2.2. How Widespread is Hydraulic Fracturing?

Hydraulic fracturing activity in the United States and worldwide is substantial. One industry cumulative estimate stated that by the time of writing in 2010, close to 2.5 million fracture treatments had been performed globally (Montgomery and Smith, 2010). In 2002, the Interstate Oil and Gas Compact Commission (IOGCC) stated that close to 1 million wells had been hydraulically fractured in the United States since the 1940s (IOGCC, 2002). A recent U.S. Geological Survey (USGS) publication analyzed 1 million hydraulically fractured wells and 1.8 million hydraulic fracturing treatment records from the United States from 1947 to 2010 (USGS, 2015). Although some form of hydraulic fracturing has been used for more than 60 years, the technological advancements that combined hydraulic fracturing and directional drilling in the early 2000s resulted in the new era of modern hydraulic fracturing, which uses higher volumes of fracturing fluids than were typically used in prior decades. Modern hydraulic fracturing is typically associated with horizontal wells producing from unconventional shale reservoirs, but hydraulic fracturing continues to be done in vertical wells in conventional reservoirs also. This ongoing mix of traditional and modern hydraulic fracturing activities makes estimates of the total number of hydraulic fracturing wells challenging.

The following series of images illustrates hydraulic fracturing activities and the scale of those activities in the United States. Figure 2-12 (taken in Springville Township, in northeastern Pennsylvania) and Figure 2-13 (taken near Williston, in northwestern North Dakota) show individual well pads in the context of the local landscape. Landsat images in Figure 2-14 and Figure 2-15 provide satellite views of areas in northwest Louisiana and southeast Wyoming, respectively, where hydraulic fracturing activities currently occur as identified by the well pads in the images. These images serve to illustrate activity at a wider scale, though they are not representative of all hydraulic fracturing activities in the eastern or western United States. The light red circles around some of the well pads identify them as hydraulic fracturing wells that were reported by well operators to the FracFocus registry (as summarized in the EPA FracFocus project database 1.0) (U.S. EPA, 2015b). (The FracFocus well locations reflect information in the EPA FracFocus project database for well operations reporting hydraulic fracturing activities between January 2011 and February 2013. The Landsat images are from a later period, July and August of 2014, so additional well pads in the images now may be represented in the FracFocus registry.)

Figure 2-12. Aerial photograph of a well pad and service road in Springville Township, Pennsylvania.

Image © J Henry Fair / Flights provided by LightHawk.

Figure 2-13. Aerial photograph of hydraulic fracturing activities near Williston, North Dakota.

Image © J Henry Fair / Flights provided by LightHawk.

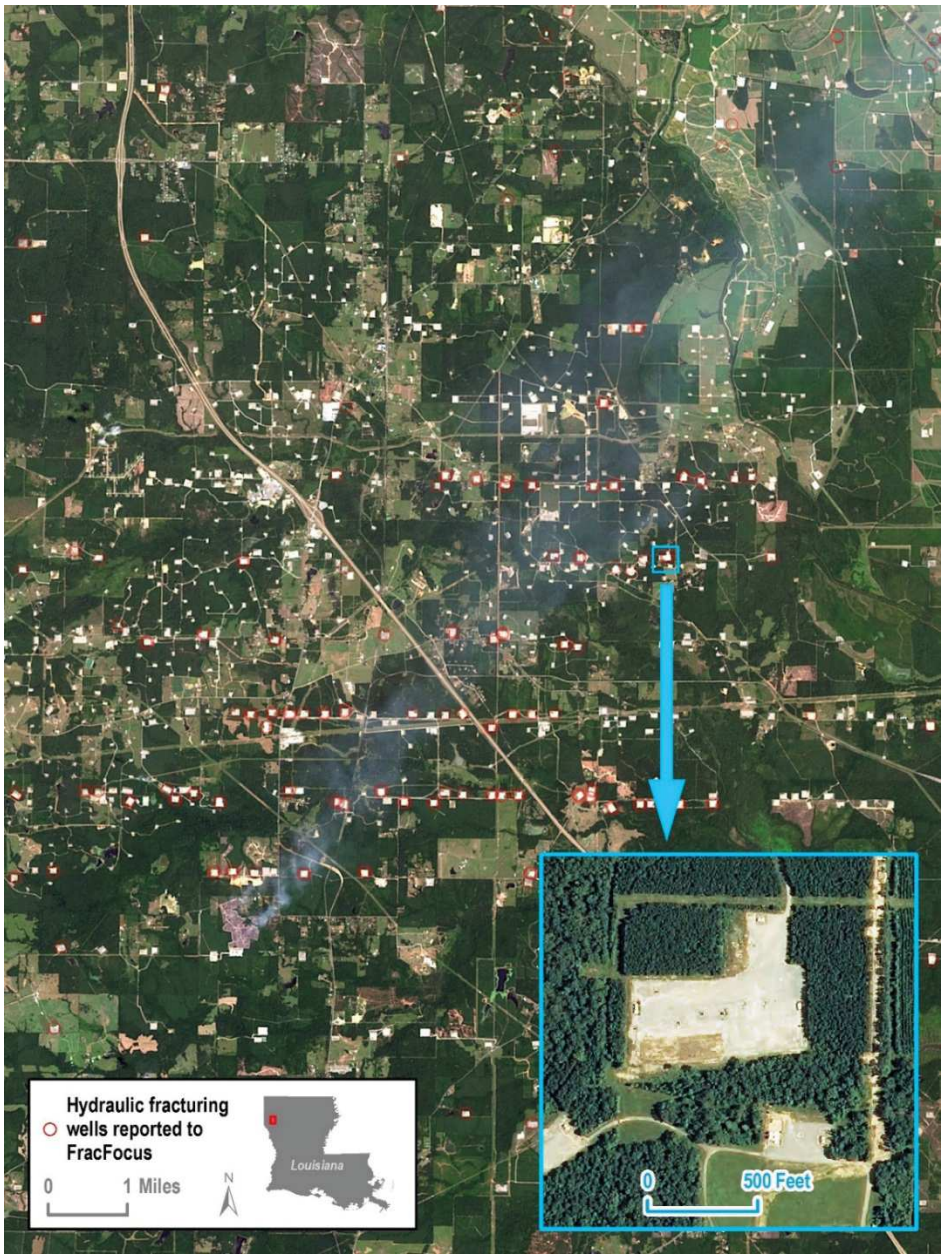

Figure 2-14. Landsat photo showing hydraulic fracturing well sites near Frierson, Louisiana.

Source: Imagery from USGS Earth Resources Observation and Science, Landsat 8 Operational Land Imager (scene LC80250382014232LGN00) captured August 20, 2014 and accessed on May 1, 2015 from USGS's EarthExplorer (http://earthexplorer.usgs.gov/).
Inset imagery from USDA National Agriculture Imagery Program (entity M 3209351_NE 15_1_20130703_20131107) captured July 3, 2013 and accessed May 1, 2015 from USGS's EarthExplorer (http://earthexplorer.usgs.gov/).
FracFocus well locations are from the EPA FracFocus project database 1.0 (U.S. EPA, 2015b).

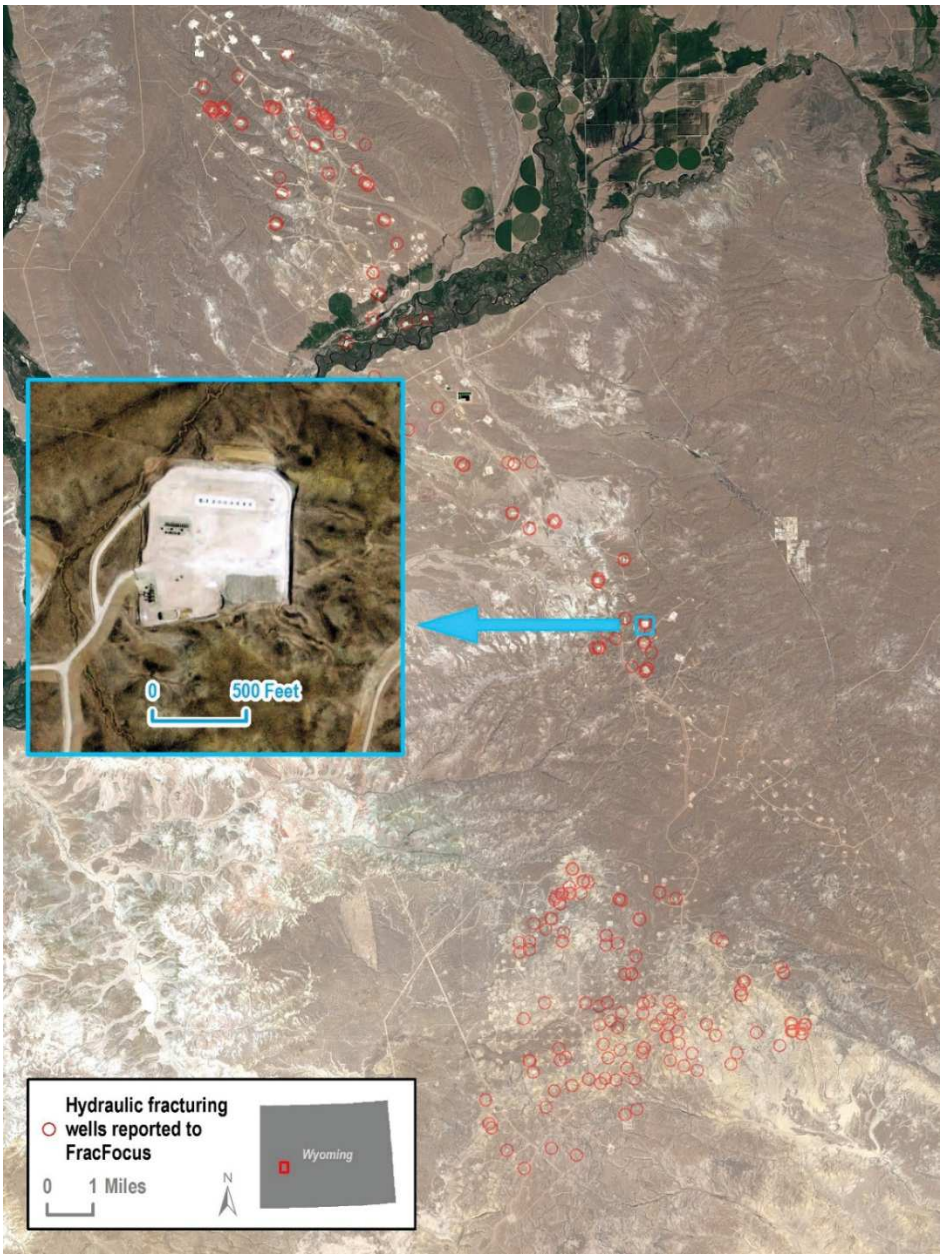

Figure 2-15. Landsat photo showing hydraulic fracturing well sites near Pinedale, Wyoming.

Source: Imagery from USGS Earth Resources Observation and Science, Landsat 8 Operational Land Imager (scene LC80370302014188LGN00) captured July 7, 2014 and accessed May 1, 2015 from USGS's EarthExplorer (http://earthexplorer.usgs.gov/).
Inset imagery from USDA National Agriculture Imagery Program (entity M 4210927_NW 12_1_20120623_20121004) captured June 23, 2012 and accessed May 1, 2015 from USGS's EarthExplorer (http://earthexplorer.usgs.gov/).
FracFocus well locations are from the EPA FracFocus project database 1.0 (U.S. EPA, 2015b).

The maps in Figure 2-16 show recent changes nationally in the geography of oil and gas production through the increased use of horizontal drilling, which occurs together with hydraulic fracturing.

Some traditional oil- and gas-producing parts of the country, such as Texas, have seen an expansion of historically strong production activity as a result of the deployment of horizontal drilling and modern hydraulic fracturing. Pennsylvania, a century ago one of the leading oil- and gas-producing states, has seen a resurgence in oil and gas activity. Other states currently experiencing a steep increase in production activity, such as North Dakota, Arkansas, and Montana, have historically produced less oil and gas and are therefore undergoing new development.

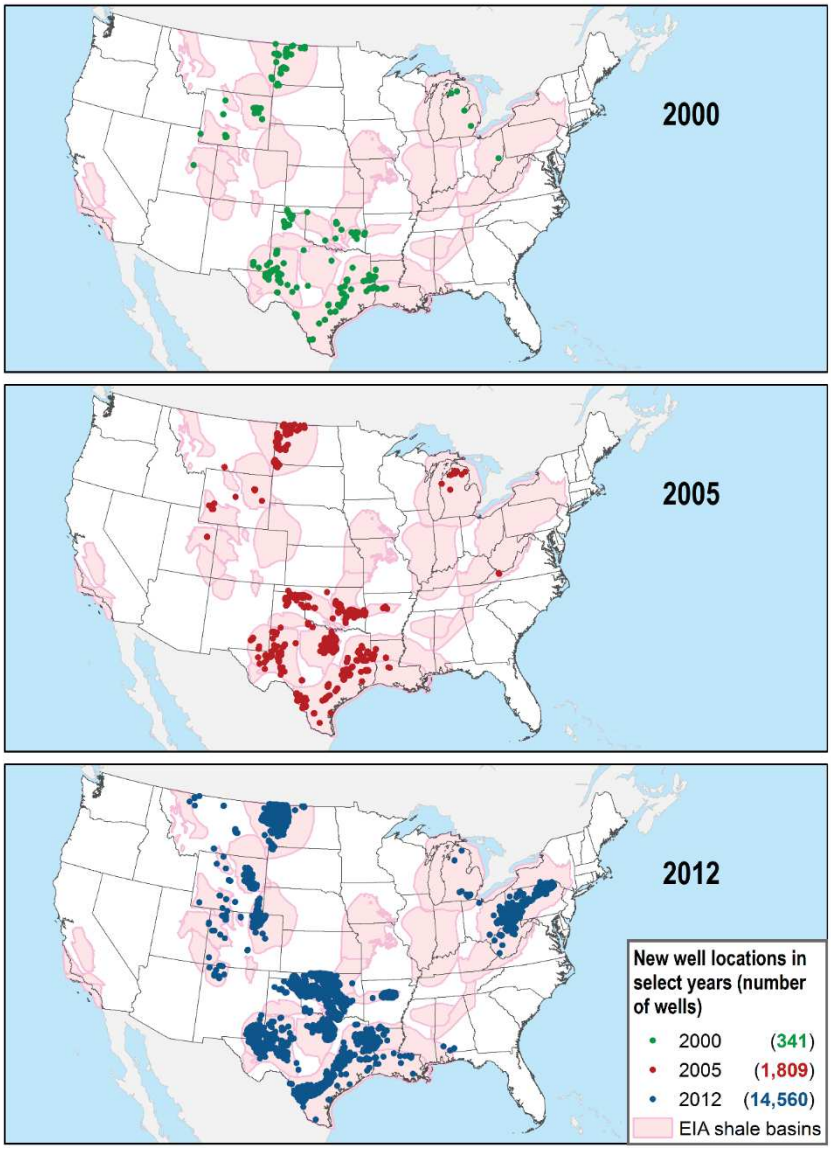

Figure 2-16. Location of horizontal wells that began producing oil or natural gas in 2000, 2005, and 2012, based on data from DrillingInfo (2014a).

2.2.1. Number of Wells Fractured per Year

We estimate that from roughly 2011 to 2014, approximately 25,000 to 30,000 new oil and gas wells were hydraulically fractured each year. Additional, pre-existing wells (wells more than one year old that may or may not have been hydraulically fractured in the past) were also likely fractured each year. Since the early 2000s, the percentage of all hydraulically fractured wells that are either horizontal or deviated has steadily grown. Our estimates are based on data detailed below from several public and private sector organizations that track drilling and various aspects of hydraulic fracturing activity. There is no complete database or registry of wells that are hydraulically fractured in the United States. Another source of uncertainty is the rate at which relatively new hydraulic fracturing wells are re-fractured or the rate at which operators use older, existing wells for hydraulic fracturing. Future trends in the number of wells hydraulically fractured per year will be affected by the cost of well operation and the price of oil and gas. Scenarios of increasing, flat, and decreasing hydraulic fracturing activity all appear to be possible (Weijermars, 2014).

The number of wells reported to the FracFocus registry provides a low estimate of the number of hydraulically fractured wells.[1] As of early April 2015, the FracFocus registry reported receiving information on a cumulative total of approximately 95,000 fracturing jobs, or roughly 22,400 per year over the 51-month period from January 2011 through March 2015 (GWPC, 2015). In a more detailed review of FracFocus data from 2011 and 2012, the EPA found there were approximately 14,000 and 22,500 fracturing jobs reported to the FracFocus website in those years, respectively, across 20 states (U.S. EPA, 2015a). These 2011 and 2012 numbers are likely underestimates of wells hydraulically fractured annually, in part because FracFocus reporting was voluntary for most states for at least a portion of 2011 to 2012 (though the increase from 2011 to 2012 in part reflects more states requiring reporting to the registry). Hydraulic fracturing practices may alternately (or in addition to FracFocus) be tracked by states. Compared to state records of hydraulic fracturing from North Dakota, Pennsylvania, and West Virginia in 2011 and 2012, we found that the count of wells based on records submitted to FracFocus was an underestimate of the number of fracturing jobs in those states by an average of approximately 30% (see Text Box 4-1).

An additional estimate of the number of hydraulically fractured wells can be obtained from DrillingInfo, a commercial database compiling data from individual state oil and gas agencies (DrillingInfo, 2014a). The data indicate an increase in the number of new hydraulically fractured wells drilled each year, from approximately 12,800 in 2000 to slightly more than 21,600 in 2005, to nearly 23,000 in 2012. The number of new horizontal wells (which are likely all hydraulically fractured) show a significant increase, from 344 (about 1% of all new production wells) in 2000, to 1,810 in 2005, to 14,560 (nearly 41% of all new production wells) in 2012 (see Figure 2-16).

[1] The FracFocus registry was developed by the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission. Oil and gas well operators can use the FracFocus registry to disclose information about hydraulic fracturing well locations, and water and chemical use during hydraulic fracturing operations. Submission of information to FracFocus was initially voluntary (starting in January 2011), but now about half of the 20 states represented in FracFocus have enacted reporting requirements for well operators that either mandate reporting to FracFocus or allow it as one reporting option. FracFocus data are discussed in more detail in Chapter 4 (regarding water volumes) and Chapter 5 (regarding chemical use). For more information see www.fracfocus.org and U.S. EPA (2015a).

Because DrillingInfo data do not directly report whether a well has been hydraulically fractured, we relied on properties of the well and the oil or gas producing formation to infer which wells were hydraulically fractured and when. First, we assumed that *all* horizontal wells were hydraulically fractured in the year they started producing. Second, we assumed that all wells within a shale, coalbed, or low-permeability formation, regardless of well orientation, were hydraulically fractured in the year they started producing.[1]

We used well-specific data provided by oil and gas well operators to the EPA to supplement our estimates of hydraulic fracturing using DrillingInfo data (U.S. EPA, 2015o). Matching wells in each dataset using API well numbers, we found that 80% of 171 newly drilled wells known to be fractured in 2009 and 2010 according to their well files were correctly identified as fractured using well and formation properties in DrillingInfo.[2] We did not correctly identify all of the vertical or deviated wells that were known to be fractured. (We were unable to identify wells for which hydraulic fracturing was inferred using the properties in DrillingInfo but were not fractured.) This comparison suggests that the estimates of hydraulically fractured wells from DrillingInfo are likely underestimates.

Another source of estimates is from a U.S. Geological Survey publication that reviewed data from the commercial IHS database of U.S. oil and gas production and well data (USGS, 2015). The study period was from 1947 through 2010. The authors estimated a total of approximately 277,000 hydraulically fractured wells between 2000 and 2010 (compared to close to 212,000 during the same time period estimated based on DrillingInfo data). This is roughly 25,000 wells per year over that time period. Approximately three-quarters of these wells were vertical. Reflecting advances in directional drilling technology over the decade ending in 2010, the percentage of total wells fractured that were horizontal or deviated wells grew from less than 10% to over 60%.

Well counts tracked by Baker Hughes provide another estimate of new wells fractured annually. Since 2012, this oilfield service company has published a quarterly count of new wells spudded; it includes only new inland U.S. wells "identified to be significant consumers of oilfield services and supplies."[3] A reported total of 36,824 oil and gas wells were spudded in the United States in 2012, with new wells per quarter fluctuating between about 8,500 and 9,500 (Baker Hughes, 2014b). While 100% of new wells are probably not hydraulically fractured (see below for estimates of hydraulic fracturing rates in new wells), a count of new wells also does not include hydraulic fracturing taking place in older, existing wells.

[1] The assignment of formation type (shale, coalbed, low-permeability, or conventional) for each well was based on a crosswalk of information on basin/play provided in DrillingInfo (2014a) with expert knowledge of those basins/plays at EIA (2012a). If formation type could not be determined, it was considered conventional by default. This is similar methodology to that used by the EPA for its greenhouse gas inventory (U.S. EPA, 2013c).

[2] An API well number is a unique identifying number given to each oil and gas well drilled in the United States. The system was developed by the American Petroleum Institute.

[3] To spud a well is to start the well drilling process by removing rock, dirt, and other sedimentary material with the drill bit.

Data collected under the EPA's Greenhouse Gas Reporting Program (GHGRP) provide information on completions and workovers with hydraulic fracturing (i.e., re-fracturing) of gas wells. Data reported to GHGRP for years 2011 to 2013 suggest that 9-14% of the gas wells reported to be hydraulically fractured in each year were pre-existing wells undergoing re-fracturing (U.S. EPA, 2014e).[1] The GHGRP requirements do not include reporting of re-fracturing in oil wells, and other data sources for information specifically on re-fracturing of existing oil wells compared to initial fracturing of oil wells were not identified. For comparison, an EPA survey of an estimated 23,200 oil and gas production wells that were hydraulically fractured by nine oil and gas service companies in 2009 and 2010 suggests that 42% of the wells were pre-existing (i.e., more than one year old) when they were hydraulically fractured (U.S. EPA, 2015o). Differences in data (including data from different years and data from gas wells only (GHGRP) versus oil and gas wells, for instance), definitions, and assumptions used to estimate the percentage of pre-existing wells hydraulically fractured in a year could account for the different results.

In summary, determination of the national scope of hydraulic fracturing activities in the United States is complicated by a lack of a centralized source of information and the fact that well and drilling databases each track different information. There is also uncertainty about whether information sources are representative of the nation, whether they include data for all production types, whether they represent only modern (high volume) hydraulic fracturing, and whether they include activities in both conventional and unconventional reservoirs. Taking these limitations into account, however, it is reasonable to assume that between approximately 25,000 and 30,000 new wells (and, likely, additional pre-existing wells) were hydraulically fractured each year in the United States from about 2011 to 2014.

2.2.2. Hydraulic Fracturing Rates

Estimates of hydraulic fracturing rates, or the proportion of all oil and gas production wells that are associated with hydraulic fracturing, also indicate widespread use of the practice. Based on an assessment described above of data from DrillingInfo (2014a), hydraulic fracturing rates have increased over time. From 2005 to 2012, rates of hydraulic fracturing increased from 57% to 64% of all new production wells (including oil wells, gas wells, and wells producing both oil and gas).

In 2009, industry consultants stated that hydraulic fracturing was used on nearly 79% of all wells and more than 95% of "unconventional" wells (IHS, 2009). A 2010 article in an industry publication noted "some believe that approximately 60% of all wells drilled today are fractured" (Montgomery and Smith, 2010). Of 11 important oil and gas producing states that responded to an IOGCC survey (Arkansas, Colorado, Louisiana, New Mexico, North Dakota, Ohio, Oklahoma, Pennsylvania, Texas, Utah, and West Virginia), ten estimated that 78% to 99% of new oil and gas wells in their states were hydraulically fractured in 2012; Louisiana was the one exception, reporting a fracturing rate of 3.9% in 2012 (IOGCC, 2015). Although estimates of fracturing rates are variable, largely ranging from near 60% to over 90% (as described above), they are often higher for gas wells than they are for oil wells. A 2010 to 2011 industry survey of 20 companies involved in natural gas production

[1] The GHGRP reporting category that covers re-fracturing is "workovers with hydraulic fracturing."

found that 94% of the wells that they operated were fractured; among those, roughly half were vertical and half were horizontal (Shires and Lev-On, 2012).

2.3. Trends and Outlook for the Future

Fossil fuels are the largest source of all energy generated in the United States. They currently comprise approximately 80% of the energy produced (EIA, 2014f). However, the mix of fossil fuels has shifted in recent years. Coal, the leading fossil fuel produced by the U.S. since the 1980s, has experienced a significant decrease in production. In 2007, coal accounted for approximately 33% of U.S. energy production, and by 2013 it decreased to approximately 24% (EIA, 2014f). On the other hand, natural gas production has risen to unprecedented levels, and oil production has resurged to levels not seen since the 1980s (see Figure 2-17). Oil went from accounting for 15% of U.S. energy production to 19% between 2007 and 2013, and natural gas (both dry and liquid) went from 31% to 35% (EIA, 2014f).

Below, we discuss recent and projected shifts in oil and natural gas production that can primarily be attributed to hydraulic fracturing and directional drilling technologies.

2.3.1. Natural Gas (Including Coalbed Methane)

Natural gas production in the United States peaked in the early 1970s, reached those levels again in the mid-1990s, and between the mid- to late-2000s has increased to even higher levels (see Figure 2-17). The recent increase in total gas production has been driven almost entirely by shale gas (see Figure 2-18).

As natural gas prices fell between 2008 and 2012 (EIA, 2014e), drilling of new natural gas wells declined markedly (EIA, 2014g) (see Figure 2-19). Nevertheless, natural gas production is expected to increase over the coming decades (see Figure 2-18). EIA (2013b) predicts that shale gas production will more than double between 2011 and 2040 and that the portion of total natural gas production represented by shale gas will increase from one-third to one-half. The EIA projects steady growth in the development of tight gas as well (about a 25% increase in production over the 30-year period) and delayed growth in the development of coalbed methane resources, for which production is not expected to increase again until sufficiently high natural gas prices are realized around 2035. Overall, the EIA projects that the share of U.S. natural gas production from shales, tight formations, and coalbeds will increase from 65% in 2011 to nearly 80% in 2040.

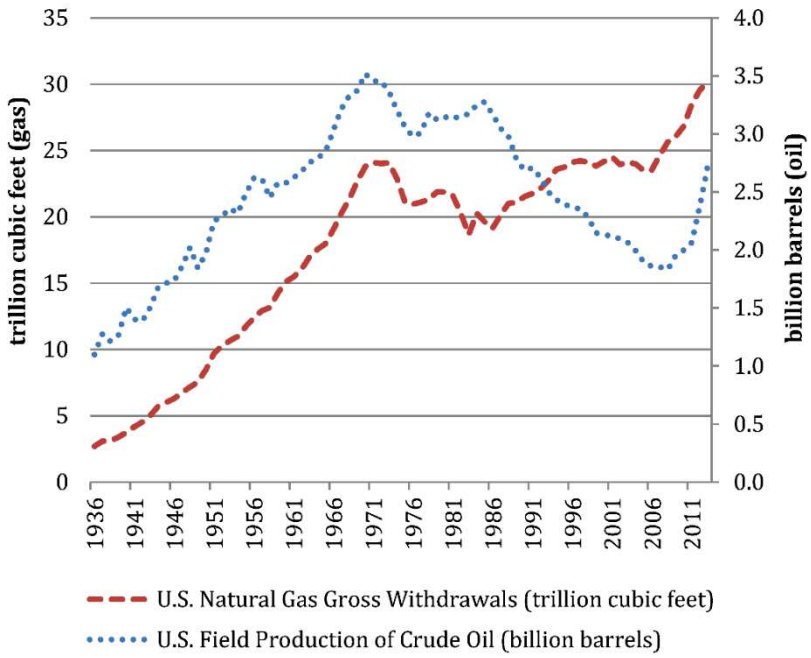

Figure 2-17. Trends in U.S. oil and gas production.

Source: EIA (2013d) and EIA (2014d).

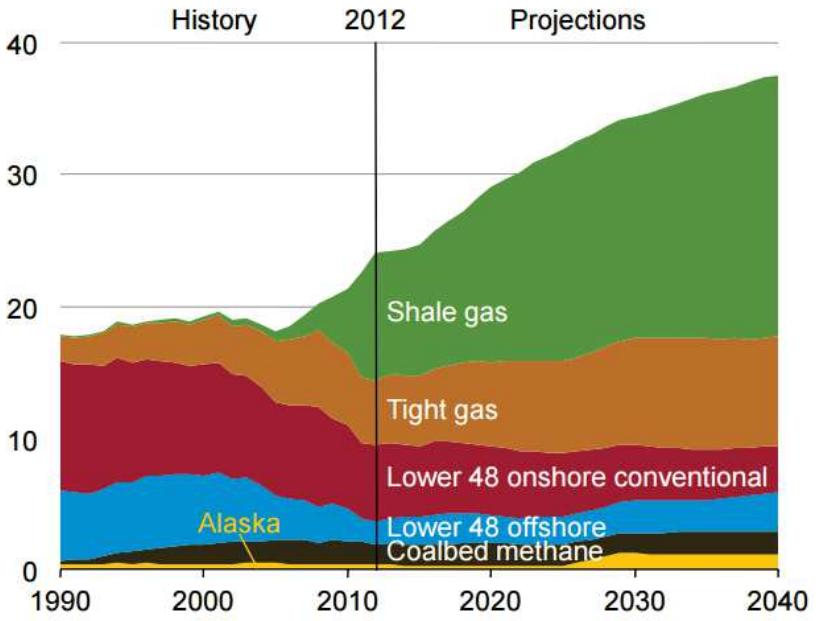

Figure 2-18. Historic and projected natural gas production by source (trillion cubic feet).

Source: EIA (2014a).