Strategy Research Project

America's Water Future and Deep Energy

by

Colonel Bernie R. Lindstrom
United States Army

United States Army War College
Class of 2012

DISTRIBUTION STATEMENT: A
Approved for Public Release
Distribution is Unlimited

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)* 21-03-2012	**2. REPORT TYPE** Strategy Research Project	**3. DATES COVERED** *(From - To)*
4. TITLE AND SUBTITLE America’s Water Future and Deep Energy		**5a. CONTRACT NUMBER**
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Colonel Bernie R. Lindstrom		**5d. PROJECT NUMBER**
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Dr. Kent Butts Director, National Security Issues Branch Center for Strategic Leadership US Army War College Carlisle Barracks, PA 17013-5049		**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army War College 122 Forbes Avenue Carlisle, PA 17013		**10. SPONSOR/MONITOR’S ACRONYM(S)**
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution: A

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Recent technological advances and an increasing demand for energy have led to an international surge of deep shale gas and oil hydraulic fracturing operations. Since 2006 natural gas and oil industries expanded the use of hydraulic fracturing to extract natural gas and oil from deep shale deposits. Increased drilling operations throughout the United States led to a frenzy of discussions, debates, and protests concerning potential impacts to the environment, and human health. Environmental experts and several reports to Congress state that oil and gas shale development will adversely impact water resources. Chemical and material byproducts introduced to water in the process could enter public drinking water. Nation and state governments, city mayors, and river compacts imposed major restrictions, banning drilling operations, increasing inspections, and began the process to revise regulations. This paper analyzes the sustainability of clean water, and the importance of energy. It identifies open strategic issues concerning public health that require immediate attention and provides recommendations for a strategy leading to increased water security to protect clean water for the public in an era of deep energy extraction.

15. SUBJECT TERMS
Shale Gas, Human Health

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Bernard R. Lindstrom
a. REPORT UNCLASSIFED	**b. ABSTRACT** UNCLASSIFED	**c. THIS PAGE** UNCLASSIFED	UNLIMITED	42	**19b. TELEPHONE NUMBER** *(include area code)* 717-462-9962

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

USAWC STRATEGY RESEARCH PROJECT

AMERICA'S WATER FUTURE AND DEEP ENERGY

by

Colonel Bernie R. Lindstrom
United States Army

Dr. Kent Butts
Project Adviser

This SRP is submitted in partial fulfillment of the requirements of the Master of Strategic Studies Degree. The U.S. Army War College is accredited by the Commission on Higher Education of the Middle States Association of Colleges and Schools, 3624 Market Street, Philadelphia, PA 19104, (215) 662-5606. The Commission on Higher Education is an institutional accrediting agency recognized by the U.S. Secretary of Education and the Council for Higher Education Accreditation.

U.S. Army War College
CARLISLE BARRACKS, PENNSYLVANIA 17013

ABSTRACT

AUTHOR: Colonel Bernie R. Lindstrom

TITLE: America's Water Future and Deep Energy

FORMAT: Strategy Research Project

DATE: 21 March 2012 WORD COUNT: 9,147 PAGES: 42

KEY TERMS: Shale Gas, Human Health

CLASSIFICATION: Unclassified

Recent technological advances and an increasing demand for energy have led to an international surge of deep shale gas and oil hydraulic fracturing operations. Since 2006 natural gas and oil industries expanded the use of hydraulic fracturing to extract natural gas and oil from deep shale deposits. Increased drilling operations throughout the United States led to a frenzy of discussions, debates, and protests concerning potential impacts to the environment, and human health. Environmental experts and several reports to Congress state that oil and gas shale development will adversely impact water resources. Chemical and material byproducts introduced to water in the process could enter public drinking water. Nation and state governments, city mayors, and river compacts imposed major restrictions, banning drilling operations, increasing inspections, and began the process to revise regulations. This paper analyzes the sustainability of clean water, and the importance of energy. It identifies open strategic issues concerning public health that require immediate attention and provides recommendations for a strategy leading to increased water security to protect clean water for the public in an era of deep energy extraction.

AMERICAS WATER FUTURE AND DEEP ENERGY

Many have lived without love, none without water.

—English poet W. H Auden

The drive to obtain new sources of energy deep beneath the earth's surface is contaminating water, and has the potential to create significant public health problems. This paper will outline why water and energy are both vital to national security, demonstrating how additional demands for energy are increasingly in conflict with the basic human need for clean fresh water. This paper will conclude that water policy should be strengthened in a new era of deep energy, recommending immediate actions to increase water security and protect clean water for human consumption without significantly impacting the profitability or quantity of production of energy.

Sources of Water

Water directly sustains plant and human life, and the availability of clean drinking water is vital to life as a basic human need. Access to safe, uncontaminated water is essential for human existence. Water is a limited natural resource. Therefore, water is vital to national security. The next few paragraphs describe the sources of water and why water is essential to human life.

Even though the world has an abundance of water, the actual percentage of useable, fresh water is relatively small and unevenly dispersed. Approximately seventy percent of the earth's surface is covered with water; however, most of it is not immediately available for human consumption. Ninety-seven percent of all water is salt water. Clean fresh water encompasses only 3 percent of our world's total water and about 2/3 of that is contained in ice caps and glaciers, leaving less than 1 percent for human consumption and use.

Sources of water include ground, precipitation, surface, biological, and desalination. Surface water encompasses all lakes, oceans, reservoirs, rivers and stream beds. Surface water elevation is visible to the observer and is easily measured, and is the easiest to access for human use. Surface water availability is the most measurable and is the easiest to test for contamination or pollution. Water quality is dependent upon its level and type of contamination. Detection of any contamination or pollution of surface water is difficult and varies with the consistency, type, and size of the pollutant. Due to its ease of access, surface water receives the most pollution from agriculture, industry, and domestic sources. Surface water sustains most plant life, and either feeds into ground water or is evaporated to form precipitation.

Groundwaters are repositories of water below the Earth's surface. Repositories include regions beneath and lateral to stream beds where there is a mix of shallow ground water and surface water typically connected to an aquifer. An aquifer is a subsurface formation of water-bearing permeable rock (gravel, sand, or slit) that is sufficiently permeable to conduct groundwater and yields economically significant quantities of water to wells and springs.[1] Groundwater supplies the majority of the nation's community water systems used mostly for agriculture and domestic purposes. Detection of any contamination or pollution of ground water is problematic due to access difficulty beneath the ground. An aquifer is dependent upon recharge and once an aquifer is depleted of water, the aquifer may not recover for centuries. The evaluation of groundwater conditions to include availability and quality is not currently tracked or assessed in any holistic manner for any region or watershed.

Precipitation includes hail, rain, and snow. Fresh water can be collected from precipitation and harvested for agricultural or domestic purposes. This method of harvesting is done frequently in urban environments. In new construction efforts urban planners typically require designs accounting for rainwater runoff. Most rain water runoff in urban areas becomes surface water and is diverted to local municipal water treatment facilities. Runoff in rural areas becomes surface water feeding streams, ponds, and lakes and is useful for irrigation purposes. The amount of precipitation that enters surface or ground water aquifers in any geographical area varies. In the eastern portion of the United States water quality is the primary concern, while the western portion focuses chiefly on water quantity.[2] This is true because of the relatively large population and moderately wet climate conditions in the East, as compared to the sparse population and predominately arid climate conditions in the South-West. Precipitation quantity is measurable but not always predictable and therefore availability will vary depending on local climate conditions, geography, and soil conditions. Precipitation quality is dependent on the source of evaporated water and air quality.

Plants are biological sources and users of water. Plants are found to be more abundant in regional areas with large amounts of precipitation and surface water. Conversely, plants are found to be less abundant in geographic areas that do not receive much precipitation and surface water. The ability to extract small amounts of fresh water (ounces) from plants is possible; however the processes to do this on a larger scale (100s of gallons) is not widely used. Polluted or contaminated water can have a direct impact on the health of plants and can sometimes be directly observed.

Desalination can provide water on a large scale and is a viable source however it is typically not economically feasible due to energy costs. Providing fresh water for domestic or agricultural purposes by this method requires large amounts of energy and infrastructure. The benefit of desalination is that some purification of water occurs as a part of the process. The most common areas in the world that utilize desalination are in arid, dry climates. With low energy costs, desalination becomes more appealing.

The water cycle is the physical process of evaporation, condensation, precipitation, infiltration, runoff, and subsurface flow as well as the continuous movement of water above, below and on the surface of the Earth. Fresh water is provided through a water vapor cycle, where it evaporates from surface water in oceans and lakes before condensing and falling as precipitation. As water transitions from liquid to vapor to solid at various places, and moves through the cycle it also provides a natural method for purification, and natural movement of minerals from ground and surface areas. This movement of water figures significantly into the maintenance of life and ecosystems on Earth.

It is important to understand why water is so useful to human existence. Water is a scarce resource. Water sources include the ground, precipitation, surface, biological, and desalination where fresh water naturally provided through the water vapor cycle. Water directly sustains plant and human life and therefore drinking water is vital to life as a basic human need. The sustainment of life on earth makes water quality important.

Water Quality

Poorly managed water negatively impacts human health. Increasing populations are escalating the demand for clean water, and human activity directly contributes to water pollution. Populations that suffer from water related health issues experience an increase in national medical costs, and social instability. Water that is poorly managed negatively impacts human health, stressing the need for strong water policy. The next few paragraphs emphasize how water quality impacts human health.

The EPA defines “drinking water resources” to be any body of water, ground or surface that could currently, or in the future, produce an appropriate quantity and flow rate of water to serve as a source of drinking water for public or private water supplies.[3] This includes both Underground Sources of Drinking Water (USDWs) and surface waters. Globally, the availability of fresh water should be more than sufficient to support the world’s population during the next quarter century. However, only 0.36 percent of the world's water in rivers, lakes, and swamps is sufficiently accessible to be considered a renewable fresh water resource.[4] Besides the inaccessibility of water due to salinity and ice caps as mentioned earlier, other primary reasons for a lack of fresh water include scarcity, and contamination.

Most scholars agree that there is in fact water scarcity, that there is a clear linkage between water scarcity and conflict, and that water demand agreements are the key to mitigate conflict and provide regional stability, particularly in arid regions.[5] Population growth and economic development are driving a steady increase in demand for new water supplies. Global demand for water has more than tripled over the past half century, and the world is anticipated to add approximately 60 million people each year surpassing 8 billion by the 2030 to 9.5 billion by 2050.[6] Most population growth is expected in developing countries. Agriculture is the source of greatest demand for water worldwide, accounting for seventy percent of total water usage. In comparison, industry accounts for only twenty percent while domestic usage remains at ten percent.[7] Water shortages already plague almost every country in North Africa and the Middle East. Developing countries use far more than the global average of water for agriculture, because of less efficient irrigation methods, and this trend is expected to increase. In countries that do not have adequate sources of surface water due to over demand, water sources in groundwater aquifers could deplete due to increasing access. Most estimates indicate nearly 3 billion; forty percent of the world's population will experience water stress or scarcity between now and 2050.[8]

The United States is also subject to water scarcity. The United States is ranked the fourth water rich country in the world and despite this, fresh water is becoming scarce in many areas.[9] The two largest consumers of water in the United States are energy and agriculture at thirty-nine percent each.[10] United States population will climb by more than 50 million to a total of approximately 355 million by the 2030s.[11] United States water issues vary by region. In the water poor western states, that have an arid climate, water is simply not readily accessible. However, the water rich eastern states are also affected. Recent 'water wars' between Georgia and Alabama, where water usage and purpose were heavily debated during extensive drought in the populated south east urban area of Atlanta, highlighted a regional water scarcity issue. Although, water scarcity is a concern, contamination and pollution of water is a much larger problem.

Numerous human activities impact water quality, including agriculture, industry, and mining, disposal of human waste, population growth, and urbanization. Water quality is affected by biological factors, changes in nutrients, heavy metals, non-metallic toxins, persistent organics and pesticides, pH, sedimentation, and temperature among many other factors.[12] Highly populated urban areas with uncontrolled chronic pollution are subject to widespread disease. The World Health Organization (WHO) estimates that globally, 1.1 billion people lack access to clean water supplies, and 2.4 billion lack accesses to basic sanitation.[13] Areas of the world impacted by water related disease demonstrate decreased productivity, increased medical costs, and social instability. Many diarrheal diseases, such as cholera, Cryptosporidium, E. coli, giardia, shigella, typhoid, and viruses such as hepatitis A reach their height during rainy seasons. Areas that suffer from lack of water are at increased risk for diarrheal and other water-related diseases because low water levels do not dilute waste as well, leading to higher concentrations of pathogens.[14] Water that is poorly managed negatively impacts human health, making water quality important.

The availability of clean, uncontaminated, unpolluted drinking water is vital to human life and is therefore a national security issue that deserves strong policy. Unfortunately, the future of clean water availability and quality is additionally threatened due to the worlds increasing appetite for more energy. Energy is also important to national security, because of its human use and increasing need to make life better.

Energy

Energy improves the human condition and is therefore vital to national security. Energy is essential to modernize and improve life. Energy sustains industry, transportation, residential, and commercial activities, and is essential for activities that drive the world economy such as; manufacturing, agriculture, mining, construction, and transportation.[15] Carbon fuels of oil, coal, and natural gas provide over eighty percent of the world's energy.[16] Since carbon fuels are non-renewable and the overall demand for energy is growing, new and diverse sources of energy are in high demand. The next few paragraphs will discuss non-renewable sources of energy, how they are sourced and transported, and how they have become essential to improve life, thus necessitating growing demand and impacting access to clean water.

Petroleum (oil) is the largest share of U.S. primary energy consumption, followed by natural gas, coal, nuclear electric power, and renewable energy (including hydropower, wood, bio-fuels, biomass waste, wind, geothermal, and solar).[17] In 2010, domestic energy production provided about three-fourths of the United States energy needs.[18] The remainder of energy was supplied mainly by imports of petroleum. The four leading geographic petroleum sources are: the Western Hemisphere, forty-nine percent; Africa, twenty three percent; Persian Gulf, eighteen percent; and Mexico, ten percent.[19] The five biggest nation state sources of net crude oil and petroleum product imports were Canada, twenty-five percent; Saudi Arabia, twelve percent; Nigeria, eleven percent; Venezuela, ten percent; and Mexico, nine percent.[20]

Crude oil is a naturally occurring flammable liquid consisting of a mixture of hydrocarbons and other organic compounds that are found in geologic formations beneath the earth's surface. An oil well produces predominantly crude oil. It is a non-renewable energy source because it takes millions of years to create. After crude oil is removed from the ground, it is sent to a refinery by pipeline, ship, or barge. At a refinery, different parts of the crude oil are separated into useable petroleum products (diesel, jet fuel, gasoline, etc.), then transported by pipeline or surface transportation to use.

Coal is a combustible black or brownish-black sedimentary rock composed mostly of carbon and hydrocarbons. It is the most abundant fossil fuel produced in the United States. Coal is also a nonrenewable energy source because it takes millions of years to create. The energy in coal comes from the energy stored by plants that lived hundreds of millions of years ago, when the Earth was partly covered with swampy forests. Coal is mined from surface and subsurface geologic formations. Due to its relatively low cost and abundance, coal is used to generate about half of the electricity consumed in the United States. Coal is the largest domestically-produced source of energy. Coal use, however, results in higher amounts of carbon dioxide per unit of energy than the use of oil or natural gas. Coal is mined in twenty-six states. Wyoming mines the most coal, followed by West Virginia, Kentucky, Pennsylvania, and Montana.[21] In 2010, the amount of coal produced at U.S. coal mines was 1,085.3 million short tons.[22]

Natural gas is comprised of over ninety percent methane. It is a gas, and is another non-renewable energy source that comes from the remains of plants and animals called organic material trapped in sand and silt changed to rock. Pressure and heat changed some of this organic material into coal, some into oil, and some into natural gas. Natural gas is colorless, odorless, and tasteless in its natural form. A gas well produces predominantly natural gas. However, because the underground temperature and pressure are higher than at the surface, the gas may contain heavier hydrocarbons such as pentane, hexane, and heptane in the gaseous state.[23] Most of the natural gas consumed in the United States is produced in the United States, although, some is imported, primarily from Canada, and other states.

Trends in energy production demonstrate growing demand. Total United States crude oil production has generally decreased each year since it peaked in 1970; however it increased by three percent in 2010 from 2009.[24] The increase in 2010 was led by escalating horizontal drilling programs for shale, notably the North Dakota section of the Bakken formation. Coal produced from surface mines increased from twenty-five percent in 1949 to sixty-nine percent in 2010 with the remaining extracted from underground mines.[25] In 2010, natural gas production exceeded coal production for the first time since 1981. More efficient, cost-effective drilling techniques, notably in the production of natural gas from shale formations, led to increased natural gas production in recent years. Also in 2010, total renewable energy consumption and production reached all-time highs of eight quadrillion British thermal units each.[26] This figure represents about eight percent of all energy used nationally. From 2000 through 2010, bio-fuels and wind capacity grew faster than other renewable energy sources. In 2010, bio-fuels production was eight times greater than in 2000, and wind generation was sixteen times greater than in 2000.[27] From 1949 to 2010, primary energy consumption in the United States tripled. The United States consumes energy for industrial, thirty-one percent; transportation, twenty-eight percent; residential, twenty-three percent; and commercial, nineteen percent uses.[28] Recent trends include a decrease in industrial and transportation consumption attributed to the 2008 recession however general historical trends resumed in 2010.

All of these trends depict that energy demand is growing. Specially, non-renewable carbon fuels are in increasingly high demand for agriculture, construction, manufacturing, mining, and transportation. Sustaining and improving the nation's economy is accomplished using these activities, making non-renewable sources of energy the key component for improving life, and highlighting the importance of energy to national security. Regrettably, as the next section will explain, energy sources are unstable and unpredictable.

<u>Energy Supply</u>

Disruption to energy supply has severe negative impacts on economic development, making energy a key component of national policy. There are significant consequences to energy supply disruption. High demand, coupled with potential for supply disruption necessitates policy that includes diverse sources of energy. This section will reveal how the ideological differences of suppliers, natural disasters, and global competition dramatically affect energy supply.

Most major oil producing countries are less reliable suppliers of energy due to political and ideological differences in their geographic region. The rise of socialist nationalism in Venezuela for example, highlights the ideological divide continuing between capitalism and socialism. Venezuela's Orinoco field contains an estimated 513 billion barrels of technically recoverable reserves, far larger than what is economically recoverable. As the field was being developed to produce 600,000 barrels a day with a promise to produce much more, Hugo Chavez, the nation's dictator proclaimed, "Down with the United States Empire".[29] In September of 2004 an Islamic leader and a self-described admirer of Osama bin Laden threatened all out war against the Nigerian state that pushed oil over $50 per barrel for the first time.[30] Another example is the dilemma of Iran, as sanctions on Iran for developing nuclear weapons play out through the United Nations, the probability of a global energy crisis increases. Iranian ambition to vie for control of the Suez Canal, located between Asia and Africa, where millions of barrels of oil move through every day on the way to both Europe and North America, is being disruptive. This transnational security issue will have far reaching impact on global supply since the Persian Gulf region holds sixty percent of conventional oil reserves.[31] The Persian Gulf is definitely a geopolitical hot spot; however it does not require an unfriendly nation state to cause energy supply instability but a natural act.

Natural disasters can have equal if not greater affects upon United States energy security. For example, Hurricanes Katrina and Rita that struck the Gulf of Mexico's energy infrastructure in 2005 created something the world has never seen in modern times: an integrated energy shock.[32] Everything went down at the same time: oil, and natural gas production an undersea pipelines in the Gulf of Mexico, and onshore receiving terminals, refineries, natural gas processing plants, long distance pipelines, and electricity.[33] These storms demonstrated the lack of resiliency and redundancy in an energy infrastructure reliant on communications networks, pipelines, and gas stations that run on electricity. Other examples include natural disasters like Hurricanes Katrina and Rita. Natural disasters are a risk to energy national security because of their disruptive affect on energy supply, and price. Another risk to United States energy security is with rising energy consumption competitors.

As an increasing number of nations industrialize, their need for energy increases. For example, the Peoples Republic of China is now the second-largest oil consumer in the world, behind only the United States.[34] As China's economy continues to grow so will its demand for energy, and its influence. This will inevitably increase global demand for oil, coal, natural gas, nuclear power, and renewable energy resources. China's domestic oil production makes it the fifth largest in the world ahead of large producers as Canada, Mexico, Venezuela, Kuwait, and Nigeria.[35] China depends on coal for seventy percent of its total energy and about eighty percent of its electricity.[36] China currently relies on the Malacca Strait, the narrow waterway connecting the Indian Ocean and the South China Sea to transport more than seventy five percent of China's oil imports.[37] As China's appetite for energy grows, control of its "oil lifeline", in the South China Sea is a potential geostrategic area for confrontation. China serves as a great example for competitive rivalry, however it is only one of many nation states that are growing and will be seeking more and more energy in the future.

The consequences to energy supply disruption are significant. If even a small percentage of the daily supply of oil is interrupted, our nation's economic engine, heavily reliant on transportation, could be significantly impacted. Without oil there is limited mobility. Without coal, oil, and natural gas there is limited means to produce electricity. Without electricity there are no lights and internet. Without the internet, global communication, trade and financial transactions are interrupted. Energy dependence on foreign sources highlights the importance of increasing domestic sources of supply. The United States with a world leading $15 Trillion gross domestic product is vulnerable to energy disruptions.

Unstable supply due to unpredictable suppliers, natural disasters, and competition that may lead to conflict that has large consequences to a globally connected economy, and highlights the importance of energy policy and why energy is vital to national security. To mitigate risks to disruption, energy policy seeks diversification. Instead of increasing dependence on non-renewable sources of energy from major oil producing countries, the current and predominant thought process is to develop new sources of renewable domestic energy for the future. The hope is that new sources of renewable energy will grow to satisfy demand. Unfortunately, renewable sources of energy are not yet the panacea for increased energy demand.

<u>Renewable Energy</u>

Renewable energy production is limited due to cost per unit of energy produced, sporadic availability, and overall economic feasibility. The 2012 National Security Strategy states, that “new sources of energy will reduce our dependence on foreign oil.”[38] This section will explore why new renewable energy sources are not yet feasible or available to satisfy growing demand.

Five renewable sources that are being expanded include biomass, water (hydropower), geothermal, wind, and solar energy. Over half of renewable energy goes to producing electricity. The next largest use of renewable energy is biomass (wood and waste) for the production of heat and steam for industrial purposes and for space heating, mostly in homes. Biomass also includes bio-fuels, such as ethanol and biodiesel, used for transportation.

Renewable energy has generally been more expensive to produce than fossil fuels per unit of energy. Most renewable sources are not always available (cloudy days reduce solar power; calm days reduce wind power; and droughts reduce the water available for hydropower). Also, the energy output of renewable energy is far less than coal, gas, or oil per unit of energy. All of these factors make renewable energy a good idea that is not yet practical for widespread application. The use of renewable fuels is expected to continue to grow over the next thirty years. Although the Energy Information Administration (EIA) projects reliance on non-renewable fuels to meet most of our energy needs, renewable energy sources are not yet economically feasible or available to satisfy energy demand.[39]

Industry, transportation, residential, and commercial activities all rely on energy, making energy essential to modernize and develop. To quickly summarize, non-renewable sources of energy are limited and supply reliability is problematic, and renewable sources of energy are not feasible or available to satisfy growing demand. So, how can the United States decrease its dependence on foreign energy if non-renewable sources of energy are not feasible? One of the ways to do this, which is becoming very popular, is to expand domestic oil and gas drilling.

<u>Deep Energy</u>

By using new methods to drill deeper than ever before, new sources of 'deep' energy can be resourced. Deep energy is growing in popularity and appears to be the answer for some of the United States energy needs. However, the Hydraulic Fracturing (HF) process adds carcinogenic and hazardous health deteriorating substances, that if not properly controlled will make their way into USDW or ecosystems. The next few paragraphs will explain deep energy, the HF process, and how it impacts the environment and USDW.

Deep energy is the extraction of deep formations of oil and gas. New technologies to stimulate the production of oil and gas from unconventional oil and gas deposits, which include shale, coal beds, and tight sands coupled with the ability to conduct vertical and horizontal drilling is increasing the importance of unconventional energy development. The hope is that deep gas and oil will provide additional variety and contribute to a “rebalance of global demand so that America saves more and exports more, while emerging economies generate more demand.”[40] In particular, shale rock formations are becoming ever more important as a source of natural gas in the United States. Gas derived from shale adds diversity to the United States’ energy mix, and enhances fuel supply resilience.[41] Also, increased access to shale gas lowers natural gas prices, mostly paid by the electric power sector.[42] These two factors have combined to promote the current development and production of deep energy shale gas using HF and horizontal drilling.[43]

It is a long established fact that additional oil and gas are locked in shale and other geologic formations across the United States. Reserves of deep oil and gas shale deposits were discovered in the United States during the gasoline famine of World War I but were inaccessible due to high costs and a lack of technology. Plus an abundance of conventional oil eliminated the need. Horizontal drilling where wells in the past that went straight down, can now be drilled vertically for the first few thousand feet and then driven at an angel or laterally with drilling progress tightly controlled and measured every few feet. Horizontal drilling increases recovery of natural gas and makes drilling more economical. Horizontal drilling means that much more of a reservoir can be accessed, thus increasing production. New technology for liberating shale gas and oil horizontal drilling and HF opened up these reserves to provide new access to deep energy. Horizontal drilling and HF are used for both oil and gas production. For the purpose of this paper however, the focus topic will be on natural gas since it uses more water and is therefore more relevant to concerns about water sustainability.

The HF process is a five step process. The first step is to acquire water. HF requires large volumes of water that must be transported to the well site. The second step is chemical mixing. Once onsite, the water is mixed with chemicals and a propping agent, ‘proppant’ such as sand, bauxite, or ceramic beads. The third step is well injection. The resulting fracturing fluid is pumped down the well under high pressures, causing the targeted formation to fracture. The fourth step is flow-back from produced water. As the injection pressure is reduced, the fluid is returned to the surface, leaving the proppant behind to keep the fractures open. The resulting fractures create pathways in otherwise impermeable gas-containing formations, resulting in gas flow to the well for production. A portion of the injected fracturing fluid; water, chemical additives, and proppant, as well as naturally occurring substances released from the formation is then returned to the surface as flow-back and produced wastewater. The fifth step is wastewater treatment and waste disposal. Wastewaters are stored on-site in tanks or pits before being transported for treatment, disposal, land application, or discharge.

At the end of 2009, the five most productive shale gas fields in the country; the Barnett Shale in Texas, the Haynesville in Louisiana and East Texas, the Fayette in Arkansas, Woodford in Oklahoma, and the Marcellus in Pennsylvania, New York, Ohio, and West Virginia were producing 8.3 billion cubic feet of natural gas per day.[44] According to the Energy Information Administration (EIA), shale gas constituted fourteen percent of the total United States natural gas supply in 2009, and will constitute forty five percent of the United States natural gas supply in 2035.[45] Depths for shale gas formations, commonly referred to as “plays”, can range from 500 to 13,500 feet below the earth's surface.[46] The energy potential of HF must be tempered with an understanding of longer term environmental and human health impacts in these areas.

Energy sources all have varied impacts upon on the environment. Some of these effects may include emissions, waste, and land or water use impacts, among others. In any drilling or excavating operation there will be concerns about road traffic, production noise, land use, and mineral rights. Shale gas production impacts the local populace in similar ways to other drilling operations that bring in many people who utilize roads to haul in equipment, transport the extracted energy for processing, and support to the overall production effort. Local and state environmental concerns in any drilling operation include the impact on the land, the air, the geology, and local water sources. Effects to consider include; air quality, wildlife habitat fragmentation, soil contamination, land use, impact to farming, restoration of drill sites, seismic risks, public and worker safety, and even the sociological effects as a community adapts to a large temporary influx of workers. These are all valid concerns; however more at issue is the direct impact to human health due to exposure of hazardous chemicals.

One of the highlighted concerns portrayed in the documentary film "Gasland", vividly demonstrates higher levels of methane in drinking water from local wells where residents living near shale gas drilling facilities experience symptoms of headaches, diarrhea, nosebleeds, dizziness, blackouts, muscle spasms, and other problems.[47] In response, Robert Jackson, a professor of environmental sciences at Duke University sampled 60 residential drinking water wells for dissolved methane levels and found that, on average, wells near active drilling sites were contaminated with methane at levels seventeen times higher than those found in wells in areas without drilling.[48] Moreover, the average found, 19.2 mg/L, was within the defined action level of > 10 mg/L but < 28 mg/L recommended for hazard mitigation by the U.S Department of Interior.[49] Although methane exposure has acute symptoms and large dose exposure over time could be fatal, the EPA states that methane is “not classifiable as to human carcinogen, and that there is no animal or human test data to prove chronic health issues.”[50] Although exposure to methane is widely known to cause poor heath symptoms, the more important issue above methane exposure is the longer term impact to human health caused by hazardous HF chemicals in water.

The effect of HF on water availability is the first concern. HF additionally threatens water availability in general due to the sheer magnitude of water used. The amount of water required varies from 2 to 5 million gallons per drilling site depending on the geology of the drilled substrata.[51] The EPA estimates 35,000 wells undergo HF annually in the United States, requiring from 70 to 140 billion gallons of water that could be used each year by up to 5 million people.[52] This is equivalent to the total amount of water used each year in roughly forty to eighty cities with a population of 50,000 or about 1 to 2 cities of 2.5 million people.[53] Due to this substantial need for water there are local, regional, and global implications.

Locally and regionally, this rate of water usage could impact the availability of USDW in areas where HF is occurring. The removal of large volumes of water could stress or permanently harm drinking water supplies, especially in drier regions where aquifer or surface water recharge is limited. This could lead to lowering of water tables or dewatering of drinking water aquifers, decreased stream flows, and reduced volumes of water in surface water reservoirs.[54] The diversion of already scarce water resources needed to extract energy from underground formations will further limit supplies for agriculture, drinking wells, and other human purposes.[55] In the Marcellus shale region, stakeholder concerns have focused on large volume, high rate water withdrawals from small streams in the headwaters of watersheds supplying drinking water rather than overall water use.[56] Fortunately, the region that defines the Marcellus shale has a moderately wet climate and water use is less significant. For other “gas plays” in the arid, dry, west this could be a significant concern for water availability. The negative influence of HF on water availability is more pronounced in regions that have dry, arid climates. Globally, 1.1 billion people lack access to clean water supplies, and 2.4 billion lack accesses to basic sanitation.[57] Thus, water availability in general is additionally threatened by the HF process. Water availability can be a significant concern depending on the water source location. However, a larger concern is the potential impact to water quality.

There are three ways water quality is affected by the HF process. The HF process negatively affects water quality by lowering water levels, introducing chemicals directly into the water, and eroding naturally occurring materials at depth. First, water quality is affected by lowering water levels. Lower water levels in aquifers may affect water quality by exposing naturally occurring minerals to an oxygen rich environment. This may cause salination of the water and other chemical contaminations. Additionally, bacterial growth may be stimulated by increased oxygen causing biological contamination. Also, the removal of significant volumes of water may reduce the dilution effect and increase the concentration of contaminants in surface water resources.[58]

Second, the HF process introduces hazardous chemicals directly into the water. In September 2010, ten companies were issued a court subpoena requiring them to release information about chemicals that were publically known to be used in HF. As of December 2010 all companies provided full disclosure. One particular firm, Halliburton provides full public disclosure on their website at: http://www.halliburton.com/public/projects/pubsdata/Hydraulic_Fracturing/fluids_disclosure.html. The overall concentration of chemical additives in HF fluids used in shale gas plays ranges from 0.5 to 2 percent by volume with water and proppant comprising the remainder. This indicates that 15,000 to 60,000 gallons of the total fracturing fluid consists of chemical additives (assuming a total fluid volume of 3 million gallons).[59]

The third way that HF process affects water quality occurs during the injection and flow back steps where erosion of materials at depth is added to water. Along with the introduced chemicals, HF water is in close contact at high pressure with rock and hydrocarbon formations during the course of the stimulation treatment. After the fracturing event, the pressure is decreased and the direction of fluid flow is reversed, allowing fracturing fluid and naturally occurring substances to flow out of the wellbore to the surface as wastewater. HF wastewater contains many substances such as sand, polyacrylamide, guar gum, hydroxyethyl cellulose, ethylene glycol, glutaraldehyde, n,n-dimethyl formamide, trace elements of mercury, lead, arsenic and other Naturally Occurring Radioactive Material (NORM), radium, thorium, and uranium.[60] These substances are considered to be health deteriorating.

By lowering water levels, introducing chemicals into the water, and eroding naturally occurring materials at depth, the HF process contaminates water with carcinogenic and hazardous chemical and material substances. In addition, these contaminating substances are being introduced to fresh water sources that will negatively impact the environment, ecological systems and ultimately human health.

These substances are contaminating USDW. The sources of contamination of USDW are attributed to accident, lack of wastewater treatment, and by hydraulic fractures extending beyond the target formation to fresh water aquifers. First, accidents happen due to well casing breakage or surface spillage due to a transport pipe or truck introducing harmful HF wastewater to surface or ground waters. Second, a lack of adequate wastewater treatment introduces HF chemicals into USDW. Wastewater treatment at publicly owned treatment works is not an option, because publicly owned treatment works are not designed to treat HF wastewaters. Contaminated wastewater contains high levels of Total Dissolved Solids (TDS), which are measureable microscopic minerals and organic materials dissolved in the water. Municipal water treatment plants are not equipped to handle large amounts of TDS. If dissolved solids with hazardous contaminates pass through sewage plants to streams and rivers, they can kill fish and change ecosystems. Not only is there a potential for harm due to large amounts of corrosive and highly dissolved solids content found in HF waste water that have significant health concerns, also public treatment works do not treat fluids that contain radio-nuclides.[61] If HF wastewater produced carcinogenic chemicals, especially radioactive nuclide materials attach to dissolved solids enter USDW there is added exposure risk to the environment, ecological systems, and human health.

Third, hydraulic fractures extend beyond the target formation to fresh water aquifers. The extension of HF fractures in the ground to water aquifers will contaminate

USDW with hazardous materials due to a lack of understanding of the geological conditions at depth. When hydraulic fractures combine with pre-existing faults or fractures that lead to aquifers or directly extend into aquifers, injection contaminates fresh ground water. HF trace elements of mercury, lead, and arsenic and/or Naturally Occurring Radioactive Material (NORM), radium, thorium and uranium then migrate into USDW supplies.[62] The opportunity for contamination will depend on the distance to fresh water resources and the geochemical and transport process.

Accidents, insufficient HF wastewater treatment, and hydraulic fractures extending beyond the target formation to fresh water aquifers demonstrate clearly how chemicals from the HF process are finding their way into USDW. The discussion then turns to what; if any consequence does exposures to HF contaminated water have on human health?

Impacts to Human Health

It is important to recognize that clean water; essential to sustain human life is being threatened by HF. More importantly, at the right exposure level, there will be negative biological human impacts due to exposure of chemicals produced in the HF process that cause toxic substance poisoning, auto-immune diseases or cancer. This section will look at the biological human impact; establish that there is a potential for human and ecological disease due to materials found in water contaminated by HF chemicals; and discuss why there is a current lack of definitive scientific proof linking exposure of HF chemicals in water to human disease.

Two factors determine biological human impact; toxicity and dose. Toxicity is the degree to which a substance can damage a living organism. A dose is a quantity of something that may impact an organism biologically; the greater the quantity, the larger the dose. The following recent studies describe the toxicity, potential exposure, and effect of HF chemicals on humans. Many of the HF additives like sand, polyacrylamide, guar gum, and hydroxyethyl cellulose are benign; however chronic toxicity to humans has been associated with some identified chemicals, such as ethylene glycol, glutaraldehyde, and n,n-dimethyl formamide.[63] Testing done on rats for ethylene glycol oral exposure found definite health effects such as renal and kidney problems at different exposure levels for some of these substances, however a complete evaluation and determination for evidence of human carcinogenic potential has not been conducted.[64]

Another example of human health impact caused by HF is highlighted by the use of benzene. Between 2005 and 2009, oil and gas service companies injected 32.2 million gallons of diesel fuel or hydraulic fracturing fluids containing diesel fuel in wells in 19 states."[65] Benzene, a common chemical in diesel fuel is classified as a 'known' human carcinogen where many experimental animal studies, both inhalation and oral, support the evidence that exposure to benzene increases the risk of cancer in multiple organ systems including the hematopoietic system, oral and nasal cavities, liver, fore stomach, preputial gland, lung, ovary, and mammary gland.[66] Benzene is insoluble in water, and exposure at any level is considered hazardous to human health. Fortunately, benzene contamination, measured in parts per billion in water, is tested for at most public wastewater treatment facilities. Another test conducted looks at levels of radioactive poisons in HF wastewater. A limited time series monitoring program of post-fracturing wastewater fluids in the Marcellus shale indicated increased concentrations through time of total dissolved solids, chloride, barium, and calcium; water hardness; and levels of radioactivity, which are often used in the HF process.[67]

All three of these research studies demonstrate clearly that there are hazardous carcinogenic and radiological substances in HF wastewater, some of which are known disease causing substances. This is important, and establishes that there is potential for human and ecological disease due to materials found in HF water. However, the problem remains that there is no definite proof that the materials found in HF water have directly caused disease in humans. For instance, some studies debunk the possibility, reasoning that humans, if exposed would only experience small doses. The American Petroleum Institute (API) cited in a 2010 guide to water management associated with hydraulic fracturing that while a small number of potential fracture fluid additives such as benzene, ethylene glycol and naphthalene have been linked to negative health effects at certain exposure levels outside of fracturing operations, these are seldom used and/or used in very small quantities.[68] The API also stated that, 'most additives contained in fracture fluids present very low risks to human health and the environment.'[69] All of these studies agree that there are potential health issues; however the first three highlight the risk while the other downplays the risk to human health. So, if scientific study is in contradiction, there is a knowledge gap. So what is known and what are the known unknowns of the impact to human health?

It is known that hazardous, toxic and sometimes carcinogenic HF chemicals can be found in HF wastewater and are being introduced to freshwater sources. It is known that some of these HF chemicals cause human disease. It is also known that the hydraulic fracturing service companies have claimed this data to be confidential business information, and although they have disclosed there proprietary ingredients under mostly generic names and in accordance with the law, they do not represent the entire set of chemicals used in hydraulic fracturing activities.

Known unknowns include toxic effects of these substances at potential release concentrations. It is unknown about the frequency, quantity, and concentrations of chemicals used in the HF process. This knowledge could be used to better understand the toxic effects of hydraulic fracturing. Also, it is unknown what the mechanism is for connecting HF hazardous substances to disease. For instance; The National Academy of Sciences Institute of Medicine Committee concluded that "there is inadequate/insufficient evidence to determine whether an association [exists] between exposure to uranium and kidney disease, various cancers, cardiovascular, geotaxis, cardiovascular, immunologic and skeletal effects.[70] This study highlights the complexity, depth and general lack of scientific knowledge of determining disease causation for just one substance. The pathology, health effect, and disease causation science is difficult, expensive, and not well understood for many substances. Therefore, proving that there is a definite connection between hazardous chemicals and materials found in HF wastewater and human disease will require additional research.

All of these unknowns are interesting, however it is more important to understand it that there are consequences to human health if these ill defined chemicals are not properly controlled. A lack of current research that proves biological human impact due to HF chemicals in water does not negate the potential threat of disease in humans. The next section will discuss how the United States currently regulates these hazardous substances through policy.

Regulatory

It is important to understand that current federal regulations do not adequately address the potential risks of HF wastewater to human health. Water policy is mostly kept at the states, watersheds, water cooperatives, and local level. In general, wastes generated by the exploration, development and production of crude oil and natural gas are “exempt” by Federal Law from being regulated as hazardous waste. The most pertinent regulations include:

- Solid Waste Disposal Act of 1980 prohibits EPA from regulating drilling fluids, produced water and other waste associated with the exploration, development or production of crude oil or natural gas as hazardous waste.
- Federal regulation subjects all drillers to the federal Clean Water Act which controls the disposal of flow back fluids into surface water.[71]
- The Energy Policy Act of 2005 specifically excludes underground injection for purposes of hydraulic fracturing, except where it involves injection of diesel fuels, from regulation by the United States EPA under the Safe Drinking Water Act (SDWA).[72] This exemption gave the drilling companies full rights to contaminate water to conduct hydraulic fracturing.
- The Fracturing Responsibility and Awareness of Chemicals Act of 2009 (FRAC Act) legislation was introduced in both the United States House of Representatives and the Senate to eliminate the SDWA exemption for hydraulic fracturing. [73] The FRAC Act is still in the legislative process.

What this means is that oil and gas wastes produced in the HF process are currently referred to and regulated at the state level as “non-hazardous waste.” The problem is not going away, however it can be abated either through litigation or better yet, through good policy and procedure.

Water Policy

It is essential that policymakers increase the importance of water in national security. Water sustains life. The HF issue exposes weakness in water policy with respect to energy to protect from threats to human health. Water sustains life, energy only makes life better. So policymakers should make changes now based on precedent, adequate logic that explains current counter objections, reasonable cost, and the consequence of not taking action. This section will make the argument why there is both a need for increased inspection and research and a need to strengthen water policy.

This paper adequately describes how drinking water is being contaminated from HF chemicals, and how HF chemicals can cause human biological disease. The precedent for HF chemicals to negatively impact human health has been established. This paper also adequately describes the gap in scientific knowledge that has not yet been able to prove disease causation in humans due to potential exposure of HF chemicals in water. Industry uses this gap in knowledge to exploit any efforts to fund additional methods to protect USDW from HF contaminated wastewater. However, the counter-objection stated by industry that, “conclusive scientific evidence has never linked hazardous chemicals in HF fluid to human health issues,” is a false logic argument. Concluding that there is no problem, because the problem has not been seen yet or thinking that there is no problem because there is no ‘unequivocal scientific evidence’ proving a problem is a false logic argument. This argument is analogous to the promotion of cigarettes for health in the 1950s. Because the toxicity of tobacco substances that caused cancer was not well understood, the potential for harm was ignored. This thinking led to enormous long term legal and cost consequences for the tobacco industry. The next section will demonstrate how funding costs could be allocated that are reasonable and do not significantly impact the profitability or quantity of deep gas energy.

In 2011, the wellhead price on natural gas was $3.95 per thousand cubic feet and gross withdrawals from shale wells were 3,383,532 million cubic feet.[74] This equates to a producer gross domestic sales of natural gas from shale wells to be approximately $3.4 billion per year. Assuming producers could match U.S. corporations who spend on average 2.62 percent of GDP annually on research and development, then industry could potentially budget up to $89 million dollars per year to seek better ways to extract deep energy and protect water for human health without additional taxation to the consumer.[75] In contrast, if actions are not taken, the consequence for health litigation costs and political repercussions in 40-80 cities that have increased cancer cases directly attributable to HF waste could be much more of a problem than paying for adequate, and redundant safeguards to protect people from chronic disease.

The precedent for causing disease in humans is determined, counter-objections have no basis in logic, adequate protection can be provided at a reasonable cost, and the consequence of not taking action will be much worse in the future. There could be no better time for action. So, what can be done now? Increased research and inspection in the following areas will prevent HF wastewater from entering USDW due to accident, lack of geological knowledge, or lack of adequate waste treatment. Also, taking these actions now will assist industry to mollify public distrust.

- Amend Standards for Well Construction and Casing to Prevent Leaks and Accidents: Ensure stringent design and construction criteria for deep extraction well casing. Increase steel and concrete cross section design to assure well casings are non-permeable. This will prevent leakage of HF wastewater from the well into surrounding water aquifers limiting the potential exposure pathways for contaminated HF wastewater to enter fresh water aquifers.
- Systematically Sample Drinking Water Wells and Deep Formation Waters: Baseline sampling in the region surrounding deep extraction wells would provide the basis for chemical characterization of the shallow ground water and should then be followed with monitoring to evaluate the long-term impact of HF. A national database should be established to share and compare testing results.
- Increase Quality Assurance Inspection of HF Water Handling: Unbiased inspectors should be employed to assure proper oversight of the HF water throughout the entire HF water life cycle. Additional effort for oversight should be made during the water removal and transport steps to provide additional quality assurance.
- Conduct Geological Analysis of Potential Deep Pathways for HF Wastewater to Migrate into Fresh Water Aquifers: Standards for the minimum safe distance between HF wells and fresh water aquifers needs to be established. This should be done to ensure to ensure fresh water aquifers are not in 'the vicinity' of drilling operations. This needs to be done for each geological

substratum to make informed decisions on the best location to conduct HF operations. These standards, once set, can become industry best practices for deep drilling operations.

- Study Disposal of Waste Waters from Hydraulic Fracturing and Shale Gas Extraction: Individual states have different regulations for disposal of HF wastewater. Disposal ranges from direct re-introduction into streams and rivers and treatment. Methods to treat HF wastewater include dedicated commercial water treatment facilities, evaporation storage tanks, injection into deep ground storage, municipal water treatment facilities, and reuse. Approaches are varied and non-comprehensive. This should be started now, and an evaluation of the long term impacts of wastewater disposal should be conducted. This should be particularly done if the method of disposal is to streams or rivers. The study should evaluate what amounts of different contaminants, including naturally occurring TDS, and radioactive chemicals, are removed in the wastewater treatment process.
- Initiate Medical Review of the Health Effects of Methane: Methane is not regulated as a contaminant in public water systems through the EPA. Since methane makes a great media story by providing graphic displays of kitchen water faucets that can be ignited with a lighter, referring to the movie 'Gasland', then a panel of health-care professionals needs to conduct research to quickly examine the consequences of ingesting and breathing methane. Depending on the panel's recommendation, the EPA might consider defining a max contaminant level, or if the panel concludes that

systematic research is not necessary, and then their findings would alleviate concerns about the gas and its potential public health liabilities.

The water policymaker should take these actions now to protect the public from contaminated HF wastewater that will negatively impact human health by entering USDW. In addition to the more immediate steps to conduct research and inspections, efforts to improve water policy should be made.

Sustainable Water Policy

The science to fully understand the HF implications on human health is extremely complex, and therefore will require expert study by environmental, petroleum, ground water hydrology, epidemiology, fate and transport modeling, toxicology, and many other disciplines. Research will need to analyze the full lifecycle of water in hydraulic fracturing, from water acquisition through the mixing of chemicals, to the ultimate treatment and/or disposal. Understanding the factors that may lead to human exposure and risks is important however, it will take years of research. In between, since the EPA fails to directly regulate the disposal of wastewater that contains known carcinogenic and other hazardous substances, states and watersheds must be vigilant. The mitigation, containment, and treatment of HF waste should be handled as hazardous waste. Full disclosure of the chemicals used in HF must be made mandatory. Specific disclosure of chemicals used, such as the Chemical Abstract Service (CAS) number and specific chemical formula information must be provided by industry. A way to do this is to make HF subject to the same requirements as the Safe Drinking Water Act (SDWA). The SDWA sets standards for drinking water quality and oversees the states, localities, and water suppliers who implement those standards. Industry needs to be more transparent, and government needs to provide for public health protection and safety through regulation. Also, any movement in the direction of transparency by industry in this area would strengthen public confidence in HF and natural gas extraction.

In a larger global context, policymaker's should develop sustainable policy between energy development and water quality to ensure security for future generations. Policymaker's should also consider if water is being utilized in the best way as a resource that directly sustains basic human health on a global scale? Is there a basic human right to clean water that sustains life? Should fresh water be better allocated for the purpose of improving human security and providing for future generations over the need to improve the existing conditions of life for those who already have fresh water? These are complex questions that have extensive cultural, economical, political and social factors. The efforts to manipulate the global supply of petroleum, and natural gas have been a leading phenomenon of the final decades of the 20th Century; however control of the sources of fresh water could be equally significant in the opening decades of the next.[76]

Conclusion

Energy and water are both vital natural resources that should be promoted with equal vigor. Energy makes life better; however water is vital for life. The immediate debates being conducted about HF bring to light the importance of access to adequate supplies of clean water and calls for stronger water policy that sustains human health and is thus vital to national security. Water protection procedures for HF needs to be strengthened now to address the potential threats to water availability, quality, and human health. It is imperative that sound water policies are adopted in a new era of deep shale gas extraction to ensure the future of water resources required for both energy security and water sustainability.

Endnotes

[1] American Petroleum Institute, *Water Management Associated with Hydraulic Fracturing*, API Guidance Document, HF2, First Edition, API Publishing, (NW, Washington D.C. June 2010), 1.

[2] Butts, Kent Hughes, "The Strategic Importance of Water," *Parameters* 27, no. 2 (Spring 1997): 65.

[3] United States Environmental Protection Agency, *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*, (Washington, D.C: Office of Research and Development U.S. Environmental Protection Agency, February 2011), 10.

[4] Peter H. Gleick, *Water in Crisis: A Guide to the World's Fresh Water Resources* (New York: Oxford Univ. Press, 1993): 3.

[5] Butts, "The Strategic Importance of Water,"65.

[6] Joint Forces Group, *Joint Operating Environment,* (United States Joint Forces Command, Suffolk, VA, 2010), 12.

[7] ibid., 33.

[8] ibid.

[9] United States Government Accountability Office, *Freshwater Supply,* (Washington, D.C.: October 29, 2010) www.gao.gov/cgi-bin/getrpt?GAO-03-154, (accessed January 24, 2012).

[10] United States Department of Energy, *The connection: Water Supply and Energy Reserves*: (Washington, D.C. U.S. Department of Energy, 2007). http://www.waterindustry.org /Water-Facts/world-water-6.htm, (accessed February 3, 2012).

[11] Joint Forces Group, *Joint Operating Environment,*12.

[12] United Nations Environment Programe: *Clearing the Waters, a focus on water quality solutions*, (Pacific Institute, Oakland, CA, 2010). http://unep.org/PDF/Clearingthewaters.pdf. (accessed February 7, 2012). 11.

[13] United States Department of Energy, *The connection: Water Supply and Energy Reserves*, 3.

[14] United Nations Environment Programe, *Clearing the Waters, a focus on water quality solutions,* 21.

[15] United States Energy Information Administration, *U.S. Energy Facts Explained,* (Washington, DC. U.S. Department of Energy), http://www.eia.gov/energyexplained/index.cfm?page=us_energy_home, (accessed February 2, 2012).

[16] Daniel Yergin, *The Quest: Energy, Security, and The Remaking of the Modern World,* New York, NY, The Penguin Press, 2011) 3.

[17] United States Energy Information Administration, *U.S. Energy Facts Explained,* (Washington, DC., U.S. Department of Energy), http://www.eia.gov/energyexplained/index.cfm?page=us_energy_home, (accessed February 2, 2012).

[18] Ibid.

[19] United States Energy Information Administration, *Oil, Crude, and Petroleum Products Explained,* (Washington, DC., U.S. Department of Energy), http://www.eia.gov/energyexplained/index.cfm?page=oil_imports. (accessed February 2, 2012).

[20] ibid.

[21] United States Energy Information Administration, *Where our Coal Comes From,* (Washington, DC., U.S. Department of Energy), http://www.eia.gov/energyexplained/index.cfm?page=coal_where. (accessed February 2, 2012).

[22] ibid.

[23] United States Energy Information Administration, *How was Natural Gas Formed*. (Washington, DC., U.S. Department of Energy), http://www.eia.gov/energyexplained/index.cfm?page=natural_gas_home. (accessed February 2, 2012).

[24] United States Energy Information Administration, *U.S. Energy Facts Explained,* (Washington, DC., U.S. Department of Energy), http://www.eia.gov/energyexplained/index.cfm?page=us_energy_home, (accessed February 2, 2012).

[25] ibid.

[26] ibid.

[27] ibid.

[28] Ibid.

[29] Yergin, *The Quest: Energy, Security, and The Remaking of the Modern World,* 258.

[30] ibid., 136.

[31] ibid., 5.

[32] ibid., 266.

[33] ibid.

[34] ibid., 192.

[35] ibid., 207.

[36] ibid., 210.

[37] ibid.

[38] National Security Strategy, 2012, pp 4.

[39] United States Energy Information Administration, *U.S. Energy Facts Explained,* (Washington, DC. U.S. Department of Energy), http://www.eia.gov/energyexplained/index.cfm?page=us_energy_home, (accessed February 2, 2012).

[40] National Security Strategy, 2012, pp 4.

[41] Cadet Nathaniel Freeland, *The Strategic Importance of Shale Gas*, (Center For Strategic Leadership, U.S. Army War College), September 2011. 2.

[42] United States Energy Information Administration, *Assumption to the Annual Energy Outlook 2011*. (Washington, DC. U.S. Department of Energy, Jul 2011), 109.

[43] Soeder, D.J., and Kappel, W.M., *Water resources and natural gas production from the Marcellus Shale:* (U.S. Geological Survey Fact Sheet, U.S. Department of the Interior, 2009), 6.

[44] United States Environmental Protection Agency, *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*, 8.

[45] ibid.

[46] ibid.

[47] Fox J., “Gasland”, 2010 documentary film, (Brooklyn, NY: International WOW Company, 2010).

[48] Charles W. Schmidt, *Blind Rush, Shale Gas Boom Proceeds amid Human Health Questions,* (Environmental Health Prospective, August 2011). 352.

[49] ibid.

[50] United States Environmental Protection Agency*, Integrated Risk Information System,* http://www.epa.gov/iris/subst/ 0522.htm#woe. (accessed February 6, 2012).

[51] Harper J.A., “The Marcellus Shale – an old “new” gas reservoir, in Pennsylvania Geology”, (Pennsylvania Department of Conservation and Natural Resources, 2008). 20.

[52] ibid.

[53] United States Environmental Protection Agency, *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*, 19.

[54] ibid., 20.

[55] Joint Operating Environment, United States Joint Forcs Command, Suffolk, VA, 2010, pp 28.

[56] United States Environmental Protection Agency, *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*, 19.

[57] Hoffman, A., *The connection: Water Supply and Energy Reserves,* (The United States Department of Energy, 2007) http://www.waterindustry.org/Water-Facts/world-water-6.htm, (accessed February 3, 2012).

[58] United States Environmental Protection Agency, *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*, 21.

[59] ibid., 24.

[60] ibid.

[61] ibid., 40.

[62] ibid., 27.

[63] ibid., 25.

[64] United States Environmental Protection Agency*, Integrated Risk Information System*, http://www.epa.gov/iris/subst /0238.htm, (accessed 27 February 2012).

[65] United States Environmental Protection Agency, *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*, 25.

[66] United States Environmental Protection Agency*, Integrated Risk Information System*, http://www.epa.gov/iris/subst /0238.htm, (accessed 27 February 2012).

[67] United States Environmental Protection Agency, *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*, 37.

[68] American Petroleum Institute, *Water Management Associated with Hydraulic Fracturing*, 7.

[69] ibid.

[70] McKay, L. K., *Science and the reasonable development of Marcellus Shale natural gas resources in Pennsylvania and New York.* (Energy Law Journal, 2011) 125.

[71] ibid.

[72] ibid.

[73] ibid.

[74] Energy Information Administration, *Natural Gas Summary.* http://205.254.135.7/dnav/ng/ng sum lsum_dcu_nus_a.htm (accessed March 6, 2012).

[75] Organization for Economic Co-operation and Development, *Science, Technology, and Industry Outlook*,(OECD, 2008), http://www.oecd.org/dataoecd/17/53/41558958.pdf (accessed, 6 March, 2012).

[76] Butts, "The Strategic Importance of Water,"2.