INSTRUCTOR'S LESSON PLAN

SUBJECT: The process of natural gas extraction from the Marcellus shale		**INSTRUCTOR:**
TITLE OF LESSON: Extracting Natural Gas from the Marcellus Shale		**DATE OF INSTRUCTION:**
TIME PERIOD (TOTAL) <45 min.>	**TYPE OF LESSON:** Lecture	**PLACE:**
TRAINING AIDS: <Starts here>		
OBJECTIVE(S): Provide an overview of the processes used to explore, develop, and produce natural gas from shale gas reservoirs such as the Marcellus shale.		
INSTRUCTOR'S REFERENCE: Harper and Kostelnik, The Marcellus Shale Play in Pennsylvania (2010); Carter, OFOG 07-01.1 (2007); Flaherty and Flaherty, ES 8 (2002); Hyne, Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production, 2nd 3d. (2001)		
STUDENT'S REFERENCE:		

TIME	LESSON OUTLINE	AID CUES
	INTRODUCTION	
00:00	a. Production of shale gas in the Appalachian basin has its roots in NY: William Hart hand-dug a well 27 ft deep in 1821 to produce natural gas from Devonian shale in Fredonia, Chautauqua County; subsequently, other shallow gas wells were dug along the Lake Erie shoreline from Buffalo, NY to Sandusky, OH. b. In 1859, "Colonel" Edwin L. Drake ushered in the modern petroleum industry by applying salt-well drilling tools and techniques to complete a 69.5 ft deep oil well in Titusville, Venango County, PA; from this point on, oil and gas wells were drilled, rather than dug. c. PA has a rich history of oil and gas drilling; for example, operators have known for decades that much gas exists in the Marcellus Fm; they would encounter it when drilling for deeper Devonian-age targets like the Oriskany Sandstone. In addition, oil and gas wells have been drilled directionally and hydraulically fractured for the past 50-70 years, with much of the technology being developed right in PA's backyard. d. The PA Geological Survey participated in the Eastern Gas Shales Project (EGSP) of the late 1970s; major findings of the U.S. DOE-funded work were that (1) Devonian organic-rich shales could be important gas reservoirs if better technologies for inducing/enhancing fractures in the shales were developed; and (2) the Marcellus Fm could not effectively compete with conventional gas reservoirs (e.g., Oriskany Sandstone) until drilling and hydraulic fracturing technologies advanced and the price of natural gas rose to a much higher level. e. The Bureau of Forestry's Oil & Gas Leasing Program began in 1947. Since that time, natural gas exploration and development has been occurring almost continuously. These activities have provided the necessary revenues to allow DCNR to continually invest in stewardship, conservation and recreation (via the Oil and Gas Lease Fund – note at	

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	least 26 State Parks have been purchased/created with these revenues). f. What has changed since then? Natural gas demand and prices have risen, drilling and hydraulic fracturing technologies have been developed/improved in other places and basins (e.g., the Barnett and Haynesville shales), and there is more acceptance/an increased comfort level of exploring/investing in unconventional gas reservoirs, that is, reservoirs where the source rock and reservoir rock are one and the same. g. Unconventional reservoir, defined – source rock elements remain in the formation; the reservoir and seal materials are noticeably different than what we see in conventional (e.g., sandstone and carbonate) reservoir systems; reservoir porosities and permeabilities are very low, meaning it is can be notably difficult to get the petroleum hydrocarbons out	

DEVELOPMENT

10:00 1. The current Marcellus play began in 2004 with the completion of the Renz #1 in Washington County, PA, by Range Resources, LLC. In 2008, the first well specifically targeting the Marcellus Shale was drilled on the Sproul State Forest in Clinton County. Three steps in the "lifetime" of a natural gas play include: **prospecting, exploration, and development**.

a. *Prospecting* – desktop studies show potential in an area or for a formation
b. *Exploration* – remote sensing (seismic surveys), exploratory wells (typically vertical), borehole geophysics, etc.
c. *Development* – petroleum has already been discovered, so infill drilling takes place
d. Different companies are at different stages in this process with respect to the current Marcellus play (some claim exploratory, some development)

12:00 2. **Marcellus Drilling Process**

a. *Site selection* – geology and topography are favorable
b. *Site preparation* – clearing trees, leveling the land surface, building a well pad/access road with rock and stone
c. *Spudding* – when drilling starts
d. *Types of drilling*
  1) Vertical – straight well bore / up and down
  2) Deviated – angled well bore
  3) Horizontal – a specific type of deviated boring where the well bore has 90 degree turn / up and down, then side to side
e. *Drilling fluids*
  1) air / foam – most often used in Marcellus development when drilling the vertical portion of the well
  2) drilling mud (water-based, oil-based) – most often used in Marcellus development when drilling the non-vertical portion of the well (e.g., during horizontal drilling)
f. *Casing* – steel pipe placed in the ground to protect the formation and

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	associated water from the fluids and gases moving through the pipe g. *Cementing* – cement is pumped down the casing and forced up along the outside of the casing to further isolate the formation/waters from any produced fluid or gas h. *Water usage* 1) Drilling process – requires ~100,000 gal 2) Completion process – requires 2-5 million gal, depending on data source a) freshwater – water taken from an approved source (stream, municipal water authority, etc.) that is used in the completion process described below b) “gray water” – water that has been previously used in another well completion that is treated/reconditioned for another use	
27:00	3. **Marcellus Well Completions** a. *Perforations* – the casing and cement is perforated (“perfed” or “shot”) at known distances and angles to allow water and sand to flow from the well bore into the rock, and gas to flow out of the rock into the well bore b. *Hydraulic fracturing* – better known as “fracing” (pronounced fracking); water is combined with sand and other, mostly food-grade, additives and injected underground to break the rock up and create fractures, or cracks. Sand carried by the frac fluid will be deposited in the newly formed cracks to prop them open and allow gas to flow from the reservoir rock into the well bore. c. *Flowback and well testing* 1) Flowback – the fluid that was injected into the well during completion is allowed to flow back to the wellhead (the injected sand remains in the rock fractures). This fluid is contained in the casing until it reaches the surface, at which time it is piped to storage containers for processing and/or disposal. Flowback water recovery estimates vary greatly, from as little as 9% to upwards of 40%, depending on data source. 2) Well testing a) Flaring – a well must be flared when a pipeline is not available. As gas begins returning to the surface with the fluid, the substances are separated – the fluid is piped to storage containers and the gas is piped to a flare stack where it is lit and allowed to burn under control. Gas is burned in this manner for safety reasons (i.e., methane can be highly flammable) as well as to measure (and estimate) the volume of gas a well can produce. Flaring may last up to several weeks. Eventually, if the estimates determine a well will be a good producer, a pipeline is built to this well. b) Flow Testing – a well can be flow-tested when a pipeline is available. In this case, gas is sent through a dehydrator to ensure there is no water vapor in the gas stream and then	

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	moved directly into a pipeline where it can be marketed and sold. The gas volume and other traits are continually measured during flow testing. After a while, the well will be shut-in and properly conditioned for permanent production.	
35:00	4. **Water Management** a. *Sourcing* – a water plan must be approved by PA DEP and the appropriate river basin commission (where applicable) before a well permit is issued. Before a water use is approved, several analyses are performed to ensure that water is being used in an environmentally safe manner. Water may be transported by truck, pipeline, or a combination of both. b. *Usage/handling* – water is used during every phase of the gas shale drilling and completion process. Water is stored in centralized locations (i.e., tanks, lakes, pits) until it is needed. Water is often stored away from the well site thereby requiring that it be moved on-site; more and more, water is being piped to the well site in lieu of trucking. Once on location, the water necessary for completion operations c. *Disposal* – any flowback water/fluid that returns to the surface must be properly disposed. Fluid is captured at the wellhead and stored in a tank until: a) Recycle/reuse – fluid is treated and reconditioned for the purpose of reusing in future well completions. Recycling operations can occur on the well pad (mobile units) or at a recycling center (requires trucking of fluid). Several methods of treatment can be used to recycle this water. Once the recycling process is complete, the water is transported to the next operation site where it can be used again. The Susquehanna River Basin Commission (SRBC) estimates that wells permitted under their jurisdiction may reuse as much as 400,000 gal of flowback water from well to well. b) Permanent disposal – fluid is taken to an approved treatment facility where it is processed to remove any chemicals, dissolved solids, or high concentrations of naturally occurring elements (mostly chlorides). Prior to being released back into a watercourse, the treated waters must meet DEP requirements and are to be released in a way that does not adversely impact aquatic environments or downstream users.	
40:00	**<u>QUESTIONS & COMMENTS</u>**	
43:00	**<u>SUMMARY</u>** 1. The petroleum industry has a rich history in the Appalachian basin	

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	in general and in Pennsylvania in particular. We are the home of the modern petroleum industry, and have known for some time that Devonian-age shales, like the Marcellus Formation, yield lots of gas. Technological advances and mind shifts have placed much attention on the Marcellus shale in our backyard and have made it the popular play that it is today. 2. The PA Geological Survey has been involved with shale gas research since the late 1970s, at which time they participated in the Eastern Gas Shales Project, which has laid the foundation for much of the basin-wide geologic mapping and reservoir research conducted today. 3. The Bureau of Forestry has been managing natural gas development on State Forest land since 1947; the economic benefits from these activities have been invested in stewardship, conservation, and recreation. 4. The Marcellus drilling process is conventional in many regards; however, what is unique to this current play is the way operators drill horizontally, use millions of gallons of water/fluids to perforate and stimulate the wells, complete several wells on a given pad, and produce millions of cubic feet of gas per day. 5. Water management has become a key issue with respect to the exploration and development of the Marcellus shale as a natural gas reservoir. Technological advances, happening monthly, are changing the way that operators procure, transport, use, reuse, and eventually dispose spent frac waters.	