sustain

a journal of environmental and sustainability issues

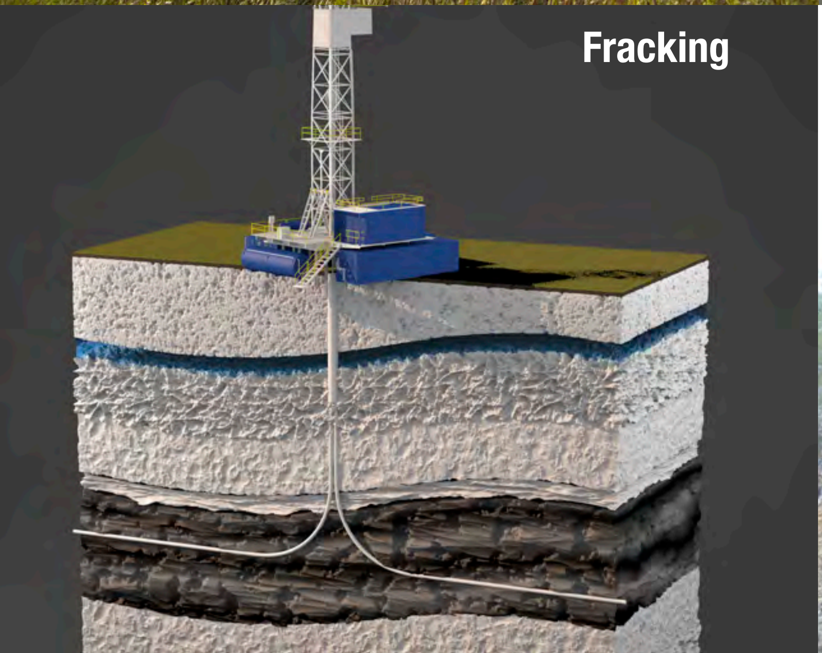
Issue 31
Fall/Winter 2015

The
Kentucky Institute
for the Environment
and Sustainable
Development

Unconventional Energy

Methane Gas

Algae Farms



Fracking

Oil Shale

sustain

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The Kentucky Institute for the Environment and Sustainable Development (KIESD) was created in July 1992 within the Office of the Vice President for Research, University of Louisville.

The Institute provides a forum to conduct interdisciplinary research, applied scholarly analysis, public service and educational outreach on environmental and sustainable development issues at the local, state, national and international levels.

KIESD is comprised of eight thematic program centers: Environmental Education, Environmental Science, Land Use and Environmental Responsibility, Sustainable Urban Neighborhoods, Pollution Prevention, Environmental and Occupational Health Sciences, Environmental Policy and Management, and Environmental Engineering.

Sustain is published semi-annually by the Kentucky Institute for the Environment and Sustainable Development, University of Louisville, 203 Patterson Hall, Louisville, Kentucky 40292.

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Issue 31 - Fall/Winter 2015

Unconventional Energy

UNIVERSITY OF
LOUISVILLE.

Affordability
Efficiency
Sustainability

Cheapest Energy? The Energy That You Don't Use!

Mary Joyce Freibert, CEM, LEED Green Associate

Report Finds Energy Efficiency is America's Cheapest Energy Resource

According to a new report released today by ACEEE, energy efficiency is the cheapest method of providing Americans with electricity. Energy efficiency programs aimed at reducing energy waste cost utilities only about three cents per kilowatt hour, while generating the same amount of electricity from sources such as fossil fuels can cost two to three times more.

"The cheapest energy is the energy you don't have to produce in the first place," said ACEEE Executive Director Steven Nadel. "Our new report shows that when utilities are examining options on how to provide their customers with cheap, clean electricity, energy efficiency is generally the best choice."

The Boston Globe reports that Burlington, Vermont, Vermont's largest city, now gets 100% of its electricity from renewable sources, such as wind, hydro, and biomass.

POPULATION, ENERGY AND CLIMATE CHANGE

Ronald R. Van Stockum, Jr.

POPULATION

The human population of the Earth at the beginning of the Christian Era (CE) was approximately 300 million. By 1500 CE, it was at 500 million people. Around 1800, it was approximately 1.0 billion. In 1950, it had climbed to more than 2.5 billion.[1] In 2014, the world's population was greater than 7.1 billion people.[2] Reasonable projections of the Earth's human population in 2050 are at 9.6 billion people.[3]

The number of Native Americans inhabiting Kentucky over time prior to 1500 is unknown. Archaeological evidence, however, indicates that the Commonwealth was thoroughly settled at different times prior to European contact.[4] Regardless, after obtaining firearms from the Dutch during the "Beaver Wars" of the 1600's, the Iroquois drove out the Shawnee from Ohio and Kentucky.[5] Land explorer Christopher Gist, in 1751, found only one Native American settlement in Kentucky, that of forty dwellings in lower Shawneetown in South Shore, Kentucky opposite modern Portsmouth, Ohio and the mouth of the Scioto River.[6] That and Eskippakithiki (Indian old fields) near Winchester, Kentucky, may have been the only permanent Native American villages at the time of European colonization of the Commonwealth.[7]

Kentucky was rapidly settled by Europeans and their descendants in the period between 1780 and the end of the War of 1812. In 1850, Kentucky's population was 982,405 thousand. By 1950, it had risen past 2.9 million, and in 2013 to almost 4.4 million.[8] It is projected to have a population of greater than 5.3 million in 2050.[9]

HISTORICAL PERSPECTIVE

Thomas Malthus, in his 1798 publication, "An Essay on the Principle of Population," was the first to note the problem when population grows exponentially, and the resources to support that population grows only arithmetically.[10] Paul Ehrlich based his dire projection of the future on the concepts of Malthus in his controversial 1968 work, *The Population Bomb*.[11] Yet the global population of humans continues to rise.

In 1972, The Club of Rome published its study of population and the depletion of natural resources in its book, *Limits to Growth*. This highly controversial work used computers to model different scenarios of future growth, concluding that world growth was unsustainable.[12] The controversial use of computers to model the future continues today to be a centerpiece of the opposition against the conclusion that we are in a time of human-induced "climate change."

In 1956, M. King Hubbert, a geologic scientist, developed a controversial theory on "peak oil," that period of time after which the amount of oil production worldwide would begin to decline. Hubbert predicted that peak would occur in the United States and Texas by 1970 with the peak in world oil production occurring between 1995 and 2000.[13] He was aware of the contribution of oil shale and tar sands as potential hydrocarbon sources and figured such unconventional sources in his calculations.[14] Regardless, the explosion in exploration and production of oil, natural gas and natural gas liquids from unconventional sources adds to the fierce debate over when "peak oil" may become a reality. It is interesting to note that Dr. Hubbert expressed his belief that nuclear power was the fuel for the future.[15]

Each of these scholarly efforts appears to have underestimated the marketplace, human ingenuity and the extent of the Earth's complex resources. They are wrong, and significantly so, but perhaps only in the timing of the consequences that their analysis portend. The "green revolution," genetic engineering, the greater availability of energy resources to make fertilizers, and the extraction of more of the Earth's energy resources have fed a much greater global population than that imagined by Malthus.

The development of unconventional fuels worldwide, and here in Kentucky, significantly pushes out into the future the coming of "peak oil." Techniques to reach these new sources of energy, or develop new mechanisms in its production, allow for the greater exploration and exploitation of the natural resources of this planet needed to support the larger, increasing human population.

Whether this continued growth in population, energy use and resource exploitation is advisable, in either the short or long term, is not the topic herein. Those issues are important and worthy of much analysis and debate. Yet, the consequences of our growth may already be upon us in the form of fresh water limitations and climate change.

THE CARBON CYCLE

The massive growth of human population was made possible by food and fuel. Both are still linked to the prosperity of our species and originate (with the exception of nuclear fission) in the power of the sun.[16]

Although some primitive bacteria and archaea can obtain energy by reducing hydrogen sulfide, humans trace their fuel use to energy originating in the sun. For example, wind power is derived from the sun's variable heating of the atmosphere and water power by the cycling of moisture through the atmosphere and over uplifted continental surfaces. Yet our greatest source of energy from the sun is that trapped by life forms and stored in the carbon-to-carbon bonds of organic molecules. Thus sunlight energy is trapped and released by life forms through what was popularized in the early 1800's by Sir Humphrey Davy as, "The Carbon Cycle," and known commonly as Photosynthesis and Respiration. [17]

A. Photosynthesis is:

CO2 (carbon dioxide) + H2O (water) + energy (sunlight) = C6H,2O6 (glucose) + O2 (oxygen)

B. Respiration is essentially the opposite:

C6H,2O6 (glucose) + O2 (oxygen) = CO2 (carbon dioxide) + H2O (water) + energy (ATP & heat)

Carbon dioxide (CO2) was originally produced by geologic processes such as volcanism during planet formation. It is now also a waste product of life form respiration, or the product of hydrocarbon combustion. Glucose (G6H12O6) is the simple sugar hydrocarbon produced by plants in photosynthesis and slowly "burned" in cellular function through respiration.

Approximately (and varying significantly by plant species and calculation method) 5% of sunlight hitting a leaf results in a net increase in organic production (beginning as glucose but converted to other carbohydrates, lipids, proteins, and nucleic acids).[18] The energy released through combustion of glucose in respiration (the breaking of the carbon to carbon bonds) is initially trapped in the phosphate bonds of adenosine triphosphate (ATP). In the presence of oxygen (aerobic respiration), up to 38 ATPs are produced from the combustion of each glucose molecule.[19] In the absence of oxygen (anaerobic respiration, or "runner's fatigue"), a net of only two ATPs are produced. In aerobic respiration, approximately 40% of the energy in the glucose bonds is converted to ATP for use in cellular activity. The remainder is used up in the production process or wasted off as heat.[20]

EARLY FUEL

Humans first exploited hydrocarbon fuel on a significant scale through the uncontrolled burning of plant or animal matter for heat, cooking, illumination and safety. Although such combustion releases most of the energy stored in the fuel's carbon bonds, the effect is fleeting with little energy retained, except perhaps as body heat. Although plant and animal biomass are a renewable resource, limited exploitation of existing natural resources restricted early population growth and diversification.

In fact, climate change and its impact on the availability of plant and animal biomass for food and fuel may have contributed to the collapse of the Anasazi culture (ca. 1,000 CE) in the American Southwest and the Mayan civilization (ca. 1,500 CE) in Southern Mexico. Recent evidence of drought may explain, in part, the end of the Bronze Age in the Levant (ca. 1,000 BCE) and the Mississippian culture in the American Midwest (ca. 1,350 CE) just before European contact.[21] All of these societies were dependent on the availability of plant life to "fix" the sunlight's energy into organic matter upon which humans fed and which provided for their health, safety and progress.

SEQUESTERED ENERGY

We know from the geologic record approximately when free oxygen released by early life forms began to accumulate in the Earth's environment. Roughly 2.4 billion years ago enough oxygen had been released through photosynthesis that oxidized sediments, such as the banded iron formations, began to be deposited.[22] Abundant life forms were present then and, upon reproduction, death or catastrophe, began to accumulate as organic matter in the primitive ocean sediments or in marshes and sloughs surrounding the early landmasses.

Upon the crushing weight of overlying deposits and the subsidence of its surface, these materials became compressed, heated, and altered. Over time, they were changed into what we would find in seeps and rock strata and for which we mined or drilled deeply beneath the surface seeking coal, oil, natural gas, natural gas liquids, and coal bed methane. These sources of hydrocarbon are the result of ancient sedimentary deposits of organic matter, matter that still maintains the carbon bonds containing trapped sunlight energy, energy stored deep beneath the surface for millions of years. There, over time, the pressure and temperature slowly crushed and congealed this organic matter to kerogen and other high molecular weight compounds

such as asphaltene, material from which coal, oil, and gas would develop.

Sedimentary plant remains, especially as coal, provided an early, accessible, concentrated reservoir of energy trapped and sequestered by geologic processes. This newly exploited energy source fueled the Industrial Revolution, especially in England which had extensive coal reserves.[23]

Oil, present in seeps worldwide, was used in small quantities in fire, boat caulking and battle. In the 1800's, Russia produced small quantities of oil around Baku on the Caspian Sea. Simultaneous well drilling in Canada and Pennsylvania around 1860 brought forth "gushers," and the modern commercial production of oil.

Natural gas also has a history, and may have been associated with ethylene gas at the Temple of Apollo in ancient Delphi, Greece (The Oracle of Delphi).[24] It was the product of an early coal gasification industry in the 1800's and 1900's. The Louisville Gas and Water Company originally operated coal gasification plants in Louisville, Kentucky, one of which is the reclaimed site under the downtown baseball field. The first Louisville coal gasification plant was built in 1838 and the last plant closed in 1960.[25] Nationally, the industry surrounding commercial use of naturally occurring gas can be traced to the development of those early 1860's oil wells in Pennsylvania.

Into the 20th Century, it was the conventional fuels of wood, fat, coal, oil and gas that powered our population and its progress. Wood and animal fat are in limited supply. Conventional oil and gas discoveries have slowed, and existing supplies are caught up in political cartels or facing inordinate expense in extraction (such as in the Caspian Sea). Coal use is burdened by modern environmental controls on air contaminant release and ash disposal.[26] And coal combustion in electrical generation facilities generates significant carbon dioxide emissions which may be contributing to climate change.[27]

Fortunately, there are abundant additional sources of energy from unconventional sources, but they can be tricky and costly to extract or produce.

CLIMATE CHANGE

No growth in human population can be sustained without fresh water. In the human consumption of this vital nutrient, the natural system is strained, whether by drought conditions in California, Rocky Mountain River drainages diverted by front-range cities on the plains in the United States, or in whole watersheds shifted in Africa and China. The world's ecosystems have been drastically altered to get at fresh water and divert it to human use whether by consumption, agriculture, or hydropower.[28] Water is abundant in Kentucky and, in this way, Kentucky has an exceptional competitive advantage. Here, the lush, temperate vegetation is fed by more navigable miles of freshwater than any state other than Alaska.[29] More water is contributed by the Ohio River than the Mississippi River at its confluence. And fresh water figures heavily into the production of unconventional fuels.

James Lovelock, a chemist, in 1972 proposed the modern concept of the world acting as a single, self-regulating organism, one he called "Gaia."[30] He incorporated the concept of "homeostasis" as part of its self-regulating activity. That hypothesis was championed in the 1970s by the preeminent cellular biologist, Lynn Margulis.[31] Yet, the Earth's systems are proving to be incredibly complex to study, and interact in a myriad of ways challenging to describe by science, much less model mathematically.

The organismic approach, however, is now being examined, even supplanted, by the voluminous research of an extraordinary group of scientists. They are using the world's most powerful super computer systems to explore, analyze, and predict the complex interactions of the Earth's major components. These scientists, gathered together in the "Intergovernmental Panel on Climate Change" (IPCC), are providing much material for public debate. They are finding that altering of even minor elements of the Earth system can act as "tipping points" to drastically impact the whole.[32] Their conclusions are, more and more, driving the political actions of our governmental bodies.[33] These actions figure prominently in the development of unconventional fuels described herein.

The IPCC was formed in 1988 by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO). The IPCC was charged by the United Nations to, "... provide internationally coordinated scientific assessments of the magnitude, timing and potential environmental and socio-economic impact of climate change and realistic response strategies..."[34] The IPCC has now produced five Assessment Reports (AR), the last of which was published in parts in 2013 and 2014.[35]

In June 1992, in response to the first IPCC report, the United Nations Conference on Environment and Development (UNCED) was held in Rio De Janeiro. Known as the "Earth Summit," the conference was attended by more than 116 heads of State (including U.S. President George H. Bush), and more than 2,400 representatives of Non-Governmental Organizations (NGO). One of the important binding agreements that came out of the Earth Summit was the Framework Convention on Climate Change (UNFCCC).[36] The Framework has 196 signatory nations and parties including the United States.[37]

The Framework called upon future meetings among the signatories to determine binding limits on the emission of CO2 by the parties. The limits were set in Kyoto, Japan, in 1997. President George W. Bush had campaigned in 2000 with a goal of regulating CO2 emissions in the United States. In 2001, President Bush reversed course, citing opposition in Congress, and decided against regulating CO2 emissions.[38] Regardless, enough nations signed the Kyoto Treaty that it went into effect. The European Union was quick to establish a "carbon exchange" whereby carbon credits could be bought and sold. Although the Kyoto Treaty expired in 2012, the European Union continues to regulate carbon emissions through a "cap and trade" system.[39]

President Barack Obama made the regulation of carbon emission one of his campaign elements in 2008. In 2009, the United States House of Representatives passed legislation regulating carbon dioxide emissions through a "cap and trade" system, but similar legislation did not pass in the Senate.[40] As a result, the Obama Administration sought to regulate CO2 emissions under the Clean Air Act. In Massachusetts v. Environmental Protection Agency, 549 U.S. 497 (2007), the Supreme Court of the United States upheld the President's authority to do so.[41] The Obama Administration has proceeded accordingly, proposing regulations that will limit CO2 emissions from fossil fuel electrical generating units. These regulations could have the effect of greatly reducing the use of coal in electrical generation and facilitating increased use of renewable sources of energy.[42]

The Fifth Assessment of the IPCC (AR5) made the strongest statements to date concerning the threat of climate change to the planet. "Warming of the climate system is unequivocal, human influence on the climate is clear and limiting climate change will require substantial and sustained reductions of greenhouse gas emissions."[43]

The premier scientific organization in the United States, the American Association for the Advancement of Science (AAAS), has recently added its scholarly weight to the concern over climate change, "97% of climate scientists have concluded that humans are changing the climate ... the evidence is overwhelming: levels of greenhouse gases in the atmosphere are rising. Temperatures are going up. Springs are arriving earlier. Ice sheets are melting. Sea level is rising. The patterns of rainfall and drought are changing. Heat waves are getting worse as is extreme precipitation. The oceans are acidifying."[44]

KENTUCKY'S NATURAL RESOURCES

Kentucky is an ancient land surface. It was never covered with ice during the Glacial Ages.[45] Surface bedrock ranges in age from the late Ordovician through to the early Permian Periods of geologic time (approximately 450-280 million years ago) and include the more recent late Cretaceous, Tertiary and Quaternary deposits of the last 75 million years.

Most rock in Kentucky is sedimentary in nature, laid down as various strata in the great oceans that covered this continental landmass over geologic history. There are, however, great fault lines related to ancient continental collisions and the resultant uplift of the Appalachian Mountains. Here, as in the Fluorspar District of Western Kentucky, molten igneous flows have filled in these faults with veins of valuable minerals and metals from deep within the Earth's crust and mantle.[46]

Salt springs were noted by the earliest European settlers in Kentucky. They had attracted abundant buffalo herds from the western grasslands. Many of Kentucky's early pioneers followed "Buffalo Roads" to these springs. They were evidence of the existence of valuable resources trapped deep within Kentucky's rock strata.[47] For the next 100 years, they would be used in a health and hot spring hotel industry serving southerners fleeing the heat and disease of southern states. It wasn't long until wells drilled for these saltwater resources accidentally uncovered Kentucky's wealth of underground oil and natural gas.

The shale beds of the Devonian Period include the Ohio Shale in Eastern Kentucky, the New Albany Black Shale in Central and Western Kentucky and the Chattanooga Shale in Southeastern Kentucky. These shales contain abundant natural gas, natural gas liquids, and the precursors to oil. They are the probable source of hydrocarbon sought by fracturing (fracking) and horizontal drilling interests in Kentucky. Younger Pennsylvanian aged rock strata contain the abundant coal beds of the Eastern and Western coalfields of Kentucky. Conventional sources of natural gas and oil have traditionally been found in the rocks of South Central Kentucky and in the Eastern and Western coalfields. Methane gas is associated with coal beds in Eastern Kentucky and Kentucky's tar sands are located primarily at the southeastern edge of the Western coalfields.

KENTUCKY OIL AND GAS

Conventional sources of oil and gas are generally those reservoirs that have trapped natural gas and oil after it has been formed in the lower original strata (such as the Devonian Shale), and which has migrated to upper confining rock levels. These "pockets" of natural gas and oil trap the hydrocarbon as it moves up through the rocks until it is blocked by an impermeable layer of stone. Many of these formations are under pressure, hence the "gushers" when drillers are fortunate enough to punch through into such a reservoir. Kentucky has had a number of surges in historical drilling activity driven by the price of oil and the abundance of natural gas. The new drilling techniques in unconventional sources of these hydrocarbons will result in renewed exploration and production in Kentucky.

Recent activity in oil and gas has involved the extraction from the tight Upper Devonian Period Berea Sandstone in Lawrence County in Northeastern Kentucky. These sands are being exploited using water-based fracking materials and horizontal drilling. This is a newer development in size for Kentucky, as most of the existing and earlier horizontal well and fracking activities have been in shales where water is an inefficient mechanism to withdraw hydrocarbon. This is because the Devonian Shales in Kentucky contain a higher percentage of clay and, although they can be "fracked" in a similar fashion to the same age Marcellus Shales in Pennsylvania and West Virginia, they contain a higher concentration of clay particles. These clay particles will absorb fracking water and seal up the fractures created by the drilling procedure. Therefore, in Kentucky much of the fracking and horizontal drilling has been accomplished using nitrogen gas.[48]

There are many other opportunities for drilling into and exploiting the unconventional sources of both natural gas and oil in Kentucky. Many of them will involve drilling directly into the tight shales of the Devonian Period rocks, and undoubtedly will involve the development of new fracking technologies. Others will involve exploration in the tight sands or even limestone reservoirs of hydrocarbon which have not been traditionally exploited by the methods previously used to extract hydrocarbon.

KENTUCKY COAL

Kentucky has abundant coalfields in both the eastern and western portions of the Commonwealth. These coal beds were laid down in the Pennsylvanian Period during oscillations in the sea depth adjoining the landmass that was to become Kentucky. Large areas of marsh and swampy habitat created excellent conditions for the preservation of forest trees composed of massive versions of horsetails, club mosses and tree ferns which dominated the floral landscape.[49] Coal was used locally by the inhabitants of these areas for heat and became exploited more intensely with the extension of railroads into the mountains moving coal to outside markets.

Due to the OPEC Embargo after the Arab-Israeli War of 1973, and the restriction of oil exports from Iran during the Iranian Revolution of 1978, governmental decisions were made to focus the generation of electricity in the United States to an abundant, domestic source.[50] That source was coal. As a result, over the last 50 years, coal has climbed to as much as 55% of the national generation of electricity.[51] This impressive participation of coal in our energy mix now faces challenges relating to the impact of burning coal in the environment. Coal is a complex organic chemical, the burning of which releases carbon dioxide (CO2), nitrogen oxides (NOx), sulfur dioxide (SO2, acid rain) and mercury. Coal has also recently been the subject of much opposition by environmental groups due to the widespread nature of strip mining and the impact of mountaintop removal and the filling in of stream headwaters with mining overburden.

Coal has also been challenged by the almost sudden appearance of overwhelmingly inexpensive and available sources of natural gas. This natural gas is a virtual flood of hydrocarbon released from the new fracking and horizontal drilling techniques into heretofore previously under-utilized rock strata across the country. As a result, many of the nation's utilities are switching over to natural gas because of price competition and the fewer pollution controls needed compared with those associated with coal combustion.

The coal industry is concerned that these environmental controls and regulations are negatively impacting the cost and availability of coal for domestic electric generation. The burning of coal results in the discharge of conventional pollutants as well as hazardous air pollutants which are now fully addressed by the Environmental Protection Agency. The cost of removing these pollutants is exorbitant. The burning of coal has, therefore, become more expensive, making coal a less economically available source of electric generation. It appears that the utilization of coal as a source of domestic electrical generation will diminish. It is expected by 2040 to contribute approximately 30% of the electrical generation in the country.[52]

Perhaps the most significant current concern with coal as a source of fuel and electrical generation is the release of carbon dioxide. Carbon dioxide is a result of the combustion of carbon-to-carbon bonds in the organic, hydrocarbon fuel. There is significant data that the increase of carbon dioxide in the atmosphere is causing the Earth to increase in temperature, leading to global warming and climate change. There is much pressure on the political bodies of the world, as well as developing nations, to curb their use of hydrocarbon fuels that contribute to an increase of carbon dioxide concentration in the atmosphere. This is the most contentious environmental concern of our generation, and the consequences of not acting are potentially dire, if projections of the IPCC are born out to be true.[53]

KENTUCKY TAR SANDS

There are significant deposits of tar sands in Western Kentucky with smaller deposits in Eastern Kentucky. The tar sands of Western Kentucky lie on the edge of the Great Illinois Basin and literally ooze tar from the face of the rocks of the lower Pennsylvanian and upper Mississippian Age north of Mammoth Cave National Park along the Nolin River. There are large quantities available on the surface, and even more in the subsurface. Estimates range from 3 to 6 billion barrels of oil reserves.[54]

The Western Kentucky outcrop of these tar sands was the source of a once-thriving mining industry at Kyrock (Kentucky Rock), Kentucky. This industry dug out the hard sandstone rock containing the tar and ground it up in an asphalt-like preparation. The company then marketed this mixture as an early form of asphalt. In the early 1900's, this product was used to pave the Indianapolis Motor Speedway. These early days of asphalt production, however, were soon replaced by more cost effective production of asphalt using mixtures of oil and crushed rock.

Recently, companies mining the tar sands of Western Kentucky have reestablished mining operations using new techniques for removing the hydrocarbon from the crushed sandstone rocks that are mined. The application of these processes to Kentucky's tar sands may prove productive.[55]

KENTUCKY ENERGY DATA

The government of Kentucky has long had an interest in the environment and energy production in the Commonwealth. In 2005, Governor Ernie Fletcher combined the separate cabinets dealing with environmental protection and public protection into a single administrative entity. In 2008, Kentucky Governor Steven Beshear further consolidated Executive Branch Cabinets, creating the Kentucky Energy and Environment Cabinet. That Cabinet has been led since 2008 by Dr. Len Peters, a scientist

with extensive experience in the energy and applied science industries.

In 2008, Kentucky developed an energy policy for the Commonwealth entitled, “Intelligent Energy Choices for Kentucky’s Future; Kentucky’s 7-Point Strategy for Energy Independence.”[56] This 144-page document assembled voluminous data to present a picture of energy production, use and regulation in Kentucky. It developed “Seven Strategies” and stated, in part, as follows:

> “The Seven Strategies, when implemented, will restructure our energy portfolio in such a way that we can use energy in its broadest sense as a tool for economic development ... We aim to bring to the Commonwealth “green collar” jobs - jobs that will help rebuild local communities across the state. We must use our innovation and creativity in the years ahead, and as we transform our energy portfolio, it can and must be a force for economic development in the state.”[57]

In 2013, John Lyons, who for more than 10 years was Director of Kentucky’s Division of Air Quality, was named Assistant Secretary for Climate Policy. In this role, he reports directly to Secretary Peters and has assisted in the development of information reported out by the Cabinet’s Department of Energy Development and Independence, Division of Carbon Management and Data Analysis. Information collected by this agency, as well as the national U.S. Energy Information Administration, gives a detailed picture of energy use and production in the Commonwealth of Kentucky.[58]

Kentucky produced almost 9% of the nation’s output of coal in 2012. It is the third largest coal-producing state. In 2013, approximately 93% of Kentucky’s electricity was produced by burning coal. Hydroelectric produced approximately 3.9%, natural gas-fired facilities produced 2.2%, and other renewables 0.7%.

The Big Sandy Field in Northeastern Kentucky produces the largest amount of natural gas in the Commonwealth. Kentucky has energy reserves in the ground of approximately, 1) crude oil - 9 million barrels; 2) “dry natural gas” - 1,408 billion cu. ft. (there are approximately 17,936 natural gas producing wells in Kentucky); 3) “expected future production of natural gas plant liquids” - 81 million barrels; and 4) “recoverable coal at producing mines” - 1,263 million short tons (which is 6.8% of American reserves).[59]

In 2011 the 2-Megawatt Bowling Green Solar Farm (with 7,000 panels) came online, but solar cells are not currently a significant source of energy in Kentucky.[60] There are no commercial wind turbines and no nuclear energy facilities in Kentucky.[61]

CONCLUSION

Unconventional sources are revolutionizing the world of energy production worldwide. Although wind-generated energy does not appear promising for Kentucky, it is already a reality in the United States and will become even more so in Europe.[62] Solar energy will also become a larger worldwide component of energy generation and will expand in Kentucky. As with wind power, solar energy generation will expand as technological innovations and governmental programs continue to support their expansion.

Nuclear power has seen significant setbacks with the legacy of the disasters in Chernobyl in Russia (1986) and in Fukushima Prefecture in Japan (2011). Kentucky has no nuclear power plants. However, in 2008, Governor Brashear included the study of nuclear power as an addition to Kentucky’s energy future.[63] Despite the concerns over safety, nuclear power has the advantage of not contributing greenhouse gases to the environment. Regardless, many countries have reevaluated or restricted their nuclear programs and Germany has determined to eliminate its nuclear power generation facilities by 2022.

The future of energy generation in the Commonwealth will, in the short term, still be based on the fossil fuel wealth stored within Kentucky’s geologic strata. Coal will continue to support a significant portion of electrical generation in Kentucky, the nation, and internationally. Oil and gas will continue to be produced from conventional sources. But it is in the unconventional source of fuels in Kentucky that we will see the most interesting developments. Will the great revolution in oil shale fracking and horizontal well development in the United States expand more significantly in Kentucky? Will tar sands mining expand, producing significant quantities of bitumen for processing into oil? Will pipelines carrying valuable natural gas liquids from the Marcellus Shale Oil Fields of the Northeast cross the Commonwealth of Kentucky in the future?

Perhaps it will be in the growth of Kentucky’s lush vegetable life, the original “solar cells” of the Earth’s history, that Kentucky will excel. As the price of fossil fuel energy increases, the economics of biofuels in Kentucky become more attractive.

Solar and hydroelectric sources of energy are surely to improve their contribution to Kentucky’s portfolio. And even nuclear power is being discussed. It will be the cost of energy in the marketplace that will drive the opportunities in unconventional and renewable sources of energy. Conservation and energy efficiency may again become a valuable unconventional fuel. Cost, and governmental intervention in the marketplace (such as may be necessary to address climate change) will determine the future sources and use of energy in Kentucky.

Ronald R. Van Stockum, Jr.'s academic degrees include a Bachelor of Science in Biology from Santa Clara University, California, May 1972; a Masters of Science in Biology from the University of Louisville, May 1975; a Ph.D. in Biology from the University of Louisville, May 1979; and a Juris Doctor in Law from the University of Louisville, May 1979. Prior to entering the private practice of law, Mr. Van Stockum was an attorney for the Natural Resources and Environmental Protection Cabinet of the Commonwealth of Kentucky. He has been in the private practice of law as a sole proprietor since 1981.

Mr. Van Stockum is published in the areas of biology, history, and environmental law, and creative writing, and has addressed these topics in numerous presentations and seminars. He is past Chair of the Kentucky Chapter of the Nature Conservancy and has served as Vice President of the Filson HIstorical Society. He is past Chair of the Environmental Law Section of the Louisville Bar Association and past Chair of the Kentucky Bar Association Environment, Energy & Resources Law Section. He is also past President of the University of Louisville Alumni Association.

Mr. Van Stockum practices from his office in Shelbyville, Kentucky.

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1 The World at Six Billion, 1999, United Nations, Population Division, Department of Economic and Social Affairs.

2 U.S. and World Population Clock, United States Census Bureau. The United States is the third most populated country on Earth with greater than 318 million people. China is number one with greater than 1.3 billion people, with India next at greater than 1.2 billion. Mexico is 11th with greater than 120 million people and Canada 37th with greater than 34 million.

3 World Population Prospects: The 2012 Revision, United Nations, 2013. By 2028, India will exceed China in population. By 2050, Nigeria's population should eclipse that of the United States. In 2100, the world's population will be approximately 11 billion people.

4 The Archaeology of Kentucky: An Update, Volume One, 2008; David Pollack, Editor, Kentucky Heritage Council, State Historic Preservation Council, Comprehensive Plan Report No. 3; More than 24,000 archaeological sites had been found in Kentucky. Evidence for Native Americans living in Kentucky begins during the Paleoindian Period ca. 9,500 BCE. The great Wisconsin Age glaciers had begun their retreat north from what had been their most southern extent, the Ohio River only several thousand years prior. Many notable expansions of human population in Kentucky occurred later, evidenced by the late Archaic Period shell mound sites on the Green River (ca. 3000-1000 BCE), the Adena Mound building cultures of the early Woodland Period (ca. 1000- 200 BCE), and the Middle Woodland ceremonial mound building Hopewell Culture (ca. 200 BCE - 500 CE). The advance of temperate hardy corn from the south, ca. 900 CE, into the Eastern Agricultural Complex facilitated the expansion of large, complex societies of Native Americans during the Mississippian Period, ca. 900-1500 CE. That great Mississippian culture found at Cahokia (near East St. Louis, MO), Angel Mounds (near Evansville, IN on the Ohio River near the mouth of Kentucky's Green River), Kincaid Mounds (in Southern Illinois on the Ohio River across from Paducah, KY and the mouths of the Cumberland and Tennessee Rivers), and Wickliffe Mounds (in Western Kentucky on the Mississippi River just downstream of its confluent with the Ohio River) was dispersed for unknown reasons after ca. 1350 CE before European colonization. It is worthy of note that the collapse of the Mississippian culture roughly coincides with the "Little Ice Age" of 1350 to 1850.

5 The Shawnee, 1977, Clark, Jerry E., Kentucky Bicentennial Bookshelf.

6 The Journal of Christopher Gist, 1750-1751, 1929, Summers, Lewis P., Annals of Southeast Virginia, 1769-1800, Abingdon, VA.

7 "Eskippakithiki, the Last Indian Town in Kentucky;" 1932, October; Beckner, Lucien; Filson Club Historical Quarterly, 6(4). Science writer Charles Mann argues that before European contact the human population of the Americas was vastly higher than previously estimated. "1491: New Revelations of the Americas Before Columbus; 2005, Mann, Charles, C., Knoff Publishers.

8 United States Census Bureau.

9 Kentucky By the Numbers, 2012, Kentucky State Data Center, University of Louisville; Population Projections 2015-2050; Zimmerman, Julie N., Department of Community and Leadership Development, University of Kentucky.

10 "I think I may fairly make two postulata. First, that food is necessary to the existence of man. Secondly, that passion between the sexes is necessary and will remain nearly in its present state ... but toward the extinction of the passion between the sexes, no progress whatever has hitherto been made ... Population, when unchecked, increases in a geometric ratio. Sustenance increases only in an arithmetical ratio... I see no way by which man can escape from the weight of this law which pervades all of animated nature." An Essay On The Principle of Population As It Affects The Future Improvement of Society, with Remarks on the Speculations of Mr. Godwin, M. Condoret and other Writers, Chapter One, 1798, Malthus, Thomas Robert.

11 “Americans are beginning to realize that the underdeveloped countries of the world face an inevitable population-food crisis. Each year food productions falls a bit further behind burgeoning population growth, and people go to bed a little bit hungrier. While there are temporary or local reversals of this trend, it now seems inevitable that it will continue to its logical conclusion: mass starvation. The rich may continue to get richer, but the more numerous poor are going to get poorer. Of these poor, a minimum of ten million people, most of them children, will starve to death during each year of the 1970s. But this is a mere handful compared to the numbers that will be starving before the end of the century. And it is now too late to take action to save many of those people.” The Population Bomb, 1968,1971, P. 3, Ehrlich, Paul, R., A Sierra Club - Ballantine Book.

12 The Limits to Growth, A report for the Club of Rome’s project on the predicament of Mankind, 1972, Meadows, Donella H. et al. A Potomac Associates Book, Universe Books, New York; “We too have used a model. Ours is a formal, written model [see footnote to World Dynamics, Forrester, Jay W., Massachusetts Institute of Technology]. It constitutes a preliminary attempt to improve our mental models of long-term global problems by combining the large amount of information that is already in human minds and in written records with the new information-processing tools that mankind’s increasing knowledge has produced - the scientific method, system analysis, and the modern computer. Our world model was built specifically to investigate five major trends of global concern - accelerating industrialization, rapid population growth, widespread malnutrition, depletion of nonrenewable resources, and a deteriorating environment.” The Limits to Growth, Supra, P. 21. The projections in the “Limits to Growth” and the conclusions drawn therefrom have generated continuing scrutiny. In 1992, The Club of Rome published a follow-up book entitled, Beyond The Limits, Confronting Global Collapse, Envisioning A Sustainable Future, Meadows, Donella H. et al.; The Club of Rome describes itself as, “... an informal association of independent leading personalities from politics, business and science, men and women who are long term thinkers interested in contributing in a systemic interdisciplinary and holistic manner to a better world. The Club of Rome members share a common concern for the future of humanity and the planet.” (www.clubofrome.org).

13 “If the world should continue to be dependent upon fossil fuels as its principal source of industrial energy, then we could expect a culmination in the production of coal within about 200 years. On the basis of the present estimates of the ultimate reserves of petroleum and natural gas, it appears that the culmination of world production of these products should occur within about half a century, while the culmination for petroleum and natural gas in both the United States and the State of Texas should occur within the next few decades.” Nuclear Energy and the Fossil Fuels, P. 27, 1956, Hubbert, M. King, Chief Consultant (General Geology), Shell Development Company, Exploration and Production Research Division, Houston, Texas.

14 As an example, Hubbert (1956 Supra at P. 19) estimated that there were 300 to 500 billion barrels of oil (actually the more viscous bitumen) that could be extracted from the Athabascan oil sands of Northern Alberta, Canada; Canadian authorities estimate that there are between 1.7 and 2.5 trillion barrels of bitumen in the sands of which 150 to 300 billion is extractable by current methods. Such reserves would rival the total known oil reserves of Saudia Arabia. Oil Sands Discovery Center, Fort McMurray, Alberta, Canada, (www.energy.alberta.ca).

15 “There is promise, however, provided mankind can solve its international problems and not destroy itself with nuclear weapons, and provided the world population (which is now expanding at such a rate as to double in less than a century) can somehow be brought under control, that we may at last have found an energy supply adequate for our needs for at least the next few centuries of the ‘foreseeable’ future.” Hubbert, 1956, Supra at P. 36.

16 The sun is 300,000 times larger than Earth. Pressure at the center of the sun is about 700 million tons per square inch. That is enough to crush atoms, allowing hydrogen nuclei to smash into each other, fuse into hydrogen, and produce the radiation that gives off light and warmth to our planet. The sun has a core temperature of 154 million degrees kelvin. If a pin on Earth was heated to the same temperature as the center of the sun, its heat would set alight everything within 60 miles of it. On the surface of the sun, an area the size of a postage stamp shines with the power of 1.5 million candles.

17 The Age of Wonder, 2008, Richard Holmes, Pantheon Books.

18 Renewable Biological Systems for Alternative Sustainable Energy Production, 1997, Miyamoto, Kazuhisa, Ed., Food and Agriculture Organization of the United Nations (FAO).

19 Biology: Today and Tomorrow, Fourth Edition, 2013, Cecie Starr, Ed., Cengage Learning.

20 The Handy Biology Answer Book, 2004, James Bobick, et. al; For comparison, crystalline silicon solar cells achieve up to 25% light conversion efficiency. Progress In Photovolatiles, 2012, Martin A. Green, Et. al, Vol. 2, Issue 1, PP. 12-20.

21 Climate and the Late Bronze Collapse: New Evidence From the Southern Levant, 2013, Israel Finkelstein, et. al, Tel Aviv, Vol. 40, 149-175.

22 Evolution of Minerals, March 2010, Robert M. Hazen, Scientific American.

23 Coal, A Human History, 2004, Barbara Freese, Perseus Publishing.

24 Questioning the Delphic Oracle, August 2003, John R. Hale et al., Scientific American.

25 Personal communication, 2014, Robert J. Ehrler, Louisville Gas and Electric Company. See also Light Years: A History of Louisville Gas and Electric Company 1838-1988, 1988, LG&E, Louisville, Kentucky.

26 The Impact and Regulation of Air Toxics in Kentucky, 2011, Ronald R. Van Stockum, Jr., Bench and Bar, Kentucky Bar Association.

27 U.S. Energy Information Administration (EIA); IPCC, see AR5, infra. at footnotes 35 and 43.

28 How Will Climate Change Impact On Fresh Water Security, December 21, 2012, The Guardian Newspaper, England.

29 The Water Encyclopedia, 2nd Ed., 1990, F. Van Der Leeden et al., Lewis Publishers; Water Fact Sheet, Kentucky Geological Survey, University of Kentucky.

30 Gaia: A New Look At Life On Earth, 1982, Lovelock, James, Oxford University Press, USA. Lovelock expanded on Scottish geologist James Hutton (1726-1797) notions of the Earth as a super-organism.

31 Letters to the Editor, Scientific American, March 1, 1990, Lynn Margulis. "Gaia, a single enormous system deriving from common ancestors at least 3,500 million years old, is connected through time (by ancestry) and space (through atmospheric chemical signals, ocean currents and the like)."

32 What We Know: The Reality, Risks and Response to Climate Change, 2014, American Association for the Advancement of Science; "However, the geological record for the climate reflects instances where a relatively small change in one element of climate led to abrupt changes in the system as a whole. In other words, pushing global temperatures past certain thresholds could trigger abrupt, unpredictable and potentially irreversible changes that have massively disruptive and large-scale impacts. At that point, even if we do not add any additional CO2 to the atmosphere, potentially unstoppable processes are set in motion." (Emphasis added).

33 Climate Change and President Obama's Action Plan, 2014, (www.whitehouse.gov/climate-change).

34 United Nations Assembly Resolution 43/53, Paragraph No. 5. The action was initiated by a proposal from Malta entitled "Conservation of Climate as Part of the Common Heritage of Mankind." The first report was requested in time for review by the second World Climate Conference in 1990. This first Assessment Report stated that "There is a natural greenhouse effect which already keeps the Earth warmer than it would be otherwise [Sec. 1.01] ... The size of the warming over the last century is broadly consistent with the prediction by climate models, but is also of the same magnitude as natural climate variability. [1.0.5]"

35 IPCC, Fifth Assessment (AR5), 2013-2014, (www.ipcc.ch/report/ar5/). There are four parts to AR5: 1) Climate Change 2013, the Physical Science Basis (2013); 2) Climate Change 2014, Impacts, Adaptation, and Vulnerability Volume I: Global and Sectorial Aspects; 3) Climate Change 2014, Mitigation of Climate Change; and 4) The Synthesis Report, yet to be issued.

36 Two additional binding agreements were adopted: 1) Convention on Biological Diversity; and 2) United Nations Convention to Combat Desertification. In addition, three documents were adopted: 1) Rio Declaration On Environment and Development; 2) Agenda 21; and 3) Forest Principles.

37 50 signatory nations were needed to bring the Framework Convention on Climate Change into force. That was achieved in 1994. The United States signed in 1992. The Framework sets up negotiating principles to set later binding greenhouse gas emission limits by each signatory. Article 2 of the Framework states, in part, "The ultimate objective of this convention ... is to achieve ... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system ... achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to occur in a sustainable manner."

38 Bush Reverses Course on Carbon Dioxide, March 13, 2001, Scott Lindlaw, ABC News; see Text of a Letter From the President to Senators Hagel, Helms, Craig, and Roberts, March 13, 2001, George W. Bush, White House, Office of the Press Secretary, partly reproduced as follows: "As you know, I oppose the Kyoto Protocol because it exempts 80% of the world, including major population centers, such as China and India, from compliance, and would cause serious harm to the U.S. economy. The Senate's vote, 95-0, shows that there is a clear consensus that the Kyoto Protocol is an unfair and ineffective means of addressing global climate change concerns... Caps on carbon dioxide emissions as part of a multiple emissions strategy would lead to an even more dramatic shift from coal to natural gas for electric power generation and significantly higher electricity prices ... Coal generates more than half of electricity supply ... We must be very careful not to take actions that could harm consumers. This is especially true given the incomplete state of scientific knowledge of the causes of, and solutions to, global climate change..."

39 The EU Emissions Trading System (EU ETS), European Commission, Climate Action; "The EU Emissions Trading System (EU ETS) is a cornerstone of the European Union's policy to combat climate change and its key tool for reducing industrial greenhouse emissions cost-effectively. The first - and still by far the biggest - international system for trading greenhouse gas emission allowances, the EU ETS covers more than 11,000 power stations and industrial plants in 31 countries, as well as airlines." (www.ec.europa.eu/clima/policies/ets/index_en.htm).

40 House Passes Bill to Address Threat of Climate Change, June 26, 2009, John M. Broder, New York Times; The American Clean Energy and Security Act of 2009 (Waxman-Markey Bill, H.R. 2454).

41 “Under clear terms of the Clean Air Act, EPA can avoid taking further action only if it determines that greenhouse gases do not contribute to climate change or if it provides some reasonable explanation as to why it cannot or will not exercise its discretion to determine whether they do.” Massachusetts et al. v. Environmental Protection Agency et al., 2007, 549 U.S. 497, P. 30.

42 Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units; Proposed Rule, June 18, 2014, Federal Register, 79 FR 34829; “Under the authority of Clean Air Act Section III (d), the EPA is proposing emission guidelines for states to follow in developing plans to address greenhouse gas (GHG) emissions from existing fossil fuel-fired electric generating units (EGUs) ... nationwide, by 2030. This Rule would achieve CO2 emission reductions from the power sector of approximately 30% from CO2 emission levels in 2005.” Ibid, A. Executive Summary, 1. Purpose of the Regulatory Action.

43 Climate Change 2013: The Physical Basis, IPCC, 2013; The Headline Statements from the Summary for Policymakers contain the following statements: a) “Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.” b) “Each of the last three decades has been successively warmer at the Earth’s surface than any preceding decade since 1850. In the Northern Hemisphere, 1983-2012 was likely the warmest 30-year period of the last 1400 years (medium confidence).” c) “Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (high confidence). It is virtually certain that the upper ocean (0-700 m) warmed from 1971 to 2010, and it likely warmed between the 1870s and 1971.” d) “The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.”

44 What We Know: The Reality, Risks and Response to Climate Change, 2014, Mario Molina (Chair), American Association for the Advancement of Science (AAAS). For example, the following statements are made: 1) “Climate scientists agree: climate change is happening here and now. Based on well-established evidence, about 97% of climate scientists have concluded that human-caused climate change is happening... Average global temperature has increased by about 1.4° F over the last 100 years. Sea level is rising, and some types of extreme events - such as heat waves and heavy precipitation events - are happening more frequently.” 2) “Earth’s climate is on a path to warm beyond the range of what has been experienced over the past millions of years. The range of uncertainty for the warming along the current emissions path is wide enough to encompass massively disruptive consequences to societies and ecosystems: as global temperatures rise, there is a real risk, however small, that one or more critical parts of the Earth’s climate system will experience abrupt, unpredictable and potentially irreversible changes. Disturbingly, scientists do not know how much warming is required to trigger such changes to the climate system.” 3) “The evidence is overwhelming: levels of greenhouse gases in the atmosphere are rising. Temperatures are going up. Springs are arriving earlier. Ice sheets are melting. Sea level is rising. The patterns of rainfall and drought are changing. Heat waves are getting worse as is extreme precipitation. The oceans are acidifying.” 4) “After remaining relatively stable at around 280 parts-per-million (ppm) for millennia, carbon dioxide (CO2) began to rise in the 19th century as people burned fossil fuels in ever-increasing amounts. This upward trend continues today with concentrations breaking the 400 ppm mark just last year. The rate of increase during the last 100 to 150 years has been much more rapid than in other periods of the Earth’s history.” 5) “The oceans are absorbing much of the CO2 that smokestacks and tailpipes emit into the atmosphere. As a result, the oceans are rapidly acidifying, with early impacts on shelled organisms such as oysters already documented. The current acidification rate is likely the fastest in 300 million years.” 6) “According to the IPCC, given the current pathway for carbon emissions the high-end of the ‘likely’ range for the expected increase in global temperature is about 8° F by the end of the century. This is similar to the roughly 9° F warming that ended the last ice age. It is important to remember that temperature change due to CO2 emissions is essentially irreversible for several hundred years since this CO2 is removed from the atmosphere only very slowly by natural processes.”

45 Glaciers did leave some deposits along the northwest border of the Commonwealth, especially in Boone and Trimble Counties along the Ohio River. See Glaciers, Eugene J. Amaral, in The Kentucky Encyclopedia, John E. Kleber, 1992, University Press of Kentucky; see also the Boone County Cliffs State Nature Preserve.

46 President Andrew Jackson in 1836 sought to extract lead from the mineral, Galena, excavated from the Columbia Mine near Marion, Kentucky; see the Ben E. Clement Museum in Marion, Kentucky (www.clementmineralmuseum.org.)

47 Salt, a Factor in the Settlement of Kentucky, 1938, The Filson Club Quarterly, Volume 12, P. 44.

48 Personal communication, 2014, Rudy F. Vogt III, Geologist/Operations Manager, Cumberland Valley Resources, LLC.

49 These plants included representatives of the Lycopsis group, Lepidodendron and Sigallaria, giant horsetails of the Calamites group, Asterophyllities and Annularia, seed ferns Neuropteris and Mariopteris, the tree fern Mariattiales and the Cordaltes. These plants would, over evolutionary time,

be replaced by the Gymnosperms (naked seed plants such as the conifers and cycads), and later by the Angiosperms (flowering plants with seeds contained in ovaries).

50 The Quest: Energy Security, and the Making of the Modern World, 2011, Daniel Yergen, Penguin Press, New York; Conservation and energy efficiency were also pursued on a national basis as a result of the oil crises. In 1975, Congress enacted the Corporate Average Fuel Economy (CAFE) Standards. The difference in application of these standards to passenger cars and trucks promoted the development of sports utility vehicles (SUV).

51 Kentucky Coal Facts, 14th Edition, 2014, Kentucky Coal Association and the Kentucky Energy and Environment Cabinet; The Science and Law of Oil Shale and Tar Sands Development in Kentucky, April 2013, Ronald R. Van Stockum, Jr., presentation to the Day-Long Environmental Law Seminar, Kentucky Bar Association, Frankfort, Kentucky.

52 Lower U.S. Electricity Demand Growth Would Reduce Fossil Fuels' Projected Generation Share, April 30, 2014, U.S. Energy Information Administration.

53 Climate Change: The Underlying Science, April 2014, Ronald R. Van Stockum, Jr., presentation to the Day-Long Environmental Law Seminar, Kentucky Bar Association; see also Climate Change, Spring/Summer 2007, Allan Dittmer, Editor, Sustain, A Journal of Environmental and Sustainability Issues.

54 Renewed interest in heavy oils and Rock Asphalt in South Central Kentucky, 2009, Michael T. May and Kenneth W. Cuehn, Western Kentucky University, World Oil, Volume 230, No. 8. It is not clear whether this heavy oil (bitumen) is oil in which the lighter fractions have volatilized or been degraded by microorganisms.

55 Our Petroleum Challenge, Canadian Resources, Global Markets, Eighth Edition, 2013, Canada Center for Energy Information.

56 Strategy 1) Improve the Energy Efficiency of Kentucky's Homes, Buildings, Industries, and Transportation Fleet; Strategy 2) Increase Kentucky's Use of Renewable Energy; Strategy 3) Sustainably Grow Kentucky's Production of Biofuels; Strategy 4) Develop a Coal-to-Liquids Industry in Kentucky to Replace Petroleum-Based Liquids; Strategy 5) Implement a Major and Comprehensive Effort to Increase Gas Supplies, Including Coal-to-Gas in Kentucky; Strategy 6) Initiate Aggressive Carbon Capture/Sequestration (CCS) Projects for Coal-Generated Electricity in Kentucky; and Strategy 7) Examine the Use of Nuclear Power for Electricity Generation in Kentucky.

57 Intelligent Energy Choices for Kentucky's Future, 2008, P. 115. Commonwealth of Kentucky.

58 2012 Energy Profile and 2013 Annual Summary, Kentucky Energy and Environment Cabinet, Department for Energy Development and Independence.

59 Kentucky State Energy Profile and Energy Estimates, U.S. Energy Information Administration (EIA).

60 The Solar Industry in Kentucky: A Brief Review, October 25, 2011, Andy McDonald, Director, Kentucky Solar Partnership. Available through the Kentucky Resources Council, posted January 8, 2012.

61 Division of Renewable Energy, Department for Energy Development and Independence, Kentucky Energy and Environment Cabinet. "In general, Kentucky has low wind speeds and, therefore, limited wind energy potential."

62 Wind Power Hopes For Sea Change, July 31, 2014, Jan Hromadko, Wall Street Journal.

63 "Strategy 7)," Footnote No. 56, Supra.

Geology of Fossil Fuel Bearing Strata in Kentucky

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Abstract

Kentucky has a long history of deriving fossil-fuel resources from the ground such as coal, oil, natural gas and asphalt rock and this history is intertwined with the development of many communities throughout the Commonwealth. The importance of coal is decreasing however, as there are many new ideas for extracting less C-heavy fuels resulting in less environmental disruption as well as a growing interest in developing alternative energy sources. There is an increase in the use of natural gas for power plants, and perhaps society now recognizes the "tragedy of the commons" associated with mountain top removal and strip mining and is looking at working more with natural systems rather than against them. Kentucky's two coal fields or basins are also rich in natural gas and oil and the geological forces responsible for the formation of these basins of huge economic importance are rooted in plate tectonics, as well a changing ancient geography replete with shifting shorelines associated with multiple sea-level changes, climate change, mountain building and associated sedimentary processes of erosion, transportation and deposition. Additional hydrocarbon-rich areas are being developed between both eastern Kentucky (Appalachian Basin) and western Kentucky (Illinois or Eastern Interior Basin) such as in south central Kentucky (e.g., Cumberland Saddle). A review of the basic geologic context of our energy resources from the Cambrian through the Pennsylvanian is warranted especially considering that technological advancement for drilling, stimulating formations and transporting hydrocarbons is rapidly changing the fossil-fuel industry in Kentucky and adjacent areas. Kentucky will remain dependent on fossil fuels in the coming decades albeit those with a lower C footprint. The Commonwealth simultaneously will be challenged with requirements for sustainability, protecting groundwater and surface-water resources and soil resources as well as balancing and maintaining biodiversity in our ecosystems.

Introduction

Extraction of fossil fuels is becoming less difficult due to technological advances, and there is a concomitant increase in integration of power grids with less polluting natural gas, establishing natural gas condensates, and relatively cleaner oil, as well as investments in alternative energy sources (solar, wind, geothermal etc.). Alternative energy sources can be thought of as augmenting the still very strong fossil-fuel base. In the context of Kentucky's geographic location in the temperate zone, we could do well to encourage use of geothermal resources to increase the efficiency of homes, offices, institutional buildings, and manufacturing centers thereby reducing our consumption of fossil fuels. As a society, we must also recognize the transformation needed for consuming more of the relatively lower C fuels for transportation. We must also understand the basic consideration of C-loading to the atmosphere, C flux, C sinks and mineralization or trapping of CO2 as ways to deal with rapid global change manifested as acidification of oceans and change in climate due to the combustion of fossil fuels. Understanding the basic age, depth, and general geographic distribution of fossil-fuel resources permits citizens to better use and have improved stewardship of what the Kentucky Geological Survey refers to as the Commonwealth of Kentucky's "uncommon wealth."

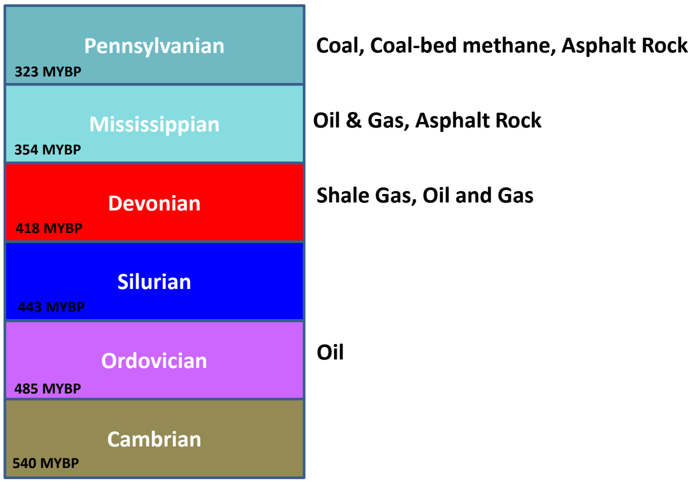


Figure 1. Generalized stratigraphic column illustrating major fossil fuel resources in Kentucky in context of geologic Periods. Note that all Periods illustrated produce some hydrocarbons, but only the primary commercial market is shown. Beginning ages in million of years before present (MYBP) for Periods based on November 2012 GSA scale: http://www.geosociety.org/science/timescale/.

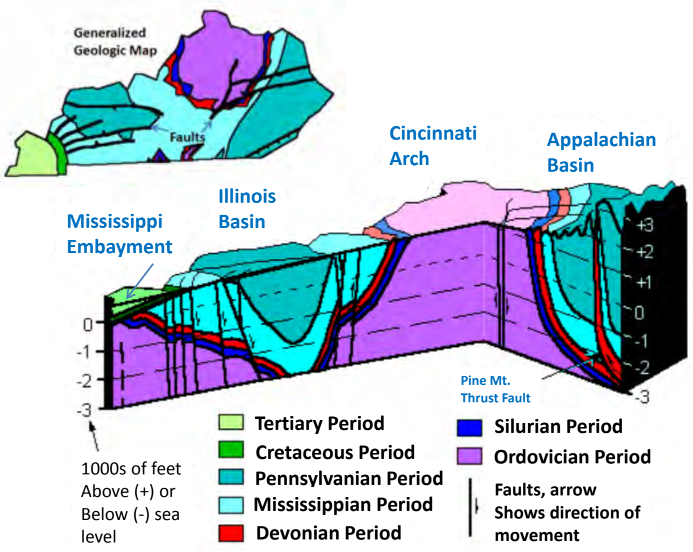


Figure 2. Cross Section and Generalized Geologic Map of Kentucky showing main structural features such as basins that contain coal fields in the Illinois and Appalachian basins. For clarity, cross section has vertical exaggeration (Modified from KGS online http://www.uky.edu/KGS/geoky/beneath.htm - accessed July 2014).

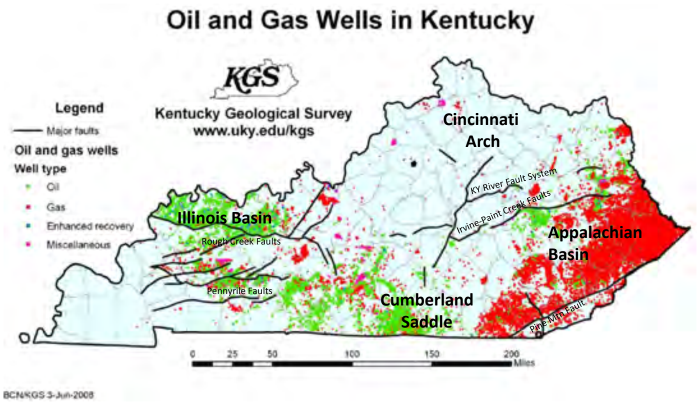


Figure 3. Map of oil and gas wells in Kentucky in context of basins, arch and saddle areas and major faults. Note major faults and hydrocarbon (oil and gas) producing areas in Kentucky. (Modified from KGS online http://www.uky.edu/KGS/education/oilgas.pdf - accessed July 2014).

Geographic and Geologic Context of Fossil Fuels

Kentucky is well known for its fossil- fuel resources, most famously for its coal and to a lesser extent, for its oil and gas resources. These are all known as conventional energy resources, but Kentucky also contains regionally if not nationally important unconventional (or nonconventional) energy resources mostly in the form of asphalt rock (informally referenced as tar sands) and shale gas and some coal-bed methane gas. One focus of this article is on unconventional resources, but these must be placed in the context of conventional energy resources to best understand the energy switch occurring presently (interested readers should view the Movie "Switch" produced in 2011- see http://www.switchenergyproject.com/). As noted in a July 2014 article in the American Association of Petroleum Geologists Explorer (Saucier, 2014), unconventionals may just be the energy source needed for society to switch to more sustainable energy sources. Asphalt (bitumen or tar) rock found in Mississippian and Pennsylvanian-aged rocks (Figure 1) has a quite storied history and it possesses value not only as paving material but as a source of crude oil important for specialized products such as jet fuel, and there are a number of companies engaged in pilot studies to reduce the viscosity of bitumen for extraction (http://energy.gov/sites/prod/files/2013/04/f0/SecureFuelsReport2011.pdf). Shale gas from the Devonian is most important in eastern Kentucky, and over the last few years has caused a boom with lower commodity prices and overshadowing from the Marcellus Shale production further northeast of Kentucky, interest is somewhat subdued for continued rapid gas development in Kentucky. Coal has been an important part of Kentucky's economy and is found in rocks of Mississippian and Pennsylvanian age (Figures 2 and 3) but with the Pennsylvanian strata comprising almost the total commercial market which is tied to truck, barge and rail transportation systems in both the Illinois and Appalachian basins.

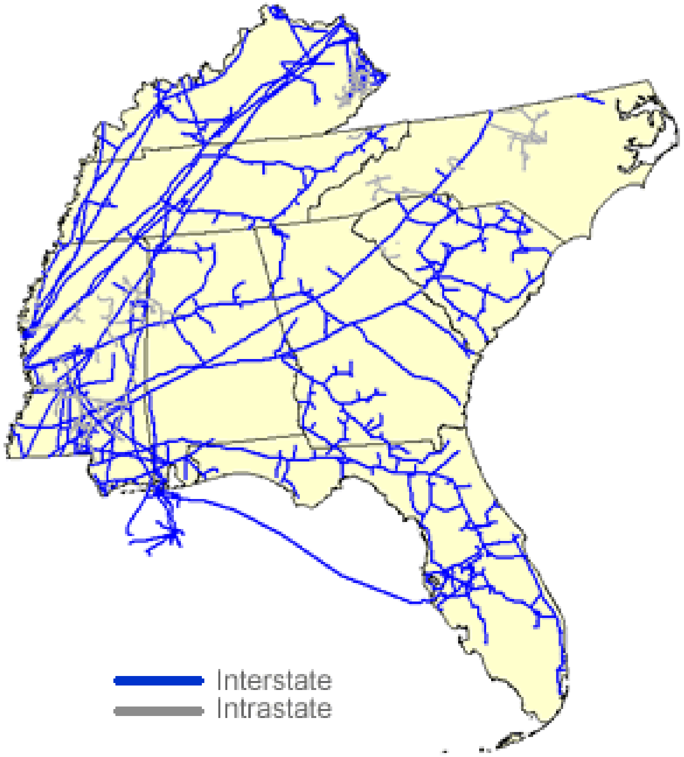


Figure 4. Map showing gas pipelines serving Kentucky and other southeastern states. Note gray lines and patches in eastern Kentucky are for intrastate transmission whereas blue lines represent interstate transmission. (After http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/southeast.html -accessed July 2014)

Most of the shale gas is feeding pipelines in eastern Kentucky (Figure 4) whereas the most prolific oil productive area is typified

Table 1

Oil and Natural Gas Production in Kentucky 2011*		
	Oil	Natural Gas
Producing wells (KyDOG status "PR")	24,364	18,228
Counties	61	36
Top counties (2010 data*)	Lee (264 Mbo[1]) Union (256 Mbo) Henderson (238 Mbo) Leslie (168 Mbo) Perry (123 Mbo)	Pike (38 bcf[3]) Letcher (21 bcf) Knott (14 bcf) Perry (12 bcf) Floyd (11 bcf)
2011 Total	2.32 MMbo[2]	126.4 bcf
2011 Total value (tax paid)	$201.5 million ($9.1 million)	$575.6 million[4] ($25.9 million)
Top counties (all years)	Henderson (112 MMbo) Lee (88 MMbo) Union (86 MMbo) Daviess (58 MMbo) Ohio (50 MMbo)	Pike (762 bcf) Floyd (396 bcf) Knott (270 bcf) Perry (175 bcf) Martin (162 bcf)
Statewide total	790 MMbo	6.3 trillion cubic feet

*2011 data are confidential
[1] Mbo – thousand barrels of oil
[2] MMbo – million barrels of oil
[3] bcf – billion cubic feet
[4] Includes NGL and dry gas

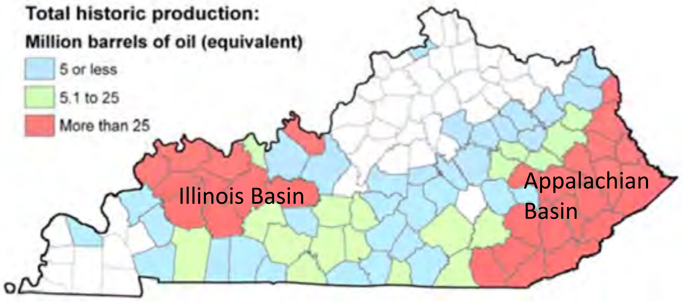


Figure 5A. Map showing range of total historic production volumes in barrel equivalents of oil in Kentucky (includes oil and gas). Note especially rich Illinois and Appalachian basins. Compare to Table 1.

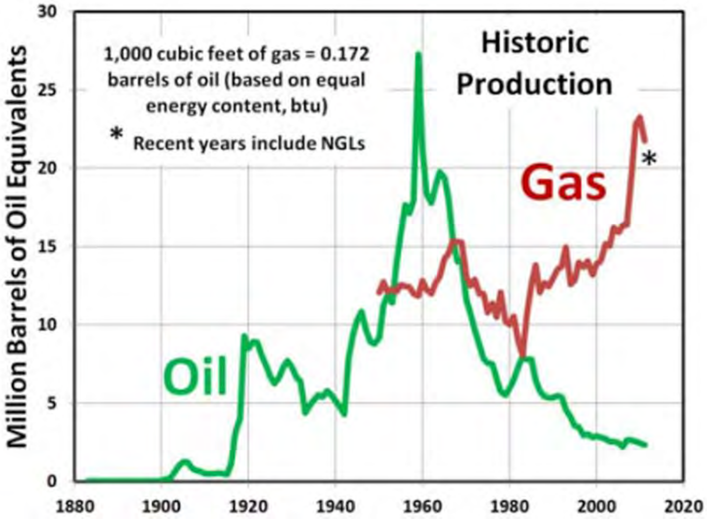


Figure 5B. Million barrels of oil equivalent historic production for both oil and gas. (Both images after a portion of KGS Factsheet No. 7, 2012, accessed July 2014 online.)

by a few northwestern tier counties bordering the Ohio River and just to the south, although there are a couple of eastern Kentucky counties that also produce significant oil (Table 1; Figures 5A). It is clear from historical data (as in Table I) that out of over 24,000 (24,364) producing wells from 61 counties with reported cumulative volume of 790 million barrels of oil, that the average cumulative production for Kentucky is 32,425 barrels per well. Historically gas (including natural gas liquids NGLs) has been on the upswing compared to overall oil production in Kentucky (Figure 5B).

Both the Appalachian and Illinois basins contain oil and gas from Cambrian up through Pennsylvanian-aged rocks but with major production only from the Ordovician, Devonian, Mississippian and Pennsylvanian (Figure 1). The Illinois Basin is producing mostly from the Mississippian limestone units with some productive sandstone units, while south central Kentucky obtains most of its oil from fractured limestone and dolomitic (magnesium-rich cousin to limestone) reservoirs of Ordovician age (Cumberland Saddle proper – see Figure 3) and from Devonian and Mississippian limestone and dolomite west of the Cumberland Saddle such as near Bowling Green. In eastern Kentucky's Appalachian Basin, the majority of gas is derived from Devonian shale at about a mile depth into the Earth. This natural gas contributes to the surge of natural gas production in the USA of which shale gas is now about 40% of the total USA natural gas production (compare with Malakoff, 2014). Multiple coal beds of Pennsylvanian age typify both the Appalachian and Illinois basins and these beds have and continue to produce coal and to a lesser extent coal-bed methane or natural gas. New technologies will bring an expansion of oil and natural gas production in the near future. With high oil prices near $100 per barrel and the relative ease of obtaining natural gas from heretofore what were considered rock formations that were "too tight", Kentucky will face challenges of balancing increased drilling activity with water quality and other resource protection issues. Moving from coal to natural gas is a plus and is more sustainable. In essence, we are crossing the energy bridge or making the "switch."

Geologic Framework

The geology of Kentucky and adjacent areas is responsible for the wide distribution of multiple beds of coal and multiple-pay horizons for oil and gas, especially within the formally designated basin areas (e.g., Figures 2 and 3). Basins provide greater accommodation (with Earth's crust subsiding) and hence higher preservation potential for fossil-fuel rich strata deposited throughout the Paleozoic Era (Cambrian through Pennsylvanian in Kentucky). Most of these strata are marine in origin but with increasing transitional and terrestrial representation in units present in the younger Mississippian and Pennsylvanian rocks (Figure 1). Low-lying coastal swamps for example typify the Pennsylvanian Period when there was a vast accumulation of plant material to form numerous beds of coal. The basic geologic history of basin formation can be explained in the context of plate tectonics or uplift and subsidence of Earth's crust in response

Figure 6. Oil in reservoir rock: (A) stained core – Mississippian sandstone from the Illinois Basin in Kentucky showing crude oil flowing out of the core. The Misssissippian is a common target for conventional oil resources, but locally also contains heavier oil similar to asphalt pictured here (B) Close up of view in same reservoir shown in (A). Photos by author in 2008.

to plate movement, formation of oceanic crust, subduction, and mountain building episodes (orogenies). The region in which Kentucky is a part has experienced multiple episodes of mountain building. It has also experienced erosion of sediment from highlands, transportation of sediment from uplifted regions, deposition of sediment in adjacent basins and concomitant subsidence or downwarping as sediments were delivered to what was to become the Appalachian and Illinois basins (e.g. Figure 2 cross section). Earth's crust in Kentucky can be thought of as a series of arches and basins appearing much like a crumpled rug but with these stretched over tens or even hundreds of miles. Crustal deformation resulting from compression or convergence of tectonic plates (e.g., Africa and North America) occurred primarily during classic orogenies in the eastern U.S.A. during the Ordovician (Taconic), Devonian (Acadian) and the late Pennsylvanian and Permian Periods (Appalachian).

Basins and nearby arches or saddle areas (e.g. Figures 2 and 3) were all affected at various times by dynamic changes of Earth's crust as well as by local compressional, extensional, or shear events that are exhibited in features such as faults and rifts (or sub-basins or grabens). Such features were superimposed on the overall broadly defined series of basins and arches (Nelson, 1990). Some good examples include the Rough Creek graben (a deep down-dropped block) portion of the Illinois Basin as well as the Rough Creek Fault zone and Pennyrile Fault zone. Similarly, faults along the Cincinnati Arch such as the Kentucky River and Irvine-Paint Creek faults positioned south and southeast of the Lexington area developed actually as a series of faults (Figure 3). The Pine Mountain Thrust Fault (visible in cross section in Figure 2 and as the southeasternmost linear fault in Figure 3) in eastern Kentucky developed directly from crustal shortening associated with compressive tectonic forces as tectonic plates crashed about a few hundred million years ago. It should be noted that many of these fault systems are of great importance in Kentucky's oil and gas industry in that they are responsible for the entrapment of impressive volumes of hydrocarbons. Much of the oil and gas prospecting over the last several decades has targeted mapped fault zones. In other cases, a number of unmapped faults continue to be discovered through the drilling process. A record of successful drilling and completion of oil and gas wells for example is noted by inspecting Figure 3 showing oil and gas being closely associated with mapped fault systems.

Conventional Oil and Gas Resources – a brief history and today's challenges – horizontal drilling comes to KY

The history of drilling for conventional (flowable at room temperature) oil in Kentucky goes back to the beginning of wells dug or drilled for salt or brine waters where the oil was actually not sought out but was discovered accidently, as was the case for a well in McCreary County in 1818. The oil was however placed into wooden barrels and barged down the Cumberland River and marketed to not only the region but also in Europe (KGS Fact Sheet No. 7, 2012). Other oil wells were drilled such as a well in Cumberland County in 1829, a few decades before the famous Drake well of Pennsylvania (see May, 2013, p. 374 and the history of oil in Kentucky complied by Brandon Nuttall at KGS: http://www.uky.edu/KGS/emsweb/history/modern.htm).

Many wells were subsequently drilled to shallow depths throughout Kentucky, even into this century, however, as noted below, this is beginning to change.

We now recognize that "conventional" natural gas is one of the major globally important energy resources and it is commonly associated with oil, having also formed via decomposition of organic matter primarily in marine settings (e.g., see http://www.

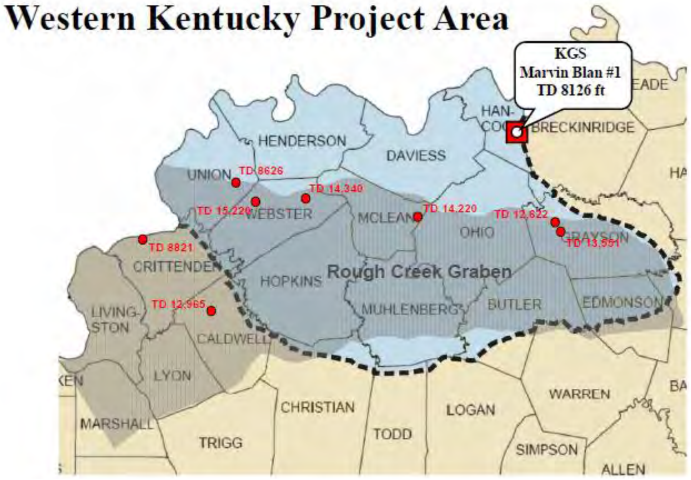
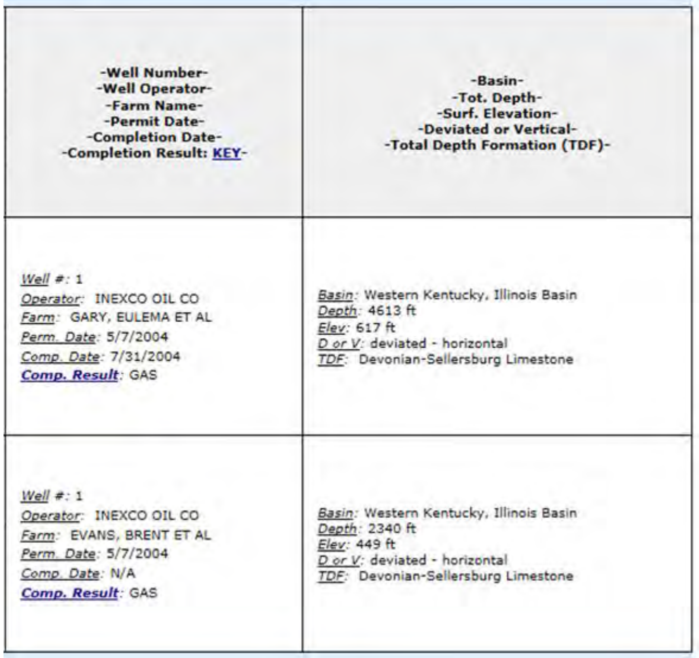


Figure Figure 7. Select deep wells drilled in vicinity of the Rough Creek graben (modified from Bowersox and Williams 2009). The Blan well is the first well drilled to test CO2 sequestration in the southeastern Illinois Basin in Kentucky. Total Depth (TD) of wells shown in red are in feet . These wells range from about 1.5 to 2.9 miles deep. Most wells in Kentucky are much shallower.

window.state.tx.us/specialrpt/energy/nonrenewable/gas.php). It can be found as an isolated light hydrocarbon in the subsurface or lying just above oil, or very commonly dissolved in oil. In the latter case, much of the "drive" to get oil to the wellbore is to get to the dissolved gas and it is important to manage gas in petroleum reservoirs in order to maintain the drive or the push. Unfortunately, much oil has been left behind because of poor reservoir management, or in places like Kentucky, industry may not have established infrastructure to better manage natural gas resources as both a petroleum reservoir driving mechanism and a sellable commodity (i.e., there were no established gas pipelines, processing plants etc.). However Kentucky and adjacent areas have tapped into the liquefied petroleum gas (LPG) market, a market best described as a series of gaseous hydrocarbons that are obtained from crude oil and/or natural gas. Most of the LPG is a mixture of propane and butane and sometimes just propane. Propane is usually found as bottled gas for domestic use or for cooking grills mostly used in rural Kentucky, and less popular in urban areas. It is also used in transportation particularly for fleet vehicles such as police cars, public works trucks, public transportation buses etc. in the U.S.A. (e.g., see http://www.afdc.energy.gov/vehicles/propane.html).



-Well Number- -Well Operator- -Farm Name- -Permit Date- -Completion Date- -Completion Result: KEY-	-Basin- -Tot. Depth- -Surf. Elevation- -Deviated or Vertical- -Total Depth Formation (TDF)-
Well #: 1 Operator: INEXCO OIL CO Farm: GARY, EULEMA ET AL Perm. Date: 5/7/2004 Comp. Date: 7/31/2004 Comp. Result: GAS	Basin: Western Kentucky, Illinois Basin Depth: 4613 ft Elev: 617 ft D or V: deviated - horizontal TDF: Devonian-Sellersburg Limestone
Well #: 1 Operator: INEXCO OIL CO Farm: EVANS, BRENT ET AL Perm. Date: 5/7/2004 Comp. Date: N/A Comp. Result: GAS	Basin: Western Kentucky, Illinois Basin Depth: 2340 ft Elev: 449 ft D or V: deviated - horizontal TDF: Devonian-Sellersburg Limestone

Figure 8A. View of Horizontal Well Data available on KGS online oil and gas service database. Example is from Butler County. These online records provide X, Y and Z (depth) coordinates for a given well and also provide information on extent of lateral traverse associated with the deviated hole. Wells were advanced in 2004.

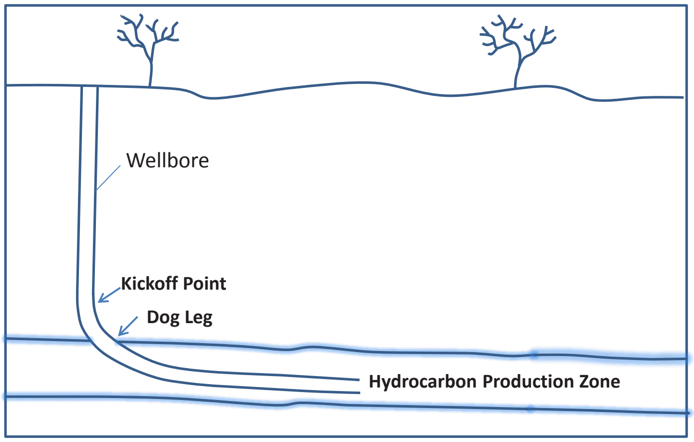


Figure 8B. Schematic showing basic anatomy of a horizontal well. Depending on the situation, many of these wells are completed open hole with casing only in the "elbow" or "dog leg" portion of the hole.

Most oil development in Kentucky is oil extracted from the first encountered zone where hydrocarbon shows (actual bubbling of gas noted in a hole with a video camera, oil stained rocks or dripping from hole sides or cores (e.g., Figure 6), or as fluorescence in rock samples that contain oil). This practice makes sense in that small operators, like those historically in Kentucky, can minimize costs and stop drilling at the first occurrence of oil or gas. By contrast, some major oil companies have explored to great depths in Kentucky, such as Exxon's No. 1 Duncan well drilled in Webster County in western Kentucky to a depth of 15,200 feet in 1977 (KGS Fact Sheet No. 7, 2012). A number of relatively deep wells –between 8000 and 14,000 feet or more, have been drilled in western Kentucky also (see Bowersox and Williams 2009; Figure 7).

With the increase in oil prices, drilling in Kentucky is now occurring in vertical holes, and the wiser operators are mapping prospective areas with multiple oil zones rather than working

Figure 9. Asphalt rock or tar sand in Edmonson County: A) close up view of typical flow of hydrocarbon out of rock - for scale note that hammer head is 7 inches long (18 cm) B) view of reopened quarry with rock devoid of bitumen overlying asphalt productive zone (both photos by author in 2010).

the first encountered or shallowest zone and they are drilling deeper. This practice ensures a greater duration of oil production and better chances of long-term success. And now Kentucky is seeing more horizontal drilling with increasingly larger hydraulic fracturing sites with the goal of stimulating increased productivity. This advancement in drilling technology is being applied in North Dakota (Bakken Shale) and Appalachia (the Marcellus Shale) Pennsylvania, Huron (Ohio) Shale development in southeastern Kentucky (Wozniak 2010) etc.).

Search for oil and gas well data: http://kgs.uky.edu/kgsweb/DataSearching/OilGas/OGSearch.asp

By using the interactive oil and gas map, one can learn about permits, drilling activity, initial production of wells and more.

Interactive oil and gas well map: http://kgs.uky.edu/kgsmap/kgsgeoserver/viewer.asp)

The KGS online site can also help one ascertain the geographic and stratigraphic distribution of horizontal wells to get an idea where, and at what depth wells are being drilled horizontally (Figure 8A). Additionally, one can see map views of the top and bottom of the hole as well as the length of the horizontal drilling pathway. For example, in some parts of the Illinois Basin operators have drilled a vertical "pilot" hole, started deviating from the vertical at a "kick off" point by bending the drilling path through a "dog leg" with the goal of drilling perpendicular to the vertical hole and then proceeding to drill horizontally two or three football or soccer field lengths (Figure 8B). In North Dakota's Bakken Shale, wells are commonly 10,000 feet vertical holes with 10,000 foot-long horizontal portion.

Directional drilling (anything not vertical) or more commonly referred to as horizontal drilling, has created an energy- industry revolution in the U.S.A. In Kentucky over the past decade, there

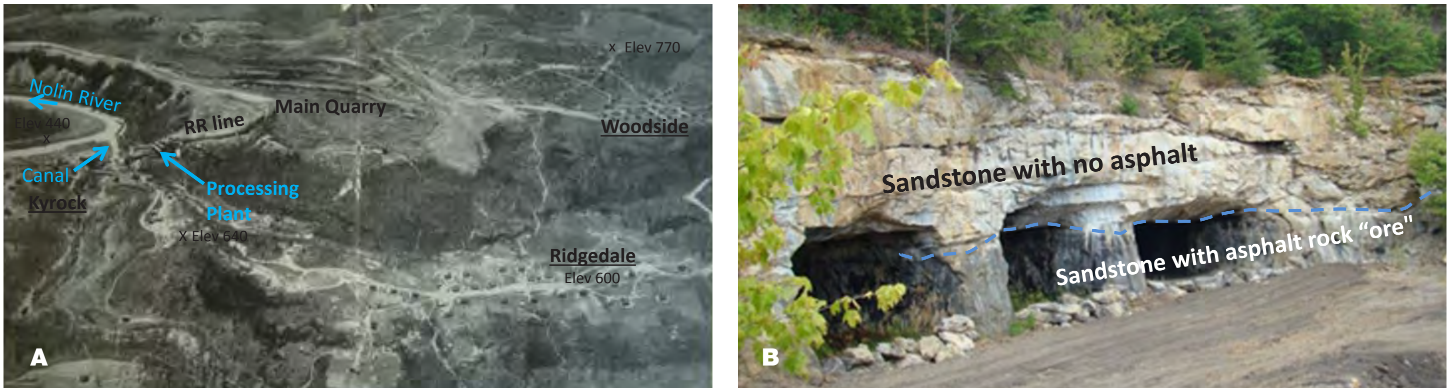


Figure 10. Views of various ways of extraction of asphalt rock in Kentucky (A)strip mining and (B)room and pillar accessed through tunnels or adits. View A is an early 1900s aerial view of the communities of Kyrock, Ridgedale and Woodside (extant today) along the Nolin River in Edmonson County where strip mining or quarrying occurred. View B is a 2007 photo by author near Sweeden, KY in Edmonson County – Indian Creek Quarry (historic image in (A) courtesy Kentucky Museum Library – Western Kentucky University, Bowling Green).

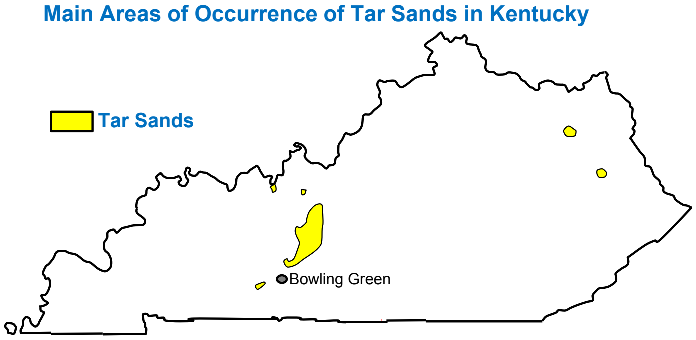


Figure 11. Map showing tar sand or asphalt rock resources in Kentucky (modified from Kentucky Geological Survey and May (2013).

have been a few horizontal wells drilled. (Figure 8A). Evidence of this revolution in Kentucky is illustrated by recent (2013-2014) workshops presented for engineers, geologists, and oil field workers by the Petroleum Technology Transfer Council (PTTC) based out of the University of Illinois (e.g., Robinson, 2014). These workshops and continuing education short courses have focused on reassessment of well-completion practices, and horizontal drilling and geosteering techniques. Geosteering is a procedure whereby the drill bit is advanced and its location in the subsurface is measured while drilling (MWD tool). Geosteering provides control of the advancing drill bit resulting in the process of following the stratigraphic pay zone for as long as possible to increase surface area between the oil or gas reservoir and the well bore (e.g., Figure 8B). This practice results in a significantly greater recovery volume than traditional vertical drilling. These are topics that energy industry people in the Illinois Basin and Appalachian basins in Kentucky could have scarcely imagined in the late 1990s early 2000s.

An argument can be made that we should be concerned about the increase in the hydrocarbon industry in Kentucky and throughout the USA because of the sheer volume of wells. Alternatively, an argument can be made that the developed technology (directional drilling in particular) is actually decreasing the long-term surface footprint versus for example wells drilled in the 1980s and earlier. This is because a single drilling pad can be established for multiple wells rather than for just a single well. There are some sustainability issues that need to be addressed related to hauling relatively large volumes of water, fracturing (fracking) sands, and associated fluids over aging infrastructure or inadequate roadways. Furthermore, there needs to be an assessment of viable, deeper formations that can safely accommodate injected fluids. This past summer in 2014 a national news story suggested that not fracking itself but fluids to be injected from fracking operations perhaps from hundreds of wells into a single injection well induced small to moderate earthquakes or seismic activity in Oklahoma (e.g., Hand, 2014). Thus far these concerns have not been an issue in Kentucky but needs to be watched considering some of the changes taking place in the oil and gas fields of North America.

Unconventional Oil and Gas Resources – A brief history and modern activity

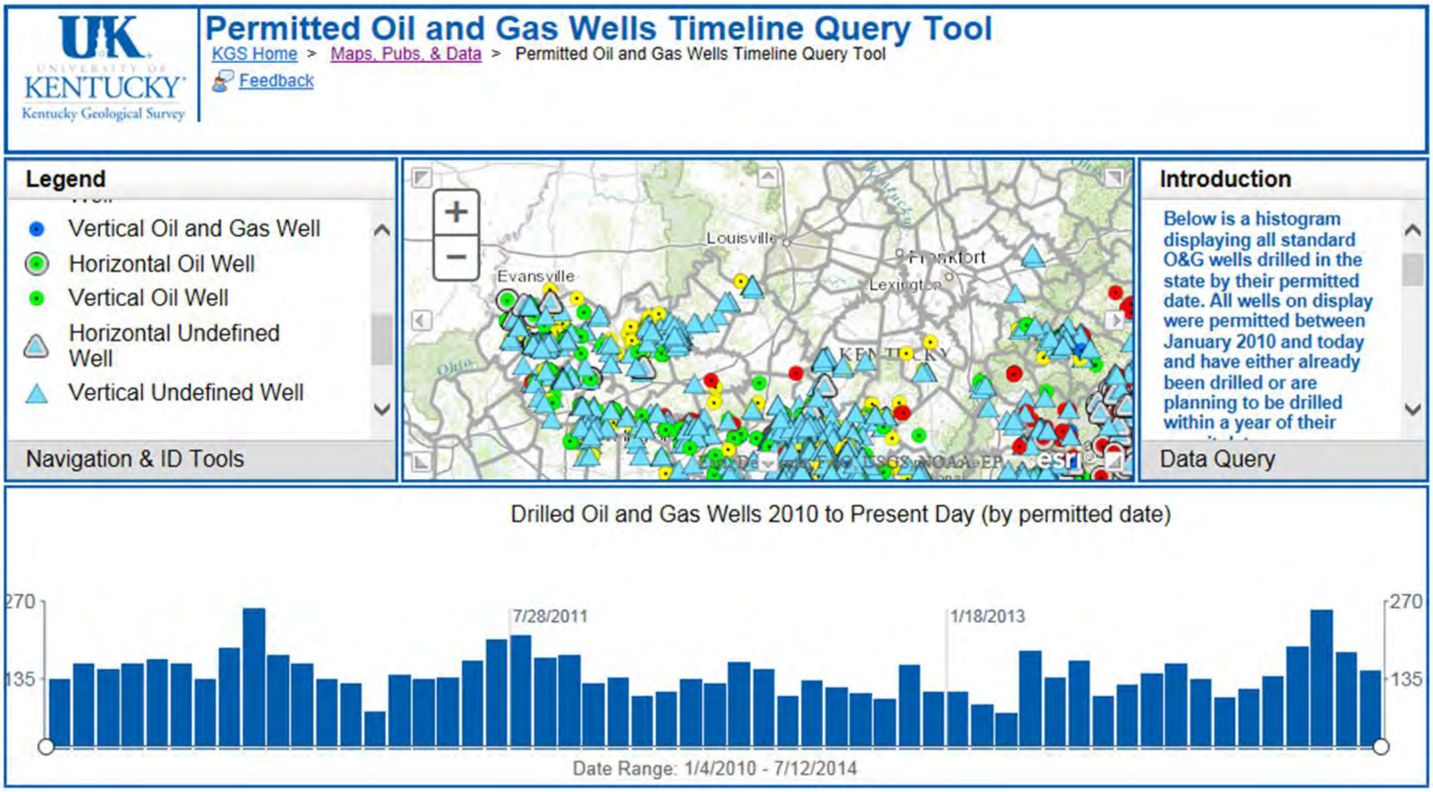
Asphalt Rock (Tar Sands)

Seminal work emphasizing asphalt rock or tar-rich deposits began with field and laboratory work conducted by State Geologist David Dale Owen in the early 1850s on material oozing from rocks just west of present day Mammoth Cave National Park along a deeply cut gorge of the Nolin River in Edmonson County (May, 2013). Orton's (1891) account based on field work conducted in 1888 and 1889 was one of the earlier summaries of where petroleum, natural gas and asphalt rock could be exploited in Kentucky. He compiled information for the Kentucky Geological Survey (KGS) with the goal of documenting the geographic distribution of hydrocarbon-based resources that were to be used to build and develop the Commonwealth as energy supply as well as road building or paving material. By 1891 Grayson County could boast the first commercial development of bituminous rock and nearby Logan County could claim some of the earliest extracted material used for asphaltic paving. Today, one can find outcroppings and quarries with heavy oil or tar oozing out of the rocks, particularly on hot summer days (Figures 9A and 9B).

Throughout the early 1900s and up to the late 1950s, asphalt rock was strip mined (Figure 10A) or room and pillar mined underground through horizontal entry tunnels (Figure 10B). The boom for this activity was centered on the little community of Kyrock, (acronym for Kentucky Rock Asphalt Co). The extraction of tar sands or asphalt rock included mining and processing the "ore" and shipping it for paving use around the world to exotic destinations like Rio de Janeiro, Brazil and Havana, Cuba as well as closer to Kentucky such as Chicago and the Indianapolis 500 Motor Speedway track. From about 1960 through the early 1990s, there were many more oil companies interested in the asphalt not as paving material as had been the case prior, but more as a source of extractable crude oil (for summary table see May, 2013 p. 377). Estimates for the barrel of oil equivalent for asphalt rock in Kentucky have ranged from about 3 billion barrels (e.g., Noger, 1984) to 5 or 6 billion barrels (e.g., May, 2013). The majority of the tar sands or asphalt rock deposits are in south central Kentucky north and east of Bowling Green and there are several smaller deposits that are exposed on the surface elsewhere in Kentucky (Figure 11). Many heavy oil and bitumen petroleum systems characterized as unconventional are being developed globally (e.g., Hein et al., 2013) as technology changes to aid in more environmentally responsible extraction.

Coal-bed Methane

Coal-bed methane is currently being developed where there are easily exploited thick coal beds such as in Utah (Uinta Basin) and Colorado (San Juan Basin) and this unconventional resource has been studied by the KGS in Kentucky as well, but is minor compared to the much greater methane deposits associated with



Permitted Oil and Gas Wells Timeline Query Tool

KGS Home > Maps, Pubs, & Data > Permitted Oil and Gas Wells Timeline Query Tool

Feedback

Legend

- ● Vertical Oil and Gas Well
- ◉ Horizontal Oil Well
- ● Vertical Oil Well
- △ Horizontal Undefined Well
- ▲ Vertical Undefined Well

Navigation & ID Tools

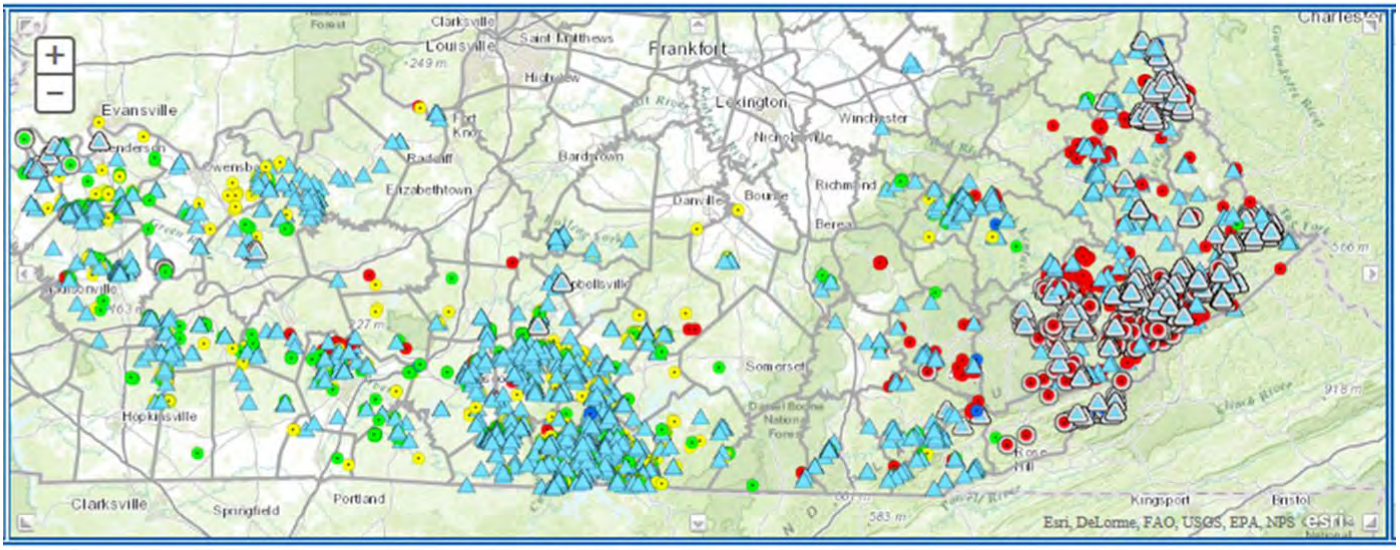
Introduction

Below is a histogram displaying all standard O&G wells drilled in the state by their permitted date. All wells on display were permitted between January 2010 and today and have either already been drilled or are planning to be drilled within a year of their

Data Query

Drilled Oil and Gas Wells 2010 to Present Day (by permitted date)

Date Range: 1/4/2010 - 7/12/2014



Legend

Kentucky Oil and Gas Wells

- ◉ Horizontal Dry and Abandoned Well
- ● Vertical Dry and Abanoned Wel
- ◉ Horizontal Gas Well
- ● Vertical Gas Well
- ◉ Horizontal Oil and Gas Well
- ● Vertical Oil and Gas Well
- ◉ Horizontal Oil Well
- ● Vertical Oil Well
- △ Horizontal Undefined Well
- ▲ Vertical Undefined Well

County

Navigation & ID Tools

Figure 12. Drilling permits in Kentucky from 2010 through early July 2014 showing increase in activity related mostly to drilling for shale gas. (A) – screen view of permitted oil and gas wells timeline query tool showing map view of most of Kentucky and histogram of permitted wells. (B) Map with legend illustrating that most horizontal wells are in eastern Kentucky and these are gas whereas most activity from the Appalachian basin through the Cumberland Saddle (see Figure 3) and into the Illinois Basin is associated with vertical drilling.

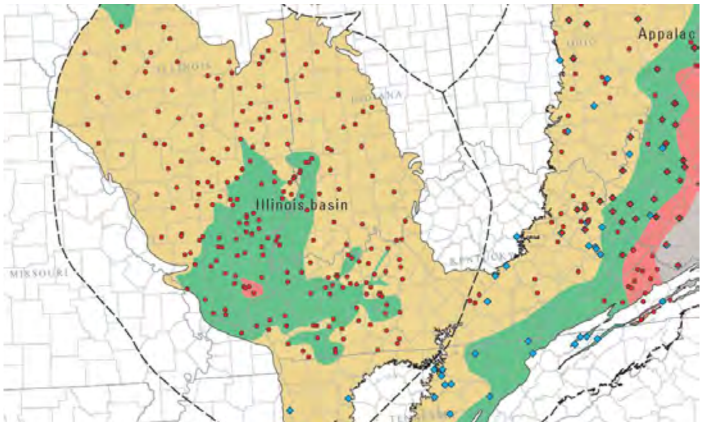


Figure 13. – A thermal maturity map of Devonian shale in Illinois, Michigan and Appalachian Basins. After East and others (2012). Oil prone areas are shown in green, gas prone areas in red. For additional legend see East and others (2012).

Devonian-aged shales. Extraction of coal-bed methane requires breaking up the coal and piping the gas to a collection area (KGS fact sheet 2, 2003): http://www.uky.edu/KGS/education/methane.pdf

Gas from Shale

Considering that prior to the last decade (about 2004 to 2014), most gas from Kentucky was associated with sandstone and limestone oil field reservoirs with characteristically high porosity (percent void space/total bulk volume) and permeability (connectedness of pores or capability of transmitting fluids), it is remarkable that the vast majority of methane (CH 4) gas today is being extracted from a somewhat unconventional source – low permeability shale. If one looks at the number of drilling permits issued in the last decade, it is evident that most of this drilling has occurred in eastern Kentucky in the Appalachian Basin (see KGS Oil and Gas Factsheet 7 and Figures 12A and 12B). By contrast, most of the oil drilling activity is in northwestern Kentucky centered on Henderson and Union counties in the Ohio Valley (Table 1). The shales from which gas is being extracted are known as the Ohio Shale and Huron Member of the Ohio Shale in eastern Kentucky. There is some gas potential also within the Chattanooga or equivalent New Albany Shale in the western half of the state and some scattered gas in south-central Kentucky. KGS online has reported that shale gas in the Illinois Basin thus far has limited success, even when a nitrogen fracturing stimulation procedure is used. Thus, eastern Kentucky remains the target for shale gas and this can be explained succinctly as a function of the depth of shale burial and basin history. For example, generation of some natural gas results from the thermal action associated with deeper parts of basins, whereas biogenic gas results from microbial activity nearer the edge of basins (Figure 13). East and others' (2012) compilation of thermal maturation of Devonian shales in and surrounding Kentucky illustrates the oil prone areas (green) and gas prone areas (red) and highlights areas that are generally thermally immature or below the "oil window" temperature required for oil generation. Most of the gas in the Illinois Basin portion of Kentucky (and adjacent Illinois and Indiana areas) is thought to be biogenic in origin showing little red on the map indicating there is not much thermal input to produce thermal gas (below the gas generation window or no thermogenic gas). The situation is obviously different in the Appalachian basin where most of the gas generated migrated from deeper basinal settings to the east with associated higher thermal maturation.

Related to the shale gas issue is the fact that market forces are moving many of the Commonwealth's electrical generation plants away from coal and to natural gas (Associated Press (2014): http://bigstory.ap.org/article/kentucky-plant-emblematic-move-coal-gas) and thankfully this is obviously much better for the environment as natural gas has a much smaller C footprint per BTU versus coal (see Aubrecht, 2006 p.232). There is also no risk of slurry pond impoundment failure as unfortunately has been the case with coal (e.g. Martin County Coal Slurry disaster of 2000 and Kingston, TN Coal Slurry disaster of 2008 see http://en.wikipedia.org/wiki/Martin_County_coal_slurry_spill and http://en.wikipedia.org/wiki/Kingston_Fossil_Plant_coal_fly_ash_slurry_spill).

Furthermore, natural gas can be developed and transported in Kentucky in the same locations were coal has been "king" for at least the last two hundred years. Although still a fossil fuel, natural gas is a much better choice than coal and overall is more sustainable, especially considering the minimal surface damage associated with its extraction versus mountain top removal or strip mining. Also, natural gas (and oil) does not have the deleterious effect of metals loading (most notably mercury) to the environment as coal.

Oil from Shale

Interest in oil from shale has been in locations such as western Colorado and the Rocky Mountain region where western shale has been assessed for decades, however eastern shales, such as in Kentucky, have also been drilled and assessed. Most of this activity has been in Kentucky, Ohio, Tennessee and Indiana with estimates of over 420 billion barrels of oil to be extractable according to a 2011 report by INTEK, Inc. The INTEK report estimates that there is in the Kentucky Knobs region 16 billion barrels of oil with about 25 gallons of oil per ton of rock. Eastern shales have less desirable organic content and would take more energy to retort (heat and extract), but with technologies using hydrogen, the retorting process could approach economics similar to western shales. However, with natural gas and conventional oil and the fact that oil from shale would necessarily mean strip mining broad areas, this is not a sustainable or desirable option. The Knobs is a scenic area and has great value as a natural setting encircling Kentucky's famous Bluegrass region.

The Role of Geology in the Carbon Equation

Kentucky, even though blessed with "uncommon (mineral and energy) wealth," has a long history of participating in the "tragedy of the commons" with little or no attention paid to removal of sensitive ecosystems ranging from the Appalachian highlands to the broad and rich alluvial valleys of its major river systems. This is due in large part because of its politically charged mantra of "cheap electricity," which helps to outpace other states economically. The disasters in heavy-metal contamination, coal-slurry impoundment failures and associated spoils are obviously non-sustainable. Yet we know that in the coming decades we must decrease our carbon footprint and use lower carbon-rich fossil fuels as a bridge to the future, such as oil and natural gas. At the same time, we must strive to keep additional carbon from our atmosphere by sequestering it in the subsurface. The role of geology and geochemistry will be important as we begin to understand that we can "mineralize" some carbon, but this comes at a significant cost (Gislason and Oelkers 2014). Carbon sequestration can be done safely and for all practical purposes, permanently. Even if the carbon dioxide is not mineralized, it can be trapped in strata thousands of feet down in the subsurface. We already have trapped and stored natural gas throughout our region in geologic domes or anticlines. Louisville's utility company has done this for years. Much time and research has been invested by state geological surveys and the USGS, DOE, EPA and others in studying ways to sequester carbon dioxide in the subsurface by trapping the gas but not mineralizing it, or by locking it up in solid form. In Kentucky, this effort has been partially funded through House Bill 1 in 2007 for the KGS. (see http://www.uky.edu/KGS/kyccs/ and http://www.uky.edu/KGS/kyccs/ppt/080110_harris_eky.pdf.) The KGS has taken the lead and organized the Kentucky Consortium for Carbon Storage (KYCCS). The goal of this group is to drill deep wells in eastern and western Kentucky coal fields (Appalachian and Illinois basins) to estimate the potential for sequestering CO_2 in the subsurface. Additionally, the KYCCS is also attempting to enhance oil and gas recovery and coal-bed methane as well as test Devonian shale for CO_2 enhanced gas recovery. The carbon dioxide can also be used as a secondary or tertiary (third order) recovery method for oil in mature fields. A brochure explaining in general terms the rationale and technical considerations behind sequestration is available for interested readers: http://www.uky.edu/KGS/kyccs/CO2sequestrationBrochure.pdf

The KGS received $5 million in funding under HB 1 to help better understand carbon dioxide sequesteration (see http://www.uky.edu/KGS/kyccs/). These projects have had support from Federal entities like the EPA, DOE and USGS, but they also require some cost-sharing or matched funding from other governmental entities and industry. As retiring KGS Director and State Geologist Dr. Jim Cobb noted recently in an interview, "Kentucky can be proud of its publically available data but it also is challenged to create a future that is sustainable and carbon dioxide sequestering is but one way the Commonwealth is responding to the problem of global change related to unbridled burning of C-laden coal for many years."

Summary and Conclusions

Kentucky possesses two economically important coal basins, one in the east and one in the west that are also rich in oil and natural gas. The majority of conventional fossil fuel resources include coal from Pennsylvanian-aged rocks in both the Appalachian and Illinois basins, and oil and gas in both basins ranging from the Cambrian to Pennsylvanian Periods. Historically, the most important oil province has been established from Mississippian limestone units with some sandstone in northwest Kentucky in the Ohio Valley. There are some important eastern Kentucky counties that produce oil, but this region is mostly associated with what is referred to as unconventional fossil fuels in the form of shale gas which has developed significantly in the last decade. There are also important oil and gas regions located geographically between the two coal basins in fractured and dolomitic oil-bearing strata of Ordovician age in the Cumberland Saddle area (e.g. Cumberland County, Clinton County), and important oil and natural gas from Mississippian and Devonian limestones and dolomites in areas west of the Cumberland Saddle near Bowling Green. Additional unconventional resources are present as asphalt rock deposits primarily in south central Kentucky. This material literally helped to pave the world in an earlier time, but today such Mississippian and Pennsylvanian asphaltic rocks are viewed as an additional source of crude oil. The fossil fuel rich basins and the intervening arches or domes were formed from differential compression, uplift and subsidence associated with tectonic activity. Fossil fuel rich strata resulted from myriad processes that provided environments of deposition conducive to the accumulation and preservation of organic material that provided the source of the Commonwealth's natural gas, coal, oil, and asphalt rock.

Challenges for continued safe shale gas development, sequestering of CO2, transition from coal to natural gas for electric power generation, along with a whirlwind of technological advances in fracking and horizontal drilling in the Kentucky region are transforming the Commonwealth. It is hoped that the fossil fuels we have in abundance will help us bridge to even more sustainable energy resources. As we move forward we must use lower C fuels and continue to conserve fuel when we can while encouraging more sustainable building and transportation modes.

Michael May is a Professor of Geology at Western Kentucky University where he has taught geology courses over the past 18 years including those focusing on environmental issues and sustainability. He was awarded the Ogden College of Science and Engineering Public Service Award for his engagement in Kentucky Brownfields, public hearings on sustainable development, and as a pro bono consultant for the Bowling Green Stormwater Committee over the past decade. Prior to

his academic appointment he worked for two environmental consulting companies near Kansas City and prior to that he worked for Shell and Exxon in Texas. He earned B.S. and Ph.D. degrees from Indiana University and an M.S. degree from the University of Kansas.

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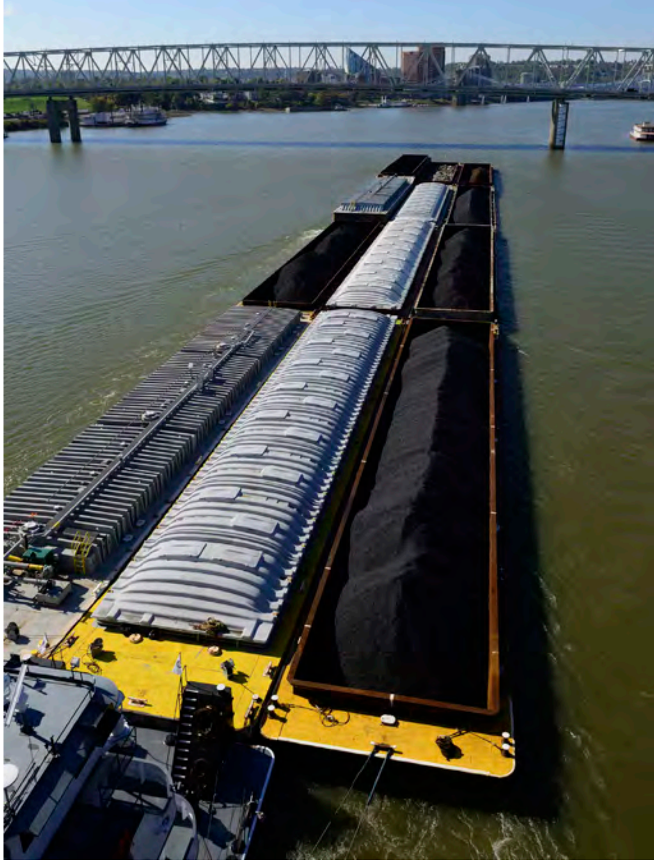
Transition to the Tipping Point – Coal-Fired Electricity in Kentucky



Robert J. Ehrler

Introduction

A variety of generating technologies and fuel options are available to generate electricity. These include traditional choices such as fossil-fired facilities using coal, natural gas, or oil as fuel, hydro facilities, and nuclear facilities. More recently, renewable energy options including wind, solar, and biomass have become increasingly common across the nation. Historically, coal-fired generation has enjoyed compelling advantages – low cost, reliability, and abundant supply. In Kentucky, coal-fired power generation has been the dominant energy supply choice for more than 50 years. In 2013, 93% of electricity generated in Kentucky was produced by coal-fired power plants. This is more than double the national average of 39%. Kentucky's reliance on low cost coal-fired electricity has resulted in utility rates historically among the lowest in the nation. Low cost electricity has been a competitive advantage in recruiting energy–intensive manufacturing and industrial businesses. Kentucky is the nation's largest aluminum supplier and the fifth largest auto manufacturer. Unquestionably, coal-fired electricity has played a key role in shaping Kentucky's economy.

While coal-fired power generation has traditionally had significant cost advantages over other generation options, owners of coal-fired power plants have faced the challenge of managing their environmental impacts. Coal-fired power plants are major sources of air emissions including sulfur dioxide, nitrogen oxides, and particulate matter. They withdraw substantial volumes of water for cooling purposes and discharge effluent into waterways. Coal-fired power plants generate coal combustion residuals which are disposed of in ponds or landfills. As coal-fired power plants became subject to increasingly stringent environmental rules in the 30 years following the passage of the key environmental laws of the 1970's, coal power's cost advantage over other generation options narrowed. However, the cost of pollution controls and other environmental requirements, while substantial, were not of a magnitude to compel significant change in the nation's power generation mix.

The significant cost advantages of coal-fired generation began to erode in the early 2000's as the U.S. Environmental Protection Agency ratcheted up regulation of power plants under the air program and laid the groundwork for significant new rules in the water and waste areas. More recently, the transformation of the natural gas industry as a result of new production technologies has challenged coal's position as the lowest cost fuel and new greenhouse gas rules have essentially eliminated the option of constructing new coal-fired plants to replace the aging generation fleet. With the percentage of coal-fired power generation dropping below the 40% threshold nationally, some ask if coal-fired generation in Kentucky has reached a tipping point.

Kentucky Coal

Kentucky's heavy reliance on coal-fired power generation is largely driven by the fact that Kentucky has long been one of the nation's top coal producing states with ample supplies of coal in close proximity to the state's power plants. In 2013, Kentucky was third in coal production with total production of 80.5 million tons. The Central Appalachian Basin coals found in the eastern Kentucky coalfield have relatively low sulfur content and high heat input. In the past, burning these lower sulfur coals allowed some power plants to defer the cost of installing sulfur dioxide removal devices or "scrubbers." The thicker, more accessible seams of Illinois Basin coal found in the western Kentucky coalfield yield less expensive, high sulfur coals. These high sulfur coals have been attractive from a cost standpoint for power plants equipped with scrubbers capable of controlling the resulting

higher sulfur dioxide emissions. In 2013, 77% of the coal mined in Kentucky was burned in power plants located in 17 states. Almost 30% of Kentucky's coal production fueled power plants located within the state.

Kentucky's Power Generating Fleet

Electric utilities in Kentucky are obligated by law to develop power generation on a "least cost" basis and coal-fired plants have long represented least cost in most applications. While coal-fired plants represent approximately 71% of the state's total generating capacity, they provide 93% of its electricity. Coal-fired power plants provide base load capacity and operate more or less continuously, while natural gas-fired combustion turbines, which make up 24% of the state's generating capacity, are operated only intermittently when necessary to meet peak demand. As of 2012, there were 20 coal-fired generating plants in Kentucky owned by various investor-owned utilities, rural electric cooperatives, municipalities, and the Tennessee Valley Authority (TVA), a federal agency. With a total state-wide generating capacity of 17,138 megawatts (MW), the individual power plants range in size from Big Rivers Electric Corporation's tiny 61-MW Reid plant to TVA's 2,558-MW behemoth at Paradise. Kentucky's generating fleet is showing its age, with five of the plants having commenced operation in the 1950's and six having commenced operation in the 1960's. The average coal-fired generating unit in the state is 43 years old. Only one coal-fired power plant has been brought online in Kentucky since 1990, with its first generating unit commencing operation in 1990 and a second in 2011.

Renewable Energy

While renewable energy is playing an increasingly important role in meeting the nation's energy needs, Kentucky currently obtains a negligible amount of energy from renewables. Kentucky has had several small hydroelectric generating facilities for many years, which have more recently been joined by a few small biomass-fired generators supplying industrial facilities. While various projects have been proposed, no utility-scale wind, solar, or biomass-fired facility is currently operating in Kentucky. There are two major impediments to widespread deployment of renewable energy in Kentucky. First, with utilities generally held to a stringent least cost standard, renewable energy options have not been viable in the past because such facilities are more expensive than fossil energy options. In 2010, the Kentucky Public Service Commission denied American Electric Power's proposed renewable energy purchase agreement for a 100-MW share of an Illinois wind farm on the grounds that it did not represent the least cost alternative. Second, unlike other states with more sunshine and stronger winds, Kentucky has only modest potential for developing renewables, although biomass has more potential than wind and solar. Indeed, in issuing its proposed existing source greenhouse gas rule, EPA assigned Kentucky a relatively modest reduction target, in part, because of the limited potential to replace coal-fired plants with renewable energy. Most states that have a significant number of renewable energy facilities have adopted a Renewable Energy Portfolio Standard that imposes mandatory requirements for utilities to obtain a portion of their overall energy needs from renewables. Kentucky has not adopted such a standard.

Renewable energy is certainly making some inroads into the Kentucky energy marketplace. In 2013, the General Assembly passed legislation exempting utility power contracts with biomass facilities from review under a strict least cost standard, although such contracts must still be found to be fair, just, and reasonable. Later that year, the Kentucky Public Service Commission approved a contract in which American Electric Power would purchase power from a 58-MW biomass plant, although the plant has yet to be built. In 2014, Louisville Gas and Electric (LG&E) and Kentucky Utilities (KU) proposed a 10-MW solar facility to be built at an existing power plant in central Kentucky. However, due to the higher cost of renewable energy facilities and the limited wind and solar potential in Kentucky, renewable energy is unlikely to constitute more than a small portion of Kentucky's generation mix for the foreseeable future.

The Generation Mix of Other Coal States

Proximity to coal supplies does not alone determine a state's power generation mix. In Illinois, ranked second in recoverable coal reserves and fourth in coal production, coal-fired power generation provided only 41% of the electricity generated in the state in 2013 – only slightly higher than the national average. 12% of electricity produced in Illinois last year came from nuclear plants, compared to zero nuclear in Kentucky. Some other states with substantial coal supplies rely on coal-fired electricity much less than does Kentucky. 39% of the electricity produced in Pennsylvania came from coal-fired power plants, while 69% of Ohio's electricity was coal-fired. Those states also have significantly higher electricity rates than does Kentucky. On the other hand, several other coal states rely heavily on coal-fired electricity, including West Virginia (95%), Wyoming (89%), and Indiana (84%). Even in states holding electric utilities to a rigid least cost standard, selecting the most appropriate power generation option involves a complex evaluation of economic, geographic, technological, regulatory, and environmental considerations. The generation mix in the U.S. varies substantially by region and that generation mix is currently undergoing significant change.

New Environmental Rules

Since the passage of the landmark Clean Air Act in 1970, the nation's power generation mix has been increasingly influenced by the environmental laws and regulations designed to mitigate the environmental impacts of coal-fired generation. For many years, the environmental rules of primary concern to owners of coal-fired power plants were those issued under the Clean Air Act. Coal-fired power plants were required to upgrade controls on a case by case basis if individual power plants contributed to nonattainment with the National Ambient Air

Quality Standards which were periodically tightened. New or modified power plants were required to install Best Available Control Technology under the New Source Review regulations. However, the U.S. Environmental Protection Agency (EPA) also specifically targeted coal-fired utilities as a major emitting sector.

Some of the key utility requirements such as the 1990 Acid Rain Amendments mandating sulfur dioxide reductions and the 1998 NOx SIP Call Rule mandating nitrogen oxide reductions adopted a "cap and trade" approach imposing an overall emissions cap on electric utilities while providing companies with substantial flexibility in how to comply. Utilities were free to install pollution controls on their larger generating units which were generally more cost-effective to control, switch to lower sulfur "compliance coal" in the case of the Acid Rain requirements, purchase excess emission allowances from utilities which over-complied, or retire plants which were no longer cost-effective to operate. In general, most utilities chose the strategy of installing pollution controls on some of their larger generating units to achieve their company-wide target. Although these programs required individual utilities to incur hundreds of millions of dollars in compliance costs, the ability to "pick and choose" units to control allowed most coal-fired power plants in Kentucky's generating fleet to remain economically viable. Throughout this period, although coal power's cost advantage over other alternatives narrowed as utilities incurred control costs, coal power's share of electricity generation remained stable at more than 90% in Kentucky and around 50% nationally.

EPA's Regulatory "Train Wreck"

The pace of regulations aimed at coal-fired power plants accelerated substantially in the early 2000's as EPA announced a flurry of new regulatory initiatives under multiple environmental statutes. These new programs posed a new level of risk for coal-fired plants as standards grew increasingly stringent with correspondingly higher control costs. In 2005, EPA issued twin rules aimed at utilities – the Clean Air Interstate Rule (CAIR) aimed at achieving additional sulfur dioxide and nitrogen oxide reductions and the Clean Air Mercury Rule (CAMR) which required, for the first time, reductions in hazardous air pollutants, specifically mercury. To achieve these additional reductions, it was necessary for utilities to install pollution controls on more of their generating units. Both of these rules were eventually struck down by the U.S. Court of Appeals for the D.C. Circuit and replaced by new, more stringent rules, the Cross State Air Pollution Rule (CSAPR) and the Mercury and Air Toxics Standards (MATS). Unlike the other rules which adopted cap and trade approaches, MATS imposed plant-specific requirement for installation of Maximum Achievable Control Technology. MATS was considered a "coal plant killer" because it was not cost-effective to install the necessary controls at many of the smaller, older coal-fired plants that were able to survive under a cap and trade approach. With the implementation of CSAPR and MATS, utilities moved into a world where, to survive, virtually all coal-fired power plants would have to install extensive pollution controls. By 2013, electric utilities in Kentucky had reduced their sulfur dioxide emissions by 72% and nitrogen oxide emissions by 76% from 1995 levels. Ironically, as the environmental footprint of coal-fired power plants decreased, the regulatory scrutiny on them only intensified.

As EPA ratcheted down power plant emissions, it also moved ahead with rules to address water and waste impacts of coal-fired plants. In 2010, EPA proposed its Coal Combustion Residuals Rule which, when finalized, is likely to require the management of coal ash in more secure and more expensive landfills in place of ash ponds. In 2013, EPA proposed revised effluent limitation guidelines for coal-fired power plants that will mandate more stringent discharge standards and implementation of additional waste water treatment technologies such as chemical or perhaps biological treatment. In 2014, EPA issued a rule requiring utilities to reduce the impact of cooling water intake structures on aquatic life. Collectively, these rules will impose substantial additional costs on coal-fired plants and threaten the viability of plants that survived previous waves of regulation. Referred to by some industry groups as EPA's "regulatory train wreck," these rules pose additional risk for utilities because they have been undertaken under multiple statutes with little coordination.

Utilities face a real risk of spending hundreds of millions of dollars on pollution controls for a coal-fired power plant to comply with one EPA rule, only to see a future EPA rule render the plant uneconomic and the prior investment in pollution controls superfluous. Adding to the complexity, virtually all of these rules have been subject to legal challenges by various industry and environmental groups. The CAMR and CAIR rules were struck down by the U.S. Court of Appeals for the D.C. Circuit only to be replaced by the MATS and CSAPR rules. The D.C. Circuit later struck down CSAPR too, but was reversed by the Supreme Court which reinstated CSAPR. A significant element of uncertainty was injected into the compliance planning process for coal-fired power plants as a result of multiple waves of poorly coordinated environmental rules followed by appeals that periodically overturned some of those rules. The uncertainties of the regulatory "train wreck" have placed additional pressure on utilities to retire coal-fired generation that is not clearly economically viable under virtually all scenarios.

Greenhouse Gas Rules

However, the most direct threat to the future of coal-fired electricity generation has been EPA's greenhouse gas rules. Unlike the situation for conventional pollutants such as sulfur dioxide, nitrogen oxides, and particulate matter, there are currently no "add on" controls to reduce emissions of carbon dioxide and other greenhouse gases. Carbon capture and sequestration technology is currently under development, but much work remains to be completed before it is demonstrated to be feasible. In 2013, EPA proposed new source performance standards for greenhouse gas emissions from new coal-fired power plants that provide for an emission limit of 1100 pounds

of carbon dioxide per MW hour for new coal-fired power plants. Because such levels are currently unachievable without carbon capture and sequestration, the standard would essentially function as a bar to the construction of new coal-fired power plants until CCS technology is developed. Although the rule does not apply to existing plants, it has serious implications for the long term viability of coal-fired plants in states like Kentucky with aging fleets of power plants. As coal-fired plants are retired, they must be replaced by some other generating option.

As a follow up to its new source rule, in June 2014, EPA released its long-awaited proposed guidelines governing greenhouse gas emissions from existing coal-fired power plants. The guidelines would establish requirements for the states to issue emissions standards for existing plants that would achieve carbon dioxide reductions from the power sector of 30% below 2005 levels by 2030. After considering regional variation in generation mix and energy consumption and assessing the potential for plant efficiency, fuel switching, renewable energy, and energy efficiency measures, EPA identified state-specific reduction targets. Concluding that Kentucky has limited options for weaning itself from coal power, EPA assigned Kentucky a reduction target of 18% below 2012 levels – among the least stringent in the nation. The basic standard proposed by EPA consists of a pound per megawatt hour rate-based standard, but EPA has provided the option of converting the reduction target to a cap. While this approach provides additional flexibility for purposes of compliance, the greenhouse gas reduction target puts substantially more pressure on Kentucky's coal-fired generating fleet, which already faced significant pressure from the prior EPA rules.

Retirement of Coal-Fired Units in Kentucky

The utility industry's response to these new developments has been clear – retirement of more and more coal-fired plants and addition of stringent pollution controls to those that remain. Of the 20 coal-fired power plants in Kentucky in 2012, 10 are or will be retired, partially retired, or idled. The coal plant retirements currently planned in Kentucky are not limited to the smaller, older generating units that generally encompassed the first wave of retirements, but also include large generating units such as those at TVA's Paradise Plant (two units with a capacity of 1,230-MW) and American Electric Power's Big Sandy Plant (one 800-MW unit). Fully 40% of coal-fired units in Kentucky will be retired by 2016. The Kentucky Energy and Environment Cabinet has projected that, without considering the new greenhouse gas rules, coal-fired power plants will provide 78% of electricity generated in Kentucky in 2020 – a substantial drop from the current 92%. Virtually all of the remaining coal-fired plants not slated for retirement are in the midst of massive pollution control upgrades. For example, a single facility - LG&E's Mill Creek Plant - is currently installing almost $1 billion in additional pollution controls.

The changing economics of power generation are evident in the two most recent decisions on construction of new power plants in Kentucky. In 2004, LG&E proposed construction of a $1 billion coal-fired generating unit – the 760-MW Trimble County Unit 2 – as the least cost alternative to meet growing electricity demand. When faced with the need for additional base load generating capacity in 2012, LG&E proposed a 640-MW natural gas-fired combined cycle generating unit at its Cane Run Plant. While the Kentucky generating fleet already has significant natural gas-fired generating capacity in the form of combustion turbines operated intermittently to meet peak load demand, the new Cane Run combined cycle unit will be the first natural gas-fired base load generating unit in the state. The selection of a natural gas-fired unit as the least cost generation option in a coal state like Kentucky is testament to the fundamental challenges currently faced by coal-fired power generation.

The Future of Coal-Fired Generation

While the electric utility industry is in a time of almost unprecedented transition, it is far too early to write off coal power from Kentucky's power generation mix. The move away from coal is driven by a convergence of two developments – deployment of new hydraulic "fracking" technologies that have freed up large volumes of low cost shale gas and greenhouse gas rules for which utilities have a dearth of options other than retiring coal-fired generation. Coal power has proven remarkably resilient in the face of past challenges. The historic volatility in natural gas prices has been a major impediment to past efforts to move the generation mix away from coal power. A return of volatility to the natural gas markets could significantly alter the "least cost" dynamics driving the generation mix toward natural gas. Just as technology developments have fundamentally changed natural gas production and prices, future technology developments in the form of carbon capture and sequestration technologies could re-invigorate coal-fired generation. Of course, future technology developments could also improve the competitiveness of renewable energy. Any reversal in the current trend away from coal power is far from certain. What is certain is that coal-fired power generation will continue to be a key part of Kentucky's generation mix for many years. Even in 2030, when the proposed EPA greenhouse gas rules will be fully implemented, EPA projects that coal-fired generation will remain the largest single part of the nation's power generation mix.

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Kentucky's Unconventional Hydrocarbon Resources

Brandon C. Nuttall, Geologist
John R. Bowersox, Geologist

Introduction

Kentucky's unconventional petroleum resources include gas shale, oil shale, and heavy oil or "tar" sands. The Commonwealth has a long history of conventional and unconventional oil and gas production. In 1815, a well was drilled for brine near Monticello, Wayne County. The well was abandoned when it produced oil thus ruining the brine (Jillson, 1952). This well was soon followed in the winter of 1818 with the Beatty well drilled by Huling and Zimmerman near the confluence of what is now Oil Well Branch and the Big South Fork of the Cumberland River (Jillson, 1920, 1952). The state has three main regions that are productive of oil and natural gas (Fig. 1). The majority of natural gas is produced in the eastern coal field region, a part of the central Appalachian Basin. Oil production is nearly evenly distributed between the eastern coal field region of the central Appalachian Basin and the western coal field region of the southern part of the Illinois Basin. The broad Cincinnati Arch region separates these two basins and the area is productive of oil in south-central Kentucky. Oil and gas are produced from conventional sandstone and carbonate reservoirs that typically occur at drilling depths of less than 4,000 feet. In addition, nearly two-thirds of Kentucky is underlain by an unconventional, low-permeability, organic-rich, continuous shale gas resource and where that resource is at or near the surface, it has been assessed for its oil shale potential.

Oil and gas production data are vital for tracking industry trends and compiling resource estimates, but those data are not readily available. Little production data exists from the antebellum era of Kentucky exploration and development. Annual oil production data are available beginning in 1873, but it's not until 1919 that monthly data by county are reported. Regional gas production records begin with 1950 and data by county begin in 1986. These data indicate cumulative statewide production in excess of 796 million barrels of oil and 7.2 trillion cubic feet of natural gas (1,240 million barrels of oil equivalent) (Fig 2). Kentucky's oil production peaked in 1959 with 27.3 million barrels of oil, most from the Greensburg Pool in Green and Taylor Counties which produced 10 million barrels of oil that year. In 1996, the General Assembly authorized the Kentucky Division of Oil and Gas to collect and publicly report monthly oil and natural gas production volumes for individual wells. This data set begins with the 1997 report year. In practice, the data are often by lease with volume from multiple wells flowing into a single collection point allocated to each reported well. The performance of Kentucky wells based on these data was recently summarized by Nuttall (2014).

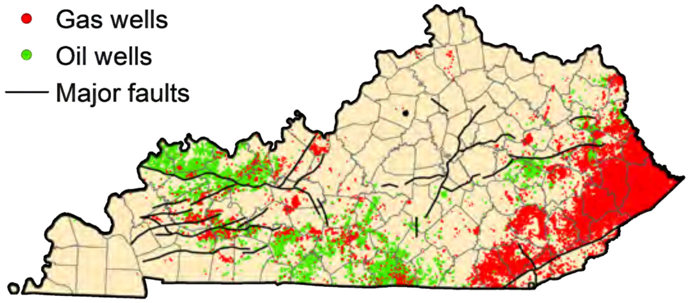


Figure 1.

Most natural gas in Kentucky is produced from the Devonian Ohio Shale of eastern Kentucky. After peaking at 89.16 billion cubic feet ("bcf") in 1967, production steadily declined until the adoption in 1980 of a federal production tax credit for low-permeability ("tight") reservoirs that require stimulation.

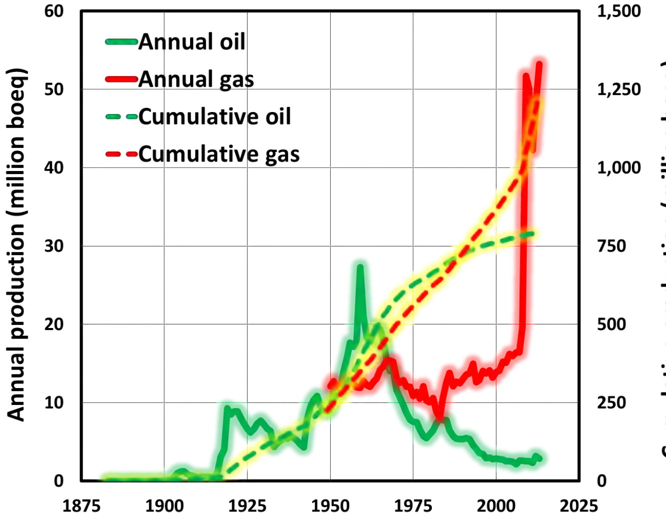


Figure 2.

Kentucky's gas production increased steadily (even after the expiration of the credit) until 2008 when production soared. Beginning in 2006, horizontal wells and nitrogen-based foam fracture stimulations led to a renaissance of eastern Kentucky shale gas and boosted production to more than 300 bcf in 2009. The 308 bcf produced in 2013 is the record annual production. Currently, more than 1,400 fracture-stimulated horizontal wells are active in eastern Kentucky, mostly in organic-rich zones within the Devonian Ohio shale. The low maturity of the organic matter in the shale, lower natural gas price, (perceived) absence of liquids, and near-normally-pressured reservoir conditions have slowed drilling in eastern Kentucky and influenced many mid-size operators to pursue the Marcellus and Utica shales outside of Kentucky. However, access to infrastructure and lower drilling and completion costs are advantages for developing natural gas in eastern Kentucky and companies are showing continued interest.

The general chaos that accompanied the development of the Greensburg Pool in Green and Taylor Counties led to the adoption of the current oil and gas well regulations in 1960. KRS 353 requires wells to be permitted and bonded to guarantee proper abandonment, specifies spacing between wells and property lines to protect correlative rights to recover oil and gas, establishes well construction standards to protect fresh water resources, requires drilling records to be submitted for public access, sets forth standards for well abandonment, and sets other provisions.

GAS SHALE

Distribution and general geology

The Devonian Shale in Kentucky is known variously as the Ohio Shale (east), Chattanooga Shale (south eastern), and New Albany Shale (west) (Fig. 3). It crops out in the Knobs physiographic province surrounding the Bluegrass Region of central Kentucky and is present at the surface from the AA Highway area near Vanceburg in Lewis County, through Berea, Madison County, to Louisville in Jefferson County. The shale consists of thin laminated sequences of alternating black, organic-rich intervals and grayer quartz- and clay-rich zones. The shales are naturally fractured which influences the ability of the shale to produce natural gas (Fig 4). Figure 5 shows the general equivalents of the names assigned to these alternating intervals.

The shale underlies nearly two-thirds of the State (Fig. 6) and generally produces natural gas where it is at least 100 ft thick and at least 1,000 ft deep. These shales are the thickest where they underlie the eastern Kentucky coal field where they can be more than 1,600 feet thick in parts of the Big Sandy natural gas field. The more organic-rich zones like the Cleveland and Lower Huron in the Ohio shale are most often targeted for completion and production. In western Kentucky, recently completed wells in the Grassy Creek section of the New Albany are showing promise not only as gas producers, but oil producers as well.

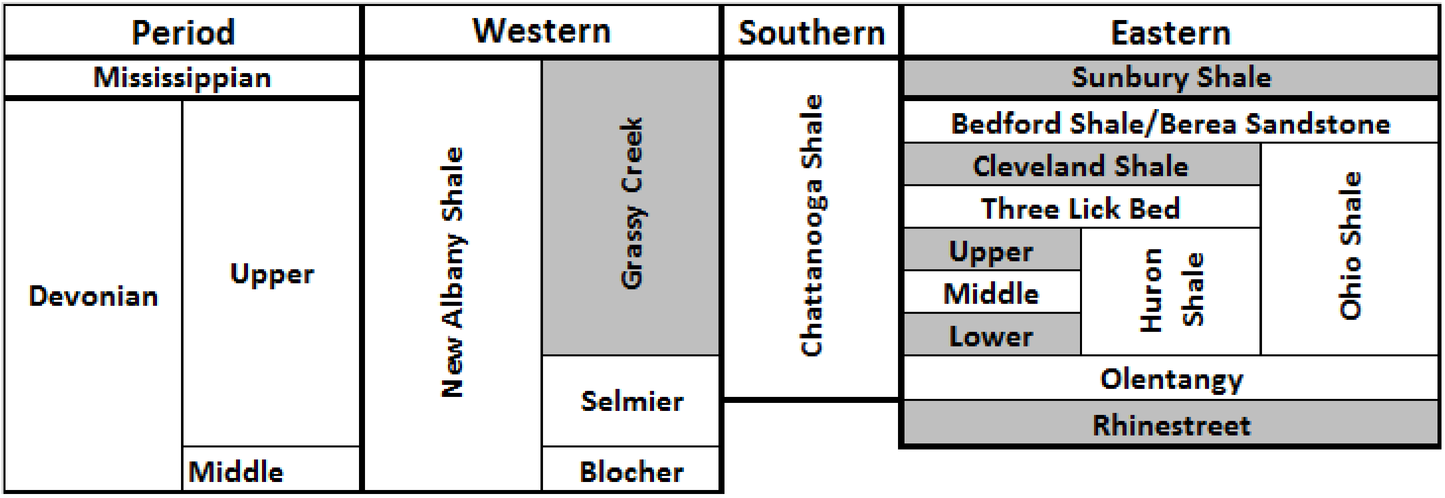
Figure 3.

Figure 4.

History

In Kentucky, burning springs and natural gas seeps were encountered by the earliest pioneers to enter the state. The first geological survey of Kentucky, conducted in 1838 by William Williams Mather (1988), noted that gas springs were not uncommon and those "evolving carburetted hydrogen are most numerous, and are capable of useful applications." It wasn't until 1858, however, that the gas was put to commercial use. In Meade County, western Kentucky, wells drilled to produce brine used in making salt often co-produced natural gas from the black shale that would become known as the New Albany Shale. This gas was captured and used as fuel for evaporating the brine (Eyl, 1922; Foerste, 1910; Jillson, 1922; Orton, 1891). Even though this activity led to the eventual gasification of Louisville, Kentucky and the founding of the Louisville Gas and Electric Company, the New Albany Shale of western Kentucky has largely been bypassed.

Orton (1891) wrote that the only example of large production from shale was the Meade County field of western Kentucky. He noted that rocks along the outcrops of the Ohio Shale from New York to Tennessee commonly exhibit oil and gas springs with characteristically small flows that were associated mostly with open fractures in the shale. The 1890s saw drilling in Floyd, Knott, Martin, and Pike counties, eastern Kentucky (Jillson, 1918). At some point in this period, the discovery of shale gas



Period		Western		Southern	Eastern		
Mississippian		New Albany Shale	Grassy Creek	Chattanooga Shale	Sunbury Shale		
Devonian	Upper				Bedford Shale/Berea Sandstone		
					Cleveland Shale		Ohio Shale
					Three Lick Bed		
					Upper	Huron Shale	
					Middle		
					Lower		
			Selmier		Olentangy		
					Rhinestreet		
	Middle		Blocher				

Figure 5.

production in what is now known as the Big Sandy natural gas field occurred (Fig. 6). It was in eastern Kentucky, then, that the drilling, gathering, compression and processing, and pipeline infrastructure was built that supports gas production. Today, the Big Sandy field is the source of the majority of the State's gas production.

Production

Natural fractures are an important control on shale gas production (Fig 4). Wells are typically drilled to maximize contact of the wellbore with the fracture system and are then stimulated to induce additional flow pathways from the fractures to the wellbore. Early wells were explosively fractured using gunpowder or nitroglycerine. Nitroglycerine is unstable and its use led to many oilfield fatalities. It was quickly replaced with dynamite. In the 1960s, experiments with hydraulic fracturing found that water caused formation damage as the water was absorbed by clays in the shale; swelling caused the induced fractures to close. By the mid- to late-1970s, it was found that nitrogen gas pumped at high rates and pressures is an effective technique for inducing fractures in shale to maximize the contact between the wellbore and the shale reservoir.

Natural gas and natural gas liquids are stored in shale as free gas in the fracture system and adsorbed gas associated mostly with organic matter in the shale matrix. During production, the free gas is depleted relatively rapidly. This gas production lowers the pressure in the reservoir inducing additional gas and liquids to desorb from the organic matter and diffuse through the shale finally entering the fracture system where it can flow freely. This desorption and diffusion of gas controls the often very long lifetime for producing wells, some in excess of 50 years. Historic annual production data are available for a limited number of vertical shale wells most of which were explosively fractured. For these wells, 50 percent produced at least 0.10 billion cubic feet ("bcf") of gas in 10 years and 0.65 bcf over a 50 year span. Less than one percent of these shale wells produced 1 bcf in 10 years, but nearly 30 percent produced more than 1 bcf in 50 years (Fig. 7).

Horizontal wells and fracture stimulation

In the 1990s, the U.S. Department of Energy conducted research in Kentucky and West Virginia to investigate the use of horizontal wells for producing shale gas. That research demonstrated horizontal wells could expect estimated recoveries of more than 1.5-times that of a vertical well. The added expense of drilling a horizontal well combined with a relatively low wellhead price for natural gas discouraged operators from using

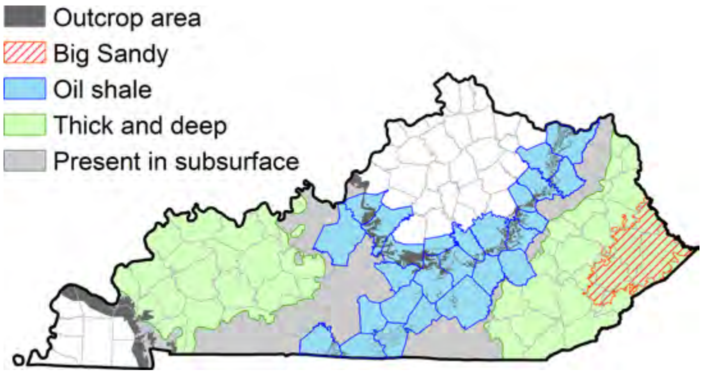


Figure 6.

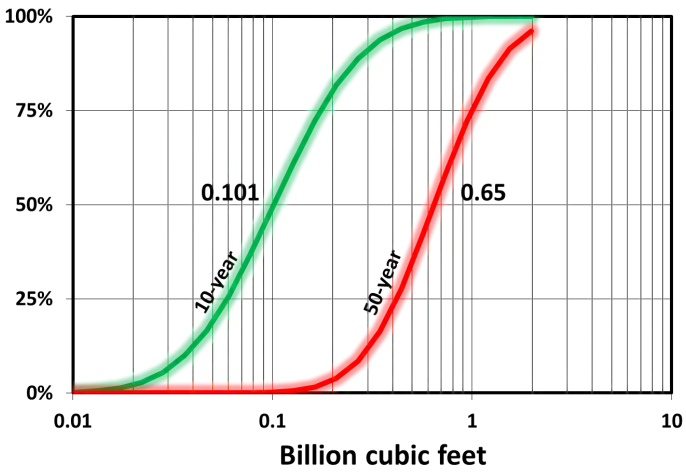


Figure 7.

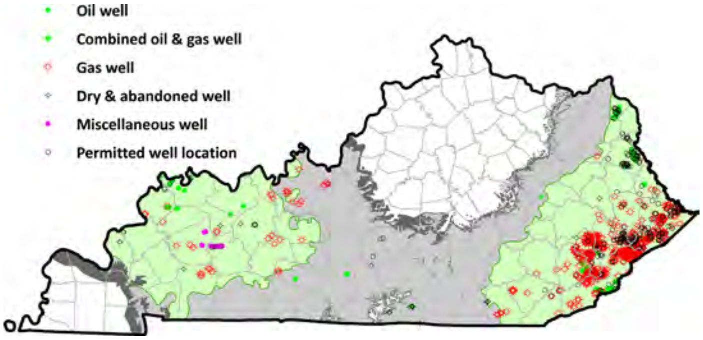


Figure 8.

this recovery technique in Kentucky. Prior to 2006, less than 50 horizontal wells had been drilled in Kentucky. In 2006, however, with a favorable natural gas price and encouraged by the success of Marcellus shale gas production in Pennsylvania and Ohio, Kentucky operators began a program of horizontal drilling that resulted in significantly lowering the cost of drilling as rigs, tools, and experience became locally available. Today, an estimated 1,400 horizontal wells are active, most in eastern Kentucky (Fig 8).

To complete a horizontal well, a vertical well is first drilled to a depth below the deepest known fresh water zone. Steel pipe called casing is installed and cement is circulated into the space between the borehole wall and casing. The well is drilled vertically to a "kick off point" where the curved section of the well is initiated. Typically, a second string of casing is installed at this depth and cemented. While drilling the curved section of the well, the target formation is penetrated and the well steered along a horizontal trajectory to a target "landing" point (typically 3,000 to 5,000 feet).

A nitrogen-based foam fracture stimulation is used in the horizontal wells of eastern Kentucky to minimize formation damage due to water interacting with swelling clays and to maximize the ability to transport sand into the induced fractures. A tool string consisting of multiple "packers" that separate ports is installed into the borehole. A packer is an expandable device that seals against the wall of the borehole to prevent fluids migrating across it and serves to isolate individual ports. A packer at the top of the tool string seals the equipment into the well bore at the base of the casing above the kick off point. During the stimulation, the ports between the packers are sequentially opened using the pressure of the fluids being pumped beginning with the farthest port at the target end of the horizontal lateral. As each successive port is opened, a "stage" in the treatment, the previous port is automatically closed. Nitrogen foam with a consistency similar to shaving cream is pumped through a port and formation pressure builds until the mechanical strength of the rock is exceeded, causing it to form a network of small fractures. Sand is then added to the mix and enters the fracture system to prop it open. After a pre-determined volume of sand and foam is pumped, foam alone is pumped to flush the system for the next stage in the treatment. Once all stages in the treatment have been conducted, the pressure is released allowing the nitrogen foam to flow back to the surface. The nitrogen is allowed to vent to the atmosphere during flow back and any produced fluids (water and chemicals) are collected for treatment or disposal. The tools are withdrawn from the well and the "completed" well is ready to begin production.

At this time, there is very little production data for comparing the long-term performance of horizontal shale wells to conventional vertical wells. Nuttall (2014) found that over a three-year period, horizontal wells typically exceeded the median reported maximum monthly production rates during the first year of 2,271 thousand cubic feet of gas and exceeded the observed median three-year cumulative production volume of 33.5 million cubic feet when compared to standard vertical wells (Fig. 9). Many eastern Kentucky operators are drilling and completing horizontal wells in areas with long-established production from vertical wells and are reporting shale gas production during the first month of operation to be as high as 25 to 32 million cubic feet of gas. In other words, some new horizontal shale wells are producing as much gas in 1 month as comparable nearby vertical wells produce over three years (Fig. 7). These observations indicate fracture stimulated horizontal shale wells are likely to perform better than vertical wells and remain economic to drill and complete. But it is not yet known whether horizontal wells will have producing life spans similar to more conventional vertical shale wells.

Future

Kentucky's Devonian Shale gas resource was estimated to be 12 trillion cubic feet (Hamilton-Smith, 1993). That estimate was compiled before the widespread application of horizontal drilling in Kentucky and before the shale gas boom in general. In light of the shale gas revolution, the U.S. Geological Survey, the U.S. Energy Information Administration, and other agencies have revised regional shale gas resource estimates upward. Most drilling and development of shale gas has taken place in the Ohio shale of eastern Kentucky where there is an extensive gathering, compression, processing, and transmission infrastructure.

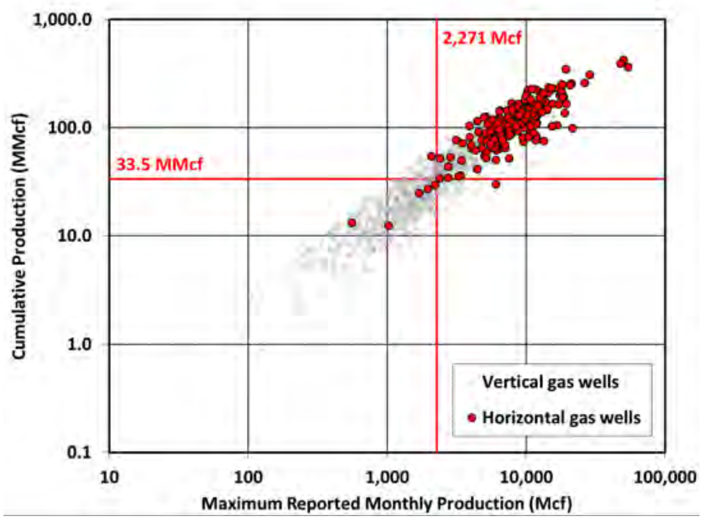


Figure 9.

In western Kentucky, Christian, Grayson, and Meade Counties are well established areas of gas production from the New Albany Shale. New Albany Shale gas production, however, contributes less than one percent to the State's annual production volume. Across much of the area where the New Albany Shale is deepest and thickest and potentially has better possibilities for production, oil producing zones that overlie the shale are the usual targets for drilling and development. Major high-pressure interstate gas transmission pipelines cross western Kentucky, but outside of the established areas of production, it is not typically economical to construct the infrastructure required to connect the wellheads to markets via those pipelines. Gas development in the New Albany Shale is more often than not inhibited by a lack of infrastructure for gathering, compression, processing, and transmission. The possibility of emerging local markets helping to spur infrastructure development should lead to more extensive development of the New Albany Shale.

Across the United States, much of the development of unconventional shale resources is being driven not by natural gas production, but by the production of natural gas liquids. Natural gas liquids are the heavier molecular weight components of natural gas that can be separated using cryogenic processing: primarily ethane, propane, butanes, and pentanes. Kentucky's natural gas production is more than 150 years old, low pressure, and, with mostly vertical well completions that until the last few decades were explosively fractured, are considered relatively "dry", that is, having a low liquids content. The few gas analyses that are available, however, indicate Kentucky's shale gas has favorable amounts of liquids comparable to some of the better known shales like the Bakken, Barnett, and Marcellus. A natural gas liquids pipeline originating at a processing plant in Floyd County, eastern Kentucky, delivers liquids to a fractionation plant in Greenup County, northern Kentucky. In Breckinridge County, western Kentucky, five recently drilled New Albany Shale gas wells are now producing both oil and gas. Kentucky doesn't track liquids production, however. As an indication, the U.S. Energy Information Administration shows Kentucky liquids production to have risen from 3 million barrels in 2007 to 5 million barrels in 2012, volumes that exceed the annual crude oil production over that same period. While Kentucky might never become a major producer of natural gas liquids, there is certainly an opportunity to participate in the development of this resource as new infrastructure and facilities are built.

OIL SHALE

Area

Oil shales are rock units that contain enough organic matter that they can be processed to extract that material as liquid hydrocarbons. Where Kentucky's Devonian Ohio, Chattanooga, and New Albany gas shales are thinner, shallower, and have a minimum organic richness, they constitute an oil shale resource. Accessible mostly by surface mining, the oil shale resource is located primarily along the outcrop of black shale surrounding the Bluegrass Region of the State and along the crest of the Cincinnati Arch in southern Kentucky (Fig. 6). Prospective areas for mining have been identified based on depth and thickness of the shale, thickness of the overburden that must be removed to access the shale by surface mining methods, and organic richness.

History

Miller (1919) relates that in 1856, a distilling plant was established in Breckinridge County, western Kentucky, to process local coals into kerosene. He notes also that at about the same time, a similar plant was established near Vanceburg, Lewis County, northern Kentucky to process the Mississippian Sunbury black shale and produce kerosene. With the emergence of the modern petroleum industry in 1859 (Drake well, Titusville, Pennsylvania), it proved to be much easier to obtain the requisite fuel by processing crude oil, and distillation of coal and shale gradually disappeared. During World War II, the lack of access to petroleum reserves spurred Germany to rely heavily on the distillation process perfected by Hans Fischer and Franz Tropsch to produce fuel for their war effort. In the United States, the oil embargo of 1973-74 sparked interest in securing America's petroleum supply with the production of synthetic fuels from coal and organic-rich shale. For that purpose, in the late 1970s and early 1980's, the U.S. Department of Energy funded a Synfuels program to conduct research to assess the oil shale resource and improve the efficiency of the Fischer-Tropsch process (among other programs). In Kentucky, this research funded construction of the Catlettsburg H-Coal pilot plant (http://www.wvcoal.com/research-development/more-on-kentuckys-h-coal-ctl-process.html). By the mid-1980s, however, offshore oil discoveries worldwide eased petroleum supply concerns and distillation plants, like the Catlettsburg facility, were mothballed and abandoned. The use of Fischer-Tropsch for coal-to-liquids production enjoyed a renaissance during the first decade of the 21st century when declining domestic oil production and increasing petroleum imports led to rising fuel prices and again sparked concerns over national energy security. While mentioned only rarely during this time, entrepreneurs actively pursued investors with promises of large domestic fuel supplies from oil shale.

Production

Little or no oil shale has been mined and processed in Kentucky since the mid 19th century. Researchers at the Kentucky Energy Cabinet Laboratory (now the Center for Applied Energy Research at the University of Kentucky) studied a 26 county area along the Devonian shale outcrop from Lewis County to Bullitt County and in south-central Kentucky along the crest of the Cincinnati Arch where the overburden is thin enough to make surface mining practical (Fig. 6). Barron and others (1986) and Barron and others (1984) defined economic shale oil resources as those shales having a total organic matter content of 8 percent or greater (from core analysis) and with ratio of resource thickness to thickness of the overlying rock material of less than 2.5:1 (from 1:24,000-scale geologic maps). Employing these criteria,

Figure 10.

“high grade zones” were identified in the Mississippian Sunbury Shale and Devonian Cleveland Shale, eastern Kentucky and the Devonian New Albany Shale, western Kentucky. The studies reported an estimated total resource of 16.03 billion barrels of oil-in-place for Kentucky shales.

Future

In the United States, horizontal wells and fracture stimulation technologies have produced an abundance of natural gas, natural gas liquids, and associated oil from deeper, unconventional shale reservoirs. Production is increasing and imports are decreasing to the point that the United States is on the brink of both record petroleum production and becoming a net energy exporter; a resource and economic position not experienced since the mid 20th century. This surge in production is easing concerns over long term energy supplies and fuel prices are attracting manufacturing back to the United States. Until these economic conditions change, oil shale is likely to remain an unexploited endowment in the fuel resource bank.

TAR SAND

Area

Heavy oil- and bitumen-saturated sandstones are found along the southern margin of the Illinois Basin in western Kentucky in a belt extending from Logan County on the south to southern Hardin and eastern Breckinridge Counties on the north (Noger, 1984; Hamilton-Smith, 1994; Fig. 10). The deposits occur in the Mississippian Hardinsburg and Big Clifty Sandstones and the Kyrock Sandstone of the Early Pennsylvanian Caseyville Formation in western Kentucky (Fig. 11, Fig. 12). The strata are part of a sequence deposited as the result of rising and then falling seas from the Beech Creek Limestone at its base through the Leitchfield Formation (Fig. 11) where limestones are overlain by sandstones and clay-rich shales (McGrain, 1976; Pryor et al., 1990; Nelson and Treworgy, 1994). The Big Clifty and Hardinsburg show patterns of deposition that are generally in a southeasterly direction (Potter et al., 1958), a factor that, in part, accounts for the distribution of the oil reservoirs. Trends in the Big Clifty and Hardinsburg that correspond with the pattern of surface faults (Fig. 13) suggests contemporaneous faulting influenced deposition. Other geologic factors that occurred after deposition of the Big Clifty (Butler, 2013) and Hardinsburg contributed to the discontinuous distribution of reservoirs observed in outcrop (May, 2013).

History

The presence of heavy oil in the Big Clifty, Hardinsburg, and Caseyville sandstones was first recognized from seeps where these rock units occur near the surface. (Fig. 13). Heavy oil also forms seeps at the surface in the tar sands belt where subsurface reservoirs are cut by faults that continue to the surface (Fig. 13). These deposits, historically called tar sands, rock asphalt and black rock, were mined for use as road surfacing from the late 19th to mid-20th centuries. Local tar sand was used to pave roads in Logan County, Kentucky, in 1894 (Weller, 1927). Other accounts relate that the streets of Havana, Cuba, Rio de Janerio, Brazil, and the Indianapolis Speedway were all paved at one time with Kentucky tar sand (Richardson, 1924). The tar sand paving industry was replaced after World War II by modern asphalt roads (Rose, 1992; May, 2013). Minor amounts of petroleum products were refined from the tar sands during this period, but production was insufficient to support commercial development (McCormack, 1925; Weller, 1927). Attempts were made to develop the tar sands in the shallow subsurface (less than 600 feet deep) with conventional vertical wellbores from

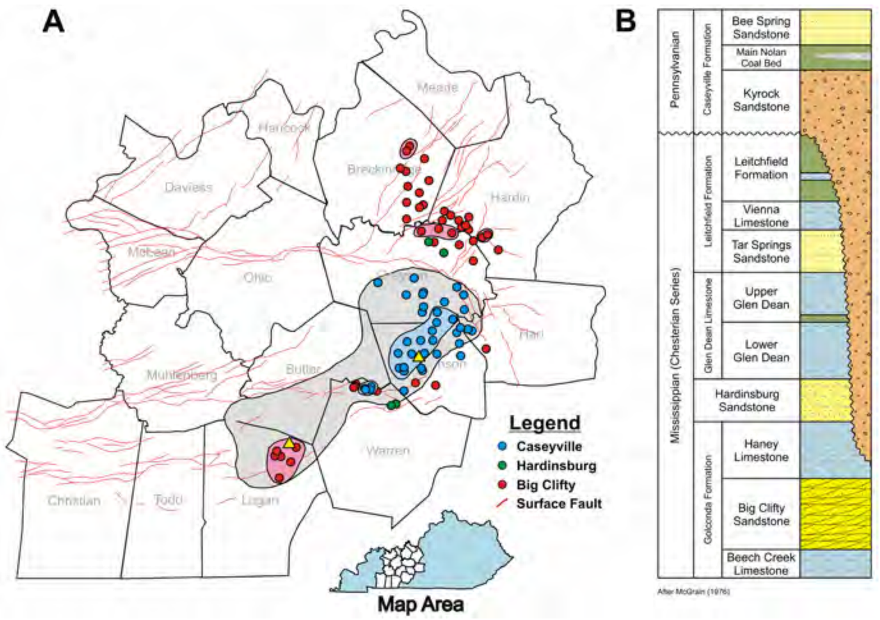


Figure 11.

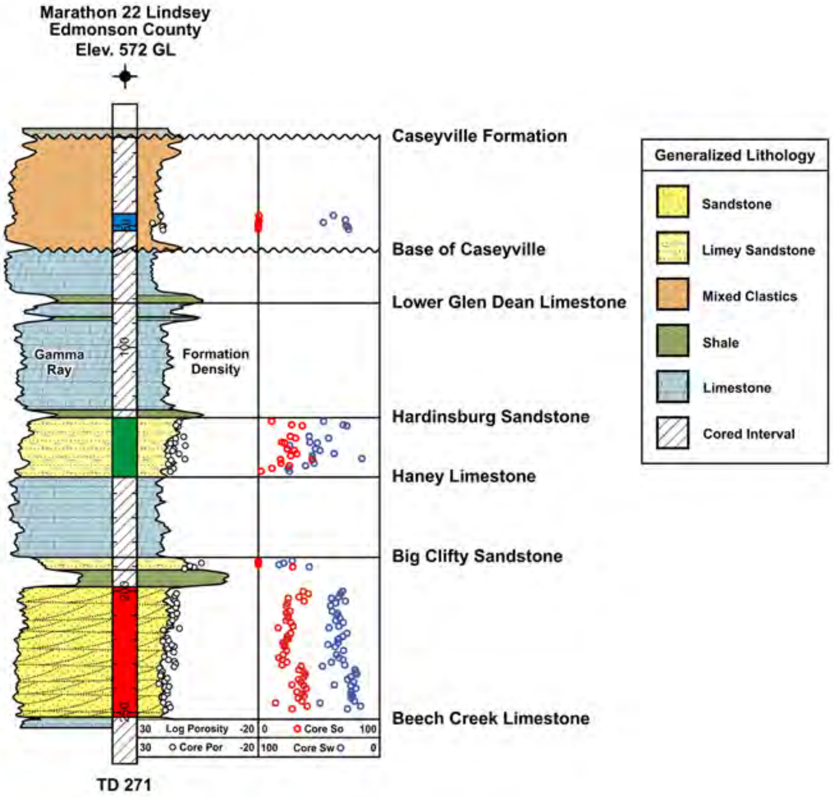


Figure 12.

the late 1950s to early 1990s using enhanced oil recovery (EOR) processes (Williams et al., 1982; Noger, 1984; May, 2013). These projects were, in part, technical successes (Terwilliger, 1976; Noger, 1984; Ward and Ward, 1985; May, 2013) but yielded low recoveries of the tar-like oil and were ultimately abandoned by the operators. Two projects in the early 1980s evaluated mining surface deposits of tar sands in Logan County and extracting the heavy oil and bitumen from the rock using solvents (Groves and Hastings, 1983; Noger, 1984; Tis, 1984; Kelley and Fede, 1985), however both projects were abandoned by 1985.

Resources

Petroleum reserves refer to a quantity of hydrocarbons that are recoverable from known accumulations with existing technology at the prevailing price; there are no identified reserves in the Kentucky tar sands at this time. The tar sand resources, an estimate of the quantity of hydrocarbons likely to exist, were calculated from the reservoir volume and bulk volume of oil in place (by petroleum industry convention as 42-gallon barrels). The preliminary estimate of heavy oil and bitumen resources in place in the tar sands are 3,861 million barrels; the volumes of heavy oil and bitumen produced by all methods to date are comparatively negligible. The largest resource is in the Big Clifty (2,458 million barrels of oil in place), followed by the Caseyville (1,037 million barrels of oil in place) and Hardinsburg (366 million barrels of oil in place).

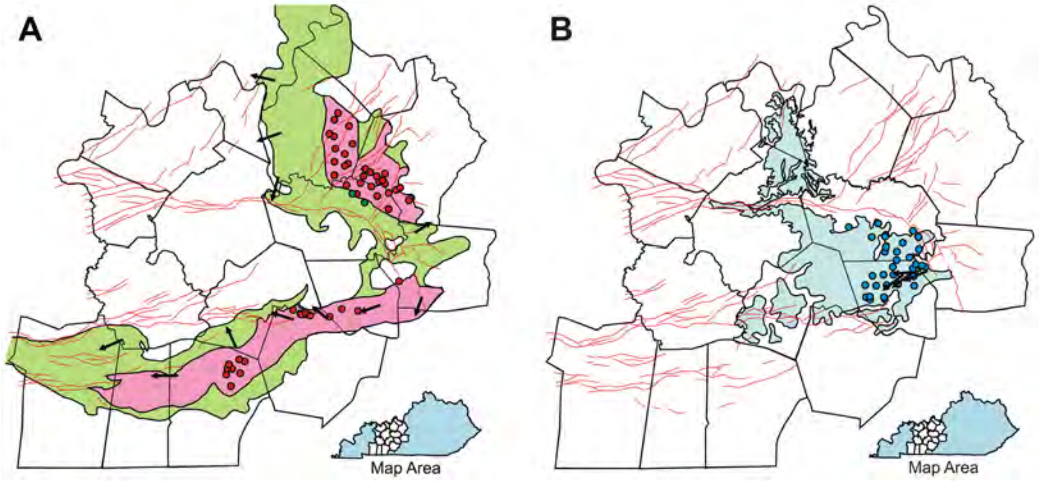


Figure 13.

Activity

Persistent world oil prices, generally exceeding $100 per barrel, have been high enough to encourage oil and mining companies to reevaluate the tar sands resources in western Kentucky and experiment with development of commercial production from tar sands. The Kentucky Geological Survey has been contacted several times during 2014 for information about the western Kentucky tar sands. There have been reports of speculative leasing of tar sands properties by operators and non-operators in the area. Several large lease tracts of 20,000 or more acres are said to have been assembled. There appear to be no specific development activities proposed for these tracts. The largest tracts reported are in Logan, Warren, and Edmonson Counties.

Archer Petroleum, Vancouver, British Columbia, in partnership with Arrakis Oil Recovery, Evansville, Indiana, operate the only tar sands development project in Kentucky. Operation of a surface tar sand mine and pilot bitumen extraction plant in northeast Logan County, north east of Russellville, began during the fall of 2013. According to reports and public information available from the companies and U.S. Securities and Exchange Commission, the extraction plant uses a recycleable, non-toxic and biodegradable, water-based chemical that cleans the oil from the sand. The company currently operates on 121 acres and has options to lease additional acreage. No production volumes have been reported.

Future

Kentucky has significant potential for tar sand production using both surface mining and enhanced oil recovery methods. However, commercially viable production has yet to be established and such efforts will largely be influenced by the prevailing price of crude oil.

Conclusion

Kentucky's shale gas production represents a vital and ongoing sector of the oil and gas industry in the State. Drilling and development of the existing known reserve is expected to continue and, given a favorable wellhead price for natural gas, it is likely that expansion of production will include a greater contribution from the New Albany Shale in western Kentucky and development of natural gas liquids. The estimated oil shale resource is not expected to be developed unless or until there is a drastic change in the price and disposition of the current oil supply. Developing oil production from Kentucky's tar sands is more likely than producing oil from Kentucky shales, but again, it is the world supply and price of oil that will control the success of any commercial ventures.

Brandon Nuttall is a Kentucky Registered Professional Geologist who received a BS in Geology in 1975 from Eastern Kentucky University and went to work evaluating coal reserves in western Kentucky. In 1978, he joined the Kentucky Geological Survey, a research and public service center at the University of Kentucky. In 36 years at the Survey, he has designed, implemented, and continues to supervise the computerized Kentucky oil and gas well record data base. In addition to tracking oil and gas drilling activity and public service duties, he is involved with a variety of subsurface mapping and research projects including oil and gas resource assessment, carbon sequestration, reservoir evaluation for enhanced oil recovery, shale gas production, and is currently investigating the possibility of enhanced natural gas recovery using carbon dioxide injection in shales. He assists other Survey researchers with GIS, GPS, computer software, and statistics applications. Brandon has served on statewide committees to formulate policy and regulations for coalbed methane development and carbon storage in Kentucky. He serves as a technical liaison to the Secretary of the Kentucky Energy and Environment Cabinet on hydrocarbon resource and development issues.

J. Richard Bowersox is a senior research geologist with the Kentucky Geological Survey and Adjunct Assistant Professor in the Department of Earth and Environmental Sciences at the University of Kentucky, having 40 years in academia and the petroleum industry. His recent research has focused on the subsurface storage of carbon dioxide in the Illinois and Appalachian basins and evaluating the heavy oil and bitumen resources of western Kentucky. Bowersox has a Ph.D. in geology from the University of South Florida, Tampa, is a registered professional geologist in Kentucky, Florida, and California, and a Certified Professional Geologist by the American Institute of Professional Geologists.

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COALBED METHANE: WHAT IS IT AND WHO OWNS IT?

Peter Glubiak

I. AN OVERVIEW:

Coalbed methane has been labeled by many names, the oldest of which was used during the Middle Ages is "fire damp." In the 1600's, as the mines got deeper, fire damp became a more prevalent problem resulting in explosions, damage to the mine and loss of life.[1] According to a 19th century account, "a massive explosion of so-called fire damp occurred with a noise of the loudest thunder….sweeps before them with horrible ruin and destruction. The unhappy miners with horses, carriages, working implements..carried along this firey, desolated area. Scores of miners could be killed in such a blast."[2]

The history of coalbed methane, beginning in Roman Times and proceeding 2,000 years to the present time, has been a history of avoidance of deadly, explosive and pervasive gases.

Beginning in the 1980's and largely becoming a viable economic resource in the 1990's, coalbed methane was viewed as more than just a dangerous, gaseous problem and the production of coalbed methane gradually transitioned into a valuable economic resource, similar to all other conventional and unconventional methane gases. There is evidence that coalbed methane was viewed as a potential economic resource, at least in West Virginia, dating back to the 1930's. But, in large part, the beginning of the modern era of coalbed methane as an economic resource began in the Black Warrior Basin in northern Alabama in the late 1980's.

Subsequent to that time, various economic development and tax exemption schemes were hatched in order to facilitate the increase in coalbed methane production.

Coalbed methane refers to methane (CH^4) that is found in coal seams. It is formed during the process of coalification, the transformation of plant material into coal. Coalbed methane is also known as CBM or virgin coal seam methane, or finally, coal seam gas or coal mine methane. It is widely considered a unconventional source of natural gas and, in the U.S., methane is a valuable resource which accounts for almost ten percent (10%) of the total U.S. natural gas production on an annual basis.[3]

The CMOP'S mission is to promote the proper recovery and use of coal mine methane (including CBM). Coal mine methane/coalbed methane is a potent greenhouse gas that contributes substantially to climate change when emitted into the atmosphere. Coal mine methane/coalbed methane can also create an explosive hazard inside mines, but if recovered safely and used as energy, it is a valuable clean burning source.[4]

Methane, whether referred to as coal mine methane (escaping from active coal mining) or coalbed methane which resides in the coal seams itself, is the second most important greenhouse gas, after carbon dioxide. In fact, coalbed methane or methane is at least twenty (20) times more potent than carbon dioxide (CO^2) on a mass basis over a hundred year time period.[5]

Methane is emitted based on three (3) primary sources: (1) degasification systems in underground mines; (2) ventilation which is referring to the dilute methane that is released from the underground mine ventilation shafts (typically less than one percent (1%) methane); and, (3) abandoned coal mine methane (emissions of methane from closed mines' ventilation pipes, boreholes and fissures in the ground).

According to U.S. EPA sources, in 2011, U.S. coal mines emitted about 62 million metric tons of carbon dioxide equivalent. That number has been decreasing as the coal mining industry increases its recovery of the valuable CBM resource and use of the drained gas. At the present time, the U.S. is responsible on an annual basis for 50 million metric tons of carbon dioxide equivalent. See CMOP Circular cited above.[6]

At the present time, technology is readily available to recover methane (including coalbed methane) as a major component of natural gas. The many uses of this gas include coal drying, heat source for mine ventilation air, supplemental fuel for mine boilers, vehicle fuel as compressed or liquefied natural gas (LNG), manufacturing feedstock and fuel source for fuel cells. Through 2011, U.S. coal mines recovered and used over 41 billion cubic feet of coal mine methane/coalbed methane.[7]

According to the U.S. Energy Information Administration (EIA), (the release date of April 10, 2014), the reserves of coalbed methane from U.S. sources total some 13.591 trillion cubic feet.[8] Estimated production from EIA sources as of 2012 is 1.655 trillion cubic feet.[9]

In accordance with the above-referenced EIA release, Kentucky is listed as not having any production. The neighboring states of WV and VA produced 9 billion and 99 billion cubic feet, respectively.[10]

II. CAPTURE AND PRODUCTION OF COALBED METHANE:

Significant reservoirs of so-called methane gas are contained within the various seams of coal contained within the overall geological strata in the coal regions. The essential technology for the release and capture of the coalbed methane has been in existence for over fifty (50) years and has been used throughout the Appalachian coalbed region, including Alabama, West Virginia, Kentucky and Virginia. There are a number of standard drilling methods for production of coalbed methane, and these include conventional drilling, drilling before mining and horizontal drilling. The recent controversy surrounding so-called fracking of coal to obtain coalbed methane is illustrated on the attached chart taken from the Kentucky Geological Survey, produced by James C. Cobb, State Geologist and Director, dated July 2003, attached as Exhibit "A." Once coalbed methane has been freed from the coal seam and flows to essentially an area of lower pressure created by the drilling pipe, it is captured and gathered into smaller lines and in turn compressed, dehydrated and shipped via increasingly larger gas lines until it reaches an interstate gas pipeline where it is sold at the prevailing rate per thousand cubic feet or MMBTU. As mentioned above, there is a significant controversy at the present time, particularly in various states involving the Marcellus shale region, concerning the use of the practice referred to as "fracking." This essentially involves the fracturing of the coal seams in order to release the gas by means of the small fractures created by the hydraulic pressure and explosive device.

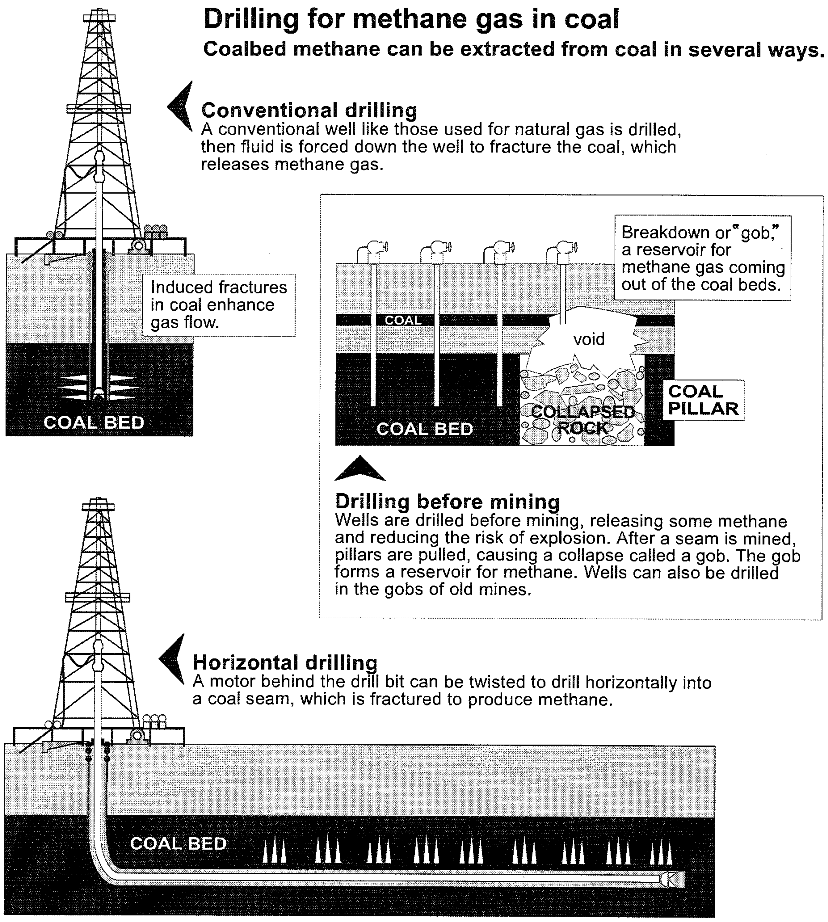
It is not the intent of this paper to deal with the fracking issues, neither pro nor con, and substantial information is available on various websites concerning the pros and cons regarding this methology. It is important to note, however, that some sort of fracture process is a necessary component to the release and capture of coalbed methane as a valuable energy resource.

The environmental constraints and choices made over the next decade will be impacted, in large part, by the gas industries' ability to produce gas safely, efficiently and in an environmentally sound manner. Various national groups have been formed in recent years to take on the challenge of the safe and sustainable production of coalbed methane. These include, most visibly, the Center for Shale Gas Sustainable Development in Pittsburgh, which has taken the lead on a national basis, with a particular emphasis on the Appalachian Basin having a goal of safe sustainable production and environmentally sound best practices.

III. OWNERSHIP OF COALBED METHANE:

The question of ownership of coalbed methane has plagued the industry since its economic inception in the late 1980's, and continues to this date. Particularly in the areas of the country where a so-called split mineral estate may exist, the issue quickly resolves into a question of the coal owner versus the other mineral or surface estate owner. This battle has taken place in at least ten (10) states, and in addition includes a United States Supreme Court Case, *Amoco Prod. Co. v. Sothern Ute Indian Tribe*, 526 U.S. 865 (1999). The basic issue is ownership, in areas where these split estates occur, particularly in the Appalachian coalbed regions of Kentucky, West Virginia and Virginia, where so-called broad form or severance deeds have been the rule, rather than the exception, since the late 19th Century. It was common for coal buyers to roll through the mountains of the Appalachian Coal Basin in the 1880's and 90's and purchase under the

Exhibit A



terms of these broad form/severance deeds the right to mine the coal and usually associated timber on a particular tract of land. This was often purchased for pennies an acre and the expectation of the landowners was that the coal would never be mined, given the deep nature of most of the coal seams.

As is now the stuff of legend, television and movies, this proved later to be a bad guess and resulted in the past 75 plus years of deep coal mining. Coal has fueled our nations' economy since World War II. At the present time, coal, although decreasing, still supplies 40% to 50% of all our fuel for plants producing electricity in the U.S. This number has been decreasing with the corresponding increased use of more clean burning natural gas, including coalbed methane, and a trend appears to be clear in favor of the development of natural gas burning power plants. This has driven the industry, along with various other uses of natural gas, and has resulted in a natural gas bonanza described in many magazine and trade publications.[11]

With the advent of production, use and sale of coalbed methane in the early 1990's, the question arose as to the entitlement of the various parties to a royalty income based on the production and sale of coalbed methane. In many states this tracked the longtime process used in Texas and other western states, and typically resulted in a royalty rate of 1/8 or 12 1/2%. The question was, however, who was entitled to this 12 ½% royalty? The coal owner claimed as a matter of common sense that the coalbed methane was derived from the coal and therefore should belong to the coal owner. Correspondingly, the argument of the surface/mineral estate owners was that when their ancestors or predecessors in interest sold the coal, they did not sell any other resource in the ground, but rather limited their severance to the "coal and associated timber."

Early cases, such as the Alabama case, *NCNB Texas Nat. Bank. N.A. v. West*, 631 So.2d 212, 228-29 (Ala. 1993), and the Pennsylvania case, *U.S. Steel Corp. v. Hoge*, 468 A.2d 1380, 1383 (1983), trended early towards the ownership of the coalbed methane remaining with the coal owner to the extent that the coalbed methane resided in the coal seam. As it was released into the surrounding strata or atmosphere, it was held to belong, at that point, to the mineral owner. For instance, in

Exhibit B
Survey of Law Determining Who Owns Coalbed Methane Gas

State	Case Citation	Summary of Law
U. S. Supreme Court	*Amoco Prod. Co. v. Southern Ute Indian Tribe,* 526 U.S. 865 (1999)	CBM is a gas, not part of the coal, and is therefore not owned by the coal owner.
Alabama	*NCNB Texas Nat. Bank, N.A. v. West,* 631 So. 2d 212, 228-29 (Ala. 1993)	Coal owner has the right to recover the CBM found within the coal seam and the owner of the gas estate has the right to the possession of the CBM that escapes into the surrounding strata.
Illinois	*Continental Resources of Illinois, Inc. v. Illinois Methane, LLC,* 847 N.E.2d 897, 901 (Ill. Ct. App. 5th Dist. 2006)	Oil and gas lessee did not have the right to produce coalbed methane gas from coal seams or voids, even though leases granted lessee the right to produce "all gases"; coalbed methane gas was a by-product of coal that was to be controlled by the coal estate, and oil and gas leases did not include coal rights.
Indiana	*Cimarron Oil Corp. v. Howard Energy Corp.,* 909 N.E.2d 1115, 1124 (Ind. Ct. App. 2009)	The court focused on the intent of the contract to decide whether the coal owner or the oil and gas lessee have the right to CBM, but found that public policy indicates that CBM should be considered part of the coal bed.
Kansas	*Cent. Nat. Res., Inc. v. Davis Operating Co.,* 201 P.3d 680, 687 (Kan. 2009)	Court declined to adopt an "artificial rule" of "first severance/container theory," and focusing on actual agreement.
Kentucky	*Michael F. Geiger, LLC v. United States,* 456 F. Supp. 2d 885 (N.D. Ky. 2006)	Property owners, rather than coal estate owner, has ownership rights to CBM, where property owners were granted "all the oil, gas, and all other minerals and mineral rights of every kind and character except the coal and coal rights."
Montana	*Carbon County v. Union Reserve Coal Co.,* 898 P.2d 680, 688-89 (Mont. 1995)	Gas estate owners have the right to drill for and produce CBM within the coal seam, but the coal owner has a "mutual, simultaneous right to extract and to capture such gas for safety purposes, incident to its actual coal mining operations.
Pennsylvania	*U.S. Steel Corp. v. Hoge,* 468 A.2d 1380, 1383 (1983)	"such gas as is present in coal must necessarily belong to the owner of the coal, so long as it remains within his property and subject to his exclusive dominion and control," but the surface owner "has title to the property surrounding the coal, and owns such of the coalbed gas as migrates into the surrounding property."
Virginia	*Harrison-Wyatt, LLC v. Ratliff,* 593 S.E.2d 234 (Va. 2004)	Surface landowners, who had conveyed all the coal in and under their land, retained the right to CBM produced from the coal seams, as CBM was a gas that existed freely in the coal seam and was a distinct mineral estate.
West Virginia	*Energy Dev. Corp. v. Moss,* 591 S.E.2d 135, 146 (W.Va. 2003)	When considering leases of "all of the oil and gas and all of the constituents of either in and under the land," court held that the lessor did not intend to convey to the lessee the right to drill into the lessor's coal seam for CBM.
Wyoming	*Newman v. RAG Wyoming Land Co.,* 53 P.3d 540, 550 (Wyo. 2002)	CBM remains landowners' property.
	Caballo Coal Co. v. Fidelity Exploration & Production Co., 84 P.3d 311, 317 (Wyo. 2004)	Deeds which conveyed landowners' "undivided interest in and to all other minerals, metallic or nonmetallic, contained in or associated with the deposits of coal conveyed hereby or which may be mined and produced with said coal" conveyed rights to coalbed methane gas (CMG) to coal company, despite language in rest of deeds which merely discussed coal and did not mention CMG or any gas; CMG existed in coal in three basic states, and other language in deed stated that purpose was to convey all rights whatsoever "which relate to said coal, or the mining, extracting, removal or use of the same."

the *NCNB Texas Nat. Bank. N.A.* case, it was held that the coal owner had the right to recover the coalbed methane found within the coal seam, however, the owner of the gas estate had the right to the possession of the coalbed methane that escaped into the surrounding strata. This trend in the early 1990's was abruptly reversed by the U.S. Supreme Court in the *Amoco Prod. Co. v. Southern Ute Indian Tribe*, 526 U.S. 865 (1999), in which Justice Kennedy held clearly that "coalbed methane is a gas, not a part of the coal, and is therefore not owned by the coal owner."

The position taken by the U.S. Supreme Court was largely followed in Virginia with the finding in the Virginia Supreme Court in the *Harrison-Wyatt, LLC v. Ratliff*, 593 S.E.2d 234 (Va. 2004) case. The court held that the surface owners, who had conveyed all the coal in and under their land, retained the right to the coalbed methane produced from the coal seams, as CBM was a gas that existed freely in the coal seam and was a distinct mineral estate. This marked the trend which continues to this day where courts have found that coalbed methane is a gas and as such is not a part of the coal. The *Harrison-Wyatt* court in Virginia found that the weak forces, known as *vander wal forces*, resulted in the adsorption of the gas to the coal seam which was broken as a process of the coal mining or the fracturing of the coal seam, thus releasing the gas into the surrounding strata and atmosphere.

Subsequent cases in Illinois, Indiana, Kansas, Montana and Wyoming held largely that the CBM remained on the landowners' property and/or the gas estate, attached as Exhibit "B." The gas estate owners prevailed in the Montana case of *Carbon County v. Union Reserve Coal Co*., 898 P.2d 680, 688-89 (Mont.1995) where it was found by the Montana Supreme Court, that "Gas estate owners have the right to drill for and produce CBM within the coal seam, but the coal owner has a "mutual, simultaneous right to extract and to capture such gas for safety purposes, incident to its actual coal mining operations". Essentially, one could argue that the trend is exemplified by the statement in the Carbon County case. The gas estate owners own the coal bed methane subject to the right of the coal owners to vent the gas for safety purposes associated with mining.

KENTUCKY ISSUES

In 2006, the Kentucky case, *Michael F. Geiger, LLC v. United States*, 456 F. Supp. 2d 885 (N.D. Ky. 2006), held that the property owners rather than the coal estate owner has ownership of the rights to CBM, where property owners were granted "all the oil, gas, and all other minerals and mineral rights of every kind and character except the coal and coal rights." This appears to have set a clear standard consistent with the developing common law trend around the country for Kentucky, but must be balanced against the holding of the Kentucky Court of Appeals in the June 2011 case, *Beverly Cardwell Bowls and Donna Faye Cardwell v. Hopkins County Coal, LLC*, 347 S.W.3d 59 (Ky. Ct. App. 3rd Dist. 2009).

"Under the definition of CBM given by *Amoco*, and adopted by this Court, CBM is actually located *within* the strata of the coal beds. Therefore, it is available to be captured only by the owners of the coal beds. At the time that the CBM is released from the coal beds, it is then available to be captured by the owner of whatever property to which it migrates, in this case perhaps that of the Appellants….Therefore, we hold that the trial court was correct in finding that the owner of the coal beds has the right to capture CBM while still located therein and Appellants have the right to capture once the mining process is complete. Although the circumstances of the case *sub judice* grant the coal bed owners the right to capture CMB while it is still located in the veins and beds of coal, our holding is not dispositive of the issue of CBM ownership as a whole. We recognize that the same issue under changed circumstances may result in a dissimilar outcome." See *Beverly Cardwell Bowls and Donna Faye Cardwell v. Hopkins County Coal, LLC*, 347 S.W.3d 59 (Ky. Ct. App. 3rd Dist. 2009).

VIRGINIA ISSUES

Four class action suits relating to the ownership of coalbed methane ("CBM") are currently pending in U.S. District Court for the Western District of Virginia against gas producers operating in southwest Virginia. They are *Adair v. EQT*, 1:10-cv-00037, filed on June 15, 2010; *Hale v. CNX*, et al., 1:10-cv-00059, filed on September 23, 2010; *Addison v. CNX*, et al.,1:10-cv-00065, filed November 9, 2010; and *Kiser v. EQT*, 1:11-cv-00031, filed on April 20, 2011.

The cases challenge the "conflicting claimant" status which the gas operators (CNX and EQT) assigned to gas estate owners and coal estate owners, and which has prevented the release of CBM royalties to gas estate owners for more than 20 years. Importantly, the cases also seek to obtain a court-supervised accounting by the gas operators of their royalty calculations and payments, and seek to recover damages from the gas operators for any underpayments and delayed payments of royalties.

Currently, more than $28,000,000.00 in CBM royalties sit in the Virginia Gas and Oil Board's escrow account, and an unknown amount sits in the gas operators' internal account, pending resolution of the CBM ownership issue. Plaintiffs contend that the Supreme Court of Virginia answered the CBM ownership question in 2004 in *Harrison-Wyatt, LLC v. Ratliff, et al*., holding that a conveyance of coal does not include CBM. Plaintiffs further contend that the General Assembly mandated the same outcome with its 2010 codification of the *Harrison-Wyatt* ruling, See VA. Code Ann. § 45.1361.21:1. The circuit courts of the 29th Judicial Circuit in S.W. Virginia, have unanimously agreed through various individual suits. For thousands of gas owners, however, it is not practical to file individual litigation, and they are dependent on the class actions being heard by the federal court.

SUMMARY

As was stated by the U.S. Energy and Information Administration, domestic natural gas has proven reserves of over 13.591 trillion cubic feet.[8]

With the onset of commercial development of coalbed methane over the past 30 years, numerous benefits have accrued including reducing greenhouse gas emissions, conserving local sources of valuable clean burning energy, enhancing mine safety, and providing revenue to both mining companies, gas operators and local state and federal governments. According to the EPA Coal Methane Outreach Program, coal methane/coalbed methane constitutes approximately 10% of the U.S. natural gas annual production. See Coal Methane Outreach Program, Circular 4-19-2013.[3,4,5,6,7]

At the present time, technology is readily available to recover methane (including coalbed methane) as a major component of natural gas. Uses include coal drying heat source from mine ventilation supplemental fuel for mine blowers, vehicle fuel as a compressor liquid to supply natural gas, manufacturing feed stock and fuel source for fuel cells. In 2011, U.S. coal mines recovery used over 41 billion cubic feet of coal mine methane/coalbed methane.

Coalbed methane has rapidly developed as a natural gas resource available to serve U.S. energy needs in the foreseeable future. Trillions of cubic feet lie under the continental U.S. and are available to serve as an energy reservoir which, according to the U.S. Energy Information Administration, could go a long way in establishing complete energy independence in the U.S. Potential for development of the resources is almost unlimited and credible sources predict that coalbed methane and other natural gas resources could supply America's energy needs for the next 100 years.

Issues of development, ownership and production continue to plague the industry, however. As has been illustrated in numerous movies and popular magazines(see Time Magazine Environmental Special issue, April 11, 2011).[11] Fracking and safe drilling, questions of pollution of ground water sources, fatalities through truck traffic constitute severe threats to the viability of the industry. It might be hoped that various national organizations including the Center for Sustainable Shale Gas Development, as cited above, may lead the way towards a sufficient safe and sustainable use of coalbed methane and other natural gas in the near and long term future.

Ownership of the resource continues to be an additional problem. As has been shown throughout the review of U.S. state and federal common law, the answer to the question of who owns coalbed methane, while seemingly trending towards an established common law, is still an open issue in many states. Kentucky, at the present time, although the cases of *Geiger* and *Hopkins County Coal*, provides some answers, is far from an established case law or statutory answers to the ownership issue.

Pending federal cases in Virginia, as well as other cases around the country, will continue to refine the answers to the ownership issue which must be answered in order to ensure the continued viability of the industry.

Ultimately, the choice of energy independence, balanced against potential pollution and disturbance of local lifestyles, is a question which must be answered in the near future in order to provide for the continued productivity of the industry particularly in the Appalachian basin, including the Marcellus Shale region.

References

1 Barbara Freese, 2003, Coal, A Human History, page 49

2 Barbara Freese, 2003, Coal, A Human History, page 50

3 For a more detailed analysis of coalbed methane and coal mine methane, see Coal Methane Outreach Program (CMOP), Frequent Questions @ www.epa.gov/coalbed/faq.html, Last Updated 04/19/2013 , a sub group of the Environmental Protection Agency, which is charged with both regulation and development of coalbed methane resources.

4 See Coal Methane Outreach Program (CMOP), Basic Information @ www.epa.gov/coalbed/basic.html, Last

5 Updated 04/19/2013 and Frequent Questions @ www.epa.gov/coalbed/faq.html, Last Updated 04/19/2013

6 See Coal Methane Outreach Program (CMOP), Frequent Questions @ www.epa.gov/coalbed/faq.html, Last

7 Updated 04/19/2013

8 Updated 04/19/2013 and Frequent Questions @ www.epa.gov/coalbed/faq.html, Last Updated 04/19/2013

9 Updated 04/19/2013 and Frequent Questions @ www.epa.gov/coalbed/faq.html, Last Updated 04/19/2013

10 See U.S. Energy Information Administration (EIA) Report of U.S. Coalbed Methane Proved Reserves released April 10, 2014 @ www.eia.gov/dnav/ng/NG_ENR_COALBED_DCU_NUS_A.htm

11 See U.S. Energy Information Administration (EIA) Report of U.S. Coalbed Methane Production released April 10, 2014 @ www.eia.gov/dnav/ng/ng_prod_coalbed_s1_a.htm

12 See EIA Report of U.S. Coalbed Methane Production released April 10, 2014 as cited above @ 9

13 See Time Magazine, April 11, 2014, by Bryan Walsh, The Gas Dilemma. Pages 40-48

Sustainability and Biofuels

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Stites & Harbison, PLLC

As the saying goes, "Be careful what you wish for; you might get it." This describes the current state of biofuels. The appealing concept of biofuels is supported by well-meaning environmental advocates, business interests, and governmental policy, but if we don't make wise choices, then the reality may not be all that we wished for. This article examines factors that relate to the sustainability of the use of biofuels to partly replace some petroleum energy sources for transportation. Key inquiries concern first the energy and emissions balance of the use of biofuels when compared to petroleum and, second, the broader environmental impact of the biofuel production. One form of biofuel in particular, cellulosic ethanol, is a strong contender for the role as a sustainable fuel. Other forms under serious consideration are corn-based ethanol and biodiesel. This article focuses on ethanol as a sustainable transportation fuel.

Why focus on transportation?

The transportation sector is a significant consumer of energy and producer of greenhouse gases (GHG). In the United States, the transportation sector accounted for approximately 39% of the total energy consumed in 2012. Petroleum products provided 97% of that energy. Table 1. (EIA, 2014). In 2012 the transportation sector produced approximately 1,743 teragrams (Tg) of carbon dioxide equivalents (Tg CO2 eq), which was about 34% of the total (excluding emissions from electricity generation). Passenger cars, light trucks, sports utility vehicles, and minivans contributed the majority of those emissions (EPA, 2014). Worldwide, transportation produces roughly 14% of total direct GHG emissions and tops emissions from industry and buildings. It follows closely behind agriculture, forestry, and other land use (AFOLU) and emissions from generation of electricity. Figure 1. (IPCC, 2014a). The Intergovernmental Panel on Climate Change (IPCC) projects the transportation-related GHG emissions to double from year 2010 to 2050 largely due to economic growth and related passenger and freight movement (IPCC, 2014a). Transportation considerations should be a component of any strategy to reduce energy use and GHG emissions. Technological advances in alternative fuels are among the several transportation-related strategies (IPCC, 2014a). Biofuels may play a major and sustainable role in those strategies (MP, 2009; WI, 2006).

Legislative Support for Ethanol-Based Fuels

The federal Energy Independence and Security Act of 2007 (P.L. 110-140, H.R. 6, now codified at 42 U.S.C. § 7545(o), the "EISA") followed similar legislation in 2005 and encouraged production of renewable fuels, including the use of gasoline blended with ethanol. EISA defined "renewable fuel" as "fuel that is produced from renewable biomass and that is used to replace or reduce the quantity of fossil fuel present in a transportation fuel." It distinguished "conventional biofuel … ethanol derived from corn starch" from "advanced biofuels" that included "cellulosic biofuel … that is derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass."

Table 1. Energy Consumption by Sector United States 2012*

Sector	Sources	Quadrillion Btu/year
Transportation (total)		26.72
	Petroleum	25.93
	Other	0.79
Industrial (total)		23.63
	Petroleum	8.06
	Other	15.57
Residential (total)		10.42
	Petroleum	1.02
	Other	9.4
Commercial (total)		8.29
	Petroleum	0.63
	Other	7.66

Source: (USEIA 2014)
* The reported values do not include electricity-related losses from transmission and distribution.

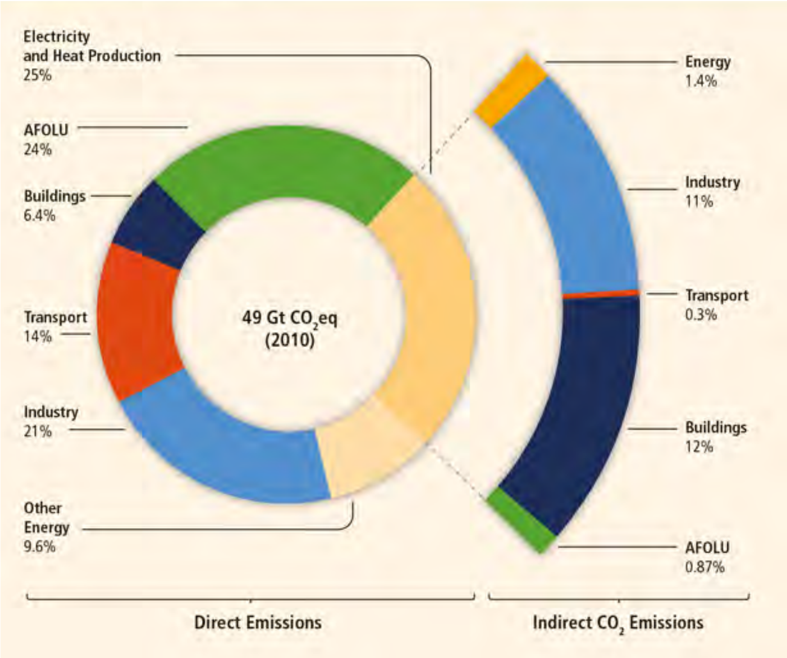

Figure 1. Greenhouse Gas Emissions by Economic Sectors

The EISA encouraged the use of renewable fuels and set the objectives to increase use of those fuels from 4.0 billion gallons in 2006, to 12.95 billion gallons in 2010, and to 36 billion gallons in 2022. Even though there were no commercial-scale production facilities of cellulosic ethanol in 2007 when the EISA was passed, Congress sought an increase in cellulosic biofuel from 0.1 billion gallons in 2010 to 16 billion gallons in 2022. Congress directed the United States Environmental Protection Agency (EPA) to establish regulations to ensure that gasoline sold in the United States contained these increasing proportions of renewable fuels.

EPA adopted a rule in 2012 that projected that year's production of cellulosic biofuel to be 8.65 million gallons (EPA, 2012). While EPA's projection was below the Congressional target, the amount was still unrealistically high. The American Petroleum Institute challenged EPA's rule adopted by the United States Environmental Protection Agency (EPA) related to the renewable fuels standard imposed by the EISA in *American Petroleum Institute v. EPA*, 706 F.3d 474 (D.C. Cir. 2013). The court held that the 2012 rule set a standard for use of cellulosic biofuels that was too high and that required petroleum refineries (suppliers of gasoline fuels) to buy and use cellulosic ethanol products that might not be produced at those quantities. Therefore, the court invalidated that part of the rule because EPA had exceeded its statutory authority. In November 2013 EPA proposed a revised rule regarding these renewable fuels (EPA, 2013). In the proposed rule EPA evaluated the commercial production of cellulosic ethanol from several industrial sources and projected a revised availability of cellulosic ethanol that is still below the ambitious levels set by Congress in the EISA.

The EISA and similar legislation at the state and regional levels encourage the use of renewable fuels in general, and ethanol-based fuels in particular. The question remains whether this is an appropriate strategy when considering the overall environmental impact and the long-term sustainability of that strategy.

Greenhouse Gas Conundrum

It is important to remind ourselves of the fundamental fact that the energy and carbon dioxide, whether in biofuels or in fossil fuels, originates with the photosynthetic activities of plants or plant-like microorganisms. With an input of light energy, living cells convert inorganic raw materials (carbon dioxide and water) into simple carbohydrates (some of which can be combined with other molecules and elements to produce various other biochemicals) and so convert the light energy into chemical energy (IPPC, 2001). Combustion merely reverses the process and releases energy in the form of heat and light, and releases matter in forms that include carbon dioxide and water.

Plants accumulate these carbon-based chemicals in their roots, stems, and leaves, so the associated forests, grasslands, and agricultural lands represent important carbon storage areas (sinks). In fossil fuels the fixation of carbon dioxide and energy took place millions of years ago, while with biofuels the process may occur within a single growing season. Our planet long-ago accounted for the uptake and long-term storage of the carbon-based molecules in fossil fuels. But our rapid extraction and combustion of fossil fuels return to the planet the carbon dioxide and other GHG in only a few centuries the amounts of carbon compounds that have been buried many thousands of centuries. Nonetheless, carbon dioxide from burning biofuels is no different from that released by burning fossil fuels. If biofuels are to be a sustainable alternative to fossil-fuel-based petroleum, then their use must produce less GHG per unit of energy than the alternative.

A final aspect of GHG considerations is how fuel production affects land. Drilling for petroleum may affect only limited amounts of land surface area, but production of crops for biofuels may alter vast areas of land and displace native plant communites. When existing vegetation is cleared for mineral extraction or for production of biofuel-related crops, the carbon dioxide stored in the roots and stems of the vegetation may be released back to the atmosphere. Therefore, a particularly difficult component of evaluating greenhouse gas emissions associated with a particular fuel is the contribution of changes in land use that may affect GHG emissions as land is converted to different types of crop production or as land management strategies change (EPA, 2009; Wang, 2007; Searchinger 2008). Recall that the IPCC found agriculture and land use change to be the second-largest source of GHG emissions. Figure 1. While the details are not certain at this time, there is concern that increased production of biofuels could also increase GHG emissions as a result of these land use changes (LUC) (MP, 2009; Searching 2008; IEA, 2011).

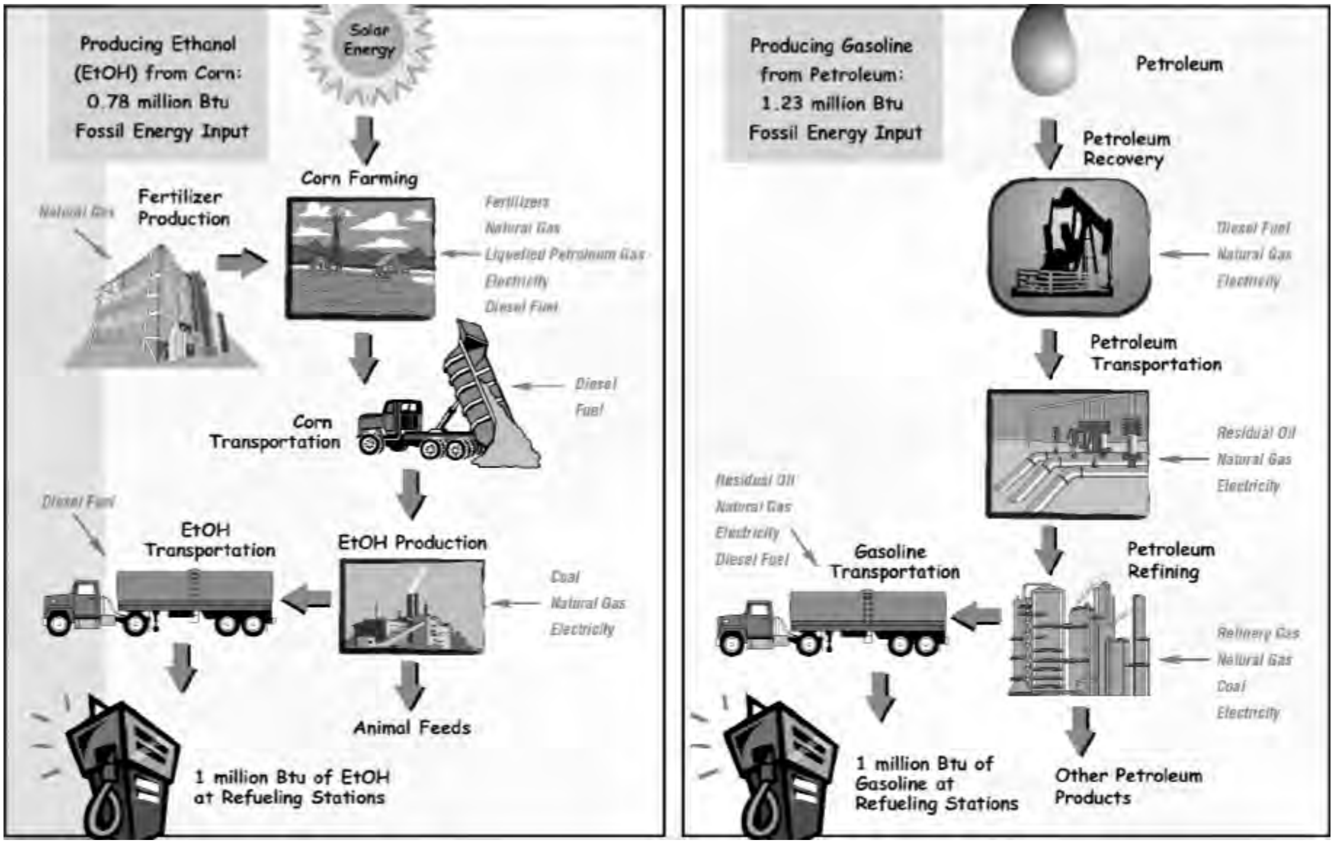

Figure 2. Lifecyle Considerations for Fuel Production

Source: Department of Energy, Energy Efficiency and Renewable Energy, Ethanol: The Complete Energy Lifecyle Picture, and Argonne National Laboratory's Technical Services Division.

Lifecycle Modeling

A concept called lifecycle modeling is developing to assist in this analysis for GHG (EPA, 2009). The U.S. Congress required consideration of these lifecycle factors when it passed the EISA, which mandates certain lifecycle greenhouse gas emissions for renewable fuels. EPA described this evaluation and stated, in part:

> The term "lifecycle greenhouse gas emissions" means the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes), as determined by the Administrator, related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential (EPA, 2009).

A lifecycle analysis (LCA) of GHG emissions for biofuels includes the emissions from combustion but also includes emissions from LUC involved with production; from combustion of fuel used on the farm during soil preparation, tilling, planting, and harvesting; from production of fertilizers and pesticides; and from energy for pumping water for irrigation, drying grain, transport, and processing/distilling the final fuel. Figure 2. One common method of LCA is a model called GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation), which was developed by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy. Applying the LCA to ethanol production suggests that corn-based ethanol may provide only modest benefits, but cellulosic ethanol on the other hand may offer many times the reduction of GHG emissions when compared to petroleum-based fuels. Table 2.

The Energy Balance and Lifecycle Analysis of Biofuels

As in a GHG lifecycle analysis, it is also appropriate to determine the net energy gain or loss resulting from biofuel production and use, considering all aspects of the energy inputs and losses. The two evaluations – energy balance and GHG lifecycle analysis – should be done side-by-side. The advantage of one biofuel compared to another, or even the fundamental question of whether use of biofuels as alternatives to petroleum is actually beneficial depends, in part, on the results of these inquiries.

Hill, *et al*. (2006) reviewed the net energy balance and environmental impact of production of two common biofuels: ethanol from corn and biodiesel from soybeans. Even when

Table 2. Comparison of Lifecyle GHG Emissions based on the California GREET Model.

Fuel and Production Type	Lifecyle Emissions Grams CO2 eq /MJ	% GHG Reduction Compared to Gasoline with 10% Ethanol
Corn-Based Ethanol Midwest, 40% of power from coal	74.3	22.5
Corn-Based Ethanol U.S. Average	68.6	28.5
Cellulosic Ethanol From Farmed Trees	1.6	98.3
Cellulosic Ethanol from Forest Residue	21.4	77.7
California Gasoline (10% Ethanol)	95.9	0

Source: Center for Climate and Energy Solutions.

considering a broad variety of energy inputs (from the energy used to produce the hybrid seed to the energy used to process the fuel) they found that both ethanol and biodiesel have a positive net energy balance, that is, the final biofuel provided more energy than was required to make it. Hill attributed this positive outcome to be caused, in part, due to improved crop yields and fuel-processing efficiencies. They found that soybean-based biodiesel produced 93% more energy than was used in production. In contrast, while its energy balance was still positive, corn-based ethanol returned only about 25% more energy than was used in production. Most of that "profit" came from the use of the leftover materials from fermentation and distillation (the distillers' dry grain and solubles or DDGS) and animal feed. If the DDGS cannot be used, then corn-based ethanol would lose its energy benefit.

Similar to the results reported by Hill, a review by Hammerschlag (2006) of six studies of the energy balance of corn-based ethanol showed positive energy balances in five instances (from 29% to 65%) and one instance where the energy balance was negative: the ethanol returned only 84% of the energy inputs. In contrast to ethanol from corn, cellulosic ethanol may yield over 5.5 times the energy needed to produce it. (NAS, 2008). Hammerschlag (2006) reviewed four studies of the energy balance for cellulosic ethanol and found energy balances from a negative value of 69% (for switchgrass) up to a positive 661% or 6.6 times the energy input.

The source of energy used for processing the fuel may dramatically affect the GHG emissions. For example EPA (2009) found that when corn-based ethanol was processed with energy from coal, the fuel resulted in a 34% increase over the petroleum baseline. In contrast, EPA reported that biofuels derived from the perennial switchgrass and from corn stover yielded greenhouse gas reductions of 124% and 116%, respectively, when compared to petroleum over a 30-year period.

A review by the Center for Climate and Energy Solutions concluded that lifecycle emissions of a corn ethanol plant powered by natural gas reduced life-cycle greenhouse gas emissions by about twenty percent, compared to gasoline, but when coal was used instead of natural gas, the life-cycle greenhouse gas emissions for ethanol were actually three percent *higher* than gasoline (CCES). In stark contrast, cellulosic ethanol produced from forest residue reduced GHG emissions almost 78% according to California's GREET model (CCES). See Table 2.

These studies did not consider the impact of land use changes (LUC) that are recognized as having the potential for significant negative impact on lifecycle emissions and to have additional adverse impacts on environmental quality and biodiversity (IEA, 2010). The International Energy Agency acknowledges that although there is great uncertainty in the modeling, some studies suggest that GHG emissions benefits from the use of biofuels could be more than offset by emissions from LUC (IEA, 2011). Interested groups continue to discuss the potential impacts of LUC, but detailed quantitative analyses are neither uniform in approach nor widely accepted (NRC, 2010; IEA, 2011).

The Promise of Cellulosic Biofuels

Corn-based ethanol depends on the enzymatic breakdown of starch in the corn kernels to form sugars that are then acted on by yeasts in the process of fermentation. Cellulosic ethanol depends on the breakdown of two other abundant carbohydrates found in plant matter: cellulose and hemi-cellulose (Hammerschlag 2006). Advances in the production of cellulosic biofuels, their higher energy balance, and more favorable emissions ratios may make these fuels more attractive for truly sustainable energy production.

Despite the energy gain and emissions reductions discussed above, cellulosic ethanol production has lagged behind that of corn-based ethanol. In fact, cellulosic ethanol has only recently become economically competitive with corn-based ethanol. Tong (2013) describes the general production process of cellulosic production of ethanol. Figure 3. The difference is the key step of getting from complex carbohydrate to the sugars that can be fermented. It has been easy to go from starch to sugars in production of corn-based ethanol but much more difficult to breakdown cellulosic biomass (NREL, 2014). The National Renewable Energy Laboratory has partnered with two companies, Novozymes and Genecor (now part of Dupont) to engineer new cellulose enzymes that are able to more efficiently break down cellulose. The partnership has developed a cocktail of enzymes that break down the complex cellulose to sugars much more effectively and more economically than before. Several other commercial projects are also pursuing production of cellulosic ethanol (EPA, 2013; MP, 2009).

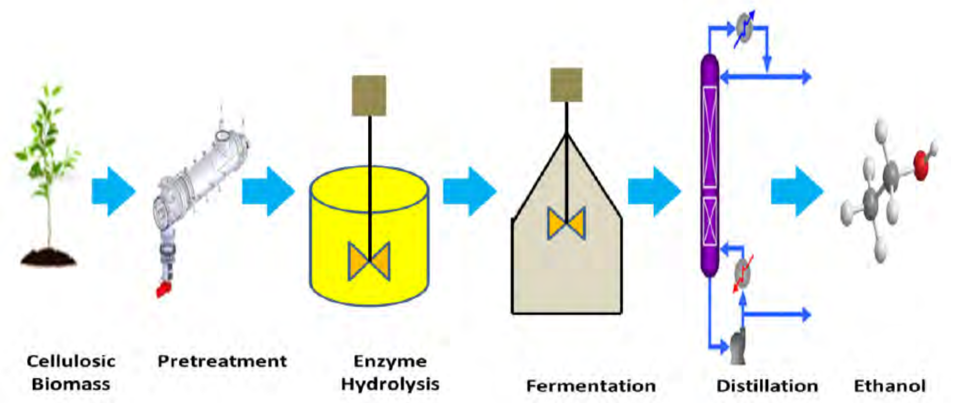

Figure 3. Production of Cellulosic Ethanol. Source: Tong (2013).

Other Environmental Impacts

In addition to GHG emissions from changes in land use, the production and processing of biofuels also affects soil and water quality. On the production side, working the soil for planting and cultivation may result in loss of topsoil by erosion and so increase sediment pollution of surface streams. In addition to soil runoff, fertilizers and pesticides may also be carried by stormwater into surface waters and cause nutrient pollution (EPA 2009; NRC, 2009; Hill, 2005). Because corn cultivation may require the addition of more fertilizers than other potential biofuel sources, its use as a feedstock for ethanol production may have additional adverse environmental impacts when compared to sources (Tilman, 2006). These impacts may be no different than the impacts of ordinary agricultural production of food crops. However, the problems may be exacerbated if crops grown for biofuel production are planted in marginal areas that are steep or of poor soil quality so that pollutant runoff is increased.

Production of cellulosic ethanol may have additional impacts on soil losses and pollution runoff. If crop residues such as corn stover are used for cellulosic ethanol production, then the organic matter is removed from the field instead of being incorporated back into the soil. That removal may not only decrease soil quality but may increase the likelihood of erosion. Use of forest residue or fast-growing trees for production may dramatically increase nutrient removal from the soil, and heavy machinery use for the harvest may compact soils and/or increase the potential for erosion (IEA, 2010).

As discussed above, the majority of the net energy gain from corn-based ethanol depends on the use of DDGS for animal feed. Use of this product may lead to manure DDG fed to animals which is generally high in phosphorus and results in the animals producing manure that is high in phosphorus (Simpson 2008). When this manure is spread on agricultural lands, the high phosphorus may lead to additional nutrient runoff.

In addition to water quality issues, the recent droughts in the American southeast (which has rarely experienced such troubles), in Texas, and in California have focused attention on the water quantity and the allocation of water for agriculture versus a variety of other uses. Even if irrigation of growing crops is not considered, the distillation and other processes required to produce the finished biofuels require relatively large amounts of water. Reports suggest that from four to six gallons of water may be required to produce one gallon of ethanol (MP 2009; NAS, 2008).

Finally, biofuel production by the same monoculture farming practices employed for other large-scale agriculture may be subject to diseases or pests just as are our food crops. On the other hand, certain biofuels may lend themselves well to production from mixes of species planted together: polyculture (MP, 2009). Tillman (2006) describes the use of diverse native grasses grown to produce biofuels. These polycultures require less fertilizer and cultivation and have shown to produce net energy gains from 5.4 to 8 times the energy used (Tilman, 2006; MP, 2009).

Conclusion

Biofuels have a logical appeal, and federal law and policy promotes their use. National and international organizations tout the widespread development of biofuels. Many of these proponents, however, downplay the adverse impacts of biofuel production. Decades ago our nation accepted the widespread disruption of mountainous terrain that was sacrificed in the name of coal production, but today the chant of "save our mountains" is heard throughout much of the country. Some critics of coal mining might say that we did not pay attention to the full scope of environmental impacts of surface coal mining in those early days of federal regulation. Could biofuels represent a similar dilemma: energy production versus environmental impact? We are at a relatively early stage of widespread development of biofuels for use in the significant transportation sector. We would be well-advised to pay attention to the environmental consequences of our choices with regard to biofuels. In a classic cost-benefit analysis, we need to ask whether the environmental impact of the use of biofuels is worth the gains in energy production and in GHG emissions that, in some cases, are modest at best.

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From Flue Gas to Fuels: Beneficial Re-use of Carbon Dioxide Emissions

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In 2008, the Kentucky State Department for Environmental Development challenged the University of Kentucky with investigating the technological and economic feasibility of biological carbon mitigation. Researchers from the Center for Applied Energy Research (CAER) and the department of Biosystems and Agricultural Engineering (BAE) teamed up to assess whether algal biotechnology was up to the task. The overall process (Figure 1) is simple: harness microalgae's ability to perform efficient photosynthesis to reduce carbon emissions while using the biomass produced to provide a revenue stream back to the utility.

The main inputs to the process are: carbon dioxide (from the coal flue gas) and nutrients such as Nitrogen, Phosphorous, Potassium, and Iron, all of which can be sourced from traditional fertilizer sources or from wastewater. The process is driven by harnessing photons from the sun to provide energy for the microalgae to perform photosynthesis and turn carbon dioxide into biomass.

The areas investigated over the course of the project include: power plant integration, algal strain (or species) selection, nutrient media development, photobioreactor design, dewatering of the harvested biomass, oil extraction, upgrading to drop-in fuels, and other utilization strategies. All of these activities have fed into a techno-economic model, which can predict the cost per ton of carbon dioxide mitigated, or consumed, by an algae based system. This type of analysis can inform the design of a process and business strategy to take carbon emissions and use them to drive a beneficial reuse strategy. The overall goal is to mitigate carbon dioxide emissions in a revenue neutral, or positive, way; using the algae biomass grown off of the CO_2 to generate a revenue stream to offset the costs of CO_2 mitigation [1].

Precedent in the industry

This concept for mitigating carbon emissions is grounded in the history of the CAER experience with post-combustion byproduct beneficiation. Fly ash, small particles generated during the combustion of coal, can be collected and re-used as a low carbon alternative to traditional cements [2]. Similarly, bottom ash is used as an aggregate or structural fill substitution, simultaneously eliminating waste and the need to turn to quarries for these products [3]. Sulfur Dioxide mitigation technology has resulted in the production of synthetic gypsum that can be used to produce traditional products such as wallboard, or innovative soil amendments [4]. The goal is to replicate this strategy with carbon dioxide, turning a byproduct of fossil fuel combustion into the input of another process, the cultivation of microalgae. The algae consume the CO_2 as it grows, and the harvested biomass is then turned into a product which can generate a revenue stream to offset the cost of the process.

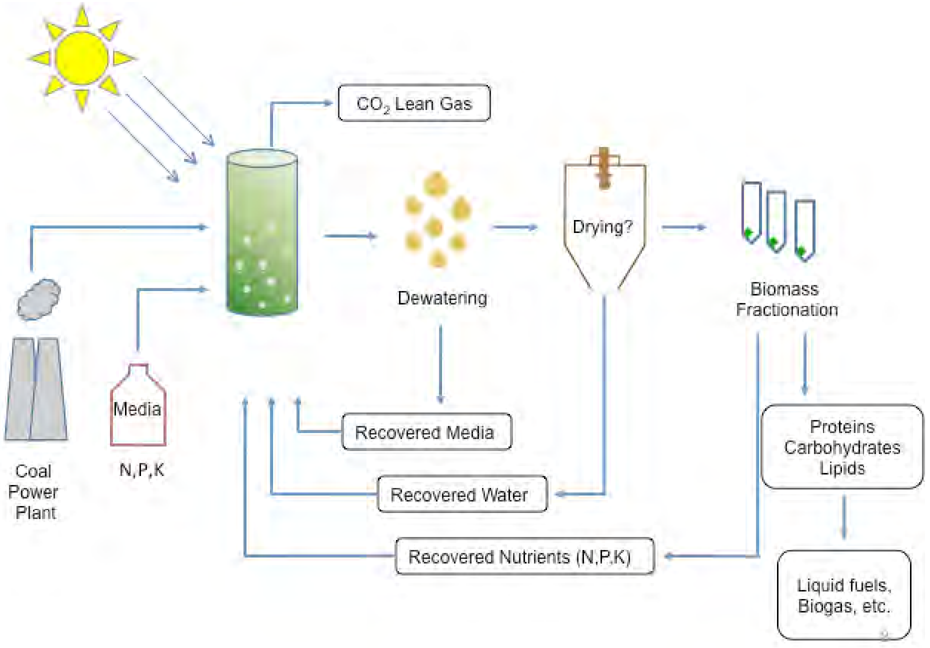

Figure 1. A schematic showing the overall process from inputs to outputs.

Algae Introduction

Algae is an extremely bio diverse group of organisms represented by conservative estimates of over 72,500 species [5]. This diversity presents an opportunity for an organism to be identified that is suitable for growing across a wide variety of conditions; from acidic to caustic, high light levels to low, and bridging different climatic conditions. Additionally, algae is the fastest growing photosynthetic organism on the planet [6] and can produce a wide variety of chemical compounds that can be used from the energy industry and fertilizers to human nutritional supplements and cosmetics [7].

One of the main attractions of algal cultivation is its ability to be grown in a variety of water sources including: fresh water, seawater, brackish water, and even municipal and industrial wastewater sources [8]. Additionally, productive farmland is not needed for the production of microalgae. This makes land, traditionally unsuited for agriculture, such as semi-arid locations, reclaimed mine sites, or old industrial locations able to be transformed into an algae production facility.

All of these reasons have led to the promise of using algae as a non-food feedstock to produce next generation biofuels, thereby eliminating the ‘food vs fuel’ debate that has been ongoing. While algae cultivation is a step forward, the immense scale required for either meaningful biofuels production or carbon mitigation may mean that we enter a ‘water and fertilizer for fuel vs water and fertilizer for food debate.’ Algae’s ability to use non-fresh water sources and reclaim nutrients from wastewater is encouraging in this regard.

Photobioreactor Design

The general foundation of the cultivation of an autotrophic organism, such as algae, is presenting the organism with a controlled growth environment by exposing it to appropriate levels of sunlight, carbon dioxide, and nutrients. The mass cultivation of algae can occur in either an open culture system (pond) or a closed loop system called a photobioreactor (PBR) [9-11]. Open ponds have been traditionally used to grow algae because they are relatively cheap to build and easy to operate. However, they are limited due to contamination issues and have lower productivity than photobioreactors. The main downside in using PBRs is the capital and operating costs associated with a more complex cultivation strategy. The team at UK chose photobioreactors over ponds as they had the most promise of improvement, both in lowering capital costs as well as improving CO_2 uptake efficiency, and seemed more appropriate for the Kentucky climate.

Figure 2. Photobioreactor design progression.

The most important factor in designing photobioreactors is to allow the algal culture to get sunlight to drive photosynthesis, thereby consuming carbon dioxide. This means that a clear material must be used in part of the reactor so that the organism can be exposed to sunlight. The photobioreactor technology developed at the UK CAER is built by integrating thin, semi-rigid tubes made of polyethylene terephthalate (PET), a material that is commonly used to make soft drink bottles. These inexpensive tubes are adapted to common plumbing parts so that they can be integrated into different configurations and enable the creation of different types of photobioreactors. A vertical orientation was chosen because it had the most promise to increase the productivity of algae culture and thereby minimize the land area needed [7]. A vertical system has a higher surface to volume ratio and enables efficient distribution of light to the algae cells in the reactor. Figure 2 highlights some of the design progression that has been undertaken at the UK CAER.

Harvesting and Dewatering

There are many reasons to harvest biomass from a production facility, whether an open raceway pond producing low cost feedstock for biofuels production or a state of the art photobioreactor producing astaxanthine for human consumption. The two most important reasons go hand in hand: reclaiming

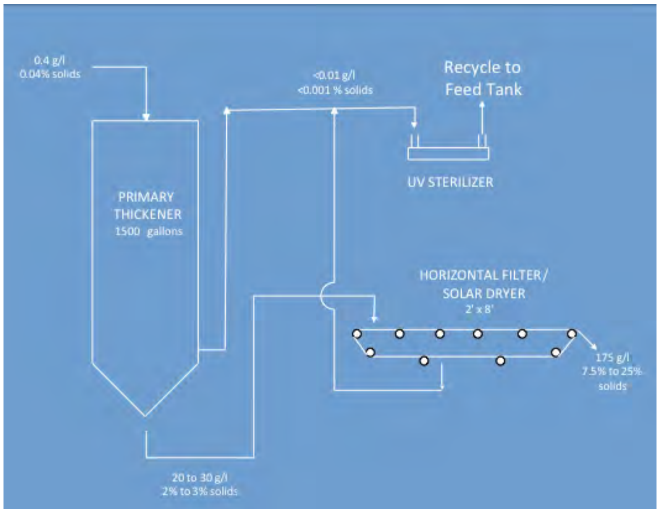

Figure 3. Harvesting and dewatering schematic.

product and diluting the culture to enable future growth. As the algae grow, there are more cells containing chlorophyll that absorbs light. It is important to harvest the algae and dilute it with water and nutrients to enable a good distribution of light penetration and maintain an environment that enables the algae culture to remain healthy and productive.

The removal of the algal biomass from the growth media slurry in which it is suspended has long been viewed as the most complex technical problem facing large-scale algae production [12]. Micro-algae typically range between 2-30 microns and are composed of approximately 80% water inside their cells. This essentially means that the challenge is to remove microscopic water balloons that are diluted in water. Traditional means of separation such as filtration, centrifugation, flotation, and sedimentation are well documented within the scientific literature and all have their trade offs. The two-staged dewatering process developed at the UK CAER leverages experience in coal preparation and post combustion byproduct utilization where large throughputs of product are required to process low value goods. Additionally these technologies are in wide use today in multiple industries, including the wastewater industry, and can readily be adapted for use in processing harvested algal biomass [13]. Figure 3 shows a flow sheet of the watery recovery process.

The majority (>95%) of the water is reclaimed from the algal culture during the primary dewatering stage. A low concentration (3-5 ppm) of polymeric flocculent is added to the harvested algae solution in order to group the algae cells together so they will settle faster. The clarified water, containing any unused nutrients, is passed through a UV sterilizer and back to the system to grow algae. The thickened biomass, now the consistency of a runny ketchup or pesto, is then transferred to a horizontal belt filter to remove the remaining water. At the end of the belt, all of the water outside of the cell wall has been removed from the product, leaving a moist algal cake behind for drying or processing.

It is important to remember that the main goal of this project is to mitigate the carbon dioxide emissions of industrial sources around Kentucky in a cost effective manner. This low energy/low cost dewatering process is extremely flexible and can deliver harvested biomass to a downstream utilization method at a variety of consistencies. Figure 4 illustrates a flow chart showing the full capabilities of the dewatering strategy.

Now that a cost effective method for harvesting and dewatering the biomass has been developed, it is important to investigate the potential markets that the biomass could be used for.

Potential Uses

The aspect of this process that captures the imagination of so many people is the potential uses for the biomass produced. Algae biomass is made up of mostly carbohydrates, proteins, and lipids, but is also known to produce high value chemicals and food additives such as docahexaenoic acid (DHA), beta-carotene, and astaxanthine [14, 15]. The make-up of the algal biomass is influenced by a variety of factors including: species, strain, and growth conditions. This presents the opportunity for biomass to be tuned to the utilization process or visa versa. For example, if the desired product is protein for aquaculture feed, a protein rich species of algae (such as spirulina platensis) is important. Growth conditions should also be controlled, enabling the culture to produce more protein than carbohydrates or lipids.

Algal biotechnology could be an important factor in improving the sustainable production of bio-products due to its high efficiency of water use and fast growing character. Figure 5 shows the potential markets available to a carbon utilization strategy.

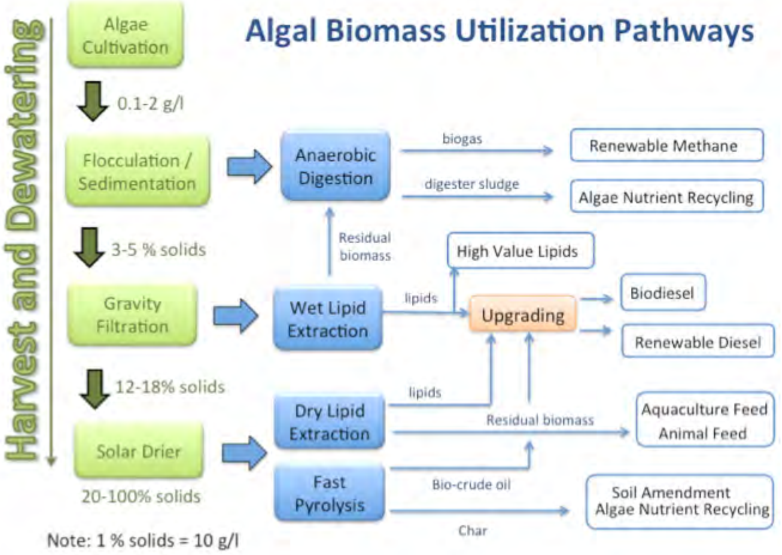

Figure 4. Flow sheet highlighting how the dewatering process can deliver feedstock to a variety of use pathways.

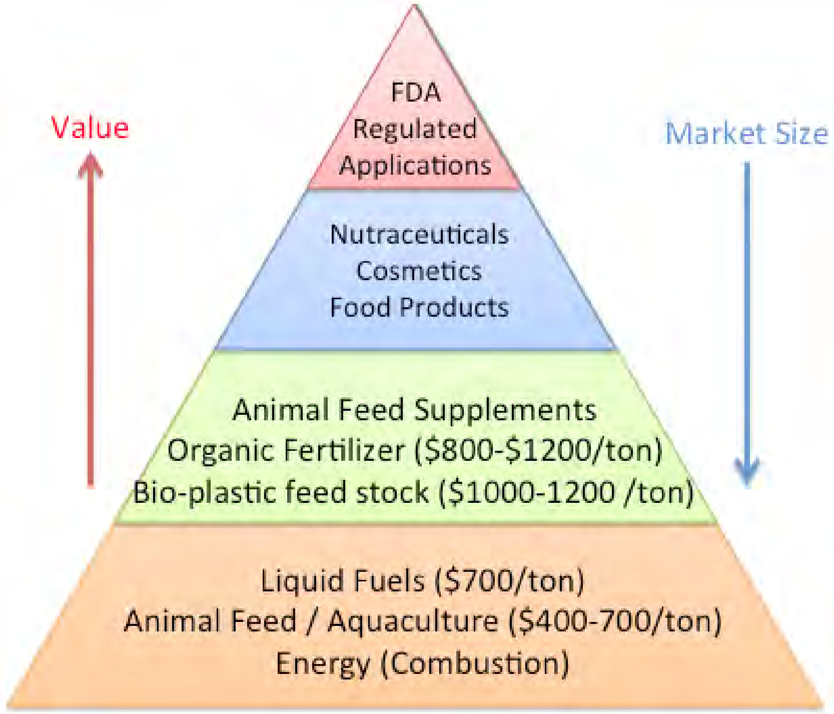

Figure 5. The market value for algal derived bio-products is inversely related to its size.

Carbohydrates could be useful as a feedstock for ethanol production, while proteins could be used as an aquaculture for animal feed. The lipids, or triglycerides, are chemically analogous to vegetable oils, and can be readily turned into biodiesel or processed to produce renewable diesel or jet fuel. One of the ultimate goals is to turn the carbon emissions from industrial point sources into fuels. To accomplish this goal a number of potential pathways can be used to produce a wide variety of fuel products [16]. One of the easiest ways to reclaim the energy in the biomass is anaerobic digestion, which can produce renewable methane while reclaiming nutrients to be fed back into the system [17-18].

Traditional methods for processing algae into fuels are based upon isolating the lipids from the rest of the cell and then processing these lipids into a hydrocarbon fuel. An added benefit of this strategy is that the remaining biomass can be used as a feedstock for the production of valuable co-products [19].

A trend popular in today's algal biofuels industry is to submit the entire algae biomass to hydrothermal liquefaction (HTL) to produce a crude oil, which can then be upgraded by using existing hydrocarbon refinery technology. Although this methodology eliminates the need to focus on lipid accumulation in the algae cultures and oil extraction steps, it eliminates the potential for co-product production in addition to the creation of renewable fuels.

Research at the University of Kentucky has led to a concept that produces a variety of products thereby increasing the value of the produced biomass (Figure 6). This is important because of the high levels of capital required to mitigate carbon emissions.

The harvested product is dewatered to a wet filter cake, removing most of the extracellular water. The biomass is then subjected to a wet lipid extraction to separate the lipid fraction from the protein and carbohydrates. The lipids are fractionated further to separate high value lipids such as omega-3's from triglycerides, which are more appropriate for fuel production. The remaining carbohydrates and proteins are fed to an anaerobic digester to produce renewable methane for power generation as well as a waste stream called the digestate. This digestate contains the same N-P-K ratio as the nutrient media fed to the microalgae and is thereby well suited to be recycled back to the algae culture to continue growth.

Another option that has recently been considered is the potential of using the harvested biomass directly as a feedstock for the production of bio-plastics. This would eliminate the need for complex processes such as lipid extractions and anaerobic digester operation, greatly simplifying the utilization strategy.

Efforts will continue to evaluate the processes and potential of biomass use as this is the area that has the greatest upside in terms of job creation and economic growth. At a large-scale facility, most of the steps will need to be performed locally due to the low energy density inherent with biomass. This means that the production of bio-products from the beneficial reuse of carbon emissions could have a real multiplying effect on local, typically rural, economies.

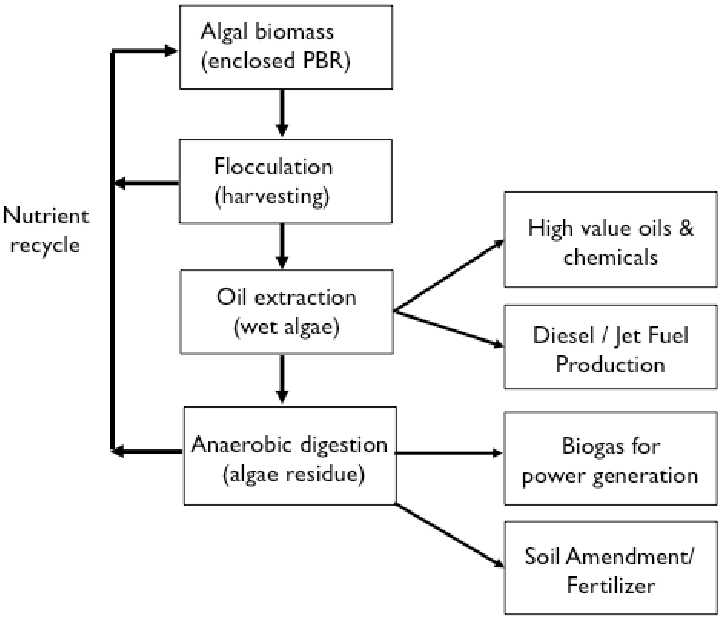

Figure 6. Flow sheet of proposed algae use strategy.

Figure 7. Feed end of photobioreactor at East Bend Station showing an operational comparison of 5” tubes (left) vs. 3.5” tubes (right).

East Bend Demonstration Project

While basic research and development of algal biotechnology is important, what happens in the lab can’t have a real effect until it is proven in a real world environment. The ultimate goal of this project was to successfully grow algae with flue gas from a coal fired power plant as the CO_2 source, to prove that it could be done while learning more about what it would take to scale up. After three and a half years of photobioreactor and process development, along with research concerning cultivation, the team sought a host site to extend its research and diversify itself from the field. Luckily a local utility partner, Duke Energy, emerged that was already doing research in algae based flue gas use. Duke has been an outstanding partner and has provided us access to their site in addition to infrastructure improvements. The UK team has been cultivating algae off of flue gas and performing applied research since the summer of 2012. Figure 7 shows the demonstration photobioreactor from the feed manifold side.

Both 3.5 inch and 5 inch tube designs were evaluated operating under real world conditions at East Bend Station. The smaller tube design was more robust and allowed better light penetration throughout the photoactive region of the tube. When it was time to scale the reactor test up, the 3.5 inch tube design was chosen. Figure 8 shows the completed reactor under operation in September 2013.

Any large-scale algae production facility needs access to large quantities of carbon for the algae to synthesize into biomass. One of the main historical problems in algae cultivation is CO_2 limitation. An inherent benefit of working with coal flue gas is the percentage of CO_2 in the gas (10-15%) compared to atmospheric conditions (.04%). The operating strategy, specifically flue gas introduction to the system, is very important to ensure that the algae culture has enough carbon to facilitate growth without flooding the reactor with CO_2 or other flue gas constituents. There are many challenges associated with using CO_2 directly from a coal flue gas source, but the initial results are promising. The demonstration project partnership between KY DEDI, UK, and Duke Energy is unique and one of the first of its kind in the United States to use algae as a mechanism for the beneficial re-use of post coal combustion flue gas.

Figure 8. Side view of completed photobioreactor at East Bend Station comprised of 500 3.5” tubes for a total volume of 18,000 liters.

Industry Activity

In addition to a very robust research and development population housed across the globe in colleges and universities, there is also a developing industry attempting to leverage the immense promise that algal biotechnology has to offer. The algae industry is currently represented by a broad portfolio of processes, products, and philosophies and some of the industry leaders will be highlighted here.

Algenol from Florida is using genetically modified cyanobacteria that produce ethanol as the culture grows [20]. The ethanol is continuously separated from the water over the lifetime of the culture and eventually the biomass is harvested and processed through HTL to produce ’biocrude’ oil. This process is interesting because it is using photobioreactors and produces both ethanol (a fuel for light duty transportation vehicles such as cars) and a bio crude, which can be refined into diesel and jet fuel. Algenol has partnered with a number of organizations and is focused now on deploying their process to use industrial sources of carbon dioxide.

Sapphire Energy is an industrial biotech company headquartered in San Diego and is solely focused on the production of renewable fuel. They have a 22-acre research and demonstration facility in addition to a 300-acre “Green Crude Farm” in New Mexico and grow their algae cultures in open ponds using brackish water. The biomass is harvested using dissolved air flotation and the concentrated biomass slurry is fed into a HTL process to recycle nutrients and produce their final biocrude product. Sapphire has long been seen as one of the leaders of the algal biofuels charge and has partnered with Phillips 66 to investigate the processing of its biocrude and has recently announced a partnership with Sinopec from China [21].

Cellana is headquartered in San Diego and has a 6-acre demonstration facility located in Hawaii. Their focus is interesting because it is more broadly focused and intended to leverage the entire product portfolio in order to maximize the value of the grown biomass. Its trademarked ReNew process produces DHA/EPA Omega-3 oils for human nutrition, a biological feedstock for biofuel production, and animal feed using its patented ALDUO process. This process grows dense seed cultures in photobioreactors that are used to inoculate open raceway ponds that are grown in batch mode. Although this presents unique challenges of its own, growing in this way eliminates the need to grow continuously and can help control contamination of the final product. Neste oil, the world’s largest producer of renewable diesel, has recently partnered with Cellana to purchase the biofuels feedstock produced at its bio refinery commercial facilities [22].

Heliae has its headquarters in Gilbert Arizona and is focused on being an algae technology company providing algae strains, growing technology, contamination control, harvesting methods, and biomass fractionation processes [23]. Their focus is to develop global technology partnerships and become a one stop shop for investors wishing to get into the algae biotechnology field.

Locally in the bluegrass, Alltech is growing algae in a novel way, heterotrophically, by growing algae in dark fermenters and feeding it sugars, bypassing the photosynthetic process. By growing heterotrophically instead of autotrophically, the algae cultures can attain much higher cell densities. Although this improves the production rate of the algal biomass it doesn’t have as strong a greenhouse gas benefit, as the culture does not take in carbon dioxide. They intend to use the algae to add nutritional value to animal feed, in the short term, before potentially moving into the aquaculture industry [24].

Challenges and Opportunities

As the field moves forward there are many technical, legislative, and regulatory hurdles that need to be overcome. There is much more to learn about flue gas introduction and ways to optimize the use of the carbon in it. Different strategies need to be investigated in order to diversify the products to be produced, while maximizing the value of the biomass. Capital and operating costs need to be better understood and minimized to improve the overall economics. Most importantly, research and industry groups need to work together in order to improve productivity rates and operational stability of this promising biotechnology.

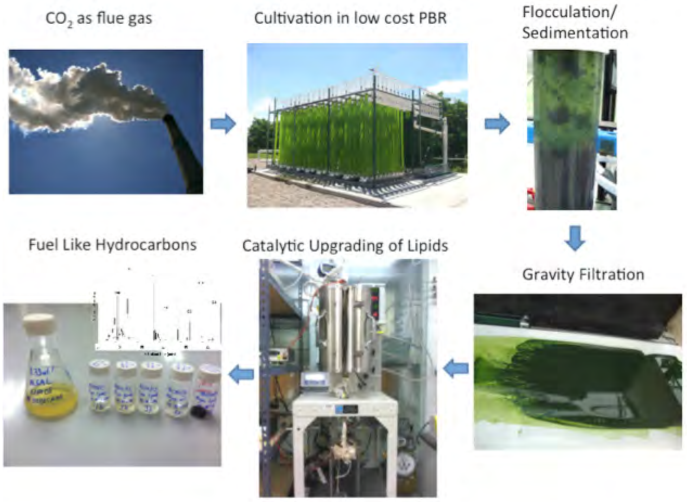

Figure 9. From Flue Gas to Fungible Fuels: Flow sheet showing the demonstrate beneficial reuse of CO_2, using algae to turn flue gas into renewable jet and diesel fuel.

Figure 9 shows a demonstrated pathway showing the potential to use microalgae to convert carbon dioxide emissions from coal fired power plants into hydrocarbon transportation fuels.

One of the most important questions that has arisen from this, and other research projects, is what is the future of coal? Is it simply a fuel used to generate electricity? Or is it a feedstock to a much more sustainable utilization strategy where there are no waste streams, simply opportunities for recycling and innovation? The beneficial re-use of waste streams from the coal combustion process, including CO_2, has the ability to extend the use of one of the commonwealth’s most valuable natural resources in a more sustainable way, while creating a robust economy centered around innovative, technology driven industries. Together, we can change the narrative about this much-maligned and misunderstood industry and shape a more sustainable future.

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