PENNSTATE

College of Agricultural Sciences • Cooperative Extension

Water Resources Extension

## Water Facts #31

# Introduction to Hydrofracturing

This publication describes the process of hydraulically fracturing, or hydrofracturing a well. It discusses the history, some common techniques, and introduces some of the equipment and chemicals commonly used in the operation. The term Hydrofracturing is often shortened to “fracing,” or “fracking,” and we will use the short form, “fracing,” here for convenience. In this publication, we remove the surrounding mystery and give a basic description of the fracing process.

Experts say that every geologic formation and every fracture within each formation is unique. We still cannot see what goes on thousands of feet underground. However, microseismic technology has advanced through analyzing sound and radio signals, enabling us to understand much more than we did even five years ago. The Environmental Protection Agency (EPA) is currently conducting a study on fracing, suggesting we will learn even more about the process in the future.

**History**

Fracing is a term used to describe the starting and extending of tiny rock cracks, using water, sand, and chemicals at high pressures. These cracks, called “fractures” provide passages allowing trapped hydrocarbons to escape. The oil and gas industry first used fracing in 1947 as a method of increasing hydrocarbon yields from rock formations.

In early well development in the late 1800’s, “shooting a well” entailed dynamiting a void at the bottom of the vertically drilled gas and oil well wellbore, so that production fluids, usually oil, flowed into what amounted to a cistern. The oil was then dipped out by a bailing bucket. The first well shot was done by Colonel E.A.L. Roberts on Ladies Well near Titusville, PA, in 1865. Gas pressure in the newly drilled shallow wells pushed the oil to the surface freely, resulting in the exciting gushers shown in early oil field development pictures.

Porous formations may have been plentiful in some areas, but wells eventually slowed in production. Wells with barely profitable output were common in gas and oil well development. Slow production could have been caused by very small pore spaces in the rock, closed passages at the wellbore, or by waxes and algae in the production fluids clogging the formation. To the person drilling the well, fracing was only half as expensive as drilling a new well, and was successful in boosting production at least 50% of the time. Added to these odds, a new well drilled in the same formation had a 50% chance of having the same production problems. Fracing developed into a sensible way to save money and increase productivity.

**Conventional Verses Unconventional**

In unconventional gas reservoirs, the gas is tightly stored in the rock itself. In conventional gas reservoirs, the gas is stored in pore spaces between individual grains. In some limestones, organic matter decomposes leaving tiny spaces in the rock like a loaf of bread. They are too small to see, but are large enough to hold fluids, including water, gas, and oil. In other limestones, grain packing and chemical processes provide open spaces for holding fluids. Sandstone sand grains pack together imperfectly, leaving tiny pores in the stone, even when composed partly of finer silt and clay. As the pores connect, the fluid can flow through the rock formation, and we rely on this flow to supply wells drilled into the “reservoir rock.” Natural fractures formed in the rock masses over millions of years as the earth’s plates moved and collided. These also allow fluids initially trapped within the rock to flow. In limestone and sandstone formations, some fracture sets develop horizontally, parallel to original sediments that settled in beds. In conventional wells, vertical holes are drilled into the porous rock formation with the hope of intercepting areas where gas has collected. As the vertical wellbore intercepts fractures oriented perpendicularly to it, drillers are able to collect gas over much larger volumes of the reservoir rock than the porous rock holding fluids next to the well. Fractures in this way permit a well to drain a larger area.

Vertical wells placed in conventional reservoirs are unable to collect fluids for a long period in very dense formations of shale or coal. The particles forming these rocks are a mixture of decomposed microbes, plants, and animals along with very fine clay minerals. Pore spaces between the components of this fine sediment are so small that as organic materials decomposed through microbial activity, gas and oil molecules formed and chemically bonded to the solidified "mud rock" matrix. These fluid molecules cannot move until more space is created.

The orientation of natural fractures often do make of fluid extraction easy. A vertical wellbore in the reservoir rock may intercept relatively few of these fractures so the well can only gather fluids from the formation next to it. To intersect more vertical fractures, the oil and gas industry developed a way to initially drill a well vertically to a certain depth and then steer the drilling over a gradual arc, so that after a quarter mile the leading drill pipe and bit can be boring horizontally in the desired direction. Horizontal wellbores may extend over 5,000 feet, enabling the driller to hit many more natural fractures in relatively thin coal and shale formations. A horizontal well can then collect much more natural gas from the reservoir rock. However, in very dense unconventional gas reservoirs, such as shale formations, the gas is so tightly stored within the rock itself that fracing has become a standard part of well stimulation.

**Preparing for the Hydrofracturing**

In drilling a horizontal well, the first portion of the hole is bored deeply enough to build a stable well foundation and prevent surface fluids from entering the well. Sections of steel pipe known as "conductor casing", or referred to as "drive pipe", are placed in the wellbore. The pipe may be driven into place by the rig, or it may be hung in open hole and cemented in position.

If it is to be cemented, a two-inch space, called "the annulus" is usually left between the casing and the borehole to create a strong bond. A calculated cement volume is pushed down the inside of the pipe by placing a system of wiper plug ahead of and sealing plug behind it, and pumping water behind it. The cement has nowhere to go at the end of the casing, and is forced back to the surface of the hole in the annulus outside the pipe.

Cement is given time to harden in a chemical process known as "curing". Next, a smaller hole is drilled deeper through the inside of the conductor casing, boring through any plugs and valve systems placed in the larger casing. The wellbore is continued to below the deepest freshwater aquifer. A second casing, called the "surface casing" or "freshwater string", is suspended inside and cemented in place completely to the surface. The surface casing separates the freshwater aquifers from the oil and gas bearing formations below. It often uses a valve and seal, called a "seat" on its base.

A third casing, known as an "intermediate " string is placed in a similar manner inside the surface casing and cemented to the surface. This casing isolates gas -bearing rock from the surface casing seat and provides a foundation for well control equipment designed to control fluids from escaping under pressure.

The drilling process continues with each step requiring successively smaller casing sizes that extend deeper into the subsurface. The final casing string is referred to as "production" casing. Several casing strings cemented in place ultimately separate the targeted gas reservoir from freshwater aquifers. Although variations in well construction are common, a typical well is configured like the cross section shown in Figure 1 on the following page.

After all casing runs are placed, a well service company perforates the production casing so that the well can collect fluids from the targeted formation. To accomplish this, the larger drill rig replaced by a smaller completion rig or a large crane. The rig or crane lowers a tool called a perforating gun into the production casing on a cable or by coiled tubing. The perforating gun is a long pipe with holes positioned along its length. The holes are loaded with explosives connected to a signal line running through the middle of the pipe. The pipe is lowered and pushed in the casing to a selected formation zone where the well is to collect oil or gas. A technician sends an electrical charge to the tool causing the explosive in each tool hole to detonate and punch through the steel casing and cement next to it. The next step is to pump diluted hydrochloric acid down the hole to clean out the well, dissolve the cement at each perforated zone, and expose the rock formation. The spent acid solution is removed as each zone is washed, and can be recycled. The gas well is now ready to be "fraced."

**The Fracing Operation**

Figure 2 shows the top of the well before the fracing begins. The pipe extending up from the ground is the gas wellhead, with a shut off valve above it. The stack of equipment includes the valve, and the six iron pipe

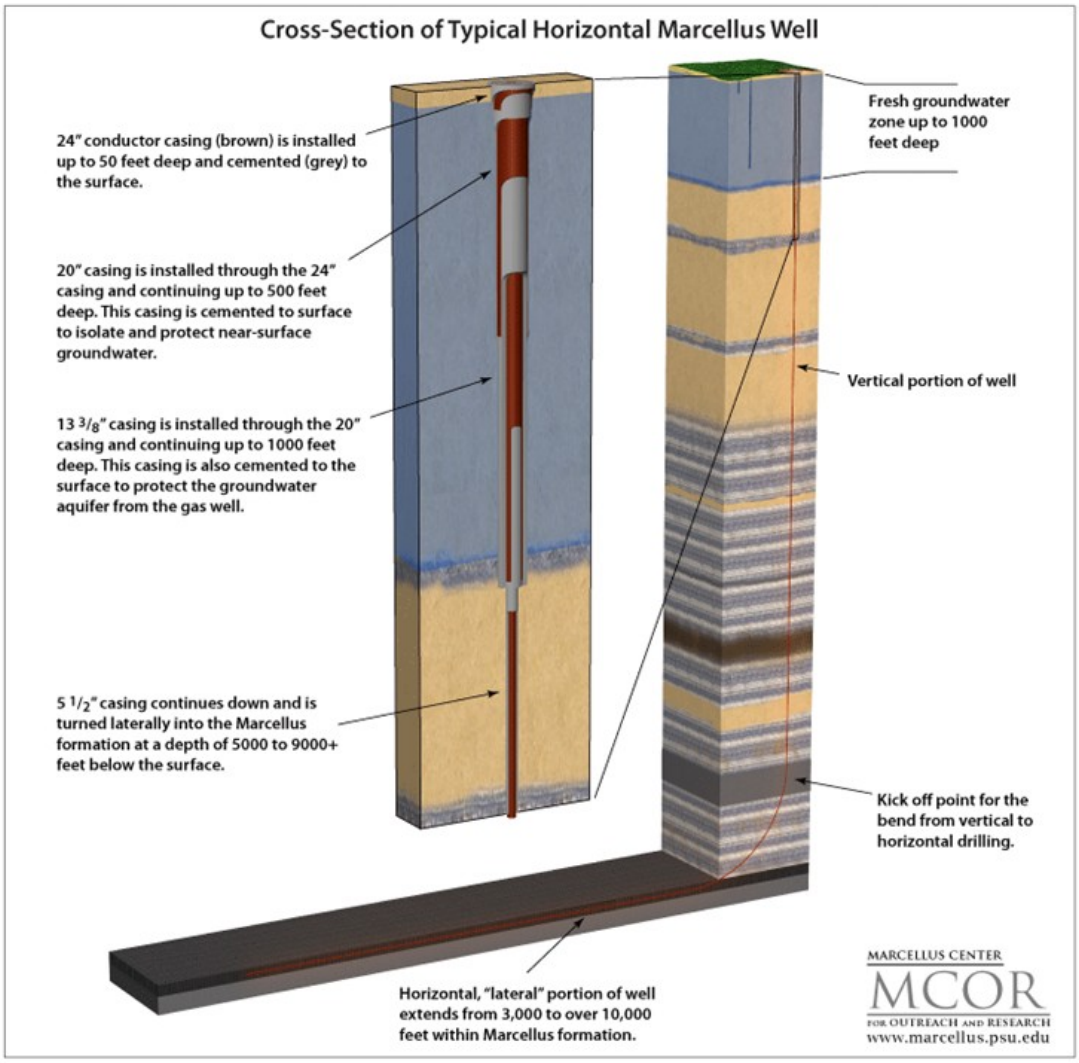


**Figure 1. Cross section of typical horizontal well drilled into the Marcellus formation (courtesy of Penn State Marcellus Center for Outreach and Research).**

lines attached to it which will each carry a specific formula of water, sand and chemicals to frac the well. This arrangement allows service companies to connect their equipment to the well to do their specialized work, and shut off, or "shut in," the well to uncouple and change equipment. Communication cables running from the top of this assembly allow geologists and operators to receive well information as the job proceeds. They can then immediately change fluids, pumping rates, or pressure as needed.

Any work in the well must be able to withstand very high pressures and temperatures, approaching 370 degrees Fahrenheit at depths sometimes exceeding 9,000 feet. The rubber and steel used must have special properties to avoid rapid wear or disintegration.

**Figure 2. Frac manifold at McKean County site. Photo Courtesy of James Clark, 2008.**

The iron pipes at the well are connected to pump trucks supplying the pressure for the fracing. The pump truck is positioned next to the well, and its powerful (1,200 to 2,500 horsepower) pumps move the materials designed specifically for the well into the formation. These trucks can pump at extremely high rates (sometimes 500 gallons per minute or more) and high pressures (as much as 14,000 lbs. per square inch) as they need to move enough sand or ceramic beads, termed “proppant” into the formation once fractures are started. Small wells may use one pump truck. As Figure 3 shows, many pump trucks may be used in a system on very large wells. The high pressure lines lead directly from the pump truck to the valve at the well site, called the “frac manifold.”

**Figure 3. Hydraulic fracturing operation on East Resources well, eastern Tioga County. Photo Courtesy of Robert Hansen, 2010.**

Behind the pump trucks is the blender truck, which pulls together the material needed to frac the well. The blender is a long mixing machine that takes sand, or ceramic bead propping agent, water, and chemicals to prepare a gel that carries the propping agent into the formation as deeply as possible. The blender driver adds antiseptic detergent chemicals to the gel to keep the formation rock molecules from swelling and clogging the well. The chemical supply truck will often be a stake-body truck with signage called placards showing if and what types of hazardous chemicals are on board. Most chemical hazards will be classified by the Department of Transportation as being corrosive, flammable, or non-flammable. The graph on page 5 (Figure 5) and table on page 6 (Table 1) give examples of what these chemical additions may be. If the blender works on more than one formation zone, the frac operator may prepare a specific recipe for each. The blender driver controls the proportions of each ingredient according to tests run by geologists during the drilling stage.

An auger or conveyor runs from the sand trailers or sand hogs to the blender, delivering sand to this unit. Powerful diesel engines drive the conveyor because the sand is very heavy. There may be several sand containers on the site. These giant sand hogs are set in position empty and loaded by an assembly line of sand trucks before the fracing can begin. The trailer shown in Figure 4 can hold about 3,000 cubic feet, or 111 cubic yards of sand, weighing about 200,000 lbs. This trailer has four compartments so the blender can pump sand, glass, or ceramic beads of very specific sizes into different areas of each formation zone as needed. They begin the frac with very fine sand and use coarser sand as the job progresses.

**Figure 4. Sand Hog being positioned at the well site, Courtesy of Universal Well Services, Inc. 2009.**

Since the practice began, fracture operations pumped relatively large quantities of water to carry small quantities of sand into formations to prop them open. During the 1980’s, plastic polymer gel use increased fluid thickness so that much more sand could be pumped in stream without dropping it in the pipe. Now, gelled suspensions containing from 20,000 lbs. (about 10 cubic yards) to 150,000 lbs. (about 75 cubic yards) of proppant are pumped into each stage of a frac operation at rates up to 15 barrels (630 gallons) per minute and at pressures reaching 14,000 psi to penetrate the formation effectively. As shown in Figure 5 and Table 1, a frac operator may use 150,000 lbs. of sand suspended in a 229,000-gallon gel volume in each perforation stage.

The final material delivered to the blender is water. One to nine million gallons of water are typically used to frac an unconventional gas well. This varies, depending on how many “zones”, or stages are planned for the well. Water is managed in several ways depending on the site. It can be stored in

freshwater ponds, usually 10 feet deep, on site or nearby, and then trucked or piped to several different sites. Exploration companies may limit pond and single site excavations to less than five acres to reduce permit requirements. Since 2009; however, it is not uncommon for 20 or more gas wells to be placed on one larger drilling site or pad. This makes water use much more efficient. Frac tanks lined up on the site are also used. Water is stored on some sites in 500-barrel frac tanks. To supply four million gallons to a well, 200 tanks must be stored on site, with supply lines to fill them and empty them as needed. Whether water is held in frac tanks or in ponds, on-site space is required on to manage water.

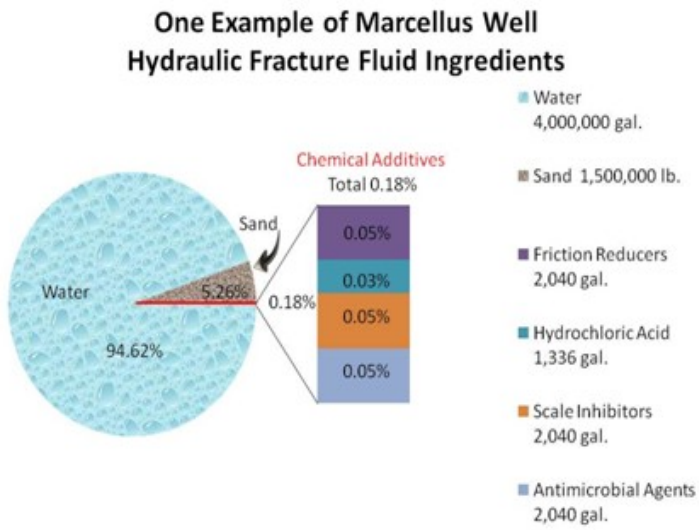


**Figure 5. Example of a hydraulic fracturing fluid combination specified for a shale well, based upon composite of Range Resources and Chesapeake Energy information released in July 2010. Every fracturing zone within a well may be prepared individually depending on results of geologic tests.**

The entire frac operation is controlled at the Frac Operator Van. The frac operator, like a job foreman, is in charge of the company performing well fracture activities. The frac operator's van, which looks like a camper, has computers, electronic monitoring and communications equipment from which to direct all fracturing operations. The frac operator tells the equipment drivers what fluids to pump into the well, when, how fast, and how much.

The gas industry has developed the ability to analyze well formation porosity by recording pressure drops and electrical signals. The operator watches pressures and signal continuity in the well; instructing the pump driver or controlling the pumps remotely in order to regulate pressure applied in an initial acid wash. As tiny imperfections in the formation rock crack, creating new fractures, the process registers right away as a recognizable pressure drop. Next, the operator tells the pump driver to begin pumping sand suspended in gel to prop the new extended crack open. All these activities, including pressures, timing, and fluids used, are carefully recorded and relayed by satellite communications to the owners of the well. With this technology, analysts can know how far a fracture penetrates into the formation, before and after treatment.

Frac operators have traced fractures with microseismic equipment that reach 500 feet or more from the wellbore, particularly if fractures extend to parallel cracks along the formation. Fractures usually deflect along formation boundaries rather than penetrating adjoining formations.

After the frac crew pumps the sand, gel and chemical suspension into the well, it pumps water or other fluids behind it to push, or displace, all the sand into the formation and out of the casing. The further it travels, the more likely the fractured formation will stay open, extending the well's productive life. The entire process to frac one zone in a well will take about three hours. The fracing will begin at the farthest end of the wellbore and move toward the surface. In horizontal well sections, the farthest end is called the "toe", and the section closest to the vertical turn is called the "heel". Each zone that is fraced will be isolated from the rest of the well using tools called packers and rubber frac balls. Each perforation zone in shale wells often produces as much gas as one conventional vertical well.

When crews finish fracing a well, most fluids pumped into the formation are eventually forced back to the surface immediately or over the life of the well. Wells in the Pennsylvania watershed region monitored by the Susquehanna River Basin Commission have returned from 8% to 10% of stimulation fluids in the first 30 days. Another large percentage will come back over the next several months with the produced gas. This must be separated using a filter before the gas can be sent to the gathering lines, blended to correct qualities, and eventually pumped to awaiting markets. It is still unclear what percentage remains unaccounted for, as it cannot be distinguished from the waxes, brines, and metals that return with the fluids created in the formation. These are all separated from the gas and must be recycled or properly disposed of over the well's producing life. A

gas well may be re-fraced several times in the future. Shale wells in Pennsylvania have not been re-fractured to date.

In July 2010, Range Resources and Chesapeake Energy each publicized the chemistry and volume of materials typically used in their well completions and stimulations. Figure 5 and Table 1 are composites of the two companies' information for wells having at least one perforation zone. Every well is treated individually, and every formation treatment is unique, depending on the company and the current research. These examples are shared as a reference only. Individual treatments have progressed to include a dozen or more perforation zones in a single well. Volumes of materials used will increase considerably for longer horizontal laterals and will be shown in the well records.

**Table 1. Example of a fracturing chemical combination in oil and gas wells.**

| | | Key of Sources | RRC<br>CHK<br><br>July, 2010 sources | Range Resources, LLC<br>Chesapeake Energy | |
|---|---|---|---|---|---|
| **Additive Type** | **Compounds** | **Purpose** | **Use and Dilution** | **Volume** | **Percent Overall** |
| Carrier fluid | Water | Creates fracture network and carries proppant to the formation | Primary ingredient | 4,000,000 gal. (RRC) | 94.62% (RRC) |
| Sand | Specifically sized sand or ceramic | Props fractures open | Second largest component | ~1,500,000 lbs. ~20,250 cu. ft. ~750 cu. yds. (RRC) | 5.17% (RRC) |
| | | Water and sand combined | ~20,250 cu. ft. | 226,000 gal. (RRC) | 99.5% (CHK) |
| **Balance of Ingredients** | | | | | |
| Acid | Hydrochloric acid or Muriatic acid (RRC, CHK) | Dissolves cement and minerals Initiates fractures (RRC, CHK) | 139 gal. ( ~ 12% conc.) per stage (RRC) | 1,338 gal. (RRC) | 0.03% |
| Friction reducer | Polyacrylamide (RRC)<br><br>Petroleum distillates (CHK) | Reduces friction between fluids and the pipe | used at 1/2 gal. per 1,000 gal. of water (RRC) | 2,040 gal. (RRC) | 0.05% |
| Antimocrobial agent | Gluteraldehyde (RRC, CHK) ethanol, methanol | Eliminate bacteria in the water that corrode the casing (RRC, CHK) | used at 1/2 gal. per 1,000 gal. of water (RRC) | 2,040 gal. (RRC) | 0.05% |
| Scale inhibitor | Ethylene glycol, alcohol, and sodium hydroxide | Prevents scale deposit in the pipe | used at 1/10 gal. per 1,000 gal. of water (RRC) | 2,040 gal. (RRC) | 0.05% |
| Iron Control | Citric acid | inhibits iron oxides from depositing (CHK) | | | |
| Corrosion inhibitor | n,n dimethyl formamide (CHK) | prevents pipe corrosion | | | |
| Gel | Guar gum or hydroxymethyl cellulose (CHK) | Thickens water to carry heavier sand load effectively | | | |
| Cross-linker | Borate salts | Maintains fluid viscosity as temperature rises downhole | | | |
| Gel-Breaker | Ammonium persulfate | Allows gel to break down to flowable fluids | | | |

## Summary

Hydraulic fracturing has become a standard practice in the gas industry. Fracing is a process that involves using water, sand, and chemical additives to initiate, extend, and prop open formation fractures for the highest gas production.

The oil and gas industry changes continually. Future studies and research will help us learn more about continually evolving fracing and other gas production technologies and their impacts.


## Acknowledgements

Sincere thanks to the following reviewers of this edition for helpful comments and suggestions:

- David Bicko and Patrick Jarrell of Universal Well Service, Inc.
- Douglas Mehan, PG, Dallas-Morris Drilling Co.
- Timothy Bruno; Rich Neville; Anthony Oprendek; Eugene W. Pine, PG, Seth Pelepko PG of PA Department of Environmental Protection.
- Thomas Murphy; David Yoxtheimer, PG; and Dr. Michael A Arthur, PG of Penn State Marcellus Center for Outreach & Research.


## References


Carlson, Carl. Range Resources Company Presentation, *Range Resources Range Resources Hydraulic Fracturing*, July, 2010, page 26 at http://b2icontent.irpass.cc/790%2F111709.pdf.

Range Resources website http://www.rangeresources.com/getdoc/50e3bc03-3bf6-4517-a29b-e2b8f0afe4f/Well-Completion-Reports.aspx.

Chesapeake Energy, Inc. *Hydraulic Fracturing and Completion.* Website: http://www.askchesapeake.com/Marcellus-Shale/PA/Drilling/Pages/Hydraulic-Fracturing-and-Completion.aspx

Clark, James, and Bryan Swistock. *Gas Well Drilling & Private Water Supplies. Portable Classroom CD. 2008.*

Marcellus Center for Outreach and Research. *Cross Section of a Typical Horizontal Marcellus Well.* Website http://www.marcellus.psu.edu.

PA DCNR Department of Environmental Protection. *Hydraulic Fracturing Overview*. Website: http://www.dep.state.pa.us/dep/deputate/minres/oilgas/new_forms/marcellus/Reports/DEP%20Fracing%20overview.pdf

Halliburton Inc. *Fas Drill® Array Bridge Plug* Website http://www.halliburton.com/ps/Default.aspx?navid=1384&pageid=377&prodid=PRN%3a%3aIVPZ6PIVK

Schlumberger Limited *Oilfield Glossary*, Website: http://www.glossary.oilfield.slb.com/search.cfm
US EPA *Hydraulic Fracturing Research Study* http://www.epa.gov/safewater/uic/pdfs/hydrosearchatstudyfs.pdf


## More Information

For more information on water resource issues related to Marcellus gas drilling in PA visit: http://water.cas.psu.edu/Marcelluswater.htm

For more information about natural gas exploration and development in PA visit : http://extension.psu.edu/naturalgas


Prepared by Scott A. Sjolander (Extension Associate), James Clark (Senior Extension Educator), Dana Rizzo (Extension Educator), and John Turack (Extension Educator).



Penn State College of Agricultural Sciences research, extension, and resident education programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture.

This publication is available in alternative media on request.





March 17, 2011