Chapter 2

Hydraulic Fracturing, Oil and Gas Production, and the U.S. Energy Sector

2. Hydraulic Fracturing, Oil and Gas Production, and the U.S. Energy Sector

This chapter provides general background information useful for understanding the in-depth technical chapters that follow. We describe the process and purpose of hydraulic fracturing and the situations and settings in which it is used (Section 2.1). Then, to place hydraulic fracturing in the context of well site operations, we describe activities from site assessment and selection through production to site closure. This helps illustrate the intensive nature of activities during the relatively short hydraulic fracturing phase during the life of a production well (Section 2.2). Finally, we characterize the prevalence of hydraulic fracturing in the United States, its importance in the oil and gas industry today and into the future, and its role in the U.S. energy sector (Sections 2.3 and 2.4).

2.1. What is Hydraulic Fracturing?

Hydraulic fracturing is a stimulation technique used to increase production of oil and gas. Hydraulic fracturing involves the injection of fluids under pressures great enough to fracture the oil- and gas-production formations. Hydraulic fracturing fluid transfers the pressure generated by equipment at the surface into the subsurface to create fractures, and it carries and places the proppant into the fractures so that they remain "propped" open after the injection pumping pressure is terminated (Gupta and Valkó, 2007). Oil and gas can then flow through the fractures into the well and through the well to the surface. Hydraulic fracturing has been used since the late 1940s and for the first almost 50 years was used in vertical wells in conventional hydrocarbon reservoirs.[1] Hydraulic fracturing is still used in these settings, but the process has evolved; technological developments have led to the use of hydraulic fracturing in low-permeability (unconventional) hydrocarbon reservoirs that could not otherwise be profitably produced (see Text Box 2-1). Wells stimulated by hydraulic fracturing may be vertical, deviated, or horizontal in orientation (see Figure 2-1), and they may be newly drilled or older at the time the fracturing is done.

[1] A conventional reservoir is a reservoir in which buoyant forces keep hydrocarbons in place below a sealing caprock. Reservoir and fluid characteristics of conventional reservoirs typically permit oil or natural gas to flow readily into wellbores. The term is used to make a distinction from shale and other unconventional reservoirs, in which gas might be distributed throughout the reservoir at the basin scale, and in which buoyant forces or the influence of a water column on the location of hydrocarbons within the reservoir are not significant.

Text Box 2-1. Is Hydraulic Fracturing "New"?

Hydraulic fracturing in one form or another has been in use since the late 1940s, when a fracturing technique was patented by the Stanolind Oil and Gas Company and licensed to the Halliburton Oil Well Cementing Company. There are precedents that go back even further: reports from the early days of the oil and gas industry in the mid-19th century show producers trying to increase production by pumping fluids or dropping explosives into wells (Montgomery and Smith, 2010). Throughout its history, hydraulic fracturing has been used as a production technique to increase, or "stimulate," production from a well (some hydraulic fracturing methods are used to stimulate production in water wells, which is outside the scope of this report).

The groundwork for the transformation to modern hydraulic fracturing was laid in the 1970s and early 1980s, when a coalition of private companies, government agencies, and industry groups began sponsoring research into shale gas development technologies. During that period, Congress began to offer tax incentives to induce producers to apply the developing technologies in the field (Wang and Krupnick, 2013; EIA, 2011a; Yergin, 2011). The first horizontal wells were drilled in the mid-1980s in the Austin Chalk oil-bearing formation in Texas (Pearson, 2011; Haymond, 1991). Directional drilling and other emerging technologies matured in the late 1990s. In 2001, the Mitchell Energy company found a way to economically fracture the Barnett Shale in Texas. The company was bought by Devon Energy, a company with advanced experience in horizontal drilling. In 2002, seven wells were drilled and developed in the Barnett Shale using both horizontal drilling and hydraulic fracturing. Fifty-five more wells were completed in 2003 (Yergin, 2011). The techniques were rapidly adopted and further developed by others. By 2003/2004, modern hydraulic fracturing in the Barnett Shale was producing more gas than all other shale gas wells in the rest of the country (mostly shallow shale gas production in the Appalachian and Michigan Basins, see Section 2.4.1) (DOE, 2011b; Montgomery and Smith, 2010). By 2005, the new techniques were being used in low-permeability hydrocarbon plays outside of Texas, and modern hydraulic fracturing soon became the industry standard, driving the surge in U.S. production of natural gas.

Despite the long history of hydraulic fracturing, the culmination of technical innovations in the early 2000s represent an appreciable change. These innovations have made hydraulic fracturing economical enough to become standard practice in the oil and gas industry. Modern hydraulic fracturing (sometimes referred to as high-volume hydraulic fracturing) is characterized by the use of long horizontal wells and higher volumes of more complex mixtures of water, proppants, and chemical additives for injection as compared to earlier fracturing practices. Wells are often deep and long: shale gas production wells are commonly 5,000 to 13,500 ft (1,524 to 4,115 m) deep with long horizontal sections of 2,000 to 5,000 ft (610 to 1,524 m) or more in length. Other important advances occurred in oil and gas geophysical survey techniques (such as downhole telemetry and 3D seismic imaging) (Wang and Krupnick, 2013; EIA, 2011a). Hydraulic fracturing continues to be conducted in vertical production wells as well as conventional reservoirs using some of these newer techniques. Modern hydraulic fracturing has made it possible to extract resources in previously untapped hydrocarbon-bearing geologic settings, altering and expanding the geographic range of oil and gas production activities.

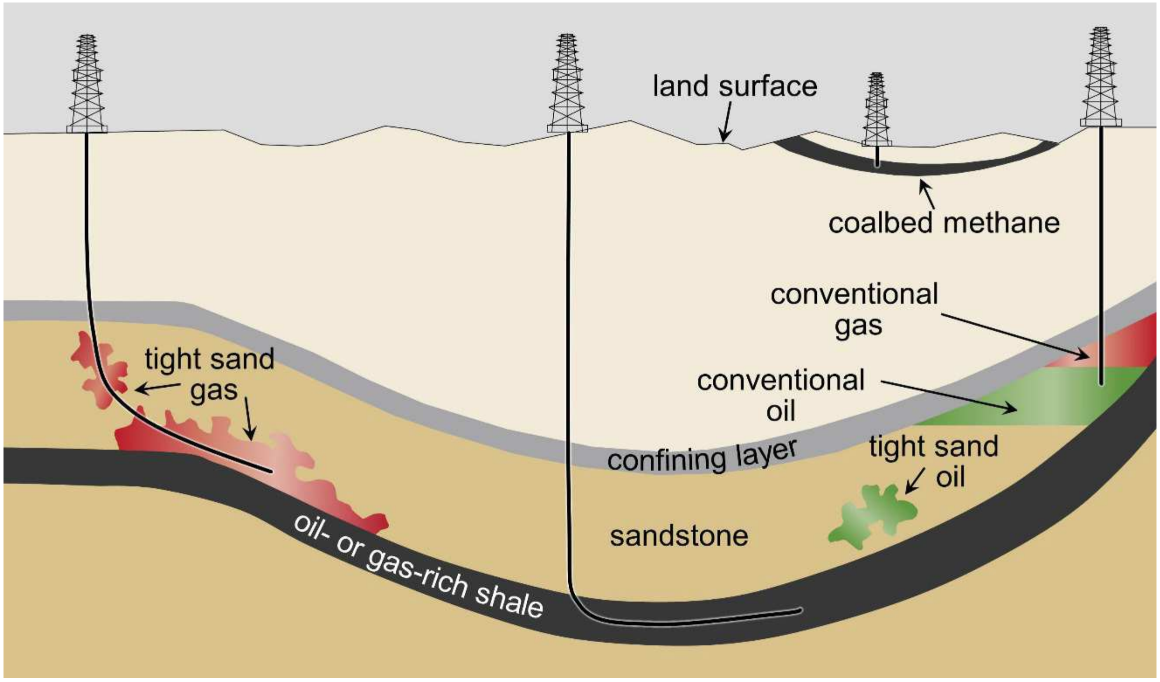

Figure 2-1. Schematic cross-section of general types of oil and gas resources and the orientations of production wells used in hydraulic fracturing.

Shown are conceptual illustrations of types of oil and gas wells. A vertical well is producing from a conventional oil and gas deposit (right). In this case, a thin, gray confining layer serves to "trap" oil (green) or gas (red). Also shown are wells producing from unconventional formations: a vertical coalbed methane well (second from right); a horizontal well producing from a shale formation (center); and a deviated well producing from a tight sand formation (left). Note: Figure not to scale. Modified from USGS (2002) and Newell (2011).

Historically, oil and gas have been extracted from conventional reservoirs that develop when hydrocarbons formed in deeper geologic source formations migrate until they accumulate underneath an impermeable layer (see Figure 2-1). Extraction practices vary. In settings where a reservoir is permeable enough and under enough pressure to yield a relatively high rate of hydrocarbon flow into a well, the economic extraction of oil and/or gas may be as simple as using a drilled well to enable hydrocarbons to flow to the surface under the natural pressure of the reservoir. In other cases, producers may inject water and/or carbon dioxide under pressure into the reservoir via one or more nearby wells to help move and enhance production of the oil and gas. But essentially, producers are drawing on hydrocarbons that have already accumulated in a relatively accessible form.

Hydraulic fracturing is one of several methods used to enhance production from oil and gas reservoirs. It is distinct from other methods of hydrocarbon extraction (known generally as enhanced recovery techniques) that involve injecting fluids to influence either reservoir pressure, fluid viscosity, or both. The primary purpose of hydraulic fracturing is to increase the surface area of the reservoir rock by creating fractures that are propped open, allowing the hydrocarbon to flow from the rock through the fractures to the well and through the well up to the surface.

Hydraulic fracturing, in conjunction with horizontal and directional drilling, has made it possible to economically extract oil and gas from "unconventional" geologic formations (see Text Box 2-2), such as the relatively low permeability shales in which oil and gas form (see Figure 2-1). With modern horizontal drilling techniques, producers can, for example, drill a single well that follows the contours of a relatively thin, horizontal shale formation. Such drilling allows fracturing to be conducted in a long horizontal section of the well that accesses an extensive portion of the oil- or gas-bearing formation. Unconventional formations include:

- ***Shales.*** Organic-rich black shales are the source rocks in which oil and gas form on geologic timescales. Shales have very low permeability, and the hydrocarbons are contained in the pore space in the shales. Some shales produce predominantly gas and others predominantly oil; often there will be some coproduction of gas from oil wells and coproduction of liquid hydrocarbons from gas wells (USGS, 2013a; EIA, 2011a).
- ***Tight formations.*** "Tight" sands (sandstones), siltstone, carbonates, etc., are relatively low permeability, non-shale, sedimentary formations that can contain hydrocarbons. The hydrocarbons are contained in the pore space of the formations. There is a continuum in permeability between "tight" formations which require hydraulic fracturing to be produced economically and sandstone (and other) formations that do not. In the literature, "tight gas" is generally distinguished from "shale gas," while oil resources from shale and tight formations are frequently lumped together under the label "shale oil" or "tight oil" (Schlumberger, 2014; USGS, 2014a).
- ***Coalbeds.*** Hydraulic fracturing can be used to extract methane (the primary component of natural gas) from coal seams. In coalbeds, the methane is adsorbed to the coal surface rather than contained in pore space or structurally trapped in the formation. Pumping the injected and formation water out of the coalbeds after fracturing serves to depressurize the coal, thereby allowing the methane to desorb and flow into the well and to the surface (USGS, 2000).

Text Box 2-2. "Conventional" Versus "Unconventional."

The terms "conventional" and "unconventional" are widely used in the literature to distinguish types of oil and gas reservoirs, plays, wells, production techniques, and more. In this report, the terms are used to distinguish different types of hydrocarbon resources: "conventional" resources are those that can economically be extracted using long-established technologies, and "unconventional" resources are those whose extraction has become economical only with the advances that have occurred in modern hydraulic fracturing (often coupled with directional drilling) in recent years.

Note that as modern hydraulic fracturing has become industry standard, the word "unconventional" is less apt than it once was to describe these resources. In a sense, "the unconventional has become the new conventional" (NETL, 2013).

Although the goal of stimulation by hydraulic fracturing is the same wherever it is employed, the way it is accomplished varies due to a number of factors. General location and geologic conditions, whether the well is existing or newly drilled, the proximity of the well to infrastructure and raw materials, operator preferences, and other factors can affect how a hydraulic fracturing operation is designed and carried out. Technological advances have made it possible to drill deeper and longer horizontal wells, to conduct fracturing through longer portions of the well, and to place multiple wells on a single well pad (NETL, 2013; Montgomery and Smith, 2010). Many facets of hydraulic fracturing-related technology have changed since they were first pioneered (see Text Box 2-1). How hydraulic fracturing is practiced now (especially in the long horizontal wells) is different from how it was conducted during the first decades of its use. As operators gain experience with both evolving and new technologies, practices will continue to change.

The following three maps show the locations of major shale oil and gas resources, tight gas resources, and coalbed methane resources, respectively, in the continental United States (see Figure 2-2, Figure 2-3, and Figure 2-4). These maps represent resources that are being exploited now or could be exploited in the future. Hydraulic fracturing continues to be used to enhance production in conventional reservoirs (not shown), although it is uncertain how often this occurs.

The formations hydraulically fractured for gas or oil vary in their depth below the surface. For example, the Marcellus Shale (found primarily in Pennsylvania, New York, and West Virginia) is found at depths of 4,000 to 8,500 ft (1,200 to 2,600 m), the Barnett Shale (Texas) is found at depths of 6,500 to 8,500 ft (2,000 to 2,600 m), and the Haynesville-Bossier Shale (Louisiana and Texas) is found at depths of 10,500 to 13,500 ft (3,200 to 4,100 m) (NETL, 2013). These represent some of the largest gas-producing shale formations or shale plays. However, some other plays are shallower. Parts of the Antrim (Michigan), Fayetteville (Arkansas), and New Albany (Indiana and Kentucky) shale plays, for example, are less than 2,000 ft (600 m) deep (NETL, 2013; GWPC and ALL Consulting, 2009). Exploitation of thin coal seams often takes place close to the surface as well. In the San Juan Basin (New Mexico), coal seams are 550 to 4,000 ft (170 to 1,200 m) deep; in the Powder River Basin (Wyoming and Montana) they are 450 to greater than 6,500 ft (140 to 2,000 m) deep, and in the Black Warrior Basin (Alabama and Mississippi) depths can range from the ground surface to 3,500 ft (1,100 m) (ALL Consulting, 2004). See Chapter 6 for more information on the depths of these formations and plays.

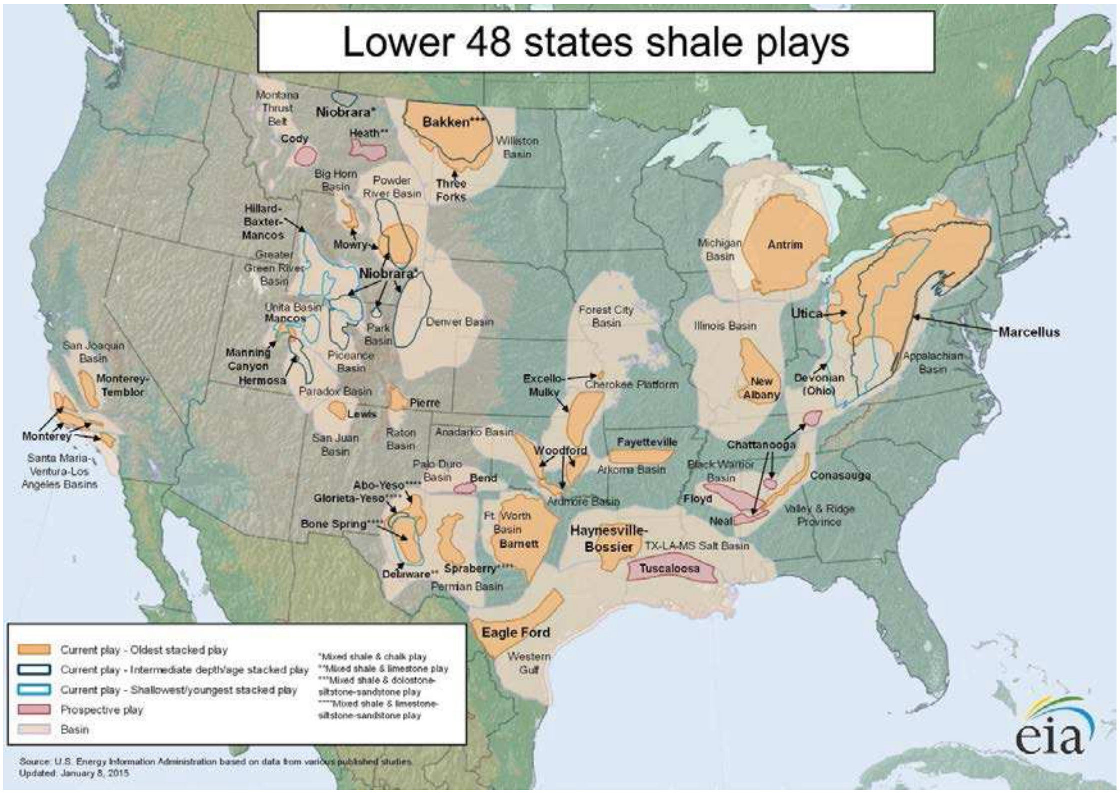

Figure 2-2. Shale gas and oil plays in the lower 48 United States.

Source: EIA (2015b).

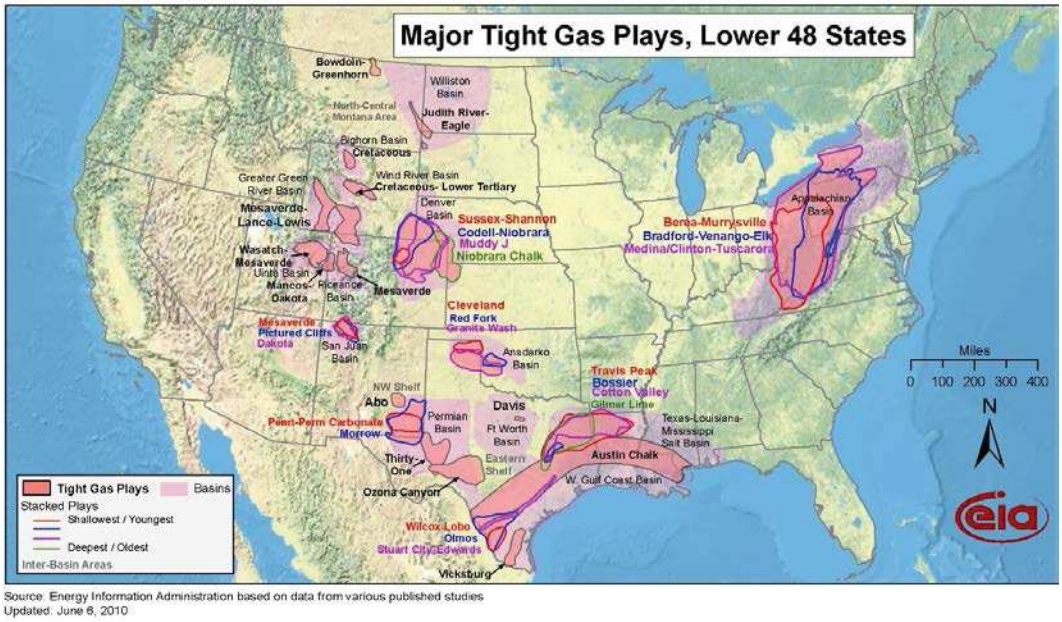

Figure 2-3. Tight gas plays in the lower 48 United States.

Source: EIA (2011b).

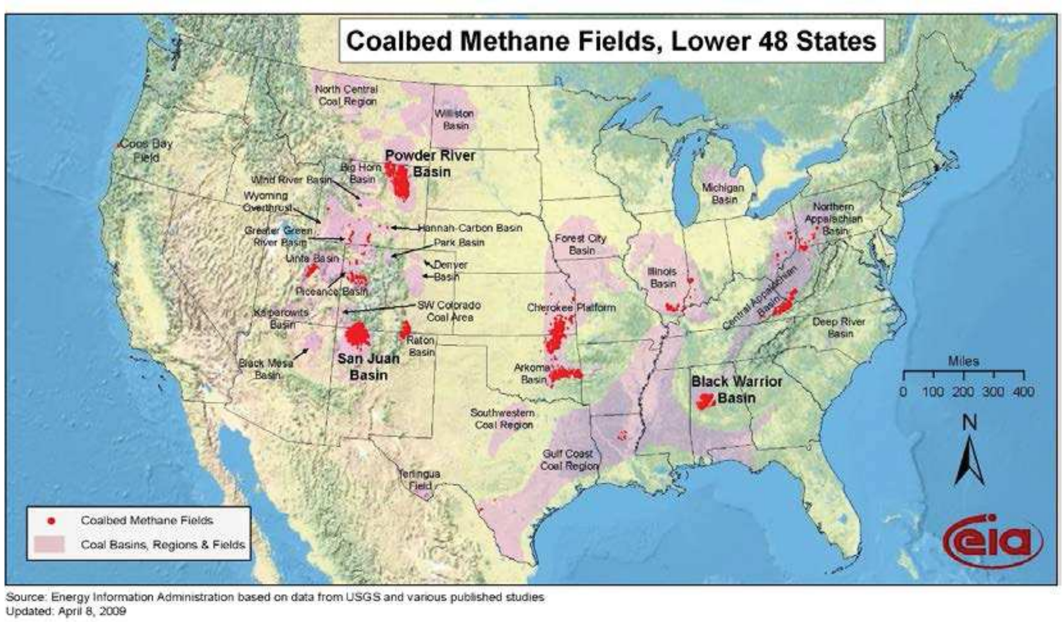

Figure 2-4. Coalbed methane fields in the lower 48 United States.

Source: EIA (2011b).

2.1. Hydraulic Fracturing and the Life of a Well

Hydraulic fracturing itself is a relatively short-term process, with the timeframe for a typical fracturing treatment being two to 10 days during which fluids are injected into the well to fracture the oil- and gas-bearing geologic formations (Halliburton, 2013; NYSDEC, 2011). However, it is a period of intense activity— the most activity that takes place at a well site during its existence.

In this section, we briefly describe some of the supporting and ancillary activities that take place at the well site, from initial site development through production and ultimately to closure (see Figure 2-5). This time period likely ranges from years to decades, depending on factors such as rate of depletion of the oil or gas, cost of production, and the price of oil and gas. The rate of oil and gas depletion in the reservoir is somewhat uncertain in unconventional formations because there is relatively little history on which to base predictions.

The overview of well operations presented in this section is broad and is provided to illustrate common activities and describe some specific operational details. The details of well preparation, operations, and closure vary from company to company, from play to play, from jurisdiction to jurisdiction, and from well to well. The various activities involved in well development and operations can be conducted by the well owner and/or operator, owner/operator representatives, service companies, or other third parties contractors working for the well owner.

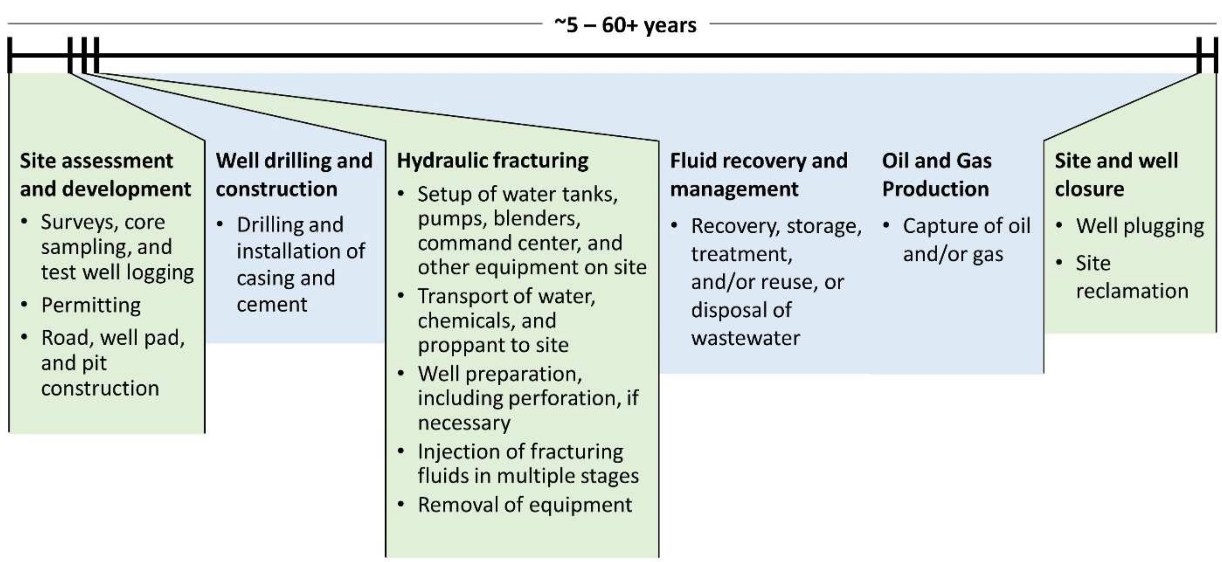

Figure 2-5. Generalized timeline and summary of activities that take place during the operational phases of an oil or gas well site operation in which hydraulic fracturing is used.

Relative duration of phases is approximate.

2.1.1. Site and Well Development

Numerous activities occur to assess and develop the site and to drill and construct the production well before hydraulic fracturing and production can occur.

2.1.1.1. Site Assessment and Development

Identifying a geologically suitable well site requires integrating data from geophysical surveys (including seismic surveys) that help to delineate subsurface features with other geologic information from rock core samples. Cores may be obtained while drilling exploratory wells or test holes. Core samples provide firsthand information on the characteristics of the oil- or gas-bearing formation, such as porosity, permeability, and details about the quantities and qualities of the hydrocarbon resource. Drilling rates and drill cuttings help identify the strata being drilled through and can help confirm and correlate stratigraphy and formation depths, including the depths of water-bearing formations.[1] Well logging (also known as wireline logging) is especially useful combined with core analysis for understanding the properties of formations (Kundert and Mullen, 2009).[2]

Logistical factors involved in the selection of the well drilling site include topography; proximity to facilities such as roads, pipelines, and water sources; well spacing considerations; well setback requirements; potential for site erosion; location relative to environmentally sensitive areas; and proximity to populated areas (Drohan and Brittingham, 2012; Arthur et al., 2009a). Before developing the site and initiating well drilling, the oil and gas company (or their representative) obtains a mineral rights lease, negotiates with landowners, and applies for a drilling permit from the appropriate state and local authorities. During the project, leases and permissions are also needed for other activities including performing seismic surveys and drilling exploratory holes (Hyne, 2012). This initial site assessment phase of the process may take several months (King, 2012).

Site preparation is necessary to enable equipment and supplies to reach the well area. Typically, the site is surveyed first, and then an access road may need to be built to accommodate truck traffic (Hyne, 2012). The operator then levels and grades the site to manage drainage and to allow equipment to be hauled to and placed on site. Next, the operator may excavate and grade several impoundments or storage pits near the well pad. In some cases, steel tanks may be used to hold fluids instead of, or in addition to, pits. The pits may hold water intended for drilling fluids, materials generated during drilling such as used drilling mud and drill cuttings, or the flowback and produced waters after fracturing (Hyne, 2012). Pit construction is generally governed by local regulations; federal regulations may also apply on federal and Indian Country. In some areas, regulations may require pits to be lined to prevent fluid seepage into the shallow subsurface or may

[1] Drill cuttings are ground rock produced by the drilling process.

[2] Well logging consists of a continuous measurement of physical properties in or around the well with electrically powered instruments to infer formation properties. Measurements may include electrical properties (resistivity and conductivity), sonic properties, active and passive nuclear measurements, measurements of the wellbore, pressure measurement, formation fluid sampling, sidewall coring tools and others. Measurements may be taken via a wireline, which is a wire or cable that is used to deploy tools and instruments downhole and that transmits data to the surface.