Curriculum Units by Fellows of the National Initiative
2016 Volume IV: Energy Sciences

What is Our Energy Past, Present, and Future?

Curriculum Unit 16.04.01, published September 2016
by Josh Bearman

Introduction

The oldest coal mines in the United States are located in Midlothian, Virginia. They were open pit mines and, beginning in the 1730s, represent some of the first industrial sites in all of North America.[1] Nearly 300 years later, roughly one third of Virginia's energy is provided by coal, with another third coming from natural gas.[2] As the coal industry wanes, there is renewed interest and technological effort being put into the extraction of oil and natural gas from the Marcellus Shale, which exists in the far western and southern portions of the state, as well as potential hydrocarbon and uranium extraction from Triassic Era basins found in the more populous Piedmont region of the state.[3] If trends hold, it appears that coal will continue to drop in use, with natural gas, nuclear, and other forms of energy production moving in to replace it.

In this curriculum unit, my goal is to provide my students with the means to research the origins of the fossil fuel and renewable resources present in Virginia, how they are extracted and used, and what could be the future of energy generation for the state. In three sections of roughly one week each, students will: 1) research how coal and natural gas were formed in shallow equatorial seas of Carboniferous-period Virginia and compare the energy emitted from different grades of coal, 2) learn about mining and usage techniques through a series of field trips to local coal mines and power plants, finally engaging in a debate on the pros and cons of hydraulic fracturing (fracking), and 3) predict what types of energy generation will best meet the needs of our state in the decades and centuries to come, culminating in an attempt to model different renewable forms.

Educational Setting

Lucille Murray Brown Middle School (LMB) is a Title I school located in the south side of Richmond, VA. One of the most populous schools in the city, LMB also boasts some of the greatest ethnic and socio-economic diversity in the city, due largely to a magnet program that takes in an additional 75 students per year from every zone in Richmond. LMB uses the International Baccalaureate (IB) curriculum for every classroom, which focuses on providing a full picture of the content to students, allowing them to view a subject through multiple lenses and from multiple perspectives. Next year will be the 2nd year that LMB is whole-school IB. A more in depth discussion of the IB method can be found in the practices section below, following the background.

My earth science students are high achieving students, about half of whom come from the magnet pool and half from the neighborhood pool. The students, roughly 100-125 per year, represent the City of Richmond well in terms of ethnicity (roughly 55/45 black/white) and socio-economic status (everything from low to upper-middle). As a rule, my students are highly motivated, either through intrinsic drive to succeed or an extrinsic desire to please (or to not displease) their parents. While talkative and easily distracted, like any middle schooler, these students are eager for challenges and bring a great amount of creativity and energy to most tasks, especially any task that they feel has relevance to their lives. They love group work and excel when given leeway to research and design in their *own* ways. That being said, they are quick to dismiss anything they view as "busy-work" or irrelevant. Many do not have easy access to computers and the internet at home. As such, I like to keep most of the research and formatting aspects of lessons and projects within the classroom.

My classroom is situated with 6 science tables, oriented as diamonds in relation to the front and back of the room. Ideally, each table would have 4 students, although the reality is more like 5 or 6. Regardless, this arrangement is great for group work. Students can either work in 6 larger groups, or 12 smaller groups, depending on the nature of the activity. The tables are attached to the floor, however, which limits my ability to change the orientation. The classroom is supplied with a fume hood and a sink in the back of the room

Rationale

In our seminar, we have spent time discussing the pros and cons of sources of energy that are currently available as well as those that are, at this stage, theoretical. Additionally, our main piece of reading – *The Quest* - addressed the economic, geopolitical, and technological history of the fossil fuel race. Counter to much of the narrative regarding fossil fuels that I have heard, scientists and statisticians who study this topic have shown that, far from being in any danger of running out of fossil fuels, we have barely scratched the surface of what is beneath us. As extraction technology advances, it seems likely that we will be able to access stores that have been previously considered out of reach – oil from the deep ocean, gas and oil that are trapped in rock layers, etc.

This is not necessarily a comforting prospect, however, as this increased access will result in the continued burning of fossil fuels, the continued addition of carbon dioxide to the atmosphere, and the continued intensification of the greenhouse effect. Above all else, this seminar has stressed to me that there is a great need for renewable energy and carbon-neutral fuels, as well as the social and political will to compel industry and government to make this a priority. With all this in mind, I was inspired to design a unit that focuses on the history of energy generation in Virginia, and the potential we have for moving away from the legacy of coal and, to a lesser extent, natural gas.

Middle and high school students are, for the most part, blissfully ignorant about the source or mechanisms by which energy is extracted, processed, and delivered to their devices. I have found that many of my students, when exposed to the supply chain of their beloved electronics, view them through a different and more informed lens. As a former environmental educator, I work hard not to color the information with any particular agenda, only to help them become informed members of society.

As I stated above, most middle schoolers, and people in general, do not spend much time contemplating the sources of their electricity and energy and even less time on the consequences associated with them, from extraction to waste removal and every step in between. I believe that a well-informed person is the most useful member of society. If I can help my students discover the facts regarding Virginia's energy sources and solutions, it will be an accomplishment. Additionally, it appeals to me because this content fits so well with so many different aspects of the Earth Science curriculum, and I am excited by the idea of a single strand that reappears throughout the year, tying one sub-category of earth science (ES) to another so neatly.

Unit Summary

The fossil fuel resources, specifically coal, found in Virginia result from large scale sedimentation and burial of organic matter mostly during the entirety of the Carboniferous Period (~359 – 299 mya). At that time, the land that would become the East Coast of the United States was a sub-equatorial rainforest The coal, mentioned above, that was mined in the Piedmont region of Virginia is younger, having formed during the Mesozoic Era. These deposits represent the smallest fraction of VA's coal resources, however. In addition to coal, Virginia also has ample natural gas resources, formed during the late Devonian (~420 – 350 mya).[4]

All of these resources originate in the massive amount of biological activity that was taking place during the Carboniferous Period, and were preserved due to the presence of a massive inland sea, the remnants of which have been thrust upward in the ensuing years and now represent the Appalachian Plateau and Ridge and Valley regions of Virginia. While not among the top producers of fossil fuels in the United States,[5] Virginia is well placed for a scientific and social examination of the role that the science and economy of energy has played in our geologic and human history, our present, and our future.

Three Foci of Unit

1) The first topic is Virginia's geologic past and the conditions that brought about the burial and subduction of organic sediments, leading to fossil fuel formation, focusing on coal and natural gas. In this unit, we will examine what Virginia would have looked like 350 million years ago. We will cover the topics of sedimentation and burial before discussing how VA got from having an inland sea to having a folded and greatly weathered mountain range.

2) Virginia's energy present is the next topic, for which we will focus on the extraction and eventual use of these fuels to generate electricity. This will involve making maps of Virginia to show the locations of the major stores of coal and natural gas, an examination of the processes used to extract the fuels, and, hopefully, a trip to a nearby power plant where students can see energy being generated. There is an extension possibility to structure a debate around one of these fuels, examining the pros and cons of their extraction and use, with students assuming the roles of different stakeholders. We will also take a field trip to the nearby Midlothian Mines Park to view the site of the original open pit mines in Virginia.

3) Virginia's energy future is the final topic, for which we will discuss the effects of burning fossil fuels and the mechanics of climate change and the greenhouse effects. We will focus on Virginia's potential for renewable and carbon-neutral energy, looking specifically at offshore wind, uranium mining, and nuclear power. Students will make models of windmills and hydroelectric turbines and will have access to small solar cells that can be used to power small motors. This unit would also be an opportunity to visit a local nuclear power plant and compare it to the coal-fired facility.

Background

The Carboniferous and Euramerica

The Carboniferous Period represents the period of time from 359 to 299 million years ago (mya). These numbers vary somewhat depending on the reference, but this is the general stretch of time. The Carboniferous is notable in Earth history for its high productivity and resultant atmospheric oxygen content, which reached 35%[6] by the end of the upper Carboniferous, known as the Pennsylvanian Epoch. This high level of productivity was due to a number of conditions – placement of the continental land masses, high levels of CO_2, warm and wet climatic conditions, and an explosion in diversity and size of plants.

During this period of time, the area of land that is now Virginia and the East Coast of the United States was part of the super-continent Euramerica which later joined with Gondwana to form Pangaea. In contrast to the temperate environment of present day Virginia, the Carboniferous environment was warm, wet, and verdant – a tropical swamp. While angiosperms – flowering plants – had yet to evolve, there was an explosion of ferns and horsetails, often in much larger sizes than what is currently seen today.[7] The warm and wet conditions, heightened CO_2 concentrations of the late Devonian and early Carboniferous period, and arrangement of so much available land in prime growing latitudes led to an explosion of terrestrial productivity on a scale unseen since this time.[8]

In addition to the swamps and thick fern forests covering the land, much of what is now the Appalachian Mountain range and land to the west would have been a low-lying basin and shallow sea, into which the sediments and plant matter were deposited.[9] You can picture modern day Indonesia or Malaysia for a snapshot into the world of Virginia, circa 350 mya[10] – hot, wet, and very green.

This growth of plants was naturally accompanied by an increase in photosynthesis, which brought CO_2 levels down from 0.40% in the middle Carboniferous to below 0.05% of the atmosphere by the end, while simultaneously increasing O_2 concentration from 17% to 35%. Due to the heightened oxygen in the atmosphere, there was the occurrence of certain familiar organisms on a size and scale unlike anything we encounter in modern times – specifically insects. There are many examples of dragonfly ancestor fossils from the Carboniferous whose wings span a meter or more[11] and centipedes that grew to 8 feet in length. In addition to the large insects were the early terrestrial amphibians, large bony fish, the first example of reptiles, and a wide variety of marine invertebrates – crinoids, brachiopods, and large ancestral foraminifera called fusulines that would eventually make up the limestone formations of the Midwest.[12]

Interestingly, as oxygen increased and carbon dioxide decreased, the rate and efficiency of plant productivity also fell. The decrease in carbon dioxide resulted in a net cooling of the Earth and an increase in the southern Gondwana ice sheets, and eventually led to the end of this boom time in primary productivity.[13] As we research this time period and students each adopt an organism from the Carboniferous, I will ask my classes to relate the atmospheric changes associated with this time period to the current fears associated with greenhouse gases and compare the time scales and conditions.

Coal Formation

As the swamp plants and fern forests grew and died, they were enveloped by a shallow basin located in what is now the area west of the Appalachian Mountains, which was subsiding at this time. The New River, which still exists today, carried first sand, then organic rich sediments and plant matter into the ever expanding delta that stretched from modern day Pennsylvania down through Ohio, West Virginia, Kentucky, and far Southwest VA.[14] As these sediment layers were covered with inorganic sediments, the coal formation process began.

Peat

The earliest stage of coal formation is peat. In order for peat to form, the rate of accretion, or gradual deposition of sediment and plant matter, must exceed the rate of bacterial decomposition.[15] It isn't difficult to imagine this being the case during the rich and productive times of the Carboniferous, with ample rainfall and high rates of production. Reach your hand deep into the nearest marsh or swamp and you will bring up a handful of the makings for peat – the woody and tough stems and leaf material, surrounded by black organic sludge of decomposing plants and animals, smelling of rotten eggs – the tell tale sign of anoxic conditions. Of special importance to peat formation is lignin and cellulose – the tough parts of plants.[16] As they are buried, the chemical structure of lignin and cellulose undergo changes as the carbohydrates, oxygen, and nitrogen are lost and carbon is preserved.[17] While the chemical composition of the lignin and cellulose structures is altered, their morphology is left intact. Identifiable plant structures like stems, roots, and even leaf cuticles can be found in heavily compressed and altered peat deposits.

Peat has been harvested and used for heat for thousands of years. Even in the modern era there are parts of the world where people venture forth into the marshy areas to carve squares of peat to bring home and burn. I have seen this first hand on the Isles of Harris and Lewis, off the Northwestern coast of Scotland. When burned, peat releases a smell that is hard to describe without using the word "peaty", but which fills the smeller with a sense of nostalgia. On cold and wet Hebridean days (and there are many, even in July), the sight and smell of peat smoke emerging from a chimney (although reminiscent of a dirty and inefficient fuel source) is a special comfort.

Coalification

If the peat is left alone and subject to the proper conditions of heat and pressure, the process of coalification will begin. This process often begins in subsiding shallow basins – where the underlying crust is sinking due to pressure or tectonic conditions, allowing more room for sediments - in which the pressure is provided by the overlying water (hydrostatic) and sediments (lithostatic). This process is characterized by an increase in the loss of oxygen and nitrogen as well as hydrogen. The first stage of coal is known as lignite, or brown coal, and is considered to be a low-grade coal due to its low energy output, high sulfur content, and high ratio of hydrogen and oxygen to carbon.[18] While the chemical content is more altered, brown coal still contains recognizable plant structures.

As the coal is subjected to increasing heat and pressure, more and more hydrogen and oxygen is lost. In addition, organic structures become increasingly altered. The color darkens from a brown to a shiny black, and the "sediments" within become increasingly homogenous.[19] At this point, the coal is known as bituminous, and then anthracite. All remaining cellulose and lignin is lost, and the rock resembles what most of us would think of as "coal". With each step in grade, the energy potential of the coal increases. For this reason, anthracite coal will garner the highest price, with each step downward having a lesser worth.

Interestingly, as coal becomes higher grade, it becomes impossible to determine the parent plants that contributed the biomass – all semblance of original morphology is lost. However, every strain of coal is slightly different due to the variance in parent material. In short, no two lumps of coal are the same. As a part of this unit, students will examine different grades of coal for their physical characteristics and also energy potential. Having a bit of background in how the coal formed will help their descriptions and understanding of the grading system.

Virginia's Coal

Virginia's coal fields are located primarily in the far southwestern regions of the state, with small amounts found in the Shenandoah Valley, and a somewhat anomalous coal region just southwest of Richmond in the center of the state that has been out of operation since the 1950s. The coal found in Virginia ranges in grade from mid-bituminous to anthracite and represent a small part of the Appalachian Coal Fields that stretch over much of the east coast, from Pennsylvania to Alabama.[20]

While its value and extraction rate are decreasing, as recently as 2003, Virginia was producing over 22 million short tons of coal per year, worth roughly $1 billion, and representing 46% of the mineral exports of the state.[21] As of 2014, the coal industry in Virginia employed 3,627 people in underground and surface mining operations.[22]

Extraction Methods

The earliest extraction of coal in Virginia, beginning in 1748, was from the Richmond coalfields. Much of this coal was mined from the surface, exploiting outcrops and cliff faces. As the most readily available coal was removed, however, companies began digging shallow and deep shafts, reaching over 1000 feet in depth, to exploit the full measure of the resource. In all, 71 different mines and associated shafts were established in this region. The coal that was extracted from these sites was used for heating, metallurgy, and eventually for steam power. The last Richmond area mine closed in 1927, and coal production moved to the southwest portion of the state.[23] The Richmond Coalfield includes the Midlothian Mines, to which my class will be going on a field trip.

Extraction of the Southwestern VA coalfields – located in parts or all of Buchanan, Dickenson, Lee, Russell, Scott, Tazewell, and Wise counties – began as early as the mid-1850s. However, it wasn't until the 1950s that the region became the primary source for the state's coal production. Strategies for removing coal from the ground include the surface and shallow shaft mining that was common in the Richmond Coalfields. Due to the long and thin nature of the southwestern Coalfield seams, very deep shafts are often required to access the coal. In addition to the underground mining, strip mining and mountaintop removal techniques are also used. Strip mining involves using large earth moving vehicles to expose the coal seam for easy extraction. Mountaintop removal is a process, as the name suggests, in which the top of the mountain is stripped of vegetation and explosives are used to expose the coal underneath.[24]

Use for energy

Of the coal extracted from Virginia mines every year, 65% of it is used for domestic energy production.[25] Virginia alone has seven coal firing power plants, supplying 1,423 thousand MWh.[26]

Environmental Impacts

From an environmental perspective, coal is fraught with negative impacts. Modern techniques of extraction –

primarily mountaintop removal – result in extensive ecosystem destruction. There is the initial stripping and explosions that destroy forested areas. This is accompanied by generation of a large amount of what is known as "valley fill." Essentially, the sediment and excess rock that is the result of the mountaintop removal is pushed into adjacent valleys, filling stream valleys and stopping up headwaters.[27] It is difficult to quantify the environmental damage of the valley fill, but it is widely believed to be severe.

Underground mining of coal has been shown to lead to contamination of surface and groundwater, increasing the total dissolved solids (TDS), making the water unsafe for consumption. Additionally, when water adjacent to mines is exposed to pyrite, a common leftover mineral of mining, it will become acidic to the point where toxic metals will dissolve into the stream and be carried in the runoff. This can lead to ecosystems that are toxic to all aquatic life, or in bioaccumulation of heavy metals and larger food web implications.[28]

The burning of coal for electricity, while affordable and efficient (provided the coal is high-grade), is also accompanied by a host of environmental issues. Combustion of coal releases mercury, sulfur dioxide, cadmium, nitrogen oxide, arsenic, and other inhalants that are known carcinogens and endocrine disruptors.[29] While these pollutants are, for the most part, regulated by the state and federal governments, many power plants in Virginia are older and require retrofitting of environmental technologies to meet the legal limits. Furthermore, state agencies rely on self-reporting of effluent by the plants – a situation that is ripe for exploitation and underreporting.

Finally, but perhaps most importantly, coal combustion results in the release of CO_2, the best known greenhouse gas. I will leave a full explanation of the physics and facts of global climate change for another unit. I will note, however, that I do not teach global climate change as a "controversial" topic in my class, but as a widely accepted, scientifically supported, and dire process with human and ecological consequences that will ripple many generations into the future.

Social Implications

Beyond the scientific specifications of origin and extraction, Virginia's coal history is wrapped up in its social and political character. The coal industry is omnipresent in the far southwest portions of the state. People make their decisions about political candidates and potential state regulations based upon what they believe the outcome will be on jobs and the coal economy.

Removing arbitrary boundaries, there is a distinct Appalachian culture whose identity is closely tied to the coal industry. Multiple generations of people have worked, lived and died in and around the mines. Songs and stories that glorify and memorialize workers are prevalent. Movies like *Matewan* and television programs like *Justified* show the tenuous relationship that exists between the mining company and the worker. Violent strikes and mine disasters are not remnants of the past, but are present reminders of the dangers and pride associated with coal.

While I am a science teacher, I am always looking for the opportunity to link science to socio-political ideas, literature, and art. As a player of traditional American music, I plan on using the available songs in my classroom to highlight how Earth Science is tied to society.

Natural Gas

Of special interest in the current era is natural gas. As the practice of hydraulic fracturing has become commonplace, it is the large stores of natural gas in the United States that have helped to ensure our energy self-sufficiency.

Natural gas forms throughout the process of peat and coal formation. Initially, methane is produced through the anaerobic activities taking place in peat. As coalification continues, this moves from a biological to a chemical and physical process, as carbon dioxide and methane are generated by extreme heat and pressure. As the coal's rank increases, more methane is produced, and can be stored in microscopic pores within the coal.[30] At present, Virginia coal beds are thought to contain as much as 400 trillion cubic feet of methane, 99 trillion of which is recoverable.[31] As coal is phased out, the extraction of natural gas, for good or ill, is taking on increasing economic and social importance.

Beyond what is found adjacent to and inside of coal seams, there is also a supply of natural gas associated with the eastern-most border of the Marcellus Shale, a large Devonian-era bed of oil and gas-rich shale that extends from central New York to Mississippi and Alabama and includes portions of Pennsylvania, Ohio, West VA, Kentucky, Tennessee, and Georgia.[32]

Fracking

The technique of hydraulic fracturing, or fracking, has existed in the United States since the 1860s in Pennsylvania,[33] and has become a predominate method of gas extraction in the last 20 years due to jumps in technology and technique. In short, the process involves injecting water mixed with sand and other chemicals at high pressure into a shale formation. The water causes the underlying shale beds to fracture (hence the name), and release fossil fuels in the form of shale oil and natural gas into a well.[34] The wastewater is then pumped back to the surface where it is either recycled for more fracking or routed to local treatment facilities.

Fracking garners strong feeling from both proponents and opponents. To many, natural gas represents a widely available source of energy that has helped the United States loosen the grip that the OPEC nations had on the price of fossil fuels, providing upwards of 725,000 jobs between 2005 and 2012, and helping to lower unemployment and increase domestic revenue.[35] To others, fracking is an environmental and societal ill that uses and contaminates millions of gallons of water, destroys aquatic and terrestrial ecosystems, poisons drinking water, causes earthquakes, and releases methane into the atmosphere, undermining any net benefit that might be provided by reducing CO_2 emissions.[36,37]

Due to the various solids that can be captured by the fracking fluid – including a variety of heavy metals, salts, and other naturally occurring toxic substances – proper treatment involves processes that are not found at most municipal facilities.[38] Some wastewater is also injected back underground for storage. This process has been shown to be responsible for an increase in earthquakes in the American Midwest, specifically in Oklahoma, although these examples have possibly been exaggerated by media hype.[39] Similarly, there are those who have found that fracking causes disruption to water tables, resulting in methane contamination of municipal and well water, a process known as "migration".[40,41] This was most famously demonstrated in the documentary *Gasland.* These findings remain contentious and have been disputed.[42]

While the jury is out regarding the environmental and health safety of fracking, there is at least one thing that is clear: natural gas has become an important part of the economic and energy profile of the United States. Bringing it back to Virginia, natural gas has overtaken coal as the number one method of electricity generation, and has been steadily rising in production as coal has been falling over the last decade.[43] Students will have the opportunity to research and debate the pros and cons in class.

Alternative Energy

Many of us are familiar with renewable energy in a general sense. We see the occasional wind turbine or solar panel and understand that they are used to "make energy" but our understanding does not go much deeper than that. Much of this seminar has been spent demystifying and explaining the different types and specifics of renewable energy – with a special focus on the many forms of solar energy.

Most people, when they think about solar energy, probably picture a photovoltaic (PV) solar panel on the roof of a building. These panels use sunlight to create an electric current by freeing electrons from certain substances. The free electrons create a direct current that can be used to power electric devices. It can also be stored on a small scale in car batteries. There are a few types of photovoltaics, but all use much the same process to create energy. Beside PV, many people use passive solar panels to heat water that can be pumped throughout the house for use as a heating source. While this is not a direct source of energy, it increases energy efficiency of a building. Similarly, houses can be positioned so that they gather as much winter light as possible while also blocking the high angle summer sun.

Sunlight can also be used to drive a piston or turn a turbine in heat engines. In a Stirling engine, mirror arrays focus solar energy on a gas-filled piston, causing a differential in heat that causes the piston to pump and turn a flywheel. This energy can be used to create electricity by powering a generator. Mirrors are also used in a process that focuses sunlight to create enough heat to melt salt. The salt is then used to heat water to run a turbine and a generator.

Less obvious to many is the role that photosynthesis plays as a source of solar energy. During photosynthesis, plants use sunlight to split water molecules into hydrogen and oxygen and store the released energy in the form of glucose and starch. There is so much more to this process, but for the purposes of middle school science, we will leave it here. When we manufacture ethanol or biodiesel, we are, in essence, using solar power. Similarly, the energy stored in coal, at its heart, is solar energy as it derives from dead and buried plant matter

Alternative Energy in Virginia

According to the American Council on Renewable Energy,

> Virginia has taken an "all-of-the-above" approach to energy policy, supporting the generation of electricity from nuclear, natural gas, coal, and renewable energy. Virginia's renewable portfolio goal aims to increase the state's use of renewable energy to 15% by 2025, but unlike renewable targets in many other states, the goal is not binding and allows existing facilities to count toward compliance.[44]

In this unit, I will be focusing specifically on Virginia's nuclear and wind potential as alternative energies. However, my students will have the option of researching any of the potential sources of alternative energy in our state.

Nuclear in Virginia

Virginia has two nuclear power plants – Lake Anna and Surry. Together, they provide the second largest amount of electricity to the state.[45] In addition to the state's capacity for producing electricity from nuclear, there is also a proposal from landowners to mine uranium from Pittsylvania County in southern Virginia and potential to exploit uranium in up to 55 other localities.[46]

Due to fears associated with water and soil contamination, a moratorium on this practice has been in place since 1982. Beginning in 2007, a variety of petitions to lift the moratorium have been issued by landowners, state and federal politicians, and uranium interest groups. Uranium is mined from only 8 countries globally, only 3% of which comes from the USA – over 52% comes from Canada, Kazakhstan, and Mexico. Domestically, there is a great deal of interest among some groups in cultivating as much fuel as possible, as the demand for and cost of uranium over the next 35 years is expected to rise faster than current global production.[47] Additionally, the Pittsylvania proposal alone is projected to result in ~1,000 jobs and "$5 billion in economic benefits across the commonwealth."[48]

This issue has reached a fever pitch among stakeholders in Virginia, with as many groups lining up to oppose the practice as there are those calling for its renewal. As with any mining practice, there are many potential environmental damages – deforestation, increased sedimentation, and loss of habitat. However, since the product of the mining is a radioactive element and a known carcinogen, there are other negative consequences to consider. Uranium and the associated byproducts of its mining can cause a litany of health problems if workers are exposed to it via touch or through inhalation. Tailings from the mine can infiltrate water systems. Massive ecosystem damages from these same factors are also possible.[49] Not surprisingly, the opponents include almost every environmental group in the state, along with many health organizations, local businesses, and landowner groups.

In 2011, there was an earthquake in central VA, registering 5.9 on the Richter scale. The epicenter was near the North Anna Nuclear Power Plant. The earthquake caused spent fuel storage containers there to shift on their bases, resulting in tritium leaking into the adjacent groundwater.[50] As might be expected, this caused a great deal of concern among the public. Earthquakes, while rare in Virginia, do take place as ancient faults in the underlying bedrock shift and settle. Catastrophic events like this, and the possibility for hurricanes striking any potential uranium mine, provide great fodder for the opponents of nuclear power and mineral exploitation in Virginia. The amount that has been written on this topic, both pro and con, and its proximity to Richmond, make it an ideal choice for class research and debate in the third section of this unit.

Wind In Virginia

In 2015, Virginia became the first state in the USA to obtain permission to study the potential for offshore wind in federal waters. According to Dominion Power, the company awarded the research grant, the proposed 113,000 acre wind farm could power up to 770,000 houses and result in thousands of jobs. This project has the support of the state legislature and governor, as well as the Sierra Club, one of the most vocal environmental groups in VA (and elsewhere).[51]

As with proposed offshore wind in other localities, this project has its detractors. A similar proposal in Cape Cod has been in limbo for nearly a decade due to opposition from a variety of stakeholders, from wealthy landowners who are opposed to a perceived threat to their viewshed to fishermen who fear they will lose the right to exploit the waters adjacent to the wind farm. Groups who are invested in preservation of bird populations also raised concerns. It can be expected that similar opposition will mount in Virginia. Like nuclear power, I expect my students to have strong opinions about wind power and am excited to use that interest in our lessons and in designing their own optimal turbines.

Summary of Unit Outcomes

Time Expectations and Strategies

At LMB, teachers of core subjects see our students daily for 70 minutes. After the various interruptions typical to any school, I can expect to see my students roughly 300 minutes per week. This unit covers multiple strands of the Virginia Earth Science curriculum and, as such, will require multiple weeks to complete. The first section, dealing with the origin of coal and the geologic history of Virginia will begin in November and will likely take 5-7 days. The second and third sections, where we focus on energy resources will begin directly afterwards, but will take longer, due to the amount of information there is to cover. In all, I expect the entire unit to be roughly 3 weeks in length. However, I'll note that there may be days when I pause to update students on the other content included in our standards.

As my students are high-achieving, I expect them to do a fair amount of reading. I will assign short – 1-2 page – readings to my students with a guided note sheet as homework. On the following day, we will spend time discussing the reading and making sure that the information I want for them to receive was clear. I have found that they are fond of group work and do well in the small-group setting, and often employ the Jigsaw strategy to disseminate the information to all students. This is especially effective for multi-part topics like renewable energy, where I can assign small groups to read about a certain sub-topic and then report back to the larger group. It cuts down on any one student feeling overwhelmed by reading, and allows them to take the role of teacher, which many of them enjoy.

Deliverable Outcomes and Activities

Each section of my unit will have at least one project, investigation, or in class assignment associated with it.

Part 1: Our Energy Past

The first section, related to Virginia's geologic past, involves a deep dive into the world of 350 mya. An important part of the Virginia standards is that students understand how certain organisms, known as "index fossils" serve as markers of a time period, existing neither before nor after a certain geologic moment. The project for this section will involve each making a fake social media profile of one of these organisms, including a picture and description of the organism. Students will have access to books, Chromebooks, and laptops in my classroom, and will have the option of creating these profiles in either digital or paper format.

Part 2: Our Energy Present

The second section deals with the extraction of coal and natural gas and has a number of components. As a class, we will test the energy output of three grades of coal and make connections to the decisions made by energy companies in terms of usage. Additionally, we will take field trips to a nearby coal-fired power plant and historical site of coal mining. We'll prepare for these trips by reading documents on the pros and cons of coal as a fuel source and on the history of mining in Central Virginia. After the trips, students will have to write reflections, answering specific questions about the power plant and mines.

Finally, as a culminating activity for the second section, we will engage in a "Crash Debate," which is a method I modified from an IB colleague in Asheville, NC. In short, students will prepare arguments on the pro and con sides of fracking in Virginia, based upon a series of readings I will suggest and on any other source they can find and clear with me. They will then engage in a tournament-style series of debates where they have to flip a coin to determine who argues which side and where classmates act as judges. It is the best kind of on-task chaos.

The debate rules that I will provide to my students are as follows:

1. You go home and research both sides of our chosen topic – the "pros" and "cons."
2. As you research, separate your arguments by themes. ***For example, if our topic was Deep Sea Oil Drilling, some Pro Themes might be: energy independence from the Middle East, jobs, and modern safe techniques of extraction.***
3. On separate notecards, write summarized arguments for each theme. ***Make sure to cite your sources!***
4. Bring at least 3 Pro and 3 Con notecards to class. You will hand these in for a grade, so make sure you have done the work!
5. Each student will be assigned a letter and be separated into groups of 3. In each trio, there will be 2 debaters and 1 judge.
6. The debaters will flip a coin to decide who is arguing pro and who is arguing con.
7. One side will begin the debate with one theme card. You will have **one minute** to present an argument that supports your position using only one of your notecards. The opposition will have **one minute** to rebut. The original debater will then have a **30 second response** followed by a **30 second response** by the second debater. You are required to stay on topic and not introduce topics from other cards unless they are related to the original topic presented.
8. Repeat step 7, except now the other debater gets to choose a topic.
9. During the debate, the judge will act as time-keeper and also non-biased scorekeeper (DO NOT GIVE YOUR FRIEND MORE POINTS JUST BECAUSE YOU LIKE HIM/HER).
10. The judge will keep a scorecard where she/he puts tick marks for each side every time a ***good point***is made or a ***valid source*** is cited. *Remember, it is in your best interest to be unbiased, as the person you are judging will end up judging you!*
11. After the round is finished, the judge will announce a winner. The winner will go on to a new debate, the loser will become a judge, and the judge will become a debater. Continue the process, following the tournament bracket until all players are eliminated and a ***Supreme Debate Winner***is crowned.

Part 3: Designing our Energy Future

For the third section, students will split into groups and I will assign/they will choose a different renewable resource to research. Each group will have to prepare an informational advertisement about their resource that includes an overall description of the method of energy generation, the associated pros and cons, and Virginia's potential in regards to this resource. If time permits, we will research and debate offshore wind in Virginia, using the same Crash Debate style format as in section 2.

As a fun design activity, I will provide student groups with materials and time to create the most effective wind turbines that they can and we will test them in our schoolyard. We will use the basic format as in the PBS windmills lesson found in the teacher resource section. Although the activity was designed for elementary school, it can be easily scaled to middle school by relying more heavily on the students to come up with their own designs.

IB Practices

Lucille Brown Middle School employs the International Baccalaureate (IB) model of teaching and learning. There are many aspects to the IB method of teaching that can be thoroughly explored through the International Baccalaureate Organization website. In short, IB stresses an inquiry driven curriculum in which students are encouraged to demonstrate a series of character traits, from risk-taking to reflection. Teachers design units and lessons that require students to examine a topic from a variety of different lenses, known as Global Contexts. For example, a unit on energy viewed through the lens of Scientific and Technological Innovation might focus heavily on the mechanics of extraction and models of the machinery used to harness the energy, while the same unit viewed using the lens of Globalization and Sustainability would be more focused on the worldwide availability of resources and how societies best manage their supply.

There are many other components of the IB pedagogy, including specialized rubrics and grades, overarching "statements of inquiry" that frame the focus of a unit, cross-cutting concepts that permeate multiple units, and specific cognitive skills – "approaches to learning" - that students need to work on throughout their years of study. Ultimately, the IB method is a well organized and semi-prescribed model of inquiry-based and constructive learning that has its own vocabulary for many concepts that would be present in the planning and teaching of any highly-effective classroom.

Resources for teachers and students

Books and Articles

Virginia's Coal Ages by Samuel O. Bird 1997

This is a scholarly article from the VA Department of Mines and Mineral Energy (DMME), but reads more like a magazine piece. Although it is Virginia specific, it has great details on the formation and provenance of coal.

Oxygen: The Molecule That Made the World by Nick Lane

I used this book to research the atmosphere during the Carboniferous period, but would recommend it to anyone interested in atmospheric chemistry and the history, importance, and devastating/life-bringing qualities of oxygen on Earth

Mineral and Fossil Fuel Production in Virginia (1999-2003) by Amy Gilmer et al.

Another DMME publication, this article is Virginia-specific, but I am including it as I am sure that most states have similar agencies that publish similar reports. It is a good resource to share with students to show them just what are the financial and mineral resources of their state.

Sustainable Energy: Without the Hot Air by David J. MacKay

This book is incredibly useful in demystifying the basic mechanics of and efficiencies of the major sources of sustainable energy that are used worldwide. It is wry and a bit dry, but well worth the read.

The Quest: Energy, Security and the Remaking of the Modern World by Daniel Yergin

This book is incredibly informative, both on the mechanisms of energy production as well as the geopolitical history of the oil and natural gas industries. It's long, but is well set up for cherry picking chapters.

Websites

The Carboniferous Period - http://www.ucmp.berkeley.edu/carboniferous/carboniferous

The Paleontology Portal - http://paleoportal.org/kiosk/sample_site/index.html.

Both of these websites have detailed but not overly academic explanations of the geologic, atmospheric, and climate conditions of the Carboniferous and other geologic time periods. The Paleontology Portal has another great feature that allows users to choose a state or region and view the specific conditions at any point in geologic history.

ZerofootprintYouth. - http://calc.zerofootprint.net/

This is one of many sites that students can use to determine their carbon footprint. I like this one for a number of reasons: it is in metric but has a conversion chart for students, it includes many aspects of student life from transportation to food, it allows students to post their data and see results from other students worldwide.

US Energy Information Agency State Info - http://www.eia.gov/state/

A good accompaniment to the Gilmer paper that has raw data and also graphs that illustrate your state's production and usage of a variety of energy sources.

Windmills: Putting Wind Energy to Work –
http://www.pbslearningmedia.org/resource/phy03.sci.engin.design.lp_windmill/windmills-putting-wind-energy-to-work/

An easily scale-able lesson from PBS that addresses wind energy and has a design challenge included for students.

Notes

1. McCartney 1989
2. EIA, 2016
3. Gilmer et al., 2005
4. Bird 1997
5. U.S. Energy Information Administration – EIA, 2016
6. Beerling et al., 1998
7. Kidston, 1901
8. Francis, 1964
9. Bird, 1997
10. Orem & Finkleman, 2014
11. Lane, 2002
12. Bird, 1997
13. Grossman et al, 2008
14. Bird, 1997
15. Orem & Finkleman, 2014

16. Bird, 1997
17. Orem & Finkleman, 2014
18. Orem & Finkleman, 2014
19. Orem & Finkleman, 2014
20. Gilmer et al., 2005
21. Gilmer et al., 2005
22. US. EIA Report, 2016
23. Wilkes, 1988
24. Mining 101, 2012
25. Gilmer et al. et al, 2005
26. EIA, 2016
27. Palmer et al., 2010
28. Keating, 2001
29. Keating, 2001
30. Orem & Finkleman, 2014
31. Orem & Finkleman, 2014
32. Milici, 2005
33. Montgomery & Smith, 2010
34. Yergin, p329
35. Feyrer et al., 2015
36. Schmidt, 2013
37. Wigley 2011
38. Schmidt, 2013
39. Rubenstein & Mahani, 2015
40. Yergin, p.333
41. Osborn et al., 2011
42. Saba & Orzechowski, 2011
43. US EIA, 2016
44. Hunter, 2013, p30
45. US EIA, 2016
46. Committee On Uranium Mining In Virginia, 2012
47. Committee On Uranium Mining In Virginia, 2012
48. Bodnar, 2012, p.30
49. Committee On Uranium Mining In Virginia, 2012
50. Bacqué, 2012
51. Dietrich, 2015

Bibliography

Bacqué, Peter. "Elevated Radioactivity Levels Found in North Anna Well." Richmond Times-Dispatch. February 22, 2012. Accessed July 18, 2016. http://www.richmond.com/business/article_6bd5b666-c2df-5b9d-869a-13e09db78e98.html.

Bird, Samuel O. 1997. *Virginia's Coal Ages.* Government Report, Dept. of Mines, Minerals, and Energy, Commonweath of Virginia, Division of Mineral Resources.

Beerling, D. J., F. I. Woodward, M. R. Lomas, M. A. Wills, W. P. Quick, and P. J. Valdes. "The Influence of Carboniferous Palaeoatmospheres on Plant Function: An Experimental and Modelling Assessment." *Philosophical Transactions of the Royal Society B: Biological Sciences* 353, no. 1365 (1998): 131-40. doi:10.1098/rstb.1998.0196.

"Uranium Mining In Virginia." Interview by Robert Bodnar. *Virgnia Issues and Answers*, January/February 2012, 28-37.

"Coal." DMME. July 4, 2015. Accessed July 14, 2016. https://www.dmme.virginia.gov/dgmr/coal.shtml.

Committee on Uranium Mining in Virginia, Committee On Earth Resources, Board on Earth Sciences and Resources, Division on Earth and Life Studies, and National Research Council. *Uranium Mining in Virginia: Scientific, Technical, Environmental, Human Health and Safety, and Regulatory Aspects of Uranium Mining and Processing in Virginia*. National Academies Press, 2012.

Dietrich, Tamara. "Virginia Gets Country's First Wind Energy Research Lease in Federal Waters." Daily Press. March 25, 2015. Accessed July 18, 2016. http://www.dailypress.com/news/science/dp-nws-wind-turbines-governor-20150325-story.html.

Francis, E. H., and A. W. Woodland. "The Carboniferous Period." *Geological Society, London, Special Publications* 1, no. 1 (1964): 221-32. doi:10.1144/gsl.sp.1964.001.01.21.

Gilmer, Amy K., Catherine B. Enomoto, James A. Lovett, and David B. Spears. *Mineral and Fossil Fuel Production in Virginia (1999-2003)*. Charlottesville, VA: Commonwealth of Virginia, Dept. of Mines, Minerals and Energy, Division of Mineral Resources, 2005.

Grossman, Ethan L., Thomas E. Yancey, Thomas E. Jones, Peter Bruckschen, Boris Chuvashov, S.j. Mazzullo, and Horng-Sheng Mii. "Glaciation, Aridification, and Carbon Sequestration in the Permo-Carboniferous: The Isotopic Record from Low Latitudes." *Palaeogeography, Palaeoclimatology, Palaeoecology* 268, no. 3-4 (2008): 222-33. doi:10.1016/j.palaeo.2008.03.053.

Grymes, Charlie. 2003. *Natural Gas Resources in Virginia.* Accessed June 15, 2016.

Hunter, Leslie. *Renewable Energy in the 50 States: Southeastern Region.* American Council on Renewable Energy. 2013. July 16, 2016. http://www.acore.org/images/documents/Southeastern_Region.pdf

Keating, Martha. *Cradle to Grave: The Environmental Impacts from Coal Cradle to Grave: The Environmental Impacts from Coal*. Pdf. Boston: Clean Air Task Force, June 1, 2001.

United States. Energy Information Administration. *Annual Coal Report 2014.* Compiled by Lance Harris and JenAlyse Arena. March 23, 2016. Accessed July 13, 2016. http://www.eia.gov/coal/annual/.

Kidston, R. "The Flora of the Carboniferous Period. First Paper." *Proceedings of the Yorkshire Geological Society* 14, no. 2 (1901): 189-229. doi:10.1144/pygs.14.2.189.

Lane, Nick. *Oxygen: The Molecule That Made the World*. Oxford: Oxford University Press, 2002.

Mackay, David J. C. *Sustainable Energy: Without the Hot Air*. Cambridge: UIT, 2009.

McCartney, Martha W. 1989. "Historic Overview Mid-Lothian Mines and Railroad Foundation - Midlothian, Virginia." December. Accessed June 2016. http://www.midlomines.org/historic-overview.html.

Milici, Robert C. "Assessment of Undiscovered Natural Gas Resources in Devonian Black Shales, Appalachian Basin, Eastern U.S.A." U.S. Geological Survey Open-File Report 2005-1268. 2005. Accessed July 15, 2016. http://pubs.usgs.gov/of/2005/1268/.

"Mining 101." Mining 101. August 30, 2012. Accessed July 18, 2016. http://www.wvcoal.com/mining-101.html.

Montgomery, Carl T., and Michael B. Smith. "Hydraulic Fracturing: History Of An Enduring Technology." *Journal of Petroleum Technology* 62, no. 12 (2010): 26-40. doi:10.2118/1210-0026-jpt.

Orem, W.h., and R.b. Finkelman. "Coal Formation and Geochemistry." *Treatise on Geochemistry*, 2014, 207-32. doi:10.1016/b978-0-08-095975-7.00708-7.

Osborn, S. G., A. Vengosh, N. R. Warner, and R. B. Jackson. "Methane Contamination of Drinking Water Accompanying Gas-well Drilling and Hydraulic Fracturing." *Proceedings of the National Academy of Sciences* 108, no. 20 (2011): 8172-176. doi:10.1073/pnas.1100682108.

Palmer, M. A., E. S. Bernhardt, W. H. Schlesinger, K. N. Eshleman, E. Foufoula-Georgiou, M. S. Hendryx, A. D. Lemly, G. E. Likens, O. L. Loucks, M. E. Power, P. S. White, and P. R. Wilcock. "Mountaintop Mining Consequences." *Science* 327, no. 5962 (2010): 148-49. doi:10.1126/science.1180543.

Rubinstein, Justin L., and Alireza Babaie Mahani. "Myths and Facts on Wastewater Injection, Hydraulic Fracturing, Enhanced Oil Recovery, and Induced Seismicity." *Seismological Research Letters* 86, no. 4 (2015): 1060-067. doi:10.1785/0220150067.

Saba, T., and M. Orzechowski. "Lack of Data to Support a Relationship between Methane Contamination of Drinking Water Wells and Hydraulic Fracturing." *Proceedings of the National Academy of Sciences* 108, no. 37 (2011). doi:10.1073/pnas.1108435108.

Schmidt, Charles W. "Estimating Wastewater Impacts from Fracking." *Environ. Health Perspect. Environmental Health Perspectives* 121, no. 4 (2013). doi:10.1289/ehp.121-a117.

Scotese, C.r., and W. S. Mckerrow. "Revised World Maps and Introduction." *Geological Society, London, Memoirs* 12, no. 1 (1990): 1-21. doi:10.1144/gsl.mem.1990.012.01.01.

U.S. Energy Information Administration - EIA. n.d. *Independent Statistics and Analysis.* Accessed June 23, 2016. https://www.eia.gov/state/rankings/?sid=US#/series/101.

USA. National Bureau Of Economic Research. *Geographic Dispersion of Economic Shocks: Evidence from the Fracking Revolution*. By James Feyrer, Erin Mansur, and Bruce Sacerdote. Cambridge, MA: NBER, 2015. Accessed July 15, 2016. http://www.nber.org/papers/w21624.

Wigley, Tom M. L. "Coal to Gas: The Influence of Methane Leakage." *Climatic Change* 108, no. 3 (2011): 601-08. doi:10.1007/s10584-011-0217-3.

Wilkes, G. P. *Mining History of the Richmond Coalfield of Virginia*. Charlottesville, VA: Commonwealth of Virginia, Dept. of Mines, Minerals, and Energy, Division of Mineral Resources, 1988.

Yergin, Daniel. *The Quest: Energy, Security and the Remaking of the Modern World*. New York: Penguin Press, 2011.