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The Many Topics within THE MARCELLUS SHALE

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In this issue...

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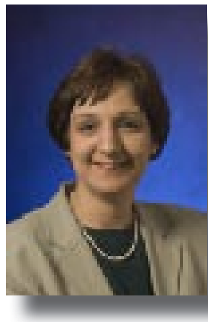
Guest Editor Column

Shale Gas Challenges and Opportunities: *The Role of the Engineer*



Jeanne VanBriesen, Ph.D.

Continental shale gas reservoir developments are a growing source of natural gas to meet the energy needs of the United States. The Marcellus Shale of the Appalachian Basin has been estimated to contain 262-500 trillion cubic feet (Tcf) of natural gas reserves and is one of the largest reservoirs of shale gas in the U.S. The Marcellus Shale underlies most of Northern and Western Pennsylvania, encompassing about 70% of the state.

Although gas production in the Northeastern US has been ongoing since the early 1800's, accessing deep shale gas has recently expanded rapidly due to two key technologies. Horizontal drilling and multi-stage hydraulic fracturing have enabled development of highly productive gas wells in the Marcellus Shale. This technologically-driven expansion is not unusual for the energy sector, where innovation drives development of formerly inaccessible resources (e.g., coalbed methane and shale gas) or leads to new ways to capture energy (e.g., wind and solar). Such technological breakthroughs are critical for Pennsylvania to retain its position as a leader in all facets of the energy market.

However, the recent growth of shale gas development in Pennsylvania has not been without concern. As this rapidly expanding industrial activity has entered multiple communities and spawned upstream and downstream activity, citizens have expressed concern for their air quality, water quality, roads, and the general management of decisions about their environment.

> *We have a duty to "hold paramount the safety, health and welfare of the public," and a duty "to issue public statements only in an objective and truthful manner."*

Pennsylvania citizens understand the value of hydrocarbon resources – we have long been an oil, gas, and coal producing center, but we have also always been a water state. Pennsylvania has more flowing water than any other state, with more than 83,000 miles of streams and rivers and more than 4000 lakes, ponds and reservoirs. This water resource provides habitat for a significant diversity of life -- more than 120 species of fish and 28 species of clams and mussels alone – as well as drinking water, water for farming, and water for our industrial activities. Protecting this abundant natural water resource has not always been a priority for our state. Exploitation of our coal resources has led to the worst abandoned mine drainage (AMD) in the nation. Over 2400 miles of our streams are severely impacted by AMD, which is the single largest source of water pollution in the state. Ongoing mining activities and power plants utilizing our extensive coal resources may also discharge water high in salt that can affect our waterways.

Having lived through hydrocarbon extraction-based booms of the past and enduring their continuing legacy in environment and health, the citizens of Pennsylvania ask quite reasonable questions of their new industrial neighbors: Are we doing it better this time around? Is the technology safe? Effective? Protective of the environment? How can we monitor the near and long term effects of this industrial development across a wide range of natural systems (streams and rivers) and engineered systems (roads and bridges and water treatment plants)?

These are engineering questions. They demand and deserve considered and reasoned engineering answers, with detailed analysis to back them up. Those answers have to come from us, from engineers. A year ago in this space, Jack Mascaro (Guest Editor of Spring 2010 *Pittsburgh ENGINEER*) reminded us that engineers need to stand up and control their destiny, to take charge of the conversation on sustainability. I urge a similar active engagement on engineering issues related to Marcellus Shale development.

Are there 'green' hydrofracturing chemicals? Is methane really a 'bridge fuel'? Can we control methane leaks during transportation? Does shale gas development imperil our groundwater or our surface drinking water sources? Are new water recycling methods working? Can they be expanded to the entire shale play? Can produced water treatment be more economical? Can beneficial products be extracted from the gas and from the flowback water? Can air quality discharges be limited to safe levels? Can road construction be improved to handle additional traffic?

These are engineering questions. It is our job to find the answers and to provide them to the public to the best of our abilities as engineers.

I want to add to Jack Mascaro's charge that we stand up and be part of the conversation. We need to be fully engaged in the conversation on controversial issues that are best addressed through engineering study and analysis. We need to remind the public that engineers ascribe to a code of ethics. We have a duty to "hold paramount the safety, health and welfare of the public," and a duty "to issue public statements only in an objective and truthful manner." This gives our voice, when we choose to use it, more weight, as it should.

It will be easy as you read the articles in this edition to get excited about the engineering aspects, and rightfully so. There is tremendous opportunity in this expanding industry. It will be important to remember, however, that there are incredibly complex and interesting challenges to go with those opportunities. As engineers, I know you will want to rise to those challenges and solve the current issues as well as design new processes, enhancements and technologies.

As you do this work, I want to implore you not to lose sight of the complicated public discussions taking place around this activity. These are our friends and neighbors seeking answers to their concerns. It is our duty not just to do the engineering work well, but also to lead the discussion of the engineering problems, solutions, and next steps. Only through this leadership will the public conversation in this area re-focus on the answers to the critical questions being raised. It is not a time to let the chaos of uncertainty swell around us. It is time to step up and talk about how engineering enables the process of gas extraction and enables the management of its potential environmental and community impacts.

It is our duty not just to do the engineering work well, but also to lead the discussion of the engineering problems, solutions, and next steps.

Natural gas, coal, oil, and timber are natural resources that have fueled our regional economic development. Clean air, fresh water, safe food and healthy environments are natural resources that fuel our human development. Engineers have a critical role in the management of both these resources and a responsibility to deploy our considerable skills to enable both economic and human development. The engineering capacity within our region continues to impress me, and it is worth remembering that this human resource is as important for our regional future as the natural resources. Engineers create the future we will all inhabit. Let's make it a good one. PE

About Our Guest Editor...

Dr. VanBriesen is the Director of the Water Quality in Urban Environmental Systems (Water QUEST) Center and a Professor in the Department of Civil and Environmental Engineering at Carnegie Mellon University. Dr. VanBriesen received her B.S. in Education with an emphasis in Chemistry from Northwestern University. After teaching high school for several years, Dr. VanBriesen returned to Northwestern for her M.S. and Ph.D. in Civil Engineering. She has published thirty-eight scientific articles and given more than 100 professional presentations. Dr. VanBriesen has received numerous awards, including the Pennsylvania Water Environment Association Professional Research Award in 2007, the Best Research Paper in the Journal of Water Resources Planning and Management in 2008, the Professor of the Year for the American Society of Civil Engineers (ASCE) Pittsburgh Chapter in 2009, and the McGraw-Hill/Association for Environmental Engineering and Science Professors Award for Outstanding Teaching in Environmental Engineering in 2009.

ENVIRONMENTAL CHALLENGES OF WATER MANAGEMENT OPTIONS

By Radisav Vidic and Kelvin Gregory

The grand challenge that natural gas producers must address in partnership with public, government and regulatory agencies is how to preserve the favorable economics of shale gas development while maintaining responsible stewardship of natural resources and protecting public health, especially through protection of current and potential sources of potable groundwater and surface water.

Water Resources

Drilling and completion of hydraulic fracture wells require usage of large quantities of water, and some consumption of this water. Along with the 2-7 million gallons of water needed for hydraulic fracturing fluid in each well, an additional 0.1 to 1 million gallons of water is needed for drilling fluids to maintain down-hole hydrostatic pressure, cool the drill head and enable removal of drill cuttings. This water is typically obtained from nearby surface waters or pumped to the well-pad from a municipal source. Although the total water withdrawal for Marcellus shale development in 2010 was less than 0.5% of total withdrawals in Pennsylvania, site-specific limitations (i.e., local drought conditions, environmental flow requirements, water allocation priorities) may limit the availability of surface water in some cases. Therefore, planning for water acquisition and management is integral to planning shale gas development projects. In addition, the availability of abandoned mine drainage (AMD) water in the vicinity of many drilling sites in Pennsylvania offers great opportunity to secure water resources with minimal transportation costs while reducing the contamination of Pennsylvania's surface waters associated with this environmental legacy issue (Barbot, Li et al. 2010).

Frac Job in Progress

Management of Flowback Water

Flowback of the fracturing fluid occurs over a few days to a few weeks following hydraulic fracturing with the flowrate as high as 25,000 gal/d on the first day. The flowback water is typically impounded at the surface for subsequent disposal, treatment, or reuse. Due to the large water volume, high concentration of dissolved solids, and complex physical-chemical composition of the flowback water, there is growing public concern about management of flowback water because of the potential for human health and environmental impacts associated with the release of untreated or inadequately treated flowback water to the environment (Kargbo, Wilhelm et al. 2010).

Treatment technologies and management strategies for flowback water are selected based on constraints established by regulations, economics of implementation, technology performance, and final disposal alternatives (Gregory, Vidic et al. 2011). Flowback water management options in Marcellus shale are additionally governed by high concentrations of total dissolved solids (TDS), geography, and a lack of physical infrastructure for some options (Arthur, Bohm et al. 2008; Kargbo, Wilhelm et al. 2010; Gregory, Vidic et al. 2011).

- Underground Injection. The majority of produced water from oil and gas production in the U.S. is disposed through deep underground injection (Clark and Veil 2009). Such operations are performed in deep formations using Class II disposal wells as defined by the U.S. Environmental Protection Agency under the underground injection control (UIC) program of the Safe Drinking Water Act (Veil, Puder et al. 2004).
However, the state of Pennsylvania has only 7 Class II disposal wells that may receive flowback. Although the number of underground injection disposal wells is expected to rise in Pennsylvania, shale gas development is currently occurring in many areas where Class II UIC disposal wells are not readily available. Moreover, permitting and construction of new Class II UIC disposal wells is complex, time consuming, and costly (Arthur, Bohm et al. 2008). There is potential for shale gas development in the Marcellus to rely on UIC wells that are available in the adjacent states of Ohio and West Virginia, which have greater capacity for injection disposal. However, transportation costs are high and the long-term capacity of these wells may be limiting. Therefore, disposal of flowback water by deep well injection is not likely to be a sustainable solution for the management of flowback across much of Pennsylvania's producing area.

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- Discharge to POTW for Dilution Disposal. Although discharge and dilution of flowback water into publically owned treatment works (POTWs) under permit has been and continues to be utilized, this is not an adequate or sustainable approach for managing flowback water. Currently there are only 8 POTWs permitted to directly receive flowback water, which is limited to 1% of average daily flow. Total permitted disposal capacity of these POTWs is less than 0.3 MGD, which is insignificant compared to

Trucks Carrying Frac Water Recovered from Drill Site fill Water Impoundment Site

the quantity of flowback expected over the development of the Marcellus play. Perhaps more importantly, these POTWs are not designed to treat dissolved salts and the majority of TDS passes directly into receiving waterways. The TDS discharge limit for produced water in Pennsylvania is established at 500 mg/L, in part because of concern over the potential for greatly elevated TDS in receiving waters that are already heavily impacted by salts and metals (PADEP 1999).

- Reverse Osmosis. Reverse osmosis (RO) is a well-known unit operation for drinking water treatment and production of high purity industrial water. During RO treatment, water is passed through a semi-permeable membrane under pressure and a treated water of high-quality is produced along with a concentrate that requires disposal. However, treatment of flowback with RO is not considered economically feasible above 40,000 mg/L TDS in the feed water (Cline, Kimball et al. 2009).
- Thermal Distillation/Crystallization. The high concentrations of TDS in flowback water is well suited to treatment by distillation and crystallization (DC) (Doran and Leong 2000). Distillation relies on evaporating the wastewater in order to separate the water from its dissolved constituents. The water vapor stream is condensed to produce the purified water effluent. Distillation removes up to 99.5% of dissolved solids and has been estimated to reduce treatment and disposal costs by as much as 75% (ALL 2003) for produced water from shale oil development. However, as with RO, distillation is an energy intensive process, and water recovery is limited by TDS in the feed stream. It has been reported that thermal distillation may treat flowback water up to and exceeding 125,000 mg/L of TDS, but even the most modern on-site technology may only do so at relatively low rates (80,000 gal/d), necessitating construction of large storage impoundments (Veil 2008). Recent developments include the use of mechanical vapor recompression systems to treat flowback water at a fraction of the cost of conventional thermal distillation. Thermal distillation recovers high quality product water (TDS below 500 mg/L) and produces a concentrated stream with up to 300,000 mg/L TDS, which is well-suited as a feed stream for subsequent crystallization process. The combination of thermal distillation and crystallization will facilitate much higher water recoveries (above 85%), but may produce more than 150 tons of salt per gas well, which must be disposed.
- Other Treatment Options. A variety of other technologies have been developed or are being investigated for treatment of flowback from hydraulic fracturing, including those from coal-bed methane recovery, but may not be appropriate for flowback from Marcellus shale due to the high TDS and variable climate. Falling into this category are ion exchange (Beagle and Dennis 2007) and capacitive deionization (Jurenka 2007), which are limited to treatment of low TDS water; freeze-thaw evaporation (Crystal Solutions 2010), which is largely restricted to colder climates; and evaporation ponds that are best suited for arid climates.
- Water Reuse for Hydraulic Fracturing. The most promising approach for management of flowback water is its reuse for subsequent hydraulic fracturing operations. Flowback is impounded at the surface and used directly, or following dilution or pretreatment for hydraulic fracturing. Reuse is particularly attractive where make-up water is of limited availability or is costly. The option to reuse flowback water has the additional benefit of minimizing the volume of flowback water that must be treated and disposed, thus reducing environmental control costs and risks and enhancing the economic feasibility of shale-gas extraction (Gregory, Vidic et al. 2011). A comprehensive reuse program in a given geographic area that would include flowback water exchange among large and small gas producers would be extremely beneficial in this regard.

Large Water Impoundment Being Sampled

Potentially limiting factors for reuse are the stability of the hydraulic fracture water constituents in brine solutions and the potential for precipitation of divalent cations in the shale formation and the well bore. The development of modifiers that retain their properties in brine solutions is likely to expand the opportunity for flowback water reuse. The divalent cations in the flowback water can form stable precipitates with carbonate and sulfate, and thus represent potential formation and well bore clogging agents if the flowback water is reinjected (Barbot, Li et al. 2010). In particular, barium and strontium form very low solubility solids with sulfate, while high calcium concentrations may lead to calcite formation. Precipitation of minerals in the formation and well-bore could impact gas production from the well, and some pretreatment to reduce concentrations of divalent cations by precipitation may be necessary.

Conclusion

The most feasible option for management of high-strength flowback water from hydraulic fracturing operations in Pennsylvania is recycling/reuse for subsequent hydraulic fracturing. Although environmentally sound, the use of deep-well injection is limited by the well's proximity and capacity. A variety of treatment options exist to produce high-quality water from flowback (RO and DC), but are costly. The recycle/reuse water management solution has rapidly evolved as a result of the unique water quality and quantity issues in Pennsylvania. The major natural gas producers in the Marcellus are striving towards the goal of 100% recycling. Smaller producers have limited capabilities in this regard but should be encouraged to work with larger producers to share flowback and enable synergy among producers to reduce road traffic and eliminate the dilution of flowback into Pennsylvania's waterways.

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Greenhouse Gas Emissions from Marcellus Shale Natural Gas

By Mohan Jiang, Mike Griffin, Chris Hendrickson, Paulina Jaramillo, and Aranya Venkatash
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While climate change due to greenhouse gas emissions is still controversial in some quarters, there is substantial scientific evidence that our global climate is being affected by greenhouse gas emissions. As production from Marcellus Shale natural gas wells begins, several climate change related questions arise: What greenhouse gas emissions are occurring from production and use of this natural gas? How do these greenhouse gas emissions compare to those for other sources of energy? This short paper reports on a study undertaken by the authors to answer these questions for the life cycle of Marcellus Shale natural gas wells (Jiang, Griffin, Hendrickson, Jaramillo & Venkatash, 2011)

Two greenhouse gases are of particularly concern with respect to Marcellus Shale natural gas. First, carbon dioxide is emitted from combustion of the natural gas (in the absence of carbon sequestration processes which are not common) as well as drilling and processing activities for the natural gas. Carbon dioxide is also emitted in clearing existing vegetation to construct access roads and well pads. Second, methane, the predominant constituent of the natural gas, itself is a potent greenhouse gas, so any leakage of methane from the drilling and processing activities will contribute to global climate change. Indeed, the 100-year equivalency factor used by the IPCC suggests that per unit of mass, typical methane emissions have a global warming potential which is twenty-five times higher than a comparable mass of carbon dioxide. We use this equivalency factor to estimate greenhouse gas emissions in carbon dioxide equivalent amounts.

Figure 1. Aerial photo of a Marcellus Well Pad under Development. Photo courtesy of Jay Apt

Our study team built up estimates of greenhouse gas emissions from a variety of sources. For initial construction of a well, we examined the individual processes required to enter production and developed emission estimates for each process for a typical well. For example, preparation of a well pad may require construction of an access roadway (with associated vegetation disruption) and facilities on the well pad (Figure 1). For these estimates, we included not only direct emissions but also indirect emissions arising from the supply chain. For example, offsite emissions from production of additive chemicals for the hydraulic fracturing process are included. For production, processing, transmission and combustion emissions, we used national averages since the Marcellus Shale natural gas is shipped and used with other sources of natural gas. Figure 2 shows the various processes included in our study. Note that processes that are important for well development but do not have greenhouse gas emissions are not included in Figure 2. Examples include land acquisition or obtaining necessary permits.

Different stages of the life cycle contribute significantly different amounts of greenhouse gas emissions. We found that the largest source of greenhouse gas emissions comes from combustion of the methane itself. Combustion with oxygen results in substantial emissions of carbon dioxide. Marcellus Shale natural gas combustion emissions have triple the global warming potential of all other production and pre-production sources.

Production of natural gas, including processing, transmission and distribution, is the second largest source of greenhouse gas emissions, with emissions that are ten times larger than pre-production emissions per unit of natural gas produced. A significant component of these emissions is the methane leakage that occurs from the natural gas industry processes. We believe that initiatives such as the EPA Natural Gas Star program could have significant effects on reducing these leakage emissions.

While pre-production well construction activities have substantial greenhouse gas emissions, they are small compared to combustion and production emissions when spread over all the natural gas produced by a typical well. Surprisingly for us, the largest amount of pre-production emissions came from completion of the well including the initial flaring (burning methane) of a well. If flaring could be either eliminated or shortened by means of gathering pipes or tanks, these greenhouse gas emissions could be reduced significantly.

We also compared greenhouse gas emissions from Marcellus Shale to other fossil fuels. Marcellus Shale greenhouse gas emissions are slightly higher than conventional gas emissions due to horizontal drilling and hydraulic fracturing processes. However, imported liquified natural gas would have slightly larger overall greenhouse gas emissions than Marcellus Shale gas due to the energy cost of liquification and the overseas transportation emissions. If Marcellus Shale natural gas was used for electricity production, it would have lower greenhouse gas emissions per unit of electricity than production from typical coal fired power plants lacking carbon sequestration processes. In contrast, Marcellus Shale gas would have higher emissions than renewable power such as wind generation.

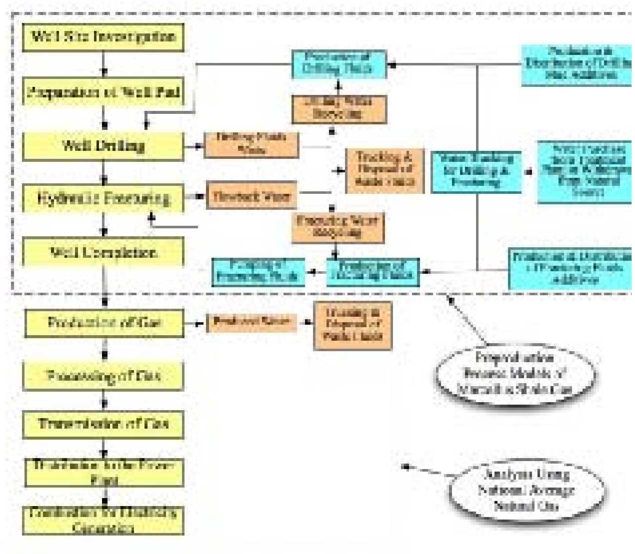

Figure 2. Marcellus Shale Natural Gas Production Processes Included in the Greenhouse Gas Emission Study

Our emission estimates are subject to considerable uncertainty. In particular, the eventual natural gas production from a typical Marcellus Shale well is still speculative. Flaring times vary from well to well. Any leakage from hydraulic fracturing external to the well itself (through disruption of the shale formation) are not included. Access roads may or may not be necessary for particular well pads. However, since the pre-production estimates are so much lower than production or combustion emissions, we are relatively confident that our conclusion is fairly robust regarding the relative small additional emissions due to the special characteristics of Marcellus Shale gas.

Finally, our study only considered greenhouse gas emissions for Marcellus Shale natural gas. There are other environmental concerns for Marcellus Shale gas development which could be considered:

- Water quality impacts from waste water,
- Overall water withdrawals in areas with limited water availability,
- Conventional air emissions from processes such as drilling,
- Disruption of natural habitats, and
- Environmental impacts of additional truck traffic.

While the Marcellus Shale gas development can provide substantial economic benefits, it would be prudent to eliminate or reduce these environmental costs through good practices and regulatory requirements.

Author Biographies

Mohan Jiang is a doctoral student in the Department of Civil and Environmental Engineering at Carnegie Mellon University. Her other degrees include a Master of Science in Civil and Environmental Engineering from Carnegie Mellon (2010) and a Bachelor of Science in Environmental Engineering from Tsinghua University (China) in July 2009.

Mike Griffin is the Executive Director of the Green Design Institute and a research faculty member in the Tepper School of Business and Engineering & Public Policy at Carnegie Mellon University. His current research interests center on the environmental impacts of production of chemicals and fuels via fermentation from renewable resources and the biodegradation of materials

Chris Hendrickson is the Duquesne Light Professor of Engineering and Co-Director of the Green Design Institute at Carnegie Mellon University. A member of the National Academy of Engineering, his is research, teaching and consulting are in the general area of engineering planning and management, including design for the environment, project management, transportation systems, and finance.

Dr. Paulina Jaramillo has a bachelor's in civil and environmental engineering from Florida International University (2003), as well as a master's and PhD in civil and environmental engineering with an emphasis in green design from Carnegie Mellon University (2004 and 2007, respectively). Her past research has focused on life cycle assessment of energy systems with an emphasis on climate change impacts and mitigation research. As a professor at Carnegie Mellon University, she is involved in key multi-disciplinary research projects to better understand the social, economic and environmental implications of energy consumption and the public policy tools that can be used to support sustainable energy development and consumption.

Aranya Venkatesh is a doctoral student in the Civil and Environmental Engineering Department at Carnegie Mellon University. She has a bachelor's degree in Chemical Engineering from the University of Mumbai (2007) and a master's degree in Civil and Environmental Engineering from Carnegie Mellon University (2009). Her research examines uncertainties in the life cycle assessment of energy technologies. PE

Writer's Note: For readers interested in delving into the issue of climate change, accessible reviews include Donner and Large, 'Climate Modelling', Annual Review of Environment and Resources, Vol. 33, 2008 and 'The Science of Climate Change,' The Economist, March 20, 2010.

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Air Emission Issues Associated with Marcellus Shale Gas Development

By E. Joseph Duckett, Ph.D., P.E.

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Natural gas, the product of Marcellus Shale drilling, is the cleanest among fossil fuels. Its principal component is methane which, when combusted under ideal conditions, produces only carbon dioxide and water vapor. On an energy release basis, carbon dioxide emissions for natural gas combustion are approximately 30% lower than those from fuel oil combustion. Natural gas is considered such a clean fuel that, under recently issued new federal regulations for hazardous air pollutant (HAP) emissions from industrial boilers, natural gas-fueled units are exempt from adding new control equipment (US Environmental Protection Agency, 2011)

Despite the positive attributes of natural gas as a fuel, environmental concerns have been raised about the process of drilling, cleaning, compressing and transporting it. As reflected by the other articles in this issue of Pittsburgh Engineer, most of the environmental attention on the Marcellus Shale gas drilling industry has focused on water-related issues. There have, however, also been questions raised about whether drilling for Marcellus Shale gas will affect air quality.(Volz, Michanowicz, Christen Malone & Ferrer, 2010) (Hopey, 2011) These air emission concerns can be grouped into four major categories, namely:

- Mobile source emissions from vehicles transporting materials and equipment to and from the gas sites;
- Stationary source emissions from engines used to generate electricity, drive equipment and compress gas;
- Volatile organic compound (VOC) emissions from vapor flaring; and
- Leaks from piping, equipment, tanks and storage ponds.

Mobile Source Engine Emissions

There is nothing unusual about the vehicles (primarily trucks) used in Marcellus Shale drilling, extraction or distribution processes. Like all motor vehicles, emissions are regulated by national US EPA standards. For the gas industry, vehicles are typically powered by large diesel engines, a category of air emission sources for which standards have recently been tightened. Allowable emissions of nitrogen oxides (NOx), from new heavy duty highway vehicles are now required to be only 5% of the 2003 limits (US EPA, 2011).

Stationary Source Engine Emissions

Because many gas well sites are remotely located, on-site equipment usually can't be driven by utility electric power. Instead, major items of equipment (for drilling, pumping and compression) are driven by stationary engines and turbine-generators. These are typically fueled with diesel oil during the drilling process (until the well starts producing natural gas) and then natural gas engines are used. All of these engines are required to meet US EPA standards for large off-road engines. Like the standards for mobile engines, these have been tightened to restrict emissions of oxides of nitrogen (NOx), volatile organic compounds (VOC's), carbon monoxide (CO) and fine particulates (PM2.5) (US EPA, 2004.)

Flaring

Flaring is the controlled combustion of flammable vapors. Flaring is actually a form of air pollution control for gases that would otherwise escape directly into the air. Flares are commonplace in any industrial process that has the potential to release vapors, such as steel mills, municipal wastewater treatment plants, oil refineries and gas wells. Flaring is intended both to relieve excessive gas pressures and to destroy (by combustion) organic pollutants in the gases.

To the extent that combustion is incomplete, flares always have the potential to emit VOC's. For the gas industry, there are at least two strong incentives to minimize flaring. First, flared gas represents a loss of product. Secondly, flares are large open flames with the potential to ignite gas site fires; minimizing flaring minimizes safety risks.

Leaks

During the drilling, completion and production processes (including dehydration), there is potential for chemicals drawn to ground level with the gas product or drilling mud/fluids to escape into the air. The presence of organic chemicals in process water and mud from gas drilling is not surprising. After all, the natural gas is being withdrawn from an organic repository more than a mile below ground. Tests of drilling fluids (e.g., produced water) have detected carboxylic acids, ketones, alcohols, propionic acid, acetone and methanol (Veil, Puder, Elcoch & Redweik, 2004.) Emissions of benzene, toluene, ethyl benzene and xylenes are low compared with oil wells because these compounds do not exist in significant quantities in the natural gas stream (US Department of Energy.) Also, these organics tend to have relatively low air-water partitioning ratio (Henry's Law constants all less than 1.0) indicating that their airborne concentrations would be low relative to their concentration in water (Lawrence, 2006.)

Hydraulic fracturing water returned to the surface can contain additives. Chemicals are added to hydraulic fracturing fluids as friction reducers, scale inhibitors and antibacterial agents (Range Resources, 2010.) Among the organic components of these additives are ethylene glycol, gluteraldehyde, polyacrylamide, ethanol and methanol (PA Department of Environmental Protection, 2010.) In total, these typically comprise less than 0.2% of the aqueous mixtures (Range Resources, 2010.)

Fugitive VOC emissions can also occur at gas processing/fractionation facilities which have been regulated since the mid-1980's by a federal New Source Performance Standard.

Although the presence of organic chemicals in drilling fluids and VOC emissions during gas processing has been demonstrated, the environmental health hazard significance of these air emissions has not. To address the significance issue, the Pennsylvania Department of Environmental Protection (DEP) tested actual air quality at several separate Marcellus Shale sites. Air monitoring was conducted at completed and operating gas wells, compressor stations and wells being hydraulically fractured. DEP's conclusion was that their testing showed "no emission levels that would constitute a concern to the health of residents living near these operations" (PA DEP, 2010 and PA DEP, 2011.) Similar measurements at Barnett Shale gas facilities in Texas have also reported "all 84 target VOC's were either not detected or were detected below their respective short-term air monitoring comparison values" (Ethridge, 2010.) The PA site testing did detect measurable concentrations of some organic compounds but not at levels that would trigger air-related health "issues". No concentrations of nitrogen dioxide, sulfur dioxide, carbon monoxide or ozone were above National Ambient Air Quality Standards at any of the sites. Methyl mercaptan, a gas with a rotten egg smell, was detected at levels high enough to produce odors (about one part per billion).

Probably the biggest current controversy concerning air emissions from Marcellus Shale gas operations is how such operations should be treated for permitting purposes

Aggregation

Probably the biggest current controversy concerning air emissions from Marcellus Shale gas operations is how such operations should be treated for permitting purposes. Most industrial facilities are permitted individually based on the emission sources at one location. In December 2010, PA DEP published a Technical Guidance Document that could have grouped multiple gas facilities together for permitting purposes (PA Bulletin, 2010.) This is termed "aggregation" of sources. If applied to Marcellus Shale gas facilities, it would raise significant questions about how extensively such aggregation would be applied. Many gas facilities are interconnected by pipelines even when miles apart. The DEP aggregation Guidance Document was rescinded in February 2011, and the issue has been re-opened for public comment as the DEP decides whether to aggregate gas industry sources (PA Bulletin, 2011.) Generally, the aggregation of sources makes the permitting process more difficult.

Improvements

The companies and regulatory agencies involved in Marcellus Shale development continue working on ways to reduce air emissions. New stationary engines are now predominantly low emitting rich-burn, gas-fired engines and new gas turbines are being required to use dry low-NOx combustion (PA Bulletin, 2010.) Efforts are under way to reduce truck traffic by connecting gas operations with pipelines wherever feasible. The extension of electric power lines to well sites would lessen the need for on-site generators. Flare controls and leak minimization are being adopted. The variety and concentrations of organic chemicals in hydraulic fracturing fluids are being reduced. Ultraviolet light disinfection is being considered in order to reduce or eliminate the need for antibacterial agents in drilling fluids. Low bleed valves and leak detection programs are intended to minimize fugitive releases. At least some gas companies have adopted so-called "green completion" techniques to reduce emissions as the wells are transitioning from drilling to production.

Summary

In summary, although Marcellus Shale drilling, completion, production and compressor operations will release air pollutants, the evidence to date is that these releases are not resulting in any short term health significance or violations of any ambient air quality standards. On balance, natural gas from Marcellus Shale appears to be a definite air quality plus.

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HYDROLOGY AND GEOLOGY IN THE MARCELLUS SHALE REGION

THE OCCURRENCE OF GROUND WATER IN PENNSYLVANIA AND HOW IT IS RELATED TO GAS RESOURCES IN THE MARCELLUS SHALE.

By Lawrence Murdock

Ground Water in Western Pennsylvania

Ground water saturates the pores of sediments and rock from shallow depths downward. Some of those rocks are permeable enough to form productive aquifers, which can be important water supplies for industry, towns and individual home owners. Productive aquifers occur locally as sands and gravels along rivers, but most wells are drilled into sedimentary rock, which is a roughly flat-lying sequence of sandstone and shale with some interbedded coal and limestone. The sandstone beds are typically the most permeable, although shales and coals can be productive aquifers where they are naturally fractured (Trapp & Horn, 1997).

Permeable rocks are required for water to flow to a well fast enough to provide an adequate supply, but acceptable water quality is also essential for water supply. Even though fresh ground water is widespread in western Pennsylvania, it only occurs at shallow depth. Wells deeper than 50m to 100m generally encounter water with salt concentration that is unsuitable for drinking. This happens because fresh water is recharged to shallow aquifers through a continuous process of infiltration of rain water that circulates through the subsurface to nearby streams. These vigorous circulation pathways are less than 100m deep in western Pa, and water deeper than that flows remarkably slowly so it has ample time to dissolve salts from the rocks (Trapp & Horn, 1997). Salts can be dissolved from many rock types, but western Pennsylvania is underlain by beds of halite, the mineral used for table salt, which causes particularly high salinities in ground water.

Water density plays an important role in keeping shallow aquifers fresh. Density increases with salt content, so shallow fresh water is literally floating on the deeper saline fluids. Density contrast allows the salt water to remain segregated at depth and not contaminate shallower wells. This delicate balance can be upset by excessive pumping from shallow aquifers, which draws the saline water up from below where is can foul water supply wells.

In some locations it is the density contrast alone that controls the depth of fresh water, but in other locations permeable sandstones are underlain by tight shales that restrict circulation of groundwater. Low permeability rocks, like shales, are called confining units because they generally confine flow to either underlying or overlying rock formations and don't permit flow through them.

Marcellus Shale

The Marcellus Shale forms a layer up to 50m thick that underlies much of western Pennsylvania and extends into New York, West Virginia, and some neighboring states (Fig. 1). The Marcellus Shale has been warped into a broad trough-like form, which is why it can be seen at the ground surface around the edges of its range, but is buried at depths of 1-2 km in most places (deWitt, Roen & Wallace, 1993). This rock unit was deposited as organic-rich mud in a shallow sea, which spanned from eastern New York to Ohio roughly 380 million years ago. It was buried under several km of sediment and the pressure and temperature created by this burial lithified the mud to shale, and created methane from the longer-chain organic molecules deposited with the sediment (deWitt et al., 1993).

Hydrologist would call the Marcellus Shale a confining unit, because its low permeability restricts water flow to meager rates. Methane (natural gas) also flows through the Marcellus Shale only very slowly, and this is important because it means that much of the gas that was created in the shale never flowed away and remains trapped there today. Narrow vertical fractures cut across the

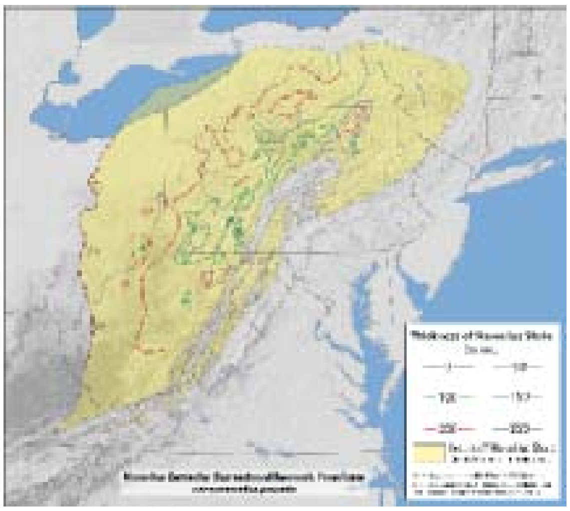

Figure 1. Thickness in ft and extent of Marcellus Shale. From Penn State Center for Marcellus Research and Outreach. http://www.marcellus.psu.edu/

Marcellus and slightly increase the bulk permeability, but they are isolated from each other so the overall effect of the natural fractures on the migration of natural gas under ambient conditions is relatively minor. Volumes of methane estimated in the Marcellus Shale are currently on the order of 1.6 $x10^{14}$ ft^3 and $5x10^{14}$ ft^3, according to Terry Engelder (http://www.geosc.psu.edu/~jte2/), a geosciences professor at Penn State. This makes it one of the largest gas reservoirs in the U.S.

Density plays an important role in the migration of gas, just as it affects the movement of fresh and salt water. Gas flows upward and it can accumulate in geologic structures that trap upward migration. Even though gas is released from the Marcellus at slow rates, the release rate is fast enough to create pockets of gas in geologic structures in the overlying rocks. Naturally occurring zones of gas have been intersected by water wells at depths of 15 to 130 m overlying the Marcellus Shale in New York (Williams, 2010). PE

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Potential Ground Water Problems with Gas Production from Shale in Southwestern Pennsylvania

By Lawrence Murdock

The past few years have seen a modern day boom in gas drilling in western Pennsylvania and neighboring states as energy companies scramble to capitalize on huge reserves recently recognized in the Marcellus Shale. This boom will create many opportunities as the regional engineering community supports the energy industry, but it has the potential to create environmental problems associated with ground water contamination. This article provides an overview of the hydraulic fracturing process and the potential issues related to groundwater.

Drilling, Hydraulic Fracturing and Gas Production

The Marcellus Shale has been known for decades to contain large quantities of natural gas, but the technology of the day was unable to recover gas economically from this low permeability formation (Harper, 2008). Recent advances in horizontal drilling and well stimulation technology have changed that. Horizontal drilling involves boring a vertical hole to within several hundred meters of the top of the shale and then gradually curving the bore until it is horizontal where it intersects the shale. The well is then extended a km or more horizontally within the Marcellus Shale. This long length of wellbore in the shale increases production of gas. Horizontal wells are particularly beneficial because they can be oriented to intersect many dozens or hundreds of natural vertical fractures, whereas a conventional vertical well may miss vertical fractures altogether (DOE, 2009).

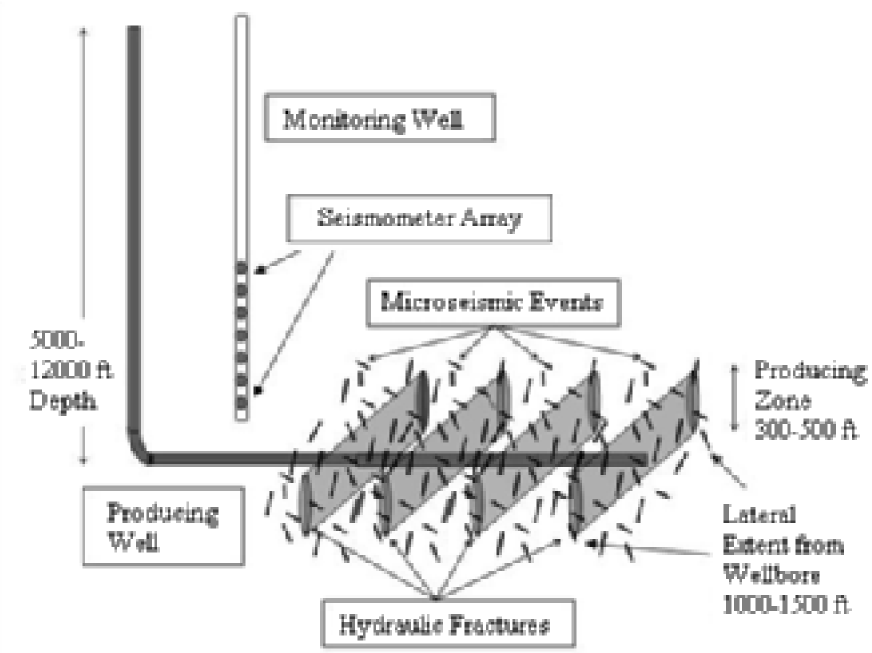

Figure 1. Schematic of hydraulic fractures enveloped by a zone of shear fractures along a horizontal well. Microseismicity from the shear fractures is used to monitor propagation. From Zoback, et al. 2010.

Hydraulic fracturing is a process of cracking rock or sediment to increase the flow of fluids to a well, or to cause other desirable effects. The technique involves injecting fluid into an existing well until the pressure exceeds a critical value and a fracture is nucleated at the wellbore. The fracture will grow in a direction normal to the direction of minimum compressive stress in the rock, and the stress state at depth means that hydraulic fractures will typically be vertical in the Marcellus Shale. Sand is mixed with the fluid and injected into the vertical fracture as it grows away from the wellbore. The walls of the fracture will tend to close after injection, but the sand props them open to maintain permeability. The injected fluid can also elevate water pressures in the vicinity of the fracture. This drops the effective stress and can cause small amounts of slip along existing fractures, which further increases the permeability of the shale. The net effect is a roughly planar vertical feature filled with sand that is enveloped by a broader region where the permeability is increased by small amounts of shear (Zoback, Kitasei & Copithorne, 2010).

The size of a hydraulic fracture increases with the volume of injected fluid. A typical injected volume in the Marcellus Shale is roughly 10^4 m^3 (half million of gallons). Monitoring data indicate that this creates a fracture that extends 500 m or more in maximum dimension, spans the full height of the formation (~50m or more), and is flanked by a zone a few hundred meters across where shearing occurs (Fig. 1; Zoback et al, 2010; DOE 2009). This is a substantial volume of affected rock, but horizontal wells are long enough so that several, to a dozen or more, hydraulic fractures may be created as separate stages along a single well.

Most hydraulic fracturing fluids are largely water with chemical additives to suspend sand, reduce friction during pumping, block microbial fouling, and cause other effects that improve the ability of the fracture to recover gas. The basic composition of additives used for hydraulic fracturing are well known (Arthur, Bohm & Lane, 2008), but each fracturing company uses proprietary mixtures to improve performance under specific site conditions, so there is considerable variation in the compositional details of these fluids.

Some of the injected fracturing fluid flows back out of the well after injection (15-80%). The fracturing fluids mix with formation water, so the composition of the flowback varies from that of the injected fluids to the native brines. Both the flowback water and the fluids used during the drilling process are considered wastes. These fluids must be removed from the well site as it is brought into production.

Potential for Ground Water Problems

Drilling a horizontal well and creating hydraulic fractures in the Marcellus Shale involves a substantial array of industrial equipment, and thus, this process has the potential contaminate both ground water and surface water. Spills and leaks of fracturing fluid and flowback water from surface operations could cause contamination if they are improperly managed. Runoff from areas recently cleared for well drilling can lead to excess sediment accumulation in streams. The potential for problems with surface water is significant, but these problems are familiar to the environmental community and strategies for managing and regulating them are known. Subsurface issues are potentially more problematic because the environmental industry and regulatory community are less familiar with processes associated with gas production from shale.

This is changing rapidly, however, as the US Environmental Protection Agency gears up for a comprehensive investigation of hydraulic fracturing in shale formations (USEPA 2011). The upcoming study was prompted by a variety of reports of problems with water quality in the vicinity of the Marcellus Shale, and similar gas-bearing shale formations elsewhere in the U.S. Drinking water wells have been reported with elevated concentrations of benzene, other dissolved organic compounds and metals, as well as alarming occurrences of natural gas with accompanying explosions. Water quantity problems are also a concern as energy companies look to draw the large volumes required for drilling and fracturing from the local ground water and surface water.

Several scenarios associated with gas production have been identified that could cause ground water contamination. First, well casings could leak chemicals during hydraulic fracturing or later during gas production. Well casings are sealed into boreholes with cement, but problems during the cementing operation may cause an incomplete seal and subsequent leakage.

The hydraulic fracturing process itself has the potential to cause contamination if chemicals injected into a hydraulic fracture find their way into fresh ground water, or if the fracturing process releases contaminants from the shale. Some chemicals used in hydraulic fracturing are potentially hazardous, and the general secrecy of the ingredient list raises concern that hazardous chemicals that are currently unknown may also be finding their way into hydraulic fractures. Shales will be both mechanically and chemically altered by hydraulic fracturing, and this may release contaminants. Methane is released naturally from the Marcellus and it seems reasonable to expect that hydraulic fracturing could also release methane that migrates upward to contaminate wells. The large organic fraction that is responsible for gas generation in shale traps uranium and other metals. Indeed, a large spike in natural radioactivity on a well log is a signature of gas-bearing shale. However, changing the redox state by injecting large volumes of oxidizing water during hydraulic fracturing may mobilize naturally occurring radionuclides or other metals.

These processes could contaminate overlying aquifers, but the relevant compounds would have to move upward by 1 km or more through confining units before they contaminated overlying fresh water aquifers. Not only must they traverse a long flow path, but contaminants would have to flow against downward ambient flows that occur once horizontal wells are put into production. These factors likely isolate fresh water aquifers from effects of gas production at many locations. Significant upward migration may be possible if there is upward propagation of a hydraulic fracture out of the Marcellus and into overlying formations, a process that could occur if the hydraulic fracture encounters a fault or is driven upward by buoyancy or stress gradients. Diesel fuel has been injected to create some hydraulic fractures, and this light non aqueous phase liquid would float upward and could potentially escape the influence of a horizontal well before it came on line.

Thus, it is possible to identify scenarios where contaminants introduced by the drilling and fracturing process could reach overlying aquifers, but little research has been done to determine if these scenarios are plausible or how to prevent them from occurring. It will be important to fill these gaps in understanding to better protect our ground water resources. The Marcellus Shale is underlain by the Utica shale (http://geology.com/articles/utica-shale/), which may hold a reservoir of gas that rivals the Marcellus, so it seems likely that gas production from shale will be an important part of the landscape in western Pennsylvania for the foreseeable future. PE

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The Shale Gas Imperative

by John W. Ubinger, Jr. and John J. Walliser

The natural gas trapped in the Marcellus and other shales offers opportunities and challenges to regulators, producers, landowners, local governments and their residents, and citizens of the Commonwealth at large. While the economic benefits and bridge fuel positives are touted; the imperative questions to address revolve around how we all can ensure that the development of the shale gas is done in the least impactful way possible.

The challenges include the assessment and mitigation of cumulative impacts of development on both human health and the environment; issues surrounding impacts to local communities including truck traffic, short-term population spikes, and localized inflation; the effective regulation of fresh water withdrawals; the need for alternatives to treat, dispose or recycle flowback water from hydraulic fracturing; and the establishment of a reasonable severance tax, both in terms of tax rate and revenue allocation.

The industrial process known as "unconventional shale gas development" has evolved impressively in Pennsylvania over the past three years. Several leaders in the industry have already come a long way in adapting their well development practices, but the performance of the industry as a whole remains uneven. At the Pennsylvania Environmental Council (PEC), we believe that the yet-to-be resolved issues relating to shale gas development require the Commonwealth to continue with an aggressive "adaptive management" approach to regulation. In other words, it is imperative that our government incentivizes where possible, and pushes if necessary, the entire industry toward better practices that reduce impacts to the environment and human health, and that agency regulation, guidance, and permit processes reflect this commitment and philosophy.

For example, we believe that more needs to be done to gather and evaluate data during the permit process, the well development process, and the production phase. We will soon be proposing to the Department of Environmental Protection (DEP) and the General Assembly a series of recommendations that, if implemented, will greatly improve the ability of the industry and the Commonwealth to comprehensively plan not only the location, baseline data, and impacts of drilling, but also look to reducing the impacts of midstream operations which have, to date, received relatively little attention.

We also believe that there is a need for better information for landowners as they enter into the leasing process. This is especially true for those landowners who wish to protect conservation values of their land. While regulations apply across the board and set the floor for operating protocols, companies can and have gone much further with their practices. Therefore it is possible for landowners, as they negotiate lease terms with production companies, to achieve commitments for best practices and further the goals of adaptive management.

The development of shale gas will be with Pennsylvania for the next century and, like every extractive industry before it, it will impact and alter the landscape. We are still early enough in the growth of this industry that we can hope to get it right this time, before the impacts have amassed. We are off to a good start, but need the Administration, the General Assembly, the industry, and all the interested parties to hold protection of human health and the environment as goal number one as policies are developed. PE

Jack Ubinger and John Walliser are co-authors of PEC's July 2010 report entitled: "Developing the Marcellus Shale: Environmental Policy and Planning Recommendations for the Development of the Marcellus Shale Play in Pennsylvania." and are coordinating PEC's Marcellus Shale policy initiatives.

The Economic Impact of Marcellus Shale

by Dennis Yablonsky

As we enter the second decade of this century, Pittsburgh finds itself sitting atop one of the most talked-about energy sources in the world – the Marcellus Shale.

At a time when global energy demands are projected to increase by at least 35% by 2030, we have a unique opportunity to combine our energy-related assets with historic manufacturing expertise and realize economic growth across our ten-county region.

Location has made us rich in a portfolio of energy resources from traditional to alternative energy sources to energy systems and distribution to green building. But it is through innovation and collaboration that southwestern Pennsylvania has become an energy leader.

We began mining coal here in 1760. A century later we were the first to refine petroleum and to drill a commercial oil well. Pittsburghers built the first natural gas pipeline, perfected the electric grid, commercialized nuclear power and developed air emissions control technologies. Now we are wrapping our arms around the Marcellus Shale, a vast natural gas play stretching across much of New York, Pennsylvania, Ohio and nearly all of West Virginia, which geologists say is the second largest proven gas reserve in the world.

Because of our long history of working together as researchers at universities, entrepreneurs, and civic and community leaders, we are well prepared to use this discovery to our advantage. We are already beginning to reap some of those benefits.

Our region already has more than 700 supply-chain providers in the energy industry, supporting some 105,000 direct and indirect jobs, and generating $13.7 billion in annual economic activity, according to a 2009 study by the Pennsylvania Economy League of Southwestern Pennsylvania.

More than $1 billion flows through the region annually in public and private energy innovation funding through the region's universities, corporate facilities and federal labs such as the National Energy Technology Laboratory (NETL), which is located here and is one of only a few facilities in the country dedicated to fossil fuel research.

A summer 2010 workforce-needs assessment funded by the Pennsylvania Department of Labor and Industry found that for each well drilled in the Marcellus Shale, 410 individuals working across 150 job types are needed. Multiply that by the 1,440 wells drilled in 2010, and the potential economic impact of the shale becomes apparent.

During the recent recession, oil and gas activity made natural resources the region's fastest growing industry. While other industries held steady, made moderate gains or saw losses, employment in the natural resources industry grew by 41 percent from 2007 to 2010. Between 2007 and 2009, the greatest gains in employment were in drilling oil and gas wells – 35 percent growth – and in support activities for oil and gas – 34 percent growth. Double-digit growth occurred in pipeline transportation (22 percent) and in oil and gas extraction (15 percent) as well.

Penn State's Cooperative Extension Marcellus Education Team found that state sales tax collections from counties with significant Marcellus drilling activity increased by more than 11 percent between 2007 and 2010, while those with no such activity decreased by more than 6 percent. State tax collections of the personal income tax and realty transfer tax followed similar patterns.

A study commissioned by the Marcellus Shale Coalition estimates that that Marcellus drillers generated $785 million for the state last year through corporate taxes and employee-paid income tax and sales tax.

The majority of shale-related business expansions have occurred in the past two years. These expansions are becoming more diverse, encompassing not just extraction activities but support services, administration, advanced manufacturing and business services (such as banking, legal and accounting services) as well. This growth has touched most of our region with Allegheny, Fayette and Washington counties seeing concentrations of activity in administration, distribution and business services, respectively.

To connect southwestern Pennsylvanians with the growing number of Marcellus Shale jobs, the Allegheny Conference helped launch Marcellus ShaleNET, a comprehensive recruitment, training, placement and retention effort. A nearly $5 million grant from the U.S. Department of Labor is being administered by the Westmoreland County Community College and the Pennsylvania College of Technology to help guide interested and qualified workers across Pennsylvania, Ohio and West Virginia into the thousands of well-paying jobs the gas boom is creating.

As civic and private-sector partners in ShaleNET, the Allegheny Conference and the Pennsylvania Independent Oil and Gas Association have devised a comprehensive network that is ramping up recruitment and training, while ensuring that individual regions can respond flexibly to rapidly changing workforce needs.

Another innovative initiative is the Energy Alliance of Greater Pittsburgh, a gathering of global leaders in material science and intelligent building technologies, academic research, and traditional and alternative energy companies. Sometimes these stakeholders compete with each other; instead, they are working together to identify the best possible energy solutions for the future. This type of unusual collaboration makes a strong case for energy-related business investment in southwestern Pennsylvania: companies are likely to locate in a region where there's demonstrated proof that many are pulling in the same direction to maximize the potential of an opportunity such as energy.

While the benefits of the Marcellus Shale boom are many, the costs must also be considered. Community leaders have raised concerns about the possible environmental and infrastructure stresses that such drilling could place on our region, and their concerns deserve to be heard and addressed. Discussions continue about how to balance energy policy, regulation and impact across the Commonwealth.

Here in southwestern Pennsylvania we know well the cost of environmental remediation. We must continue to advance our global leadership in improving our environment by addressing the development of the Marcellus Shale in a productive and responsible manner.

By working together – businesses, government, researchers and educators, landowners and residents -- we can make the most of this opportunity without sacrificing the distinctive quality of life and place of which we're rightfully proud. Through innovation and collaboration, we can make sure that the benefits of the Marcellus Shale pay off for everybody. PE

Dennis Yablonsky is the CEO of the Allegheny Conference on Community Development

Water Reuse Considerations for Marcellus Shale Development

By Pete Miller and Tim Svarczkopf

Over the past few years, much has been made about the economic opportunities that the Marcellus shale has brought to the region. Of equal importance to those opportunities are the environmental and process innovations that have been developed in the Marcellus due to Pennsylvania's environment and stringent regulatory framework. One such innovation is the advancement of processes and infrastructure that allow operators to continuously reuse water. Range Resources and Atlas Energy, recently acquired by Chevron U.S.A., Inc., have taken leadership roles to pioneer the implementation of these processes and infrastructure.

There are seven major factors to be considered when creating an effective and successful water reuse program, they are:

- Characterize the water to be utilized based on the water balance;
- Determine the target formation's geochemistry;
- Define flowback and produced water treatment strategies;
- Develop a fracturing fluid chemistry design that is compatible with the treated water and the formation geochemistry;
- Develop a completion engineering design to complement the treated water, formation geochemistry, and rock mechanics;
- Coordinate logistics to minimize infrastructure requirements and ensure cost-savings;
- Conduct a comprehensive compatibility analysis that integrates all of the aforementioned components.

The intention of this paper is to define the water balances associated with hydraulic fracturing from an operator's perspective and to review the considerations required to institute an effective water reuse program. Each of the seven major factors are worthy of technical review that is beyond the scope of this paper so we will only briefly describe them here.

Water Impoundment Pond. Photo Courtesy of Range Resources.

The Water Balance

To establish an effective water reuse program the operator must first understand the water balance. For Chevron's current completion schedule of one well per week, each fracture stimulation operation is designed to use a mixture of approximately 39 percent recycled water (flowback/produced water combination) and 61 percent fresh water in order to achieve the goal of 100 percent reuse of all of the company's flowback and produced water. It should be noted that Atlas has been engaged in completing natural gas wells in Pennsylvania since 1968 and thus has more produced water available than most operators.

For Range Resources' current completion schedule of 2.8 wells per week, each fracture stimulation operation is designed to use a mixture of approximately 19 percent recycled water (flowback/produced water combination) and 81 percent fresh water to achieve the 100% water reuse goal.

Atlas Energy internally developed a patent-pending process to address the challenges of implementing a water reuse policy that Chevron continues to use today. As of December 2010, Atlas was reusing 100 percent of its flow back water and 71 percent of its produced water while utilizing the patent-pending process. Today, Chevron has a goal to achieve 100 percent produced water reuse and 100 percent flowback water reuse by the end of 2011.

Range Resources holds the distinction of being the first operator in the Marcellus Shale to initiate a recycling program; collecting recycled water since January 2009 and completing their first well utilizing recycled water in August of 2009. Range Resources relies on simple, cost effective, and market proven technologies to condition flowback and produced water for reuse. For the calendar year 2010 Range Resources reused 95.7% of flowback water and 54.3% of produced water; 99% of the produced water not reused was sent to salt water disposal wells. Range Resources targets reuse rates of 99% and 85% respectively for flowback and produced water in 2011.

Characterizing All Water Sources Based On the Water Balance.

As previously described, understanding the water balance is of paramount importance in characterizing the contributors to the ultimate blend of water to be used. Water characterization is dependent upon a relevant sampling protocol, sample preservation protocol, a full a full analysis of anions, cations, and other testing protocols relevant to end use.

Defining Formation Geochemistry

It is not enough to characterize the water sources used to conduct hydraulic fracturing operations. The formation water and geochemistry should be defined to determine what potential interactions can occur with the water utilized and fracturing fluid chemistry deployed. Formation geochemistry can vary widely throughout the play.

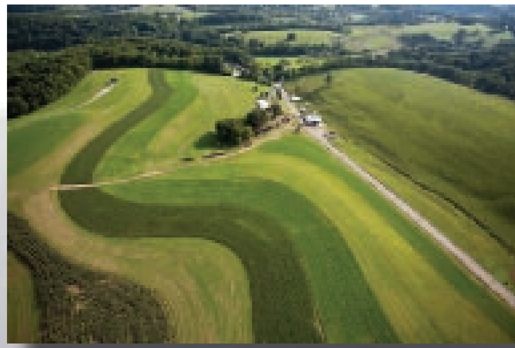
Flow Back and Produced Water Treatment Definition

Shale reservoirs are termed unconventional since they have ultralow permeability. A key principal in Range Resources reuse program is that, before fracturing, the Marcellus Shale does not contain any mobile water. Therefore any water recovered from the well is the original source water used in fracturing operations.

Chevron believes there is potential to connect to mobile water in the Huntersville Chert. A key belief of Chevron is that within their flowback they have the polymeric suspension that should be broken in order for reuse to be successful. Reuse of flow back water without breaking the polymeric suspension may result in blinding of critical gas migration pathways. There are many proven processes available for breaking the polymeric suspension including clarification and filtration. Of the technologies that do work, great care must be made to understand the potential interactions that can happen as the result of the treatment. Some treatments result in residual sulfate, pH, or metals incompatibilities, for example. The treatment techniques must result in a water quality that is compatible with the fracturing fluid chemistry deployed and the formation.

Fracturing Fluid Chemistry Design

Many companies have voluntarily reduced the number of Material Safety Data Sheet (MSDS) Section 2 listed components in their fracturing fluid formulations. Range Resources and Chevron are leaders in voluntary disclosure of fracturing fluid chemicals deployed.



Reclaimed Well Pad Site. Photo Courtesy of Range Resources.

Various chemical formulations can be utilized in hydraulic fracturing. PADEP has listed a comprehensive list of the many possible additives on their website. In reality, for a simplified slick water fracture treatment, only a handful of additives are required. For Range Resources, a typical additive package consists of diluted volumes of friction reducers, scale inhibitor, a biocide, and in some treatments, a diluted hydrochloric acid package. For Chevron, the additive package also typically consists of diluted volumes of friction reducers, scale inhibitors, a biocide and in all cases a diluted hydrochloric acid package. For both operators, typically 99.9% of the frac fluid is water and sand. Utilizing acid mine drainage for hydraulic fracturing represents a significant opportunity to improve Pennsylvania surface water quality. Due to high sulfate levels, increased use of mine water can change the fracturing fluid chemistry formulation requirement in order to be fit for purpose.

Completion Engineering Design.

There are numerous considerations where completion engineering design is concerned. The fracturing fluid friction reducer design has to match the operator's desired velocity at the perforations. This velocity is dependent on a variety of factors including rock properties, perforation efficiency, near wellbore effects, and far field effects. The mechanical properties of the shale can vary widely throughout the Marcellus play. The viscosifier has to match the carrying requirement for the specific proppant and proppant concentration desired.

Logistics

Having an on-site water reuse process allows operators to transport flowback and produced water to other local fracturing operations via direct piping or trucking. This avoids transporting flow back or produced water to centralized treatment facilities, thereby reducing water transportation. The cost of transporting water utilized for hydraulic fracturing is one of the highest cost activities encountered by the operator. Not only are there direct costs associated with water transportation, but there are also a myriad of indirect and intangible costs associated such as; road repairs, increased traffic on rural road, air emissions, and safety concerns. Given that produced water is only generated at 2 to 20 barrels per day from many different wells, a well program and site design that facilitates local collection and reuse of the water is important to reuse economics. An equally important benefit of lowering water transportation is minimizing environmental and community impact.

Final Compatibility Analysis

There may be chemical compatibility issues that arise when developing a reuse program and thus different considerations are made depending upon an operator's technical philosophy. For example, Range Resources believes that there are three key compatibility considerations for source water used in fracturing operations: Scale potential, bacteria, and permeability issues. With regard to scaling, as previously discussed Range Resources believes that there is essentially no mobile water contained within the Marcellus Shale and therefore many of the typical scaling mechanisms are not present; the remaining potential can be mitigated using minimal amounts of scale inhibitor. The second consideration is potential for biological growth and fouling; bacterial growth is controlled through the use of biocides. The final consideration is that the Marcellus shale has extremely low permeability; the pores within the shale are so small that they are virtually impossible to plug off with water-based particulates.

Based on these considerations, Range Resources believes that the Marcellus Shale is extremely forgiving with respect to completions water quality in general and readily facilitates a reuse program with minimal source water conditioning.

On the other hand, Chevron has determined that more than half of its completions in vertical Marcellus wells produced free formation water from connection to the Huntersville Chert. In this circumstance, the treatment technique for flowback and produced water should produce a final water product that is compatible with the other water sources utilized, the formation water, the formation geochemistry, and the fracturing fluid chemistry deployed. Chevron has found that simple Langelier Saturation Index (LSI) calculations on the pre-frac water to model scale only take into account potential for carbonate scales when the risk of barite scale formation is the highest risk Chevron encounters. Therefore, Chevron uses more thorough scale models to adequately model compatibility. The pre-frac water should be modeled for compatibility with the formation water in such calculations. Fracturing fluid additives should be tested for compatibility with each other, with formation water, and at formation conditions. Break down properties should be determined for friction reducers as some friction reducers may form gels at formation conditions that have the potential to foul critical gas migration pathways.

Conclusion

In summary, there are seven major considerations that need to be made to in order to create an effective water reuse program.

Although Chevron and Range Resources each use different techniques within their respective reuse strategies; both reap the environmental benefit of high recycle rates and the economic benefit of low implementation costs. Chevron's implementation costs are between $0.25 to $0.50 per barrel, while Ranges Resources implementation costs are between $0.26 - $0.45 per barrel. The authors believe it is likely that virtually all produced water and flowback water generated in Pennsylvania will be reused by the end of 2012.

Pete Miller is the Water Resources Manager for Range Resources — Appalachia, LLC and is primarily focused on water sourcing, transportation, treatment, storage, and reuse solutions. He has over 19 years of professional experience in industrial water and wastewater treatment and environmental remediation spanning a broad range of industries. He is a Registered Professional Engineer in the State of Pennsylvania and holds a BS in Civil Engineering from the University of Pittsburgh and an MBA from Robert Morris University.

Tim Svarczkopf is the Director of Water and Chemical Management for the Appalachian/Michigan Strategic Business Unit of Chevron North America Exploration and Production Company, a division of Chevron U.S.A. Inc. Mr. Svarczkopf is responsible for developing water reuse and water sourcing programs as well as leading sustainability initiatives in the company's well completion operations. Mr. Svarczkopf has 32 years of experience in upstream oil and gas production, petrochemicals, refining, coal, and water treatment industries.

The Marcellus Shale:

Challenges and Opportunities in the Midstream Market

By Karla Olsen

Natural gas reserves in the huge Marcellus Shale in southwestern Pennsylvania and northern West Virginia are providing an economic boom to the Appalachian Basin not seen in a region of the United States since the California Gold Rush in the mid-1800s. Just how big is the Marcellus Shale? It is the largest in the U.S. with an estimated 489 trillion cubic feet (Tcf) in recoverable resources. It is second largest in the world behind only the South Pars/North Dome gas-condensate field in the Persian Gulf, shared by Iran and Qatar. The Marcellus is providing opportunities not only for natural gas production companies but for midstream companies, as well.

The natural gas midstream market is made up of a network of gathering pipes and processing facilities. It is a critical component of the natural gas industry, necessary to move gas from the wells, treat it to meet quality standards required by major interstate and intrastate pipelines, and deliver it to pipelines. If gas is not within specified gravities, pressures, Btu content ranges, or water content ranges, it can cause serious damage to pipelines.

Sound Barrier. Photo Courtesy of EQT.

Tapping into the potential of the tremendous resource of the Marcellus Shale comes with challenges. From uncertain production levels to tough terrain to public perception and understanding, midstream companies have their work cut out for them. However, with the right approach, they can turn these challenges into huge opportunities.

Multiple companies are drilling wells for natural gas in the Marcellus Shale. The sheer number of producers is in itself a challenge. Fragmented acreage (leased by several different companies) and numerous construction projects in gas-rich areas can lead to disruption in those communities. However, the opportunity for midstream companies is to consolidate production with larger pipes. This not only achieves economies of scale for the different companies, but reduces the disruptions that could lead to opposition to future projects.

EQT Liberty Compressor Station. Photo Courtesy of EQT.

Another challenge is the actual production of the natural gas. The advent of horizontal drilling has led to a boom in the Appalachian Basin. Drilling in the Marcellus is new to companies, so there is a learning curve. In addition, gas prices are currently low, which often leads companies to scale back their drilling programs, impacting the volume of gas going through the pipelines. The opportunity for midstream companies? Put in large pipeline and modular compression and skid mount equipment now to accommodate production increases or decreases later.

We live in a beautiful part of the country with all of its hills, rocks, rivers and trees. But that beauty presents a challenge to midstream companies. It is often difficult to move equipment and construct pipeline in these conditions, particularly in inclement weather. The bottom line here is hire people and companies who have the right experience working in this type of terrain.

Midstream companies must comply with multiple regulations through a number of different agencies. Among them are the Federal Energy Regulatory Commission, the Department of Transportation, the Department of Environmental Protection (in various states) and U.S. Fish and Wildlife. In addition, several permits are required for pipeline construction including air, road, railroad and river crossing permits. The extensive pipeline planning, construction and management presents an opportunity for companies to establish and strengthen relationships with regulatory agencies, relationships that will serve companies well with future projects.

Finally, one of the biggest challenges natural gas companies face with new work in the Marcellus Shale is just that – it is new work, unfamiliar to people who live in the region. Our neighbors are not accustomed to drilling and pipeline construction of this magnitude, so they do not yet have the understanding that people in other parts of the country, such as Texas, have of the process. There are a number of people who are opposed to natural gas development due to a lack of understanding and misinformation they might hear or read. Our neighbors have concerns over safety, pollution and economic issues.

The response of midstream companies should be to listen, be approachable and educate our neighbors in the Marcellus. In addition, they should take the time to develop relationships in communities where new work is being done, provide information when asked and immediately address concerns. In other words, be proactive, responsive and open to our new neighbors.

Aerial view of EQT's Jenkins Compressor Statiob. Photo Courtesy of EQT.

EQT Midstream is keeping those points in mind as it takes advantage of the Marcellus' burgeoning production of natural gas. EQT Midstream is developing and operating the infrastructure needed to move natural gas from Appalachian drill sites to city gates across the Northeast. Equitrans, L.P., an EQT interstate pipeline subsidiary, currently has 770 miles of transmission lines, a total capacity of 700 MMcfd and five interstate pipeline interconnects. Equitrans' expansion project calls for approximately 1,030 MMcf capacity at a cost of $270 million over the next few years. The project will provide natural gas producers with timely, cost-effective options to reach Northeastern and Mid-Atlantic markets.

The Marcellus Shale alone is estimated to have enough natural gas to last us more than 100 years. Properly approaching the drilling, gathering and transmission processes, developing relationships and treating our environment well now will assure that our descendants will be able to use this clean and inexpensive fuel for things we cannot now imagine for years to come. PE

Karla Olsen is manager, public relations at EQT Corporation, headquartered in Pittsburgh. She recently moved to Pittsburgh from Wichita, Kan. where she was director, corporate communications at Westar Energy, Kansas' largest electric utility.

About EQT Corporation

EQT Corporation is one the largest natural gas exploration and production companies in the Appalachian Basin. Headquartered in Pittsburgh, EQT employs 1,800 people and operates in four states: Pennsylvania, West Virginia, Kentucky and Virginia. EQT owns 5.2 Tcfe of total natural gas reserves on 3.4 million acres in the Appalachian Basin. EQT Midstream has more than 11,000 miles of gathering and transmission pipeline, 256,000 horsepower and 63 billion cubic feet (Bcf) of storage capacity to move natural gas from Appalachian drill sites to city gates across the Northeast. The company's website is EQT.com.

Snapshots from ESWP 127th Annual Engineering Awards Banquet

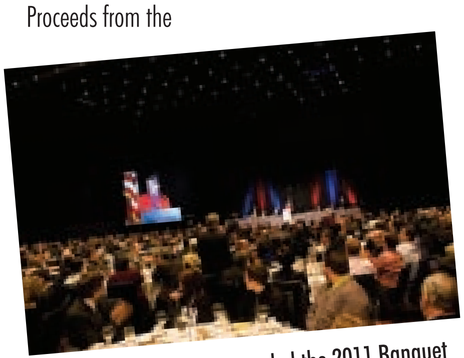
By David Teorsky

Guest browsed a Silent Auction table filled with many one-of-a-kind items

The 127th Annual Engineering Awards Banquet of the Engineers' Society of Western Pennsylvania (ESWP) was held at the David L. Lawrence Convention Center on Wednesday, February 23, 2011. More than 500 guests attended this annual event. Highlights of the Banquet include:

- Presentation of ESWP's William Metcalf Award to Dr. John A. Swanson
- Presentation of the inaugural President's Engineering Excellence Award to Mr. Floyd "Chip" Ganassi
- Guest speaker presentation by John Ratzenberger

Guests began the evening by browsing a combined Silent Auction and Chinese Auction that featured items donated by our generous supporters. Proceeds from the Auctions support ESWP's student outreach programs. During the social hour, a private reception was held in honor of our Metcalf Award recipient, Dr. Swanson, where he was joined by many friends and family, including members of the ESWP Board, past Metcalf Award recipients and other award winners.



More than 500 Guests attended the 2011 Banquet

To begin the evening, ESWP President Deborah Lange welcomed the guests, and introduced ESWP Past President Joseph Duckett who provided the invocation. The National Anthem was performed by vocalist Jeff Jimerson. Dinner consisted of a sumptuous split entrée of Petite Filet Mignon and Seasoned Breast of Chicken. Following dinner The George Washington Prize was presented by Dean Gerald Holder from the University of Pittsburgh Swanson School of Engineering. The award is made in recognition of outstanding leadership, scholarship and performance. The 2011 Winner was Laura Dempsey, and Finalists included Jennifer Kay and Alex Patterson. Semi-finalists included Michael Belair and Bradley Harken.

ESWP Awards Chairman Tom Donatelli, then presented the 2010 Awards of Distinction, including the Projects of the Year Award and the Engineer of the Year. Winners included:

- Transportation Category: "SR 19, Section A-27, West End Improvement Project" Owner: Penn DOT District 11-0, Designer: Michael Baker, Jr., Inc., Contractor: Trumbull Corporation
- 2010 Project of the Year Award-Commercial Category: "3 PNC Plaza", Contractor: PJ Dick, Engineering/Architect of Record: ASTORINO, Design Architect: Gensler
- 2010 Project of the Year Award-Civil Category:, "Taum Sauk Upper Reservoir Dam Restoration Project", Owner: AmerenUE, Engineer & Construction Manager: Paul C. Rizzo Associates, Inc.
- 2010 Engineer of the Year Award: Mr. H. Daniel Cessna, P.E., Penn DOT District 11-0

President Lange then presented the inaugural President's Engineering Excellence Award to Mr. Floyd "Chip" Ganassi, who provided interesting remarks to the audience.

The 2010 Recipient of the Metcalf Award, Dr. Red Whittaker, then introduced previous recipients of the award before calling on Dr. Swanson. Dr. Swanson provided very thoughtful remarks that described his professional journey.

Finally, John Ratzenberger was introduced as the keynote speaker, and delighted the audience with anecdotes and thought-provoking comments about preparing the next generations of the American work force.

Dessert was held for last, following the conclusion of the program. Guests enjoyed a buffet of many different sweet treats and coffees, plus more time to network.

A special thanks to these generous donors who contributed items to the Silent Auction and Raffle. Thank you for your support!

The ESWP Banquet Committee is already hard at work preparing for the 2012 Annual Banquet! Stay tuned for more details!

ESWP Directors John Kovacs (L) & Mark Urbassik with Past President Tony DiGioia (R)

Metcalf Award Recipient John Swanson (L) and ESWP President Deborah Lange

Red Whittaker presents John Swanson with the 2011 Metcalf Award

Project of the Year Award winners discussed their work

Finding Balance

By Chriss Swaney

John Ratzenberger's place in pop culture history may have been cemented by his Emmy-nominated role as the know-it-all postman Cliff Clavin in NBC's hit series "Cheers."

But his latest campaign to help Americans "Rebuild America" is perhaps his most poignant role. He is leading a national campaign to encourage business, community and government leaders to help rebuild the nation's skilled workforce.

That message of urgency was echoed loud and clear at the 127th annual Engineering Awards Banquet sponsored by the Engineers' Society of Western Pa. Feb. 23 at the David L. Lawrence Convention Center in Pittsburgh, Pa.

"The average age of skilled manufacturing workers is 55, but in the next six to 10 years we will lose that skill with retirement," said Ratezenberger. "How are we going to maintain our essential infrastructures or the very existence of our civilization," Ratzenberger quipped? Part of the slippage is due to the fact that other countries – from Singapore and South Korea to Canada and Sweden – are actively changing their laws and systems to make themselves more competitive. The United States didn't raise its corporate tax rate; others lowered theirs.


ESWP Director Tom Ferrence (L), Shoun Kerbaugh meet with Guest Speaker John Ratzenberger

But Ratzenberger argues that the United States is falling far behind in one key resource: human capital. Whether measured by the percentage of kids with high school diplomas or performance on standardized tests, America is not producing the kinds of workers needed in a knowledge-based economy. The halo is fading. The wide gap between the United States and the rest of the world is closing.


VIP's Chip Ganassi, John Ratzenberger and John Swanson

So, how do we get the mojo back?

"America must adapt to change and begin making things again," said Ratzenberger, host of "John Ratzenberger's Made In America" series for the travel channel.

"We can't stop the world from rising and doing better at innovation, nor should we want to do so: but we must begin to take action instead of being sideline spectators," he said.

For the past three decades, funding for science has slipped, the education system has continued to decline and the immigration policy has become less and less rational. Tax and regulatory policies have been made with more thought to domestic special interests than America's long-term competition. The seed capital from past decades was strong enough to carry us for decades.

"But we have continually kicked all our real challenges down the road and now we have to face them" said Ratzenberger, the son of a truck driver from Black Rock, Conn. "I learned early in life the rewards of hard work." In addition to his Cheer's success, Ratzenberger has had a voice part in all of Pixar's feature films to date.


ESWP Secretary Mike Bock (L), Chip Ganassi, and ESWP Director Manoj Sharma (R)

And his voice continues to be heard as he admonishes engineers, scientists, academics and business leaders to build a better work force for the future and continue to make innovation as American as baseball and Mom's apple pie.

The challenge is real. With the end of the Cold War, Americans stopped worrying about the Soviet threat and, as a result, R&D funding for applied science plummeted, dropping 40 percent in the 1990s. It has picked up since then, but the government's share of R&D spending remains near an all-time low. And while corporations still spend on R&D, they do not fund the kind of basic research needed for major science and engineering breakthroughs.


ESWP Director David Borneman (L) with 2011 Banquet Co-Chair Red Whittaker

Still, in spite of the sobering reminder that America needs to remake itself, the ESWP also found time to award some outstanding entrepreneurs in business and academia at it's annual gala banquet.

Chip Ganassi, the first owner to win all three major motorsports events in one season: Daytona 500, Indianapolis 500 and Brickyard 400, was the recipient of the inaugural President's Engineering Excellence Award for significant contributions to both the sporting and business world.

The prestigious Metcalf Award presented annually since 1963 by the ESWP was awarded to John Swanson, founder of ANSYS - a Canonsburg-based company that designs, develops and globally supports engineering simulation solutions used to predict product designs.

For more details on the 127th ESWP Annual Banquet, visit www.eswp.com/eswp/annual_banquet.htm

Spotlight on
ESWP Outreach Programs

Over the past year, through the generous support of our members, sponsors and volunteers, the Engineer's Society of Western Pennsylvania (ESWP) continued to fulfill its mission to develop the next generation of engineers. ESWP has been actively involved in programs throughout the Pittsburgh region that are dedicated to developing an educated future workforce of engineers who can contribute to the economic development of this region. Below is an update of some of our current education outreach activities:

- Design Lives Here- the Design Lives Here Initiative is a partnership between WQED Multimedia and ESWP created to promote learning about engineering among middle school students via interactive teaching, mentoring, and challenge events. To date, more than 200 students are participating in the 2010-11 program -- in addition, 78 participants are minorities and 102 are female. ESWP members are serving as engineering mentors for each school.
- Future City Competition - the Pittsburgh Regional Competition was held January 22, 2011 at Carnegie Music Hall. The Ellis School came was awarded first place, which was a trip to Washington, D.C., to compete in the national finals during National Engineers Week in February. Thanks to the many ESWP members participated as judges and volunteers.
- Engineer Your Life - Over the past 17 years National Engineers Week, presented in cooperation with Engineers' Society of Western Pennsylvania and Carnegie Science Center, has proven to be a great opportunity to reach young people and introduce them to world of engineering. This year at the ESWP event table, children participated in the High Rise Challenge where they competed to build a tower out of newspaper, straws, string, and tape that could support the weight of a baseball and withstand the wind from a leaf blower.
- e-Mentoring - partnering with PA Smart Futures, ESWP has provided numerous mentors who provide guidance to high school students interested in pursuing education paths in engineering.
- 127th Annual Engineers Banquet - students representing Penn State University, Drexel, and the University of Virginia and educators from the Pittsburgh Public Schools Career and Technical Education Department, Peters Township school district, and the Carnegie Science Center attended this year's banquet. Feedback from attendees revealed that they found the banquet to be not only a great networking event but also very informative.
- International Bridge Conference® (IBC) - we are pleased to announce that at this year's IBC we will be adding a student component. High school students and their teachers are invited to partake in half day learning event about engineering and bridges where they will hear presentations from engineers in the industry, participate in a bridge building competition, tour the exhibit hall and hear guest lecturers! To date, 14 schools have been invited.

It is through the generous support of members like you that we are active in these effective student outreach programs. If you would like to learn more about any of these programs our other upcoming projects or become more involved please contact ESWP Outreach Coordinator Alyia Smith-Parker at a.smith-parker@eswp.com. Thank you for your continued support!

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