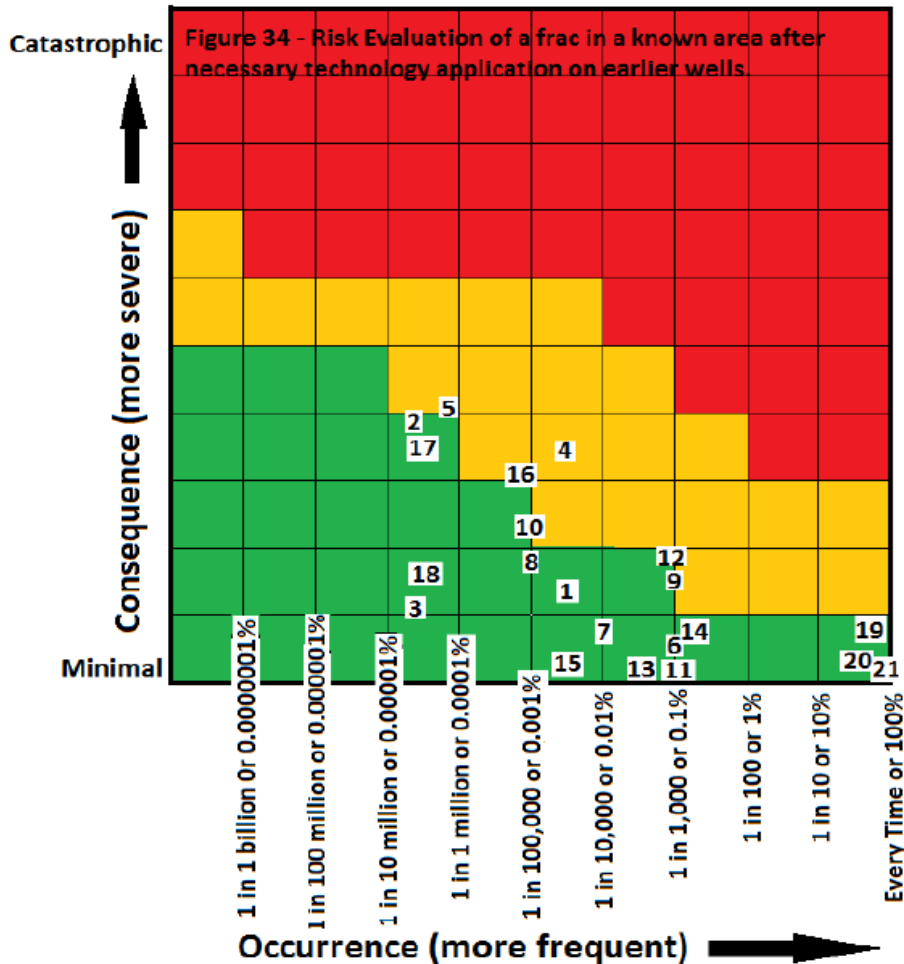
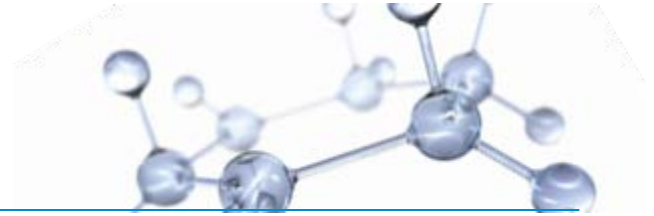


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A recent SPE publication presents a assessment of publicly available data

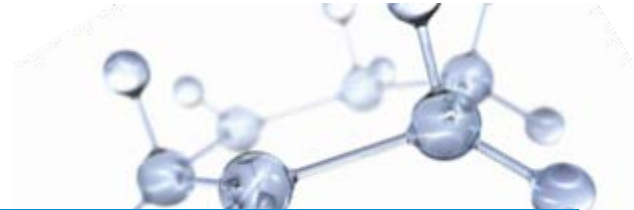
- Risks can be effectively mitigated and most activities are generally lower risk
- A reasonable and prudent regulatory framework is required to foster responsible operations by all

Key risks to consider

- Subsurface fluid migration due to poor well construction or shallow faults
- Surface chemical spills, material transport accidents
- Induced seismicity
- GHG emissions
- Public nuisances: noise, traffic, dust

Risk Assessment & Mitigation

Potential Water Contamination



Issue

- Fractures create flow paths to shallow water aquifers
- Fracture pressures open cement channels or faults in shallow wells

Data

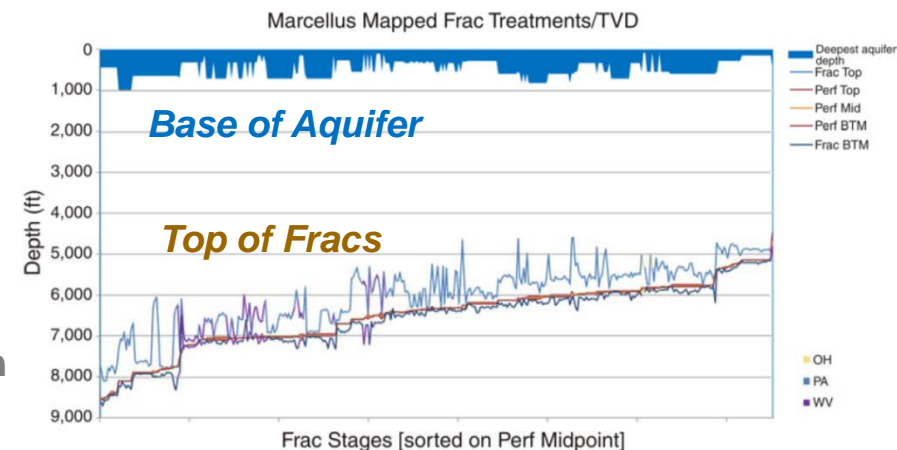
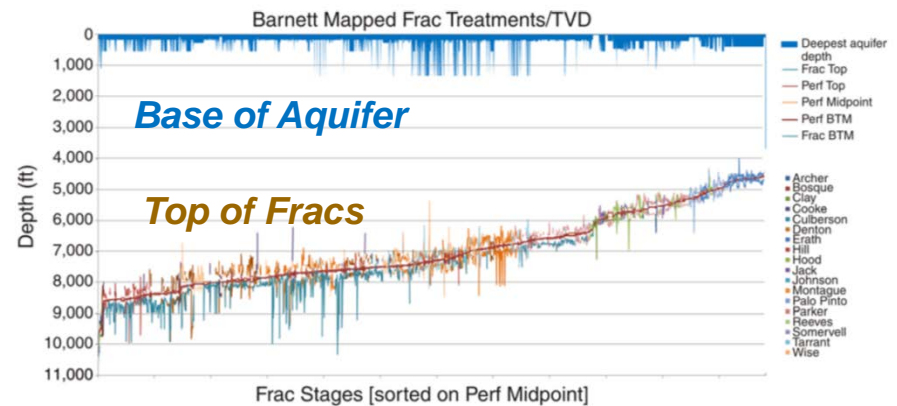
- Microseismic measurements obtained in thousands of fracture treatments
- Extensive (USA) State and Federal investigations

Risks

- Frac chemicals have not been found in any aquifer
- Isolated instances of gas migration in shallow wells due to poor well construction

Mitigation

- Engineered well designs / multiple barriers considering local geology and aquifer location
- Integrity testing of well prior to operations
- Monitoring of frac pressures
- Remediation of well construction issues if encountered



Images from Fisher, K., Warpinski, N. (2011) "Hydraulic Fracture-Height Growth: Real Data", SPE Paper No. 145949. Copyright 2011 Society of Petroleum Engineers, Reproduced with permission of SPE. Further reproduction prohibited without permission.

Risk Assessment & Mitigation

Potential Water Contamination



Issue

- Surface release and/or spill of chemicals & fluids
- Unplanned subsurface fluid migration

Data

- GWPC comprehensive review: ~389,000 wells
- Texas (1993-2008) & Ohio (1983-2007)

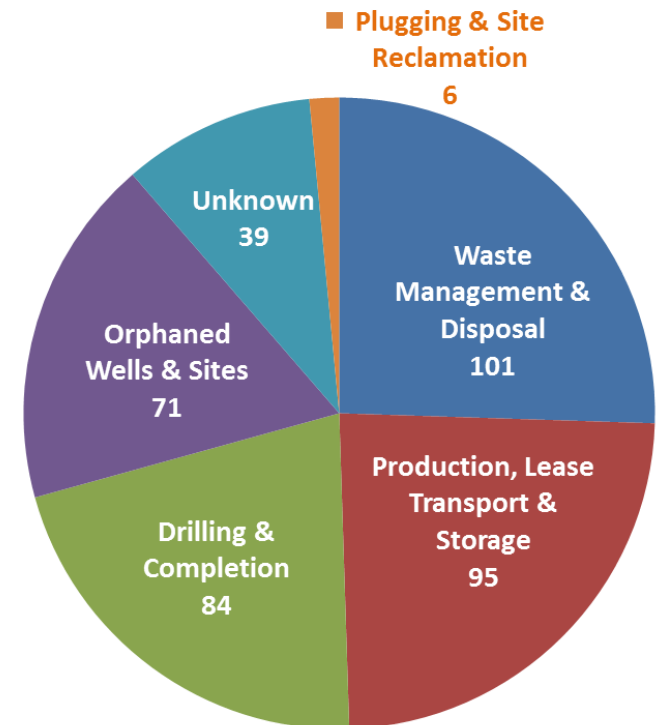
Risks

- Total documented incidents 396 (~0.1%)
- Diversity of causes / very localized impacts (not broad)
- No incidents from hydraulic fracturing / site prep
- Surface handling (< 0.06%)
- Orphaned wells / legacy sites (< 0.05%)
- Drilling / cementing / completion (< 0.04%)

Mitigation

- Prudent regulation & inspection
- Redundant barriers & containment
- Improved standards for reserve pit construction
- Improved standards for demonstrating well integrity
- Address “orphan” well & “legacy” site issues
- Remediation when issue encountered

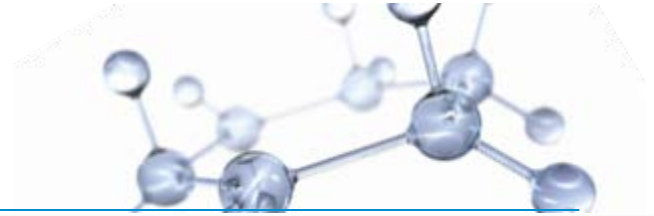
GWPC 2-State Review Texas and Ohio
~220,000 Wells Drilled & ~169,000 Wells Plugged
396 Incidents



Data Source: Kell, S. (2011) “State Oil and Gas Agency Groundwater Investigations and their Role in Advancing Regulatory Reforms, A Two-State Review: Ohio and Texas”, Ground Water Protection Council, available at http://fracfocus.org/sites/default/files/publications/state_oil_gas_agency_groundwater_investigations_optimized.pdf

Risk Assessment & Mitigation

Induced Seismicity from Injection Operations



Issue

- Seismicity can be induced or triggered when stress or pore pressure changes promote slip along a fault

Data

- USA National Academy of Sciences comprehensive study
- DECC (U.K.) report of Bowland shale
- BCOGC (Canada) report on Horn River

Risk

- Injection: 7 reports of M > 4.0 events in over 30,000 wells (localized moderate impact)
- Fracturing: 3 reports for >> 1,000,000 treatments (no significant damage or injury)

Mitigation

- Avoid high-pressure large volume injection directly into significant and active faults
- Consider a “stoplight approach” based on local conditions when a significant risk is demonstrated

NAS has recently examined induced seismicity across multiple energy sectors. Three major findings were published from this study ⁽¹⁾:

1. “The process of hydraulic fracturing a well as presently implemented for shale gas recover does not pose a high risk for inducing felt seismic events
2. Injection of disposal of waste water derived from energy technologies into the subsurface does pose some risk for induced seismicity, but very few events have been documented over the past several decades relative to the large number of disposal wells in operation; and
3. CCS, due to the large net volumes of injected fluids, may have potential for inducing larger seismic events.”

(1) NAS (June 2012), “Induced Seismicity Potential in Energy Technologies”, http://www.nap.edu/catalog.php?record_id=13355

Disposal

1. Dallas-Forth Worth Airport, Texas
2. Dallas-Fort Worth, Cleburne, TX
3. Braxton, West Virginia
4. Guy-Greenbriar, Arkansas
5. General Case – Injection Well

Hydraulic Fracturing

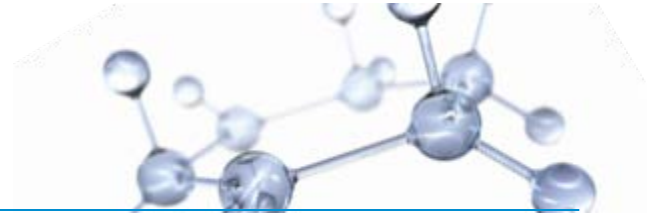
6. Horn River Basin, Canada
 - a) Etsho
 - b) Tattoo
7. Bowland Shale, UK
8. General Case – HF Well
 - Microseisms always created

		Probability				
Consequences						
			4			
			1, 2			
		3 8	6a 7 6b			5

Figure 7: Risk assessments associated with selected publicly reported examples. Image from Nygaard, et. al. (2013) “Technical Considerations Associated with Risk Management of Potential Induced Seismicity in Injection Operations”, presented at the 5to. Congreso de Producción y Desarrollo de Reservas, Rosario, Argentina, May 21-24.

Risk Assessment & Mitigation

Induced Seismicity from Injection Operations



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Example Micro-Seismic Data (Horn River, Canada)

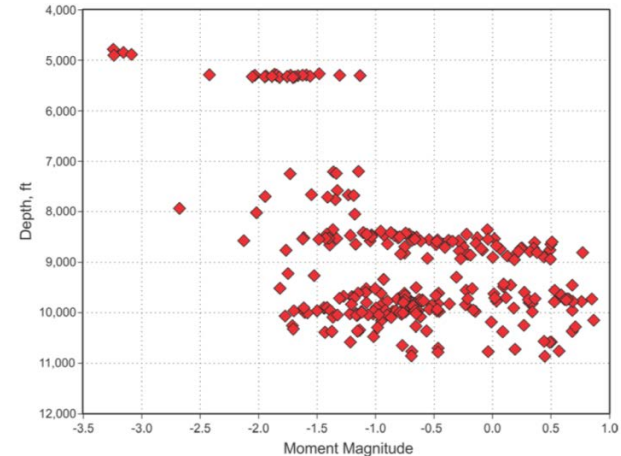
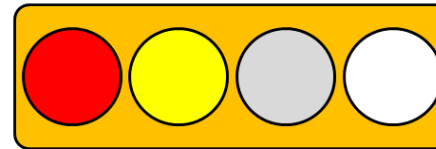


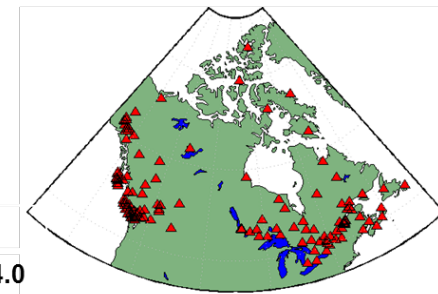
Fig. 6—Muskwa/Evie reservoir maximum moment magnitude results for monitored stages through mid 2011.

Image from Warpinski et. al. (2012) SPE Paper No. 151597, “Measurements of Hydraulic Fracture Induced Seismicity in Gas Shales”; Copyright 2012, Society of Petroleum Engineers. Reproduced with permission of SPE. Further reproduction prohibited without permission.

Example of a Stoplight System Approach (Horn River, Canada)



Suspend Operations	$M_L \geq 4.0$
Proceed with Caution	$2.0 \leq M_L \leq 4.0$
Proceed as Planned	$M_L \leq 2.0$

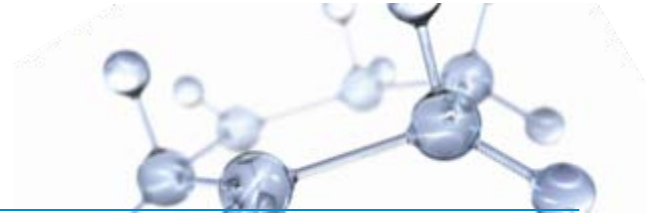


Canadian National Seismograph Network, Active Stations, 2/6/13



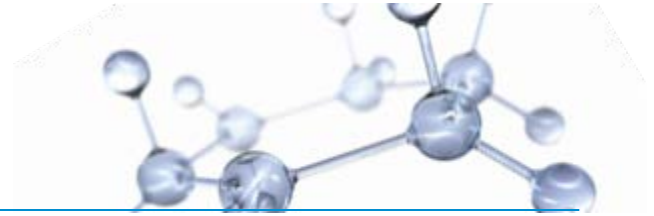
SUMMARY

In Closing ...



- Each shale play is unique and requires its own set of creative solutions to develop
- Reliable and safe development of shale resources, enabling substantial economic and environmental benefit while meeting the forecast energy demand, can be achieved with a collaborative engagement between the public, regulators, and operating companies.
- It is important that reasonable regulations considering local conditions be in place, coupled with a responsible operations philosophy and effective risk management framework implemented by all operators, supported by the consistent and appropriate use of sound engineering practices and standards.
- Transparency and reasonable regulations will help enable abundant sources of clean-burning natural gas to be economically developed in an environmentally sound manner





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