Chapter 2
Water-Energy Nexus: The Role of Hydraulic Fracturing

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Abstract This chapter considers some challenges attendant on optimising water-energy trade-offs in hydraulic fracturing, focusing on the interplays between constantly evolving technologies (e.g. use of treated effluent, brackish water or even waterless methods) and regulatory systems, using the Eagle Ford shale play in Texas as a case study. Regulators and higher level policy-makers often have conflicting preferences associated with the specific trade-offs (environmental, economic and social) that come within their purview. Therefore, it is very important to understand the basic trade-offs of the water-energy nexus when addressing nexus issues such as energy resources mining and production, water production, treatment and allocation, power plant construction and environmental impacts.

Keywords Water-energy nexus · Water security · Trade-offs · Decoupling · Technology · Eagle Ford

2.1 The Water-Energy Nexus

Consumers living in developed societies expect an immediate supply of water and energy through opening a faucet and flipping a switch. However, these consumers may be unaware of the significant interconnections between water and energy. This lack of awareness could potentially lead to abuse natural resource allocation at both the regional and national levels.

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Water and energy are drivers for economic and social growth, yet both energy and water securities are exposed due to the deep interdependency of water and energy systems on one another. Water is an input to almost all phases of energy production: fossil-fuel production, transport and refining; electricity generation; biofuel irrigation and processing; and even emission controls. Water security is crucial for energy security. At the same time, energy is needed to extract, desalinate, treat and transport water. Energy security is crucial for water security. Given the projected increase in demand for water and energy, understanding the water-energy link is key to addressing future potential resource sustainability challenges (which we call "hotspots"), developing well-rounded policies, and implementing technologies that mitigate risks (Fig. 2.1).

The drilling process for both conventional and unconventional oil and gas is a major user of local water resources. Production of fossil fuels, such as shale oil and gas, unconventional drilling techniques is rapidly increasing around the world (Mroue et al. 2018). While conventional production techniques for oil and natural gas are also water intensive (especially secondary and tertiary oil recovery processes), unconventional production processes are perceived as the main concern (Rahm 2011). Oil and gas in shale plays are produced by hydraulic fracturing, a technique that uses extensive amounts of water in drilling and fracturing the formation. Hydraulic fracturing includes horizontal drilling and multistage fracturing using water jets to reach shale gas reserves. Moreover, the large volumes of water used in hydraulic fracturing are mixed with chemicals, which is a primary reason for environmental concern, as it is associated with water reservoir contamination as well as with use of considerable quantities of land. According to the U.S. Environmental Protection Agency (EPA), hydraulic fracturing uses two to five million gallons of water per well (Rahm 2011). The wastewater produced by the fracturing process is comprised mainly of the fluid (water and chemical additives) used to drill and fracture the shale plays. Several methods of wastewater disposal

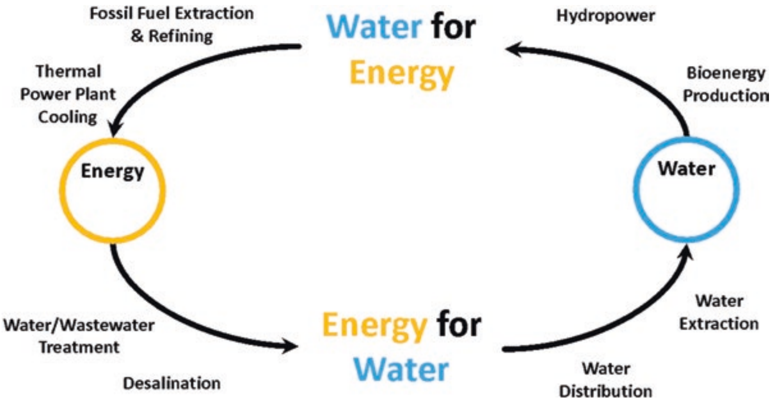

Fig. 2.1 Schematic of the water–energy nexus and the interconnected parameters

are currently used, including underground deep injection and discharge to surface water after treatment (Environmental Protection Agency 2010).

The issues around hydraulic fracturing lie squarely at the center of the water-energy nexus. The push for hydraulic fracturing is framed as a matter of energy security (increased production of oil and natural gas) yet comes with potentially significant costs to the security of water resources (Office of Research and Development 2010). Global demand for energy is rising, and consequently energy's demand for water is also rising. According to the International Energy Agency (IEA), energy accounted for 10% of global water withdrawals in 2016. Most of these withdrawals were for electricity generation, as well as for the production of fossil fuels and biofuels. The IEA projects that water demand for energy will increase over the period to the year 2040. Water withdrawn is expected to rise by 2%, while water consumed to rise by almost 60% (IEA 2016).

Yet, up to this date and despite this undebatable interdependence, water and energy are regulated independently. Policy makers often disregard the interconnectedness of water and energy, which results in contradictory water and energy policies (Hanlon et al. 2013). Both water and energy policymakers seek optimal sustainable solutions, but from an optimization point of view, neither provide optimal solutions for their sectors because the systems are decoupled in the approach to their respective policies. The nexus of these two systems is beginning to gain attention on multiple (national and international) levels (Poumadere et al. 2005). Working separately exposes the water and the energy systems to risk, introducing vulnerabilities to both: droughts, heat waves, water contamination, grid outages, and unfair competition for water.

This mutual dependency makes water a limiting factor or a weakness in the global energy system in both access and security. At the same time, energy is a vulnerability in the global water system in both supply and security. The supply, demand, management, and security of these systems are impacted by many variables, such as climate change, population growth, technology advancements, and practiced policies. Some of these variables are looked at as being out of the direct control of policymakers, such as climate change and population growth. But other variables such as technology and policy—are mainly under the control of policymakers.

Research has shown that there are ways to mitigate the risks of vulnerabilities of the water-energy nexus: policy and technology. Policies and technologies are not only capable of alleviating allocation stress points in the water-energy nexus, but also reducing water and energy demand such that an increase in energy demand would not be accompanied by an increase in water demand and vice versa. Such policies and technologies already exist; however, the implementation is accompanied by trade-offs that should be carefully considered through a robust nexus focus by policymakers, industry stakeholders, researchers and consumers. This chapter considers the importance of the water-energy nexus in the context of hydraulic fracturing, focusing on the tradeoffs inherent in the nexus and the role of policy and technology, using the Eagle Ford shale play as a case study.

Sustainable development in both energy and water requires a new, integrative approach based on the water-energy nexus. More importantly, with an integrative system, successful realization of water-energy policies and technologies can be much more effective to ensure sustainable development and avoid contradictory and unintended consequences of resource mismanagement (IEA 2016).

2.2 Unconventional Production: Hydraulic Fracturing in the Water-Energy Nexus

Hydraulic fracturing has been a technique used for over a century to increase oil and gas production, taking its first form as an exploding nitroglycerin "torpedo" to create fractures in oil-bearing rock and facilitating hydrocarbon flow to a well. Modern day hydraulic fracturing was developed in the 1990s by George P. Mitchell, who combined the use of hydraulic fracturing with horizontal drilling. This method of hydraulic fracturing combined with horizontal drilling is a form of unconventional oil and gas recovery because it produces from a different source than conventional recovery. Conventional and unconventional oil and gas come from the same geologic formation, but unconventional produces from the source formation while conventional produces from a reservoir, or cap formation. A permeable reservoir accumulates migrated oil and gas from the source rock and becomes trapped below a low permeable cap formation. This creates a pocket of fossil fuels that can be extracted through a vertical well. What makes unconventional recovery different, is that oil and gas is being extracted from the low permeable source rock, usually shale or tight sand. Using horizontal drilling, a well bore will increase its contact with the source rock as it travels through a formation, increasing the area it will produce oil and gas from. With an increased surface area, when the source rock is hydraulically fractured, large amounts of water and proppants are pressurized in a well structure to create fissures that drastically increase its permeability to allow oil and gas to flow to the well bore. This technique is valuable in that operators can artificially create flow to a well instead of relying on the natural migration and capture of the oil and gas. With the conception of these techniques, operations have been able to produce fossil fuels from resources that were once thought of as inaccessible and put countries such as the United States on a track towards energy independence.

Hydraulic fracturing is a critical point of tension in the water-energy nexus due to both its water-intensive nature and also its potential risks to water pollution. While the practice has made huge innovations to increase oil and gas production leading to increased prosperity, the many environmental issues that follow need to be weighted accordingly. The agriculture and municipal sectors are some of the main competitors for water, sustaining both food production and a modern way of life. While the total land used for oil and gas production makes up only 7% of the energy-land footprint—less than biofuel production and coal mining—oil and gas production requires a constant supply of new land to continue production, whereas agricultural sources remain in one place (Manfreda 2017). This adds potential competition for land in the future as oil and gas production grows and its need for new resources increases.

Regarding water pollution, the EPA has recorded a number of cases of water contamination due to hydraulic fracturing. These incidents, although not extensive, have tainted ground and surface water on a local scale, from flowback and produced water surface spills, breaches in well integrity of both oil/gas wells and disposal wells, and discharges of inadequately treated wastewaters into freshwater sources. An error of this magnitude has consequences in the other sectors of a community and can halt production of other life-sustaining resources. While hydraulic fracturing is a large resource in fueling the world's energy demand, it also has the potential to negatively affect other life-sustaining resources while lowering the environmental quality of communities in highly active regions.

A single hydraulic fracturing operation can use between three and eight million gallons of water, depending on the length and geology of the well. Although concerns arise over water consumption, water used in hydraulic fracturing makes up less than 1% of the total industrial water usage in the U.S. (Manfreda 2017). While this number as a whole is not alarming, hydraulic fracturing can pose threats on a regional scale where certain areas face droughts. A global study found that approximately 40% of shale plays occur in areas of high to extremely high water stress, calling for a need to assess a play's regional water resources in order to withdraw water responsibly and in a way that will not hinder the functionality of society on a micro scale (Hanson 2017).

In addition to oil and gas, oil and gas wells produce large amounts of water—called produced water—often in greater volume than the oil and gas actually produced. These production wells also provide a market for those willing to treat and sell produced water. Produced water is different than flowback water in that it is water produced from the hydrocarbon formation and is often highly saturated in dissolved solids, heavy metals, and naturally occurring radioactive materials, requiring expensive treatment to bring to reusable conditions. This has the potential to benefit a community where hydraulic fracturing is occurring but it is not usually economically feasible, leading oil and gas companies to opt for deep injection disposal. While commercializing produced water may still be uncommon, research is being done to improve costs of treatment to one day make its reuse more universal. Flowback water is the water injected into a well during the hydraulic fracturing process. Up to 40% of the total volume injected returns to the surface as flowback containing the added proppants and chemicals, along with additional dissolved solids from the formation. Treating and reusing flowback water for hydraulic fracturing is a growing practice as on-site treatment stations improve their capabilities to process more water, but once again are limited due to high operational costs.

Unconventional oil and gas production requires more tools, management, and technological applications than conventional production. In a conventional well, basic costs include the vertical well, drill stem, and casing. Unconventional wells have additional costs, including thousands of feet of extra piping for the horizontal well section, water, chemicals, and the management required to access, transport, and treat source/flowback water. Due to the added cost components of hydraulic fracturing and horizontal drilling, it is much more expensive than building a vertical well. Due to this higher production cost of unconventional wells, operators are limited to producing only when market prices are profitable, usually when oil is around $60 a barrel (Trainor et al. 2016). This causes unconventional operations to halt when prices become too low. The advantage compared with conventional production is that it is more resilient to changes in market price and can still operate when oil price is as low as $30 barrel, creating a synergy and reliance between the two forms of production.

The issue with conventional production is that many of the conventional deposits have already been tapped, creating the need for exploring new oil and gas resources. Currently in the U.S., conventional gas accounts for approximately 30% of total production and is expected to decrease to 24% by 2035 (EIA 2016). Aside from having limited source regions, conventional well counts in the U.S in 2015 show less than 1500 wells were producing more than 400 barrels of oil a day, versus over 4000 for unconventional wells (Jolly 2013). These counts reflect the fact that horizontal wells greatly outnumber vertical wells, but show just how profitable horizontal wells are. Out of the lowest rate of production, less than 15 barrels of oil per day, only 2% of the wells were horizontal (Jolly 2013). While horizontal wells produce at a much higher rate, they produce a majority of its lifetime recoverable oil and gas in its first few years of operation. Given this steep production decline in horizontal wells, there is high pressure on companies to constantly develop new sites to remain at their steady production levels. Depending on the geology of a location, production after just a couple years may drop to the point when continuing production becomes uneconomical, resulting in the plugging of the well and moving to a new location that has not been tapped yet. What this cycle results in are many abandoned wellbores not being currently maintained, serving as potential conduits of left over fracture fluid, formation water, and natural gas to seep into surrounding aquifers. While this is an issue with all wellbores, the vast number of horizontal wells could pose a more widespread risk to underground sources of drinking water.

2.3 Tradeoffs of the Water-Energy Nexus

In the water-energy nexus, complex interconnections such as cooling power plants, fracking shale, and powering desalination demand robust management solutions. Indeed, an optimization of such interconnections on various scales may be unreachable. However, rigorous tradeoff analysis and the modeling of scenarios can provide a pathway for decision makers to navigate and influence water-energy nexus synergy. The decision makers managing the water-energy nexus often have various conflicting preferences and scenarios which are always associated with tradeoffs: environmentally, economically and socially. Therefore, it is very important to understand the basic tradeoffs of the water-energy nexus when addressing nexus issues such as energy resources mining and production, water production, treatment and allocation, power plant construction and environmental impacts.

The extraction of water from deep wells, treatment, desalination and long-haul transportation are all energy-intensive activities. With sufficient energy, these water security challenges can be addressed and solved enduringly. However, questions remain as to how we can reach such a scenario, and what are the associated tradeoffs? Going toward a water-secure scenario will require vast added amounts of energy.

As mentioned earlier in the chapter, almost all energy activities require water as a major input, especially the processes of mining for energy resources and generating electricity, and that is when energy constraints become water constraints. Stillwell et al. (2017) detailed the water consumption for a variety of fuel sources. Consumption, which depends widely on technology and materials, is shown in Table 2.1. The life cycle water input of biofuel production can vary greatly by region, from rain-fed to irrigated crops. There can be no industrial fuel production, or electric power generation, without water. Power plants require water for cooling, and depending on the technology and fuel used, withdraw and consume various amounts of water. A once-through cooling system, for example, withdraws a significant amount of surface water but returns it with minimal consumption. A closed-loop cooling system reuses the same water, so has a much lower withdrawal but results in more water consumption from evaporation from cooling towers and other processes. The water footprint, or net impact on water supply, of electricity generation was also illustrated by Stillwell et al. and given in Table 2.2. These footprints are partitioned into withdrawal and consumption; most power plants remove and return a large quantities of surface water for cooling, while some is evaporated or lost through other means. This loss is considered water consumption; it is lost locally or becomes unavailable.

Water cannot be treated and transported over a great distance or from great depths without significant electricity and fuel use. In another study, Stillwell et al.

Table 2.1 Water consumption for different fuels produced

Fuel Source		Consumption (gal/GJ)
Natural gas		
	Conventional	0.19
	Unconventional	1.7–6.4
Petroleum		
	Gasoline	7.4–104
	Diesel	7.0–114
Biofuels		
	Corn Ethanol	459–1040
	Soy Biodiesel	423–2890
Hydrogen		86–131

Source: Stillwell et al. (2017)

Table 2.2 Water withdrawal and consumption for different electricity sources and cooling technology

Electricity Source		Withdrawal (gal/MWh)	Consumption (gal/MWh)
Coal			
	Open-loop	20,000–50,000	100–317
	Recirculating reservoir	300–24,000	300–700
	Cooling tower	500–1200	480–1100
Natural Gas Steam Turbine			
	Open-loop	10,000–60,000	95–291
	Cooling tower	950–1460	662–1170
Natural Gas Combined-Cycle			
	Open-loop	7500–20,000	20–100
	Recirculating reservoir	5950	240
	Cooling tower	150–300	130–300
Nuclear			
	Open-loop	25,000–60,000	100–400
	Recirculating reservoir	600–13,000	560–720
	Cooling tower	800–2600	581–845
Concentrated Solar Power			
	Cooling tower	725–1100	725–1100

Source: Stillwell et al. (2017)

(2009) examined the potential for long-haul seawater desalination. Treatment and distribution of conventional surface water requires 4.4 and 24.1 MWh/d respectively. Treating brackish groundwater or seawater increases the energy footprint of water supply to 78–195 MWh/d and 196–330 MWh/d respectively, which does not include any conveyance (Stillwell et al. 2009).

Energy production and generation has an impact on water and air quality, producing emissions and increasing the temperature in surface water where cooling water is returned, and has the potential to impact ecology. Chemicals from hydraulic fracturing have the potential to contaminate surface or groundwater through leaching or runoff if stored in lagoons. The injection of produced water from hydraulic fracturing into deep formations for disposal removes potential water supply from the hydrologic cycle. Chemicals can enter surface and groundwater through spills from oil pipelines and mines, or from refineries in disasters like floods. Water supply and quality impacts the efficiency of thermoelectric power generation and recovery in oil and gas production. Thus, water has a significant impact on energy industries that are a major economic component worldwide, and which are essential to maintaining standards of living.

These tradeoffs weave a complex web of interactions at different scales. As discussed previously, they exist within siloes of different decision makers in both private and public institutions. Energy and water have various important tradeoffs acting in both directions with clear financial, environmental, and social implications.

2.4 The Eagle Ford Case Study

The Eagle Ford shale play, located in South-Central Texas, is one of the most economic and prolific shale-oil producers in the nation. Spanning over 30 counties, the Eagle Ford contains approximately 3.4 billion barrels of technically recoverable oil and 20.8 trillion cubic feet of technically recoverable natural gas (EIA 2011, 2012). This play has seen exponential growth since the advent of hydraulic fracturing and the drilling of its first well in 2008. The region accounted for 85% of the total increase in Texas' production from 2010 to 2011. Using hydraulic fracturing technology, operators in the Eagle Ford more than doubled its natural gas production and increased its oil production six-fold (EIA 2016). Production rose drastically until 2014 when oil prices began to decline from $100/barrel to $30/barrel, causing a harsh decline in new production rigs. Production reached a minimum of less than 50 rigs in 2015 and has since been slowly increasing with only some minor setbacks. The play is currently producing from approximately 75 production rigs, compared to 2014 during its peak at approximately 1400 rigs (EIA 2018). Despite economic hindrances, the Eagle Ford currently produces 20% of the nation's oil and 10% of its natural gas (EIA 2018).

Water use for hydraulic fracturing, taken into account as water for mining in the Texas Water Development Board's State Water Plan, is in direct competition with water use for agriculture and municipal purposes in the Eagle Ford region. While mining water use is expected to peak in 2030, the region's population is expected to grow from over three million in 2020 to over five million by 2070 (TWDB 2016). This increase in population predicts the largest of potential shortages in the municipal sector where San Antonio is the largest metropolitan area of the region. Following this, are water shortages for steam electric power and manufacturing. Although demand for water in the mining sector is expected to decrease after 2030, the sector is expected to undergo potential shortages of 22% of what it demands, compared to 15% and 31% for the municipal and irrigation sectors (TWDB 2016).

Mining water use for the entire region constitutes approximately 4% of the total water demand, but at a county scale mining can account for a large majority of the water usage. McMullen County, located in the southwestern portion of the play, has a population of just over 700 people. Mining water accounts for 90% of total water use in the county (TWDB 2016). Taking its population into account this number seems reasonable, but irrigation in the county is predicted to experience shortages of 100% of what it demands, with mining at 67%. These statistics show that on a regional scale water use for hydraulic fracturing may appear minimal, but locally it can pose threats to other sectors of individual counties and may potentially harm the performance of communities that rely on these other resources for food and income.

Examples of nexus tools developed to support energy production in Texas and the Eagle Ford region to facilitate in infrastructure planning are the WET (Water-Energy-Transportation) 2.0 tool and EPAT (Energy Portfolio Assessment Tool)

(Mohtar et al. 2015; Mroue et al. 2018). These tools focus on energy and electricity production and the social, economic, and environmental impacts of these activities.

Under varying production or market price scenarios, WET 2.0 quantifies the interrelations and trade-offs between water, energy, and transportation. This tool is dynamic in selecting variables that characterize the Eagle Ford as it undergoes technical advances, such as increased lateral length of wells and increased water reuse. This tool offers a decision support system to operations in developing sustainable road integrity, controlling emissions, minimizing water use, and decreasing the energy footprint for the entire region of the Eagle Ford. A user can also create and compare varying scenarios under a social-environmental-economic index to see in what areas a plan may work more favorably.

More recently developed than WET 2.0, EPAT offers a platform designed to quantify the environmental needs as well as the environmental and economic outcomes from energy portfolio scenarios for Texas. Using this tool, a user can define current or desired energy production plans through different sectors, such as coal, oil, natural gas, bioenergy, solar, wind, nuclear, and hydropower. For each energy portfolios, the tool quantifies water consumption, land use, carbon emissions, and revenue for Texas. Both tools offer valuable insight into planning energy development impacts, and while their current focus is specific to Texas, their framework may be expanded to other entities with added data. These tools have the potential to reform policy with their holistic approaches and can help aid officials in making more informed decisions when they are able to view a snapshot of projected outcomes from a given energy scenario.

2.5 Potential Transformative Solutions in the Water-Energy Nexus

The analysis and presentation of synergies and tradeoffs between the water and energy resource systems is an important component of nexus studies because it provides stakeholders with guiding principles for reducing water loss and carbon emissions, while also meeting context-specific economic and sociocultural expectations. The inclusion of non-technical factors of a policy or technology solution are important since they set forth the system capacity of local constraints. Both a challenge and benefit of the nexus resource management approach is the array of stakeholders involved in the decision-making process, including the food and agriculture, industrial, economic, public health, financial, energy, water, and environmental sectors. Each interest helps determine the direction of policy with regards to water-energy issues.

Policies form the core of regulatory standards and have a significant role in resource allocation and use. However, the application of policy that addresses the nexus of water and energy is lacking. Mechanisms are therefore needed to assist institutions in transitioning from standard sectoral policy towards a holistic nexus approach that views the water and energy sectors simultaneously. Successful policy development can be accredited to the transparency and sharing of perceived risks and anticipated benefits across the spectrum of involved stakeholders (Dijk et al. 2015). Expert stakeholders from academia and industry have a role to play in shaping the public perception of emerging practices and technology (Eyck 2005) thus their potential for reaching the interests of policymakers. Ensuring policymakers are informed on the latest technological advancements and scientific understanding pertinent to the water-energy nexus is essential for the shaping of policy that optimize trade-offs and reduce direct and indirect negative impacts. However, this calls for the refinement of policy structures; going forward, it is fundamental for policies to be configured based on scientific evidence with direct contribution from cross-sector stakeholder collaboration.

Insufficient research and development of alternative technology applications for the water-energy nexus, in addition to low sociocultural awareness of their potential benefits, consequently results in a low priority for policymakers and low incentive for industries. A significant factor contributing to the weak investment and understanding can be related back to the knowledge gap between the scientific research community and decision-makers. Moreover, the persisting gap hinders development in terms of national and global resource management and climate objectives. Examples of existing and novel policy solutions that address key water-energy nexus challenges are presented and described below.

2.5.1 Increase Incentives for Water Reuse and Recycling in Fracking and Water Cooling

Local oil and gas producers and power plants are witnessing firsthand the impact of water availability on the success of their operations. Likewise, policymakers are taxed with figuring out the best strategies for managing scarce water resources. 27% of all US shale resources are found within areas of high water-stress (Webb 2017). It does not come as a surprise that drilling permits and opportunities for hydraulic fracturing have been denied in several states where the shale gas industry is active due to cases of low water-availability (Middleton et al. 2015). Several approaches can be applied to reduce withdrawals from freshwater resources and increase water-use efficiency:

In conventional practices, wastewater from fracking activity is disposed into injection wells, being removed from the hydrological cycle virtually forever (Webb 2017). The Fasken Oil & Ranch, Ltd. has been recognized in Texas and in the shale gas industry for its implementation of water recycling policy into its daily operations. In 2014, the small oil and gas producer discontinued all use of freshwater from the Ogallala Aquifer for its drilling and well completion operations (RRC 2017). Freshwater was replaced by recycled wastewater from fracking activity and brackish water from the Santa Rosa aquifer formation substituted the water.

Recycling and filtration facilities allow the water to be reused up to 80 times, while more than three million barrels had been processed since 2013 (Muscat 2015). To generate incentive for producers to cut-back on freshwater use, wastewater recycling needs to be a cost-competitive alternative to existing practices. Imposing fees on freshwater use may encourage industries to consider wastewater recycling and alternative water resource supplies, provided that the amount of fees meets or exceeds the cost of recycling. Similarly, disposal of wastewater from fracking activity can be discouraged by increasing injection fees, which currently go for an average rate of $2 USD per barrel of water (Webb 2017). This would force producers to seek alternative sources and explore water-less fracking techniques, or dry-cooling systems for power plants.

2.5.2 Encourage Use of Alternative Water Resources Including Brackish Water and Municipal Effluent, in Order to Preserve Fresh Water Supplies

Oil and gas producers in the Eagle Ford basin are already taking advantage of municipal effluent as an alternative to freshwater for fracking. The Apache Corporation in the area purchases three million gallons of treated effluent per day from College Station, Texas. As noted above, the Fasken Oil & Ranch, Ltd. is renowned in Texas for its use of brackish water for fracking operations. While this eliminates the dependency on freshwater resources, brackish water and municipal effluent will also face challenges of competition in the future, as both are currently being used for agriculture and municipal sectors.

2.5.3 Decoupling Water and Energy Sectors

Decoupling of the water and energy sectors means reducing the dependency of energy on water, and vice versa, in ways that are economically viable and will have low environmental impact. The decoupling begins with developing transparency of nexus tradeoffs in order to reduce sectoral dependency. Waterless fracking is one technological approach that decouples the fracking industry from water use but still requires more studies before wide-scale applications. The most significant challenge facing the energy sector is the availability of water resources. Freshwater, brackish, and municipal effluent each having competing users, and demand for them will only continue to increase into the future. Agricultural production and municipalities both are using brackish and effluent waters to meet growing demands.

2.5.4 Make Treatment Technologies more Economical

Despite the potential water savings and environmental benefits resulting from wastewater recycling policy, use remains limited due to costs of recycling treatments. Without financial incentives and regulation, industries will more likely continue use of freshwater and dispose of wastewater into injection wells. Policymakers in Texas realized this and developed a new permitting process for new recycling facilities that offers producers tax incentives to recycle (Webb 2017). Alternative fracking using non-aqueous fluids nearly eliminates the use of water in fracking. However, it is unlikely that industry will switch to non-aqueous working fluids unless there is a demonstrable and reliable increase in production that justifies the increased costs of alternative fracturing methods (Middleton et al. 2015).

2.5.5 Reduce Pollution Risks Associated with the Disposal of Fracking Water

The biggest potential source of environmental contamination is flowback and produced water, which is highly contaminated with hydrocarbons, bacteria and particulates, meaning that traditional membranes are readily fouled flowback water as well as post-well completion water (production or produced water) are contaminated with hydrocarbons many of which are classified as hazardous, which along with significant bacteriological content means that this water cannot be reused without significant treatment (Maguire-Boyle et al. 2017). Much of the concern around fracking surrounds the potential for chemicals to contaminate surface and groundwater (Webb 2017). In the case of the Marcellus Shale formation in Pennsylvania, insufficiently treated water from shale gas operations had been discharged into rivers creating a major public health concern.

2.5.6 Transformation through Technology

At the center of the nexus are the technologies producing, transporting, and channeling water and energy to fuel our livelihoods. Understanding these technologies within a nexus environment is a crucial step forward in identifying sustainable and resilient management and policy strategies that target multiple sectors simultaneously and address multi-scale resource challenges. In the context of this chapter, technology is discussed as a physical mechanism or process developed in order to gain a specified outcome (Rao et al. 2018). In the case of the water-energy nexus, technologies are physical mechanisms that have the general purposes of (a) production and provision of energy and water sources, and (b) water filtration.

Transformative solutions through the application of emerging technologies in the water and energy sectors specific to the area of hydraulic fracturing are introduced and their role in policy are described.

2.5.7 *Waterless Fracking*

Waterless fracturing technologies emerged due to concerns of formation damage, water consumption, and contamination risks associated with conventional fracking methods (Wu 2016). Liquid carbon-dioxide is one example of a non-aqueous fluid showing to be a promising alternative to water-based fracking. Results of a Department of Energy (DOE) sponsored experimental study on hydraulic fracturing showed that the use of CO_2 resulted in up to five times more gas production in comparison aqueous fluids and significant cutback on water use (Moridis 2017). Widespread application and acceptance of waterless fracturing in the shale gas industry is limited due to several technical factors noted by Middleton et al. (2015): "[the added expense] of capturing, pressurizing, and transporting carbon-dioxide, [the need for] robust accounting of CO_2 emissions and storage, pressure safety at the site, separation of hydrocarbons and brine from the flowback CO_2, and re-pressurization of flow-back CO_2." More development on waterless fracking methods is needed before they can be a viable alternative to traditional water-based methods. With successful applications of waterless fracking, the technology offers a significant step towards the decoupling of the water and energy sectors.

2.5.8 *Renewable Energy Water Integration and Zero-Liquid Discharge Desalination*

Direct reuse of wastewater from shale gas production is generally not feasible due to its high contamination which could have detrimental impacts on the health of shale formations if reused without proper pretreatment. Emerging technologies for zero-liquid discharge (ZLD) desalination provide promising applications in shale gas wastewater management. ZLD desalination uses thermal and membrane-based processes, while the selection of the most appropriate desalination method depends on physiochemical composition of the wastewater being treated (Onishi et al. 2017b). ZLD is an appealing technology for improving the overall sustainability of shale gas industry by increasing water-use efficiency (as much as 75–90% of wastewater can be reclaimed for reuse) and eliminating the environmental health risks of discharging of highly saline and contaminated wastewater

(Onishi et al. 2017a). Furthermore, integration of renewable energy resources with desalination have potential to reduce costs associated with desalination while creating opportunities to cut greenhouse gas emissions and reduce dependencies on fossil fuels (Rao et al. 2018).

2.5.9 Nanotechnology

In recent years, nanotechnology is becoming increasingly popular in the oil and gas industry, finding applications in drilling, drill-in, completion, stimulation, and exploration and exploitation of oil and gas (Fakoya and Shah 2017). In order to access oil and/or gas reservoirs beneath subterranean rock formations, high pressure pumping of fluids into the wellbores is needed to stimulate and breakdown the rock formations (Al-Muntasheri et al. 2017). Nanoparticles are of particular interest due to their small size (1–100 nm), enabling them to travel smoothly through the porous rock formations without blockage and damage (Franco et al. 2017). Other noted benefits of nanotechnologies in hydraulic fracturing include wellbore stability during drilling operations and reservoir sensing (Al-Muntasheri et al. 2017). Field trials conducted in Colombia show that applications of nanotechnology can increase the productivity and reserves of oil and gas (Franco et al. 2017).

2.6 Conclusion

In order for policymakers to make informed decisions about certain policy goals, it is critical that they have a fundamental understanding of the interplay between the technical components of the water-energy nexus, including emerging technologies and water and energy sector challenges. Policymakers must also have a broader vision and thorough understanding as to how technologies may be used as vehicles for achieving certain policy goals. Further research and development is needed to develop cost-effective policies that will discourage freshwater withdrawals for consumptive activities and encourage more efficient water use practices (recycling, brackish water, municipal wastewater). Furthermore, policy development needs to incorporate cross-sectoral dialogue in order to facilitate knowledge transfer from field experts to policymakers. From this discussion, the link between policy and technology becomes clear: while policy defines a specified goal, the application of technologies can serve as the means for achieving the policy goal. Lastly, coupling policy and technology will be essential in preparation for future challenges related to competition over water resources as more sectors resort to the use of alternative grey water resources to meet growing demand.

References

Al-Muntasheri GA, Liang F, Hull KL (2017) Nanoparticle-enhanced hydraulic fracturing fluids: a review. SPE Prod Oper 32(2):186–195

Dijk HV, Fischer A, Marvin H, Trijp HV (2015) Determinants of stakeholders' attitudes towards a new technology: nanotechnology applications for food, water, energy, and medicine. J Risk Res 20(2):277–298

Environmental Protection Agency (2010) Scoping materials for initial design of EPA research study on potential relationships between hydraulic fracturing and drinking water resources. Environmental Protection Agency, Washington, D.C. Available at https://yosemite.epa.gov/sab/sabproduct.nsf/0/3B745430D624ED3B852576D400514B76/$File/Hydraulic+Frac+Scoping+Doc+for+SAB-3-22-10+Final.pdf

Eyck TAT (2005) The media and public opinion on genetics and biotechnology: mirrors, windows, or walls? Public Underst Sci 14(3):305–316

Fakoya MF, Shah SN (2017) Emergence of nanotechnology in the oil and gas industry: emphasis on the application of silica nanoparticles. Petroleum 3(4):391–405

Franco C, Cortés F, Zabala R (2017) Nanotechnology applied to the enhancement of oil and gas productivity and recovery of Colombian fields: a review. J Pet Sci Eng 157:39–55

Hanlon P, Madel R, Olson-Sawyer K, Rabin K, Rose J (2013) Food, water and energy: know the nexus. GRACE Communications Foundation

Hanson VD (2017) The fracking industry deserves our gratitude. Natl Rev. July 6, 2017) available at https://www.nationalreview.com/2017/07/fracking-industry-united-states-energy-independence-oil-middle-east-venezuela/. Accessed 24 May 2018

Jolly D (2013) France upholds ban on hydraulic fracturing, The New York Times, October 11, 2013

Maguire-Boyle SJ, Huseman JE, Ainscough TJ, Oatley-Radcliffe DL, Alabdulkarem AA, Al-Mojil SF, Barron AR (2017) Superhydrophilic functionalization of microfiltration ceramic membranes enables separation of hydrocarbons from Frac and produced water. Sci Rep 7:12267

Manfreda J (2017) The real history of fracking. OilPricecom, 24 Feb 2017

Middleton RS, Carey JW, Currier RP, Hyman JD, Kang Q, Karra S, Jiménez-Martínez J, Porter ML, Viswanathan HS (2015) Shale gas and non-aqueous fracturing fluids: opportunities and challenges for supercritical CO_2. Appl Energy 147:500–509

Mohtar R, Blake J, Shafiezadeh H (2015) WET Tool (Water-Energy-Transportation application to assess impacts related to hydraulic fracturing in the Eagle Ford Shale). http://wefnexustool.org/wef/

Moridis, G. (2017) Literature review and analysis of waterless fracturing methods. Energy Geosciences Division. Lawrence Berkeley National Laboratory. Available at http://www.ourenergypolicy.org/wp-content/uploads/2017/04/CERC_WaterlessFracturing.pdf. Accessed 11 April 2018

Mroue AM, Mohtar RH, Pistikopoulos EN, Holtzapple MT (2018) Energy portfolio assessment tool (EPAT): sustainable energy planning using the WEF nexus approach – Texas case. Sci Total Environ 648:1649–1664. https://doi.org/10.1016/j.scitotenv.2018.08.135. Elsevier, (2019)

Muscat S (2015) US pioneers water saving in fracking, but China's nascent shale sector lags. China Dialogue. https://www.chinadialogue.net/article/show/single/en/7987-US-pioneers-water-saving-in-fracking-but-China-s-nascent-shale-sector-lags. Accessed 12 April 2018

OECD/IEA (2016) Water energy nexus. Excerpt from the World Energy Outlook 2016. Available at https://www.iea.org/publications/freepublications/publication/WorldEnergyOutlook2016ExcerptWaterEnergyNexus.pdf. Accessed 11 April 2018

Office of Research and Development (2010) Science in action: building a scientific foundation for sound environmental decisions. Environmental Protection Agency, Washington, D.C

Onishi, VC, Reyes-Labarta JA, Caballero JA, Antunes CH (2017a) Wastewater management in shale gas industry: alternatives for water reuse and recycling, challenges and perspectives. EMCEI 2017 – Euro-Mediterranean Conference for Environmental Integration. Available at https://rua.ua.es/dspace/bitstream/10045/71671/1/Poster_18EMEC_II_UA_2017pdf. Accessed 12 April 2018

Onishi VC, Reyes-Labarta JA, Caballero JA, Antunes CH (2017b) Zero-liquid discharge desalination of hypersaline shale gas wastewater: challenges and future directions. EMCEI 2017 – Euro-Mediterranean Conference for Environmental Integration. Available at https://rua.ua.es/dspace/bitstream/10045/71669/2/Poster_1EMCEI_Concept_UA_2017.pdf. Accessed 12 April 2018

Poumadère M, Mays C, Le Mer S, Blong R (2005) The 2003 heat wave in France: dangerous climate change here and now. Risk Anal 25(6):1483–1494

Rahm D (2011) Regulating hydraulic fracturing in shale gas plays: the case of Texas. Energy Policy 39(5):2974–2981

Rao P, Kostecki R, Dale L, Gadgil A (2018) Technology and engineering of the water- energy Nexus. Annu Rev Environ Resour 42:407–437

Stillwell AS, King CW, Webber ME (2009) Desalination and long-haul water transfer: a case study of the energy-water Nexus in Texas. In: Proceedings of the ASME 3rd international conference on energy sustainability. American Society of Mechanical Engineers, San Francisco, CA

Stillwell AS, Mroue AM, Rhodes JD, Cook MA, Sperling JB, Hussey T, Burnett D, Webber ME (2017) Water for energy: systems integration and analysis to address resource challenges. Curr Sustain Renew Energy Rep 4:90–98

Texas Railroad Comission (RRC) (2017) Texas energy companies win top national environmental Stewardship Award –Pioneer and Fasken recognized for water conservation efforts. Railroad Commission of Texas. Accessed on 4 Dec 18. http://www.rrc.state.tx.us/all-news/100217b/

Texas Water Development Board (TWDB) (2016) 2017 Texas state water plan. https://2017.texasstatewaterplan.org/region/L

Trainor AM, McDonald RI, Fargione J (2016) Energy sprawl is the largest driver of land use change in United States. PLoS One 11(9)

U.S. Energy Information Administration (EIA) (2011) Review of emerging resources: U.S. shale gas and shale oil plays. U.S. Department of Energy, Washington, DC. https://www.eia.gov/analysis/studies/usshalegas/pdf/usshaleplays.pdf

U.S. Energy Information Administration (EIA) (2012). Eagle Ford oil and natural gas well starts rose sharply in first quarter 2012 – on April 23, 2012. U.S. Department of Energy, Washington, DC. https://www.eia.gov/todayinenergy/

U.S. Energy Information Administration (EIA) (2016) State profile and energy estimates – Texas on September 24, 2015. U.S. Department of Energy, Washington, DC. https://www.eia.gov/state/?sid=TX#tabs-4

U.S. Energy Information Administration (EIA) (2018). Crude oil production – Texas on May 13, 2018. U.S. Department of Energy, Washington, DC. https://www.eia.gov/dnav/pet/PET_CRD_CRPDN_ADC_MBBLPD_M.htm

Webb RM (2017) Changing tides in water management: policy options to encourage greater recycling of fracking wastewater. William Mary Environ Law Policy Rev 42(1):85–144

Wu K, Paranjothi G, Milford JB, Kreith F (2016) Transition to sustainability with natural gas from fracking. Sustainable Energy Technol Assess 14:26–34

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