Will Water Issues Constrain Oil and Gas Production in the United States?

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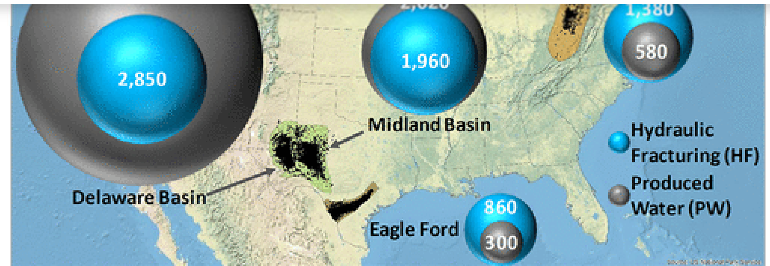
Abstract

The rapid growth in U.S. unconventional oil and gas has made energy more available and affordable globally but brought environmental concerns, especially related to water. We analyzed the water-related sustainability of energy extraction, focusing on: (a) meeting the rapidly rising water demand for hydraulic fracturing (HF) and (b) managing rapidly growing volumes of water co-produced with oil and gas (produced water, PW). We analyzed historical (2009–2017) HF water and PW volumes in ~73 000 wells and projected future water volumes in major U.S. unconventional oil (semiarid regions) and gas (humid regions) plays. Results show a marked increase in HF water use, and depleting groundwater in some semiarid regions (e.g., by ≤58 ft [18 m]/year in Eagle Ford). PW from oil reservoirs (e.g., Permian) is ~15× higher than that from gas reservoirs (Marcellus). Water issues related to both HF water demand and PW supplies may be partially mitigated by closing the loop through reuse of PW for HF of new wells. However, projected PW volumes exceed HF water demand in semiarid Bakken (2.1×), Permian Midland (1.3×), and Delaware (3.7×) oil plays,



1. Introduction

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ironmental risks related to unconventional oil and gas (UOG) development, particularly those related to water and induced seismicity, were emphasized in a 2016 U.S. National Academy of Sciences workshop, and innovative approaches to managing these risks were discussed.(1) Recovery of oil and natural gas from unconventional low-permeability shales and tight rocks increased dramatically over the past decade, supported by horizontal drilling and high water volume hydraulic fracturing (HF). Owing to UOG resource development, the United States became the largest global oil (18% of global total) and dry natural gas (20% of global total) producer in 2018,(2) with UOG production accounting for ~60% of its domestic oil and ~70% of its domestic natural gas supplies (Figure S1). The rapid growth in energy supplies decreased U.S. dependence on energy imports enhancing energy security;(3) however, those benefits come with environmental challenges that may reduce future growth in supply and the envisioned role of the United States in global energy markets. The United States and global fossil fuel consumption are projected

Abstract

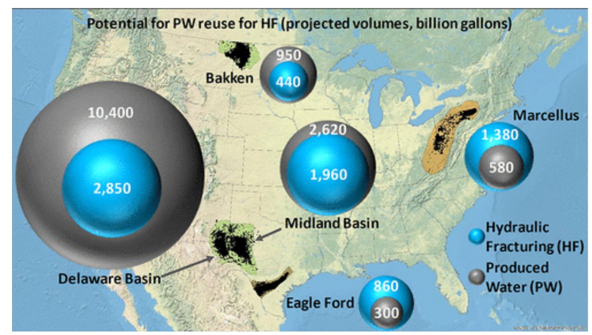

Figure 1

emerge as a major supplier in the global market through 2050, with demand driven primarily by use in developing economies, particularly China and India.(4)

Two key water issues associated with UOG resource extraction include:

(a) **rising water demand for HF and**

(b) **managing high water volumes that are co-produced with oil and gas (produced water, PW, including flowback water from HF and water from subsurface formations).**

[illegible]otal of ~95 000 horizontal wells were registered in the United States for HF up [illegible]ough 2018 (Table S2). Increasing quantities of water used for HF, highest in the Permian Basin oil play,(6,7) have led to concerns about water scarcity, especially in the semiarid western United States, where the major unconventional oil plays are located.(8−10) HF has also been linked to another environmental problem, induced seismicity in some regions.(11,12)

Water is not only used, but also produced in large volumes from UOG reservoirs along with oil and natural gas, with the highest PW volumes recorded in the Permian.(6,13,14) The prevailing approach to PW management has been subsurface injection or disposal.(15−17) PW from UOG reservoirs cannot be injected into the shale or tight rock reservoirs because of low permeability; instead, the PW is mostly injected into nonreservoir geologic units. These injections modify subsurface fluid budgets and related pressures and may result in induced seismicity. Most recorded seismicity is linked to disposal near the basement and related to critically stressed faults, such as

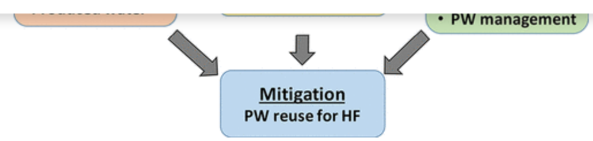

Figure 1. Schematic of the workflow for this study emphasizing data types and sources, historical and projected water demand for HF and produced water (PW) volumes, potential adverse impacts of water management and potential for mitigating water issues through reuse of PW for hydraulic fracturing. The geology and reservoir data rely on three-dimensional (3D) geocellular models (grid scale, 1 mi^2, 2.6 km^2) developed by UT BEG from geophysical logs and cores, including porosity, water saturation, pressure, and American Petroleum Institute (API) gravity data where data are available. Historical trends focused on the 2009−2017 period. Future projections of HF water demand and PW volumes focused on oil plays (Bakken, Permian, Eagle Ford) and the Marcellus gas play. More details on the workflow are provided in Figure S3.

Figure 2

expanding to address water management, exemplified by companies such as H_2O Midstream and Waterfield Midstream, with large private equity investment (e.g., $500 million in Waterfield).(27)

1.1. Hydraulic Fracturing Water and Produced Water Volumes

One of the big questions is whether increasing HF water demand may lead to water scarcity, increasing water stress in other sectors, particularly irrigation. UOG plays are found in areas with varying climate and hydrologic regimes. The major U.S. shale gas play, the Marcellus, is in the humid eastern United States relying primarily on surface water for HF. Previous analysis indicates that streamflow was not negatively impacted by diversions for shale gas development.(28) In contrast, tight oil reservoirs are found primarily in the semiarid western United States. Previous global analyses have highlighted potential water scarcity for UOG development in semiarid regions. However, many of those studies relied on global models restricting water resources to renewable surface water and groundwater supplies,(9,10) whereas water users have been mining groundwater for irrigated agriculture for over a century, including major portions of the High Plains aquifer in the Permian Basin and the Carrizo Wilcox aquifer in the Eagle Ford play.(29,30) Therefore, we suggest that water scarcity analysis in these systems needs to consider current and future water resource plans that include managed depletion in some aquifers.

Another major question is whether the rising volumes of PW may constrain UOG production because of induced seismicity concerns.(14,19,31) The high levels of induced seismicity recorded in Oklahoma are attributed primarily to high PW disposal

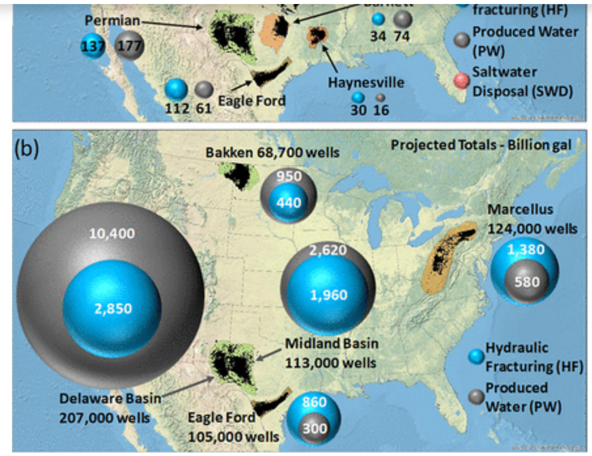

Figure 2. (a) Total volumes of water used for hydraulic fracturing (HF) and produced water (PW) (2009–2017) from unconventional horizontal wells in major tight oil (green) and shale gas (orange) plays and Eagle Ford (brown, includes oil and gas). The eight major UOG reservoirs are shown (Bakken, Barnett, Eagle Ford, Fayetteville, Haynesville, Marcellus, Niobrara, and Permian). Data for UOG development in Oklahoma are also included for context because of induced seismicity. Saltwater disposal (SWD) data are used as a proxy for PW volumes in Oklahoma because PW volumes are not reported. HF water demand in Texas (Barnett, Eagle Ford, and Permian) over the past nine years totals 283 Bgal (0.9 million acre feet, ~1.1 km^3) relative to annual water use in Texas of 14 maf (~17 km^3) in 2017. PW volumes are not reported for the Fayetteville.