Tight Oil & Gas Development – A Geologist's View of Hydraulic Fracturing

Legal Aspects of Hydraulic Fracturing
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Today's Presenter :

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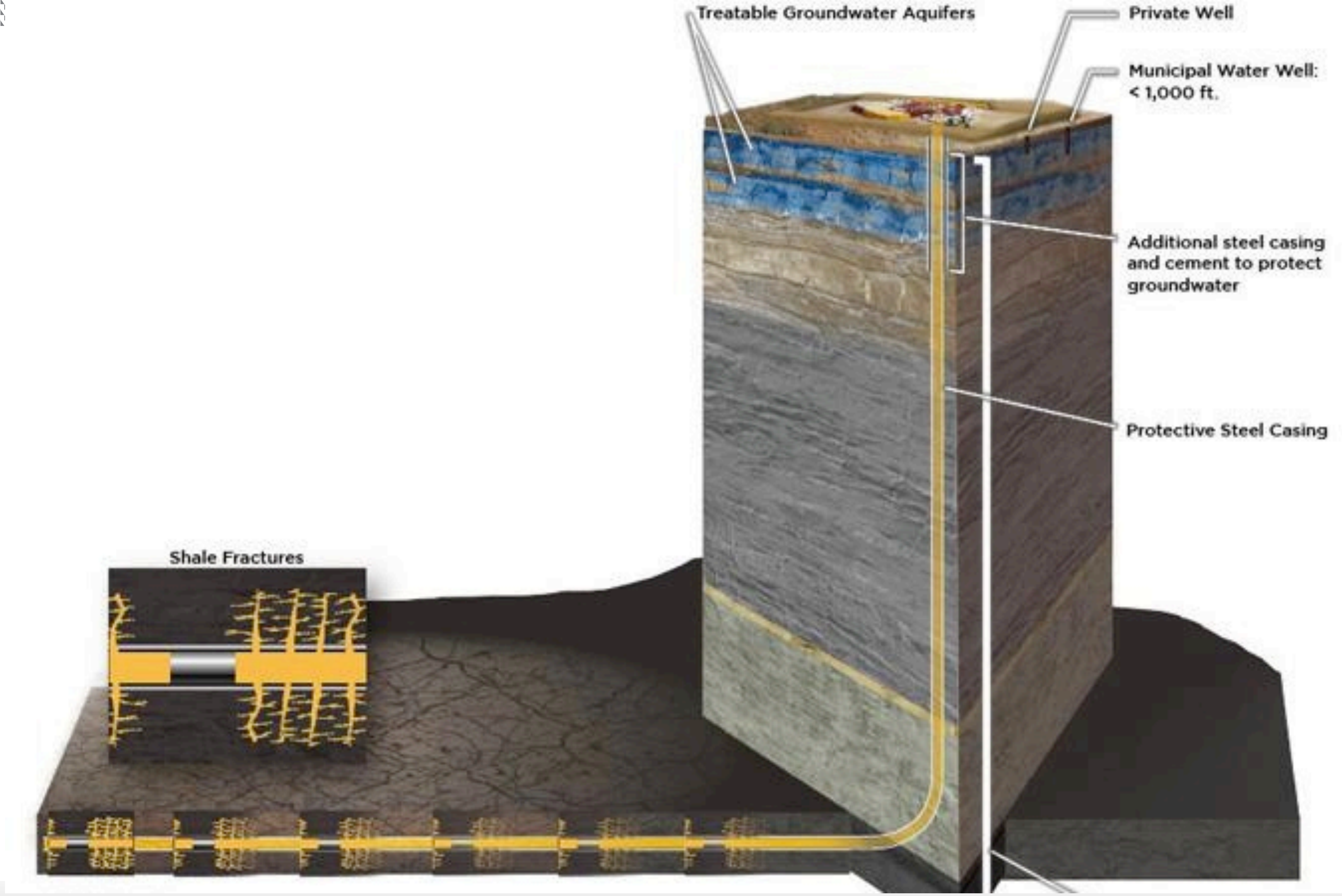
The Technology

- Hydraulic Fracturing is a proven technology with a long history:
  - 1903 - First industrial use in Mt. Airy, NC for separation of granite blocks in quarry operations.
  - 1947 - First oil and gas applications in US.
  - 1949 - Commercial Applications by Halliburton.
- Pairing Directional Drilling with Hydraulic Fracturing allows for tapping the source rock, breaking the trap, while creating the reservoir interval.
- Directional and horizontal drilling techniques enable tapping relatively thin units along a horizontal well bore that may exceed 5000 feet.
- Directional and Horizontal Drilling enable multiple horizontal wells drilled/developed from a single pad location – 4 to 8 wells from a single drilling pad not uncommon.
- Each well may have from a few as 4 to as many as 20 fracturing intervals.

Example Horizontal Well



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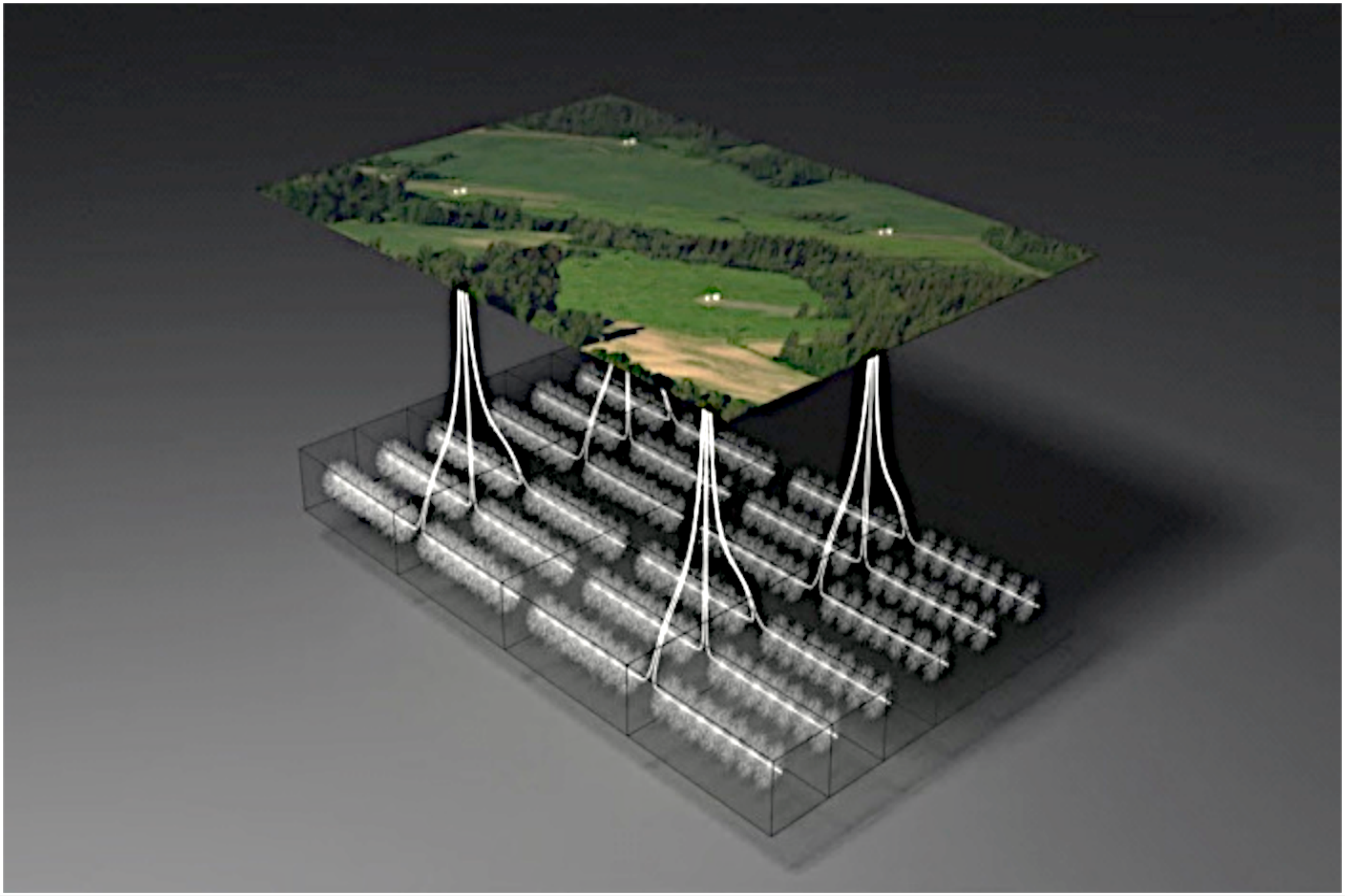
Multi-Well Pad Coverage



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Unprecedented Growth and Change

- When evaluating historical heavy industry practices – e.g. solvent use/handling – we were accustomed to generational or decade-scale change and advances.
- Historically we relied on Federal rules/regulation that were years in development and implementation when looking for benchmarks in industrial practices.
- This is an industry that started, grew, and matured under State regulation. States are more nimble and quick to respond, change, and enact rules/regulations.

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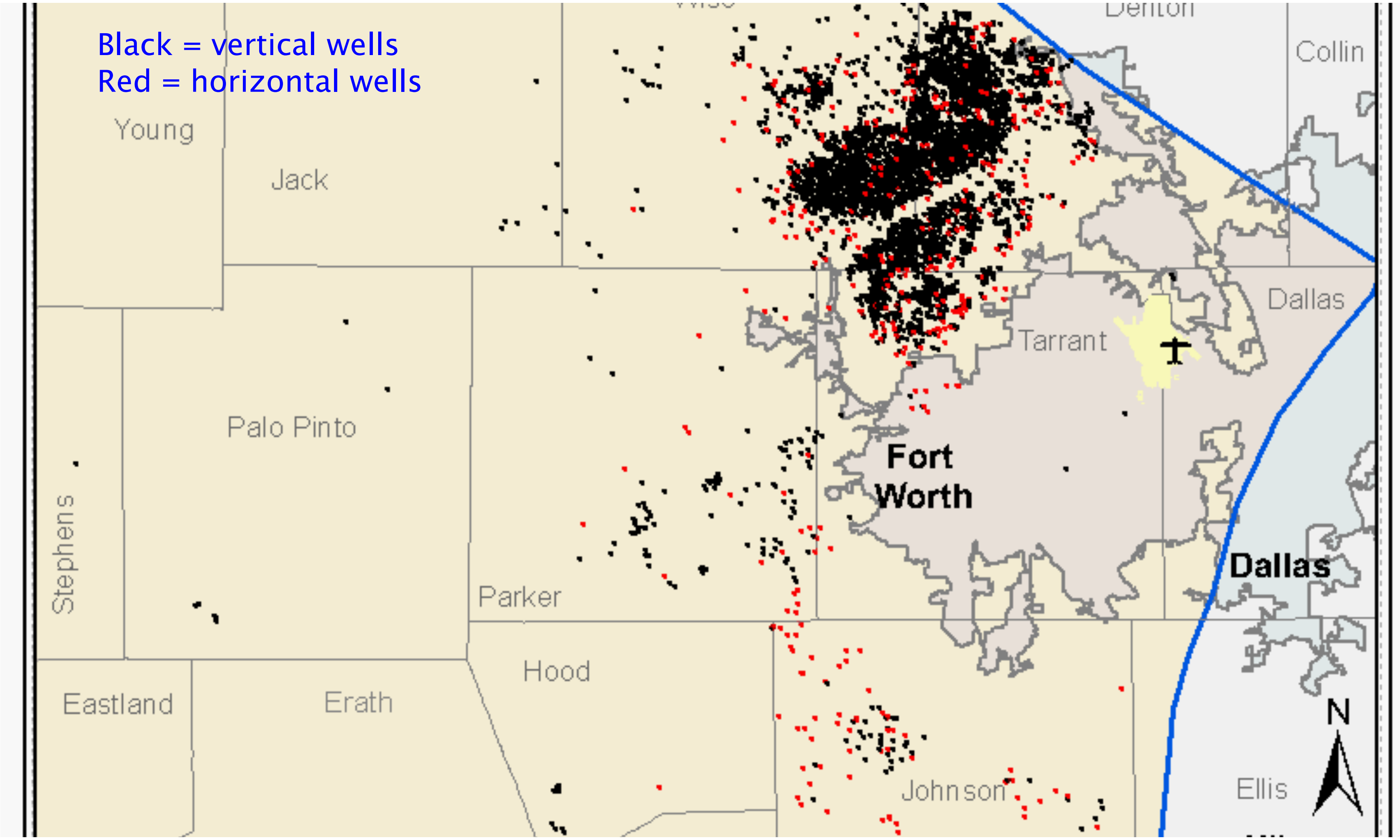
Barnett Shale - 2004



Source: EIA

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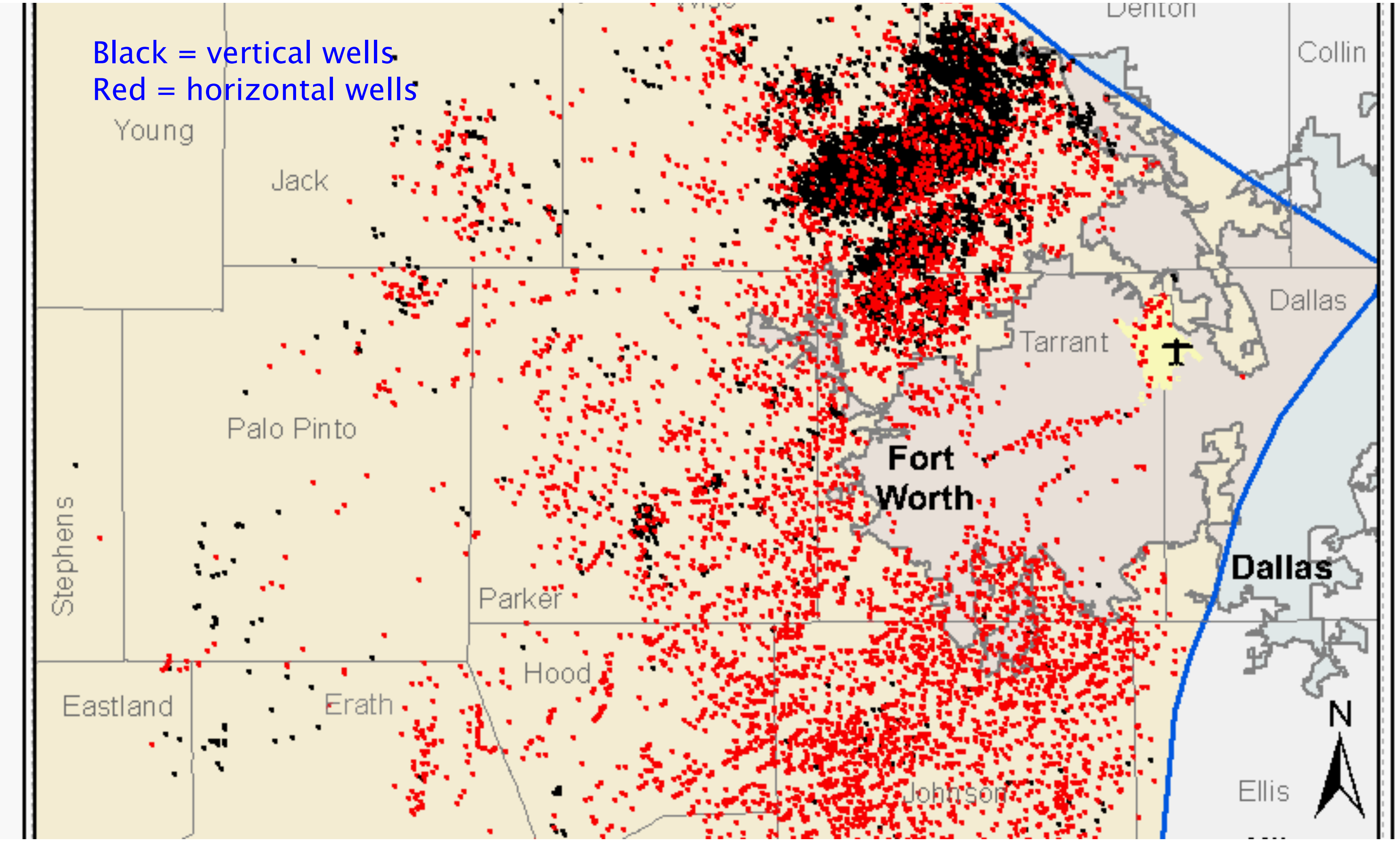
Barnett Shale - 2010



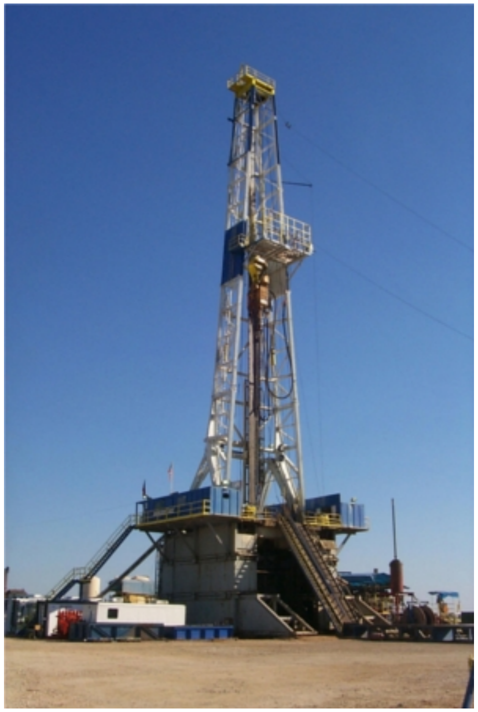
Source: EIA

The Sources of Regulations are Changing/Evolving

- Historically, industry regulated on State basis by the “Oil & Gas Commission”
- Now the Industry must satisfy a greater number of agencies, including *inter alia*:
  - State oil & gas commission
  - State environmental agency
  - State department of natural resources
  - State department of water resources
  - State engineers office
  - USEPA
- All data and reports submitted to State agencies now available on open web sites.

Potential for Exposures

Development



Drilling

Production

Compact and Mobile Industrial Sites

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Site Preparation

- Drilling Pad Construction
  - Engineered sites
  - Liners and berms for spill control
  - Structural panels for the work surface
- Materials Management
  - Chemicals handled in large volume containers
  - On-site spill response teams

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Water Needs

- Large volumes of water required for drilling as well as hydraulic fracturing.
  - Dependent on basin – 80,000 to 500,000 gals to drill the well
  - 4 million to 6 million gallons per well for the hydraulic fracturing process
  - Sources vary widely – surface water and groundwater – potable and non-potable
  - Water availability an issue in the arid West – Spring 2012 auction of CO River Basin “excess” to energy producers rather than agriculture

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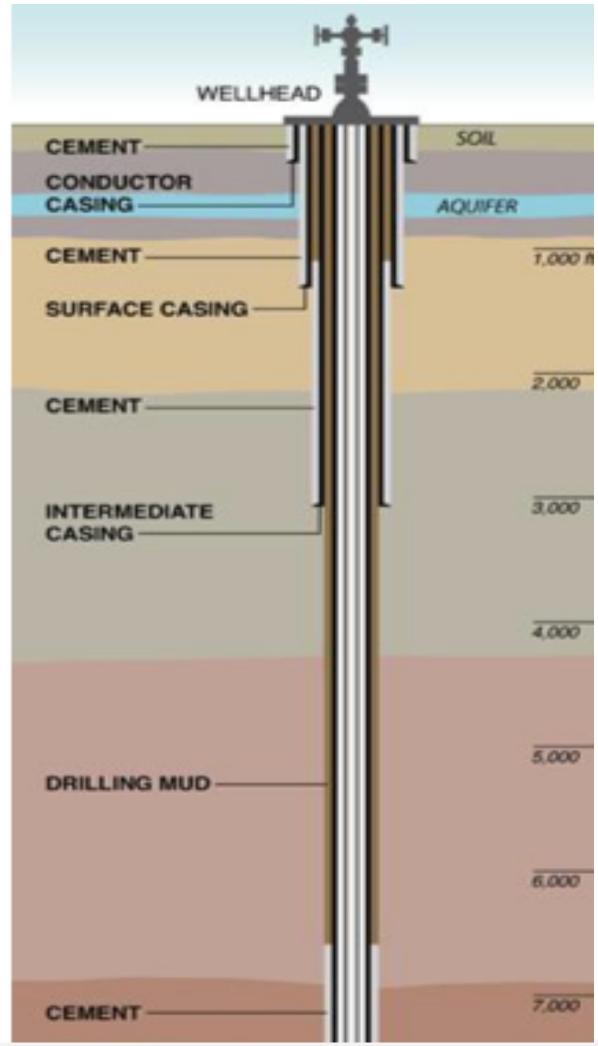
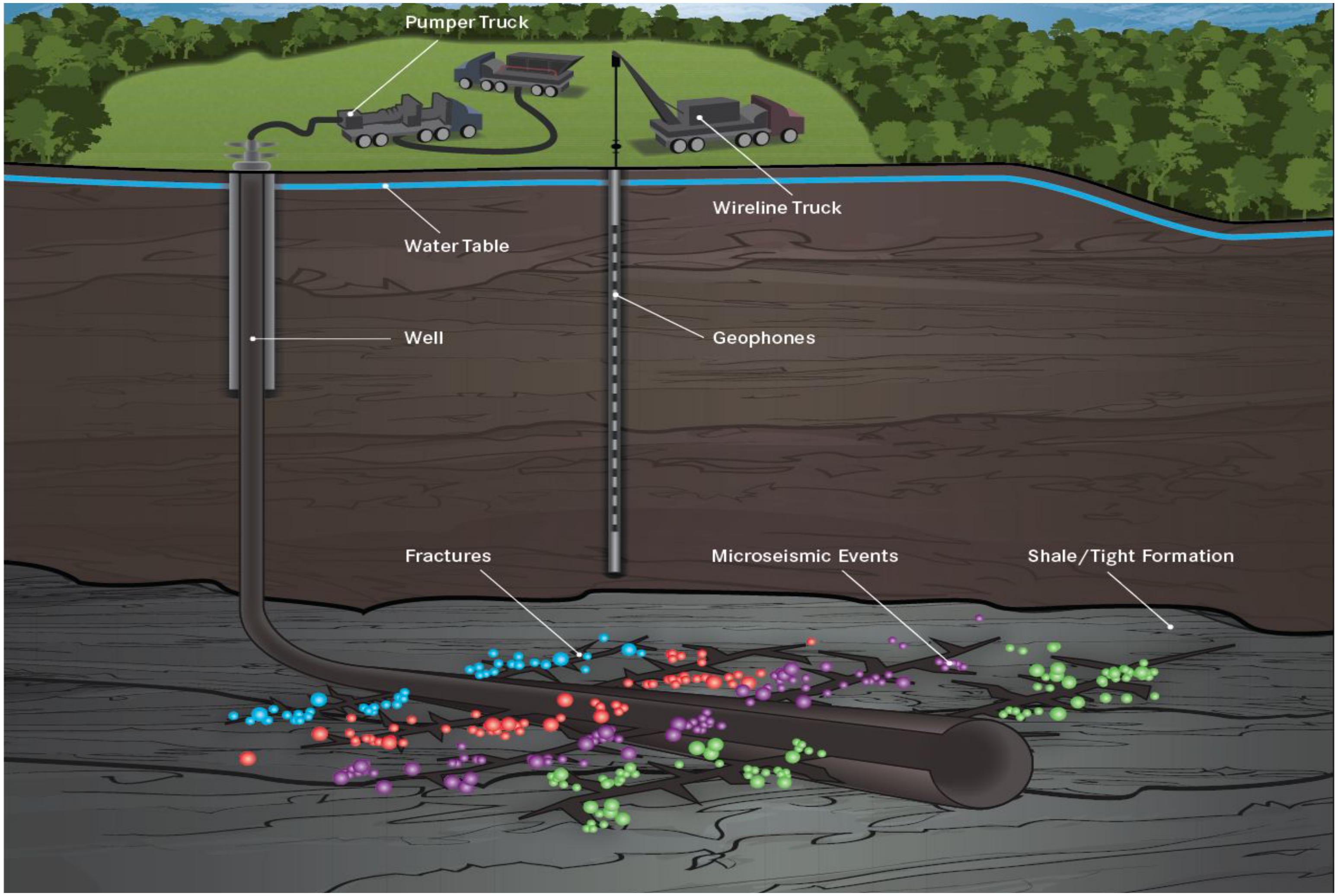


Drilling and Casing Schedule
Site Specific Design

Fracture Prediction and Mapping

- Detailed design task:
  - *In situ* stresses
  - Texture of rock that may control fracture propagation
  - Nearby geologic structures – e.g. faults
  - Desired extent (horizontal and vertical) of fractures
  - Number of fracture intervals
- Goal is to maximize fracturing in desired interval
- Fractures extending beyond area of interest are potential problem:
  - Potential for fracture fluids to migrate from production unit
  - Potential for loss of hydrocarbons – adverse effect on well economics
- Real-time fracture mapping

Real-Time Fracture Mapping



Source: ESG Solutions

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Hydraulic Fracturing Fluid

- Typical for >98% of fluid to be water and sand/proppant
- Chemicals required to:
  - condition formation
  - corrosion inhibitors to protect casing materials
  - friction reducers to enhance pressure transmission to fractures
  - biocides to prevent bacterial fouling
  - See www.fracfocus.org
- **Formulation will be vendor and basin dependent.**
- **No longer valid to state that additives are unknown or unregulated**
  - During the past 2.5 years, states have adopted disclosure requirements
  - Those states account for approximately 90% of the current drilling in the US
  - When in doubt, you can even obtain this information from company web sites

Components of Additives

- Historically the additives used for fracturing included hazardous components:
  - Diesel was used historically as a carrier solvent for components such as linear gels (e.g. guar) (USEPA, 2004, 816-R-04-003).
  - Components included use of compounds such as pentachlorophenol as biocide (see USEPA and API studies in 1986 regarding RCRA Subtitle C exemption).
- Energy Policy Act of 2005 provided exemption from regulation via the Underground Injection Control Program for non-diesel hydraulic fracturing mixtures
- The result: Additives now comprised of greener and more benign components
  - guar-based gels using food grade mineral oil carriers
  - Use of compounds such as glutaraldehyde as a biocide – also used as disinfectant for sterilizing medical equipment
- Evolution of additives driven both by public/marketplace perception as well as focus on recycling and re-usability of wastewater

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Fluid Management

- Flow Back and Produced fluids may contain the above as well as constituents characteristic of formation – elevated Total Dissolved Solids, Naturally Occurring Radioactive Materials, metals, and organics
- Historically water managed as direct discharge or trucked to POTW
- Dramatic changes and evolution of management over last 24 months
  - POTW not an option in most cases
  - Reclamation of brine or deep well injection most common alternatives
- Industry is recycling and re-using flowback water – both onsite and trucking to subsequent drill site

On-Site Waste Management

- Historically - On-site storage in open lagoons

- More common now to see closed storage vessels with vapor capture and control

Off-Site Waste Management

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- Class II UIC wells permitted, regulated, and operated for disposal of oil & gas derived waste fluids.
- Many of these wells (and there are tens of thousands across the US), may have been installed for enhanced recovery operations – not all are operated for receipt of waste as commercial disposal wells.
- Recent concerns (e.g. - volumes of waste and induced seismicity) resulting in significant changes to the State permitting processes, for example:
  - Ohio - added studies may include seismic surveys for fault identification, monitoring of seismic activity, and "Any such other tests that the [division] chief deems necessary."

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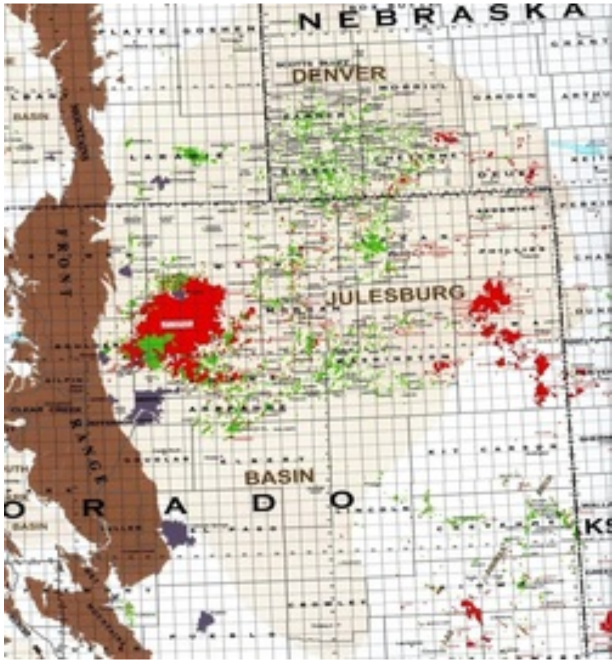
Baseline Sampling

- Only a few years ago – Baseline groundwater and surface water sampling were not required and were non-routine
- State-specific requirements now in place for surface water and groundwater – incl. residential wells – sampling prior to and after well development
- Some operators this is SOP
- During recent CO rulemaking the proposal developed and sponsored by Shell and the Environmental Defense Fund provided the basis for the final rules.
- USEPA study for retrospective and prospective sites ongoing – likely 2014 before we see results.

Growing Concern Over Air Emissions:

- Fugitive emissions from operations in addition to wells are believed to be causing increased concentrations of ground level ozone
  - Pinedale, WY
  - Uintah County, UT
  - Dallas-Ft. Worth
  - Haynesville Basin in East Texas
- Study of the Denver-Julesburg Basin in CO conducted under the direction of NOAA (Petron, et al., 2012):
  - Samples collected both fixed and mobile platforms.
  - Study concluded that 2.3-7.7% of methane produced in core of production area lost to venting.
  - Previous, bottom-up studies had estimated a lower loss rate – 1.7% of production.
- World Bank study information (*Energy & Environment EnergyWire* 7/10/2012) identifies US as #5 Flaring Country in the world largely as a result of the flaring of methane in the Bakken Field in MT/ND




Bakken Field
Salt Lake City
Denver
Dallas-Ft. Worth
Houston
Eagle Ford Shale

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Airborne Emissions Controls

- Traditional completions posed potential source of fugitive emissions
- CO and WY have had regulations in place to control fugitive emissions during drilling, development and production (Green Completions)
- See also PA requirements for emission inventory/reporting (December 2012) and new rules on gas compressor stations (February 2013)
- Final CAA NSPS MACT (April, 2012) addresses Upstream and Midstream emissions – this will become standard nationwide

- Then and now…..

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Bakken Drill Site

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Marcellus Drill Site

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Barnett Drill Site

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D-J Basin Wells – near Denver

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