Freshwater and Marcellus Shale Mining

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Overview

The demand for another source of energy is at the top of the wish list for our growing population. Civil unrest in the Middle East is leading to higher oil prices. Civil unrest is beginning to spread like a cancer: Nigeria is getting involved in the conflict and people are demonstrating in the streets. The United States gets a percentage of oil from this region. The State of Pennsylvania is sitting on a very large Marcellus Shale deposit that can trace its origin back to the Devonian Period of time. The process of removing natural gas from shale requires an enormous amount of water. People tend to think that somehow we will always have clean water to drink. Water is a universal solvent, which makes up approximately 70% of our body. The new process of abstracting the gas from shale requires approximately 2 million gallons of water per well. During this process several other chemicals are mixed into the water. Many of the chemicals used in the extraction process are lethal. The companies involved in the mining **should** have strict guidelines imposed on them. The gas mining companies have been exempt from obeying the requirements of the "Clean Air" and "Clean Water Act" of 1975. The policy that was passed by Congress would require companies to return the water in the same way that it was taken from its source. However, Marcellus Shale mining companies have been exempt from following these regulations. The water taken from various places such as wells, ponds, lakes, and streams can't return after the extraction process. The water now contains some of the following chemicals: Benzene, Sulfuric Acid, Ethylene Glycol, Surfactants, Sodium Hydroxide, Silica, Hydrochloric Acid, Calcium Hydroxide, and Polyethylene Glycol. The chemicals listed are just a few of the harmful substances that we can find in the water after the extraction process.

Rationale

Clean drinking water is something students take for granted. They do not even consider the processes involved in the collection, filtration, and distribution of water in their house. Some students tend to think that it is free. The City of Philadelphia has always been at the forefront of providing clean drinking water for its citizens. The "Waterworks," is a good example of how the city was actively involved in freshwater collection and distribution.

Marcellus mine drilling will provide the state with more jobs and revenue. A movement for providing a special tax for Marcellus Shale mining is being discussed by legislators. The federal government should also look into other ways of possibly recycling the water used in the mining process. The water cannot continue to leave our environment and return back undrinkable. The problem of the past still remains today: is the nation willing to pay the short-term price for long-term improvements? I want my students to evaluate this question and think as responsible citizens. Some of my high school students have children; this will play a major factor in how they look at clean drinking water.

Background

Marcellus Shale Geology

Marcellus Shale is a sedimentary rock formation that was deposited over 350 million years ago (http://geology.com/usgs/marcellus-shale, 1). Sedimentary rock formations are formed when algae and other organisms die and fall to the sea bottom. These organisms provide the carbon that has since changed into hydrocarbons. The water source dries up over time and a sedimentary rock formation like Marcellus Shale is born. Shale rock originally consisted of layers of clay and mud and dead organic matter. When these layers are compressed the result is fine-grained sedimentary rock (Sumi, 2). Marcellus Shale eventually became part of the Devonian Black Shale Field. During this time bony fish and early amphibians appeared on the earth. The Marcellus Shale rock formation is located where the present day Appalachian Mountains stand. The rock formation is located in five states: Maryland, New York, Ohio, Pennsylvania and West Virginia (http://geology.com/usgs/marcellus-shale, 1).

Marcellus Shale was named after the town of Marcellus, New York because of the appearance of shale on the surface. The rock formation extends over 575 miles and spans over five states (Sumi, 3). Scientists estimate that the Shale formation contains 168 trillion to 516 trillion cubic feet of natural gas. The state of New York uses approximately 1.1 trillion cubic feet of natural gas per year (http://www.dec.ny.gov/energy/46288.html, 2). The United States produces approximately 30 trillion cubic feet of natural gas. States having this rock formation have skyrocketed into the lead position as potential natural gas producers. The largest part of the Marcellus Shale minefield is in Pennsylvania.

Marcellus Shale is exposed in some areas however there are some parts as deep as 7,000 feet or more (http://www.dec.ny.gov/energy/46288.html, 1-2).

Things That Led to an Increase in Gas Production

Civil unrest in oil producing countries has contributed to finding other sources of energy. Technology has caused an increase in natural gas mining due to enhancements in gas well drilling. Gas wells were primarily dug using the vertical technique of drilling. New methods of drilling such as horizontal drilling and hydraulic fracturing proved to be an effective way of extracting the natural gas. The proximity of the cities where demands for natural gas are high and the construction of the Millennium Pipeline through the southern tier are all factors that have led to an increase in shale mining (http://www.dec.ny.gov/energy/46288.html, 2).

The government has been involved in funding projects that explored different forms of energy. In the 1970's and mid 1980's the U.S. Department of Energy (DOE) funded the Eastern Gas Shales Project (EGSP) to develop new technology. The new technology would attempt to commercially advance the extraction of Devonian shale gas. The EGSP attempted to find out the size of the resource and amount of recoverable gas. The EGSP was interested in trying to find the best method of extracting the gas. In the mid 1980's the Institute of Gas Technology (IGT) conducted experiments on the samples obtained by EGSP. The IGT lab experiments led to a "gas in place" value for the Marcellus Shale sample. The values reached during this experiment gave scientists a snapshot of the resource. The values were far above the expectation that was given by the Petroleum Council in 1980 (http://geology.com/usgs/marcellus-shale, 1, 2). Increases in natural gas prices have contributed to natural gas development. Gas prices rose from $2.00 per MCF (thousand per cubic feet) to $10.82 per MCF during the summer of 2008. It became profitable to mine gas and according the Range Resources (one of the first Marcellus Mine drillers) in 2008 the wells produce approximately 4MMCF (million cubic feet). The successes of the Barnett Shale mines in Texas have stimulated the taste buds of energy power brokers in the country.

Devonian Black Shale is profitable because it has unique qualities. These qualities include low permeability; carbonaceous (organically rich); natural vertical fractures; slight radioactivity; and it is a low-density fissile shale (http://wwwsrbc.net, 3).

Fracking Process

In order to produce a natural gas of commercial quality, scientists relied on the ability of black shale fracturing properties. A process called, "hydraulic fracturing" or "hydrofrac" is used. In the hydrofrac process high-pressure water forms fractures in the rock. The rock is propped open by the sand and other minerals (the proppant); this allows more gas to move in the well (http://geology.com/usgs/marcellus-shale, 1). Approximately two to

six million gallons of water are required for each well. The hydraulic fracturing fluid consists of many other compounds that have been added to water rendering it more effective. The chemicals can include a friction reducer, a biocide to prevent the growth of bacteria and a gel to carry the proppant into the fracture. Several of the chemicals used during the fracking process are extremely hazardous to all living organisms.

Another technique used is drilling down vertically and then making the drill go horizontally into the deposit. Miners are able to maximize the contact of the drill inside of the gas bearing rock. Multiple horizontal wells can be drilled laterally from the same well site location. Miners have the ability to drill under the property of an individual (http://www.dec.ny.gov/energy/46288.html, 3-5). A highly effective well features multiple crosscutting. You will be able to get the most out of the well because gas will come from many fractures.

Many chemicals are used during the fracturing process. Water and sand make up about 98% of the mixture. The water expands the fracture and the sand allows the fracture to remain open. Additives account for 2% of the mixture. The additives involve the use of acids to dissolve minerals and initiate cracks in the rock. The corrosion inhibitor prevents the pipes from corroding. The iron control additive prevents any precipitation of metal in the pipe while the anti-bacterial agent eliminates bacteria in the water. The scale inhibitor prevents scale deposits inside of the pipes and on the surface equipment. The clay stabilizers prevent clay from swelling inside of the pipes while the friction reducers slick the water minimizing any friction that would result from the process. The viscosity of the fracture fluid is increased when surfactants are added. The gelling agent thickens the water in order to suspend the sand in the slurry, while the breaker additive allows a delayed breakdown of the gel. A cross linker additive maintains the fluid viscosity while the temperature rises. And the final additive to this mixture is a pH-adjusting agent. The pH-adjusting agent maintains the effectiveness of the other components such as the crosslink.
(www.chk.com/Media/CorpMediaKits/Hydraulic_Fracturing_Fact_Sheet.pdf, 2)
The actual components of the additives remain a trade secret. Companies do not want to release to the public all of the concentrations of the additives. Many of the additives are carcinogens such as benzene, trihalomethane.

Water Rights

The Marcellus Shale mines obtain water from several different sources. Several questions are raised concerning the usage of the water. Are the water rights acquired with the leases? What do the water rights mean in practical terms? Can you withdraw as much as you need? The water rights in the eastern United States evolved from the principle of common law and riparian laws established approximately 250 years ago. Common law rights have been supplemented and regulatory systems have been added. The regulatory system is also called the “regulated riparian” regime. The water rights in both surface and

groundwater for Marcellus Shale are governed by common law (Weston, 4). Common law in many states has broken the water down into four basic categories. The four categories are: diffused surface water (rainfall), surface waters in defined streams and lakes, groundwater in well-defined subterranean streams and finally percolating grounds. Different rules have been developed for the four different classifications of water. Eastern States depend on common law rights to withdraw water from surface streams. This is referred to as the "riparian right doctrine," which states that it is the right of the landowner adjoining a stream to extract and use water from the stream adjoining the "riparian" land. Under the natural flow doctrine, each riparian proprietor has the right to have water flow across the land in its natural condition without alteration by others on the rate of flow, the quantity and quality of the water. The laws were changed over a period of time. The riparian right doctrine was changed due to an increase in commercial and industrial development. The natural flow theory became known as the "American rule" doctrine. According to this doctrine the riparian owner may make reasonable use of the water provided that they do not unreasonably interfere with the other riparian owners (Weston, 4).

Groundwater is found in aquifers in states containing Marcellus Shale. Many court decisions have affected the terms of water usage. Marcellus Shale development has had a large impact on many other water users. Installing and using water sources can affect downstream flows to other neighbors and wells. The process of drilling and fracking for gas would have an impact on the quality of water and the ground flow patterns. Pollution will also affect the quality of freshwater. Many chemicals placed into the fracking solutions are harmful to the environment. The state of Pennsylvania has adopted special statutory and regulatory requirements governing the usage of water. It states that any well operator who affects a public or private water supply by pollution or diminution shall restore or replace the affected supply with an alternate source of water adequate in quantity or quality for the purposes served by the supply (Weston, 19).

In some states containing Marcellus Shale deposits people have learned that they can turn a profit by charging the drilling companies access to their water. Water can be withdrawn from private lakes and ponds provided that the company has paid the access fee (www.naturalgas.psu.edu/marcelluseducationfactsheet, 7). Gas companies have even purchased water from municipal water systems. In Pennsylvania, water is sold under certain situations. The examples where water is sold include a snowmelt and runoff of storm water. Pennsylvania landowners are not permitted to sell water that passes through their land but they do have the right to charge an access fee. Landowners are putting addendums in their gas well drilling lease to reflect the change.

Water returned to the well during the hydrofracturing process contains large amounts of total dissolved solids (TDS) and other harmful contaminants. The chemicals include alcohols, oils, gels, acids, organic compounds and radioactive radon. The water quality should be a concern to everyone. However, in 2005, Congress exempted fracking from

coverage under the Safe Drinking Water Act. The regulation of fracking fluids falls with the jurisdiction of the states. Changes have been added to the law during the spring of 2009. The U.S. Environmental Protection Agency began a study that will conclude in 2012. The study is examining the potential human health and water quality threats from fracking (www.naturalgas.psu.edu/marcelluseducationfactsheet, 7). Three commissions manage the water interests in the Delaware and Susquehanna River watersheds. The federal government is a member on all three river basin commissions. The Delaware River Basin Commission brings together four states: Pennsylvania, New Jersey, Delaware and New York. The governor of each state is a member of the commission. The Commander of the Army Corps of Engineers serves as the representative of the federal government. Political influence is a concern because the governors will respond according to their party affiliation. River Basin Commissions are a form of collaboration between states. They require the adoption of concurrent state level legislation and the partners involved must adopt and agree on an interstate compact. Finally, the Congress has to consent of the agreement.

Management of Frac Flowback Water

Three methods are used to handle the fracking wastewater. The first method takes place when a large volume of flowback returns to the surface in the first few hours and lasts for several days. The flowback is collected and placed into ponds and pits. The liner of the pit is polyethylene; leakage problems have developed in these liners. The second method happens at larger sites. The flowback is collected in brine tanks. The water is filtered and reused in frac fluid for future wells. A smaller volume of produced water flows to the surface. The produced water is collected in tanks onsite. The third way of managing frac flowback water requires the collected water to be removed from the site and hauled offsite to commercial disposal wells, wastewater treatment plants or a treatment and reuse facility.

Wastewater Problems

Wastewater from hydraulic fracturing has an impact on the environment. Between 20% and 40% of the water used for hydro-fracing a gas well return to the surface as flowback and later as produced water. The water contains the chemicals required for this process along with other contaminants found deep with the earth. The major substance in wells 7,000 feet deep is salt. The fluid combination becomes a brine wastewater. (www.marcellus-shale.us/drilling_wastewater.htm, 1) The franc water is stored in an impoundment where it is later transported on tanker trucks. The tanker trucks destroy the roads in the rural towns where the wells are found. Treated brine wastewater is sold for deicing and other applications. It is applied to the roadways during the wintertime as a way of clearing the ice. Drilling is a very noisy process and the movements of the industrial trucks also contribute to the noise pollution problem. Problems occur whenever brine wastewater spills into waterways and begins to seep into the groundwater. It is

difficult to treat brine wastewater because it has a high TDS level (total dissolved solids). The water treatment plant uses chlorine to clean our water. The chlorine reacts with the high TDS water creating TTHM's (Trihalomethanes) (www.marcellus-shale.us/drilling_wastewater.htm, 2).

Many companies are responsible for causing accidents. In 2009, Cabot Oil and Gas Corporation was responsible for three spills. Approximately 8,000 gallons of fracturing fluid contaminated the environment. A wetland was polluted and the Stevens Creek. A fine was levied on the company for the amount of $56,650. Cabot Oil and Gas Corporation were fined again for contaminating water in Dimock as a result of a spillage. Many families have filed lawsuits because of the methane contamination of drinking water wells (http://nsglc.olemiss.edu/advisory/marcellus_citizens_guide.pdf, 10, 12). Untreated wastewater from Marcellus Shale gas wells contributed to the contamination of the Monongahela River near Pittsburgh. The Monongahela River provides drinking water for approximately 30,000 people. The EOG well in Clearfield County experienced a blowout and 35,000 gallons of wastewater spilled out into the Little Laurel Stream. The Little Laurel stream feeds into the Susquehanna River. Another accident occurred when a wastewater pit owned by East Resources leaked into a farm field. The Department of Agriculture placed some livestock into quarantine trying to prevent the contaminated meat from entering our food supply (www.pennenvironment.org/newroom/clean-water-news/pennenvironment-new-short-film-marcellus-shale-stories, 2).

The company called Integrated Water Technologies, Inc. opened a FracPure™ Treatment and Recycling Facility in southwest Pennsylvania. The company can chemically treat 250,000 gallons of wastewater per day. Integrated Water Technologies, Inc. claims that they will recycle 100% of the flowback, indicating that no water will be discharged into the rivers and streams.

Marcellus Shale Revenue

Marcellus Shale has the potential to generate a large amount of money for the state of Pennsylvania and other states where the shale deposit is found. Politicians look at the resource as a method of getting votes. The Marcellus Shale industry will bring jobs into the state. In Pennsylvania, 2008 estimates show the creation of 29,000 jobs and revenues of 2.3 billion dollars. Tax revenues for the state and local government generated from indirect business taxes, property taxes, and sales taxes enabled the state to net $238 million dollars. (http://pubs.acs.org/doi/full/10.1021/es903811p, 2). The economy is the driving force of the Marcellus Shale industry. Energy companies are using marketing companies to sell the public on Marcellus shale. These companies are developing very savvy commercials that glorify natural gas as the new alternative to petroleum. The price of gasoline is high and the economy is down. People are allowing the energy companies to lease their land in exchange for cash.

Legislation is being proposed in Pennsylvania to allow PA universities to keep Marcellus drilling revenues for building projects. Energy companies will drill on the university owned land. The PA university will be allowed to keep the money. Seven of the fourteen state owned universities would benefit from the passage of this legislation. Money is the overarching goal for the administration in power in Harrisburg. Sixty percent would go to the university hosting the wells for building and energy conservation projects and forty percent would be allocated to universities that don't host gas wells to use for the same purpose (http://marcellusdrilling.com/2011/04/proposed-bill-allows-pa-u, 1).

Objectives

Students will learn the following:

- How to compare and contrast the human activities that alter an environment
- How to increase awareness about water pollution using case studies
- How to test water for oxygen depletion
- How to identify the role they play in water pollution prevention
- How to examine the short term and long term effects of mining on our water supply

Strategies

Students will be engaged in debates concerning the usage of hydraulic fracking. Debating is an effective tool in studying controversial scientific topics. Students have the opportunity to strengthen their skills in research and acknowledge and understand the viewpoints of other students. Students will be engaged in creative writing as they begin to master this curriculum unit. Creative writing will serve as a motivator while the students develop their viewpoints. Identification and usage of appropriate vocabulary is essential in the unit. New vocabulary words will be posted throughout the classroom. Posting the vocabulary on the walls will make the vocabulary readily accessible for the students. The retention of the words by the students is higher when this procedure is done. Students will be engaged in laboratory experimentation. Labs provide students the opportunity to organize and analyze data. Students will develop charts and graphs with the data collected during the experimentation. Students will view the video entitled *Gasland*, followed by a class discussion. Students will complete a Frayer Model graphic organizer upon the completion the video; this will serve as a way of checking for understanding. Students will collect pictures of various hydraulic fracturing sites. They will compare the problems associated with Barnett Shale Drilling to Marcellus Shale Drilling. Examination of the state laws concerning water usage will vary. Students will have the opportunity to engage in discussions concerning the implications of the water usage laws. Students will develop a PowerPoint presentation about Marcellus shale drilling. The final project involves the students conducting a symposium about Marcellus shale. Parents and local

politicians will be invited to attend the symposium. Students will have an opportunity to have their voices heard and at the same time they will educate the public about the information they have gathered.

Classroom Activities

Lesson 1

Objective: Students will be able to identify how sedimentary rocks are formed. Students will be able to identify shale as a sedimentary rock.

Materials:

- Seashells
- clear jar with a top
- sand, pebbles, and shale rocks
- measuring cup
- rolling pin

Activity:
Students will examine sedimentary rocks from the rock collection in the classroom. They will look as different features of each rock. They will place the word sediment in the center of their graphic organizer. During this time students will have the opportunity to gather information about sedimentary rocks. How were they formed? Students will provide examples of different types of sedimentary rocks. Students will now begin to illustrate how sedimentary rocks form through experimentation. Students will crush one cup of seashells, sand and pebbles. They will place this into the jar. Students will add one liter of water to the mixture and shake. Students will observe the mixture. They will describe why some pebbles went to the bottom while others remained near the top. Students should make a sketch of the mixture and write a paragraph explaining their results.

Lesson 2

Objective: Students will be able to identify how Marcellus Shale Drilling can alter an environment

Materials: Students will be asked to bring in three pictures showing Marcellus Shale Drilling sites in the state of PA.

Activity:
Students will be asked to look at the picture they brought into school. They will write a story about how the drilling site has altered the environment. In the story, they should

make a reference about the animals that live in the habitat of the drilling site. One of the things they should highlight in their story is the negative consequence drill will have on the habitat. Once the student has completed the story they should exchange it with another student. During this activity the students will have the opportunity to see how other individuals feel about how drilling.

Lesson 3

Objective: Students will have the opportunity to reflect and make conclusions about the impact Marellus Shale on our water supply.

Activity: Students will observe the video entitled *Gasland*. At the conclusion of the video they will complete a graphic organizer. A sequencing graphic organizer will be given to the class. Students will sequence the events that led to methane in the water. The class will hold a discussion and each student will be allowed to explain the graphic organizer they developed.

Lesson 4

Objective: Students will be able to explain the role specific organisms have in our environment.

Activity: Students will be engaged in a role-play situation involving an endangered species found in the Pennsylvania forest. They will explain how hydraulic fracturing will have an impact on this organism. A persuasive essay follows the role-play, describing the possible effects of extinction and any conservation attempts.

Lesson 5

Objective: Students will be able to identify the pH of various samples of water. They will be able to distinguish between basic and acidic solutions using litmus paper. They will compare the color of the tested litmus paper to the color scale on the pH dispenser.

Materials:

- pH paper (red litmus paper and blue litmus paper)
- five samples of water from different freshwater sources
- small beakers (50 ml)
- safety goggles

Activity:
Students will place 5 ml of water from each water source into a beaker. They will place the letter “A” on beaker #1, “B” on beaker #2, “C” on beaker #3, “D” on beaker #4, “E”

on beaker #5. The students will test each sample using each type of litmus paper. Students will analyze: which substances are acidic? Which substances are basic? Students will identify which water supply would be healthy for aquatic organisms.

Lesson 6 (two days)

Objective: Students will be able to identify the pH of the chemicals found in hydraulic fracturing water. The activity requires students to work in groups.

Activity: Students will collect information about the harmful chemicals found in hydraulic fracking water. They will identify which substances are acids and which substances are bases. Students will use the Internet to determine the pH of the chemicals. The list of the chemicals found in fracturing water will be divided into six groups. They will prepare a chart illustrating where these compounds appear on the pH scale. The pH chart is going to be very large because over 200 chemicals are placed into the water. Students will also gather information about harmful affects of the chemicals.

Lesson 7 Group work (three days)

Objective: Students will be able to prepare a PowerPoint presentation about the affects of Marcellus Shale drilling and water pollution.

Activity:

Students will be divided into six groups. Each group will prepare a PowerPoint presentation. The presentation should discuss the dangers of hydraulic fracking water. Students should discuss the impact of the water on the environment and how it can affect the health of organisms that depend on it. Each PowerPoint presentation should illustrate three case studies when the contaminated water seeped into the environment and the consequences it had on the environment.

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http://www.marcellus-shale.us/drilling_wastewater.htm, Page 1-2.

http://www.srbc.net, (PowerPoint) June 12, 2008.

Annotated Bibliography for Teachers

Adler, Robert W., Landman, Jessica C., Cameron, Diane M. "The Clean Water Act 20 Years Later." Natural Resources Defense Council, Washington, D.C.: Island Press, 1993.

This book introduces you to the legislation that led the formation of the laws Congress passed in 1972.

Calhoun, Yael. "Environmental Issues, Water Pollution." Philadelphia, PA: Chelsea House Publishers, 2005.

This book is an excellent reference book for teachers. It is part of a series of books that discusses environmental issues.

Kneese, Allen V., Bower, Blair T. "Managing Water Quality: Economics, Technology, Institutions." Baltimore, MD: John Hopkins Press, 1968.

This book discusses the shortcomings of conventional approaches for managing water quality.

National Research Council of the National Academies, "Hidden Cost of Energy, Unpriced Consequences of Energy Production and Use." Washington, D.C.: National Academies Press, 2010.

This book is a good reference book. It introduces the manner in which energy is produced and the problems that arise.

Annotated Bibliography for Students

Holt. Environmental Science. Holt, Rinehart & Winston, Austin, TX: 2000.
This book provides case studies and this allows the students to think critically about several different possibilities. Every chapter has Portfolio activities and Interdisciplinary activities.

Holt, Rinehart & Winston. Modern Biology. Austin, TX: 2002.
This book offers many different types of graphs and good pictures.

Teacher Resources

Energyfactspa.com is a website that talks about the energy produced in the state of Pennsylvania
http://energyfactspa.com.

Geology.com is a website that will discuss the geological features in the earth.
http://geology.com.

Pennsylvania Department of Environmental Protection - website on Marcellus Shale.
http://www.depweb.state.pa.us.

Oil Shale gas is a website that presents the history and facts about Marcellus Shale.
http://oilshalegas.com/marcellusshale.html.

Student Resources

Marcellus Shale Coalition is a website that will introduce students to issues concerning drilling.
http://marcelluscoalition.org.

Penn State Cooperative Extension Marcellus Education is a website with up-to-date information on natural gas production.
http://www.naturalgas.psu.edu.

Appendix - Standards

The Core Curriculum of the School District of Philadelphia is aligned to the Pennsylvania Academic Standards and Environmental Health. The following topics are included in these standards: How human practices effect the quality of water and soil; Local and state environmental regulations and their impact on environmental health; Detecting pollution by using state of the art technologies; How erosion and sedimentation have changed the quality of soil related habitats.

4.3 C. Environmental Health: Explain biological diversity as an indicator of a healthy environment.

4.6 B. Ecosystems and their interactions: Explain how cycles affect the balance in an ecosystem.