

Shale Gas Supply to the Greater Toronto Area

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Prepared for the Council of Canadians

Re: Ontario Energy Board Proceedings

EB-2012-0451: Enbridge Gas Distribution Inc.; and

EB-2012-0433 and EB-2013-0074: Union Gas Limited

The Enbridge application for “order or orders granting leave to construct a natural gas pipeline and ancillary facilities” in the Greater Toronto Area is predicated on obtaining a more reliable supply of natural gas at lower prices than the current arrangement largely through imports from new basins being developed in the northeastern United States. The Union Gas applications also rely on diversifying supply through imports of natural gas from these U.S. sources. These basins, principally the Marcellus shale in West Virginia, Pennsylvania, and southern New York State, and potentially the Utica shale, in Ohio, have very recently (since 2009) become major sources of U.S. natural gas supply.

The following report offers my assessment of the validity of the projections that shale gas from U.S. sources will provide a relatively cheap and reliable long term (beyond 2020) source of natural gas supply to Ontario consumers.¹

I am a geoscientist with four decades of experience working in the area of energy resource assessment. Over the past decade, I have published and lectured widely on global energy and sustainability issues in North America and internationally. A particular area of focus has been on shale gas, tight oil, coalbed methane and considerations for long term energy security and sustainability. A copy of my curriculum vitae is attached as Schedule “A” to this report.

Shale Gas Development in the United States

The natural gas supply picture has changed recently, and dramatically, with the development of multi-stage hydraulic-fracturing of horizontal wells capable of producing natural gas from previously inaccessible impermeable shales (“shale gas”). Shale gas has gone from representing approximately two percent of U.S. natural gas production a decade ago to nearly 40 percent in

¹ Unless otherwise mentioned well-, reservoir- and field-production data used in this analysis come from the DrillingInfo/HPDI database.

2012. Projections from organizations such as the Energy Information Administration (EIA) are for shale gas production to double from 2010 levels and make up half of a greatly expanded natural gas supply by 2040, at which time the EIA projects that over ten percent of U.S. natural gas production will be available for export.²

A detailed assessment of production characteristics of shale gas plays³ in the U.S. reveals that these optimistic supply projections are unlikely to be realized, and that natural gas prices in the medium- to long-term will be much higher than at present and much higher than EIA projections.^{4,5} These characteristics include:

- High well decline rates, ranging from 77%-89% over three years with an average of 84%. This necessitates high levels of drilling and capital expenditure to maintain, let alone increase, production.
- Overall field declines ranging from 28%-47% each year, which must be replaced by more drilling just to keep production flat. The annual capital expenditure to do this as of mid-2012 is estimated at \$42 billion.⁶ This amounts to a drilling treadmill.
- The fact that all shale plays have relatively small, high productivity, “sweet spots”, which are drilled first and provide the lowest cost natural gas. These sweet spots have been nearly exhausted in plays older than about five years. This means that drilling to replace field declines must move into progressively lower productivity portions of the reservoir requiring even more wells to maintain production as a play matures.
- Four of five shale gas plays comprising 80% of shale gas production in the U.S. are in or near decline. The Marcellus continues to grow, but is a relatively new play and is likely to follow the pattern of declining production after maturity observable in other shale gas plays.
- The fact that well documented adverse environmental effects of hydraulic fracturing (fracking) have resulted in a great deal of public opposition to shale gas drilling in many shale plays (eg. Marcellus of Pennsylvania and Barnett of Texas). This opposition has led some jurisdictions to impose moratoriums on fracking which are currently in place in New York State, the Province of Quebec and France. Public opposition to fracking has become progressively more organized and vocal as the shale plays have developed. Documentaries such as Gasland, Gasland Part II, and “Promised Land” have vividly portrayed the adverse impacts of fracking and have fueled opposition, which is likely to continue to restrict access to the many drilling locations required to maintain, let alone increase, production, and as a result increase costs.

² Energy Information Administration, 2013, Annual Energy Outlook 2013, <http://www.eia.gov/forecasts/aeo/> .

³ A “Play” is a term commonly used in the oil and gas industry for production from a common reservoir in a restricted geographic area from one or more fields.

⁴ Hughes, J.D., 2013, A Reality Check on the Shale Revolution, *Nature*, Volume 494, p 307-308.

⁵ Hughes, J.D., 2013, Drill Baby Drill: Can Unconventional Fuels Usher in a New Era of Energy Abundance?, Post Carbon Institute, 166 pages, <http://www.postcarbon.org/reports/DBD-report-FINAL.pdf> .

⁶ Op. Cit.

Evidence for each of these characteristics is briefly reviewed below, followed by a summary of the risks entailed in the Enbridge and Union Gas applications which would significantly increase the reliance of Ontario consumers on shale gas from U.S. sources.

Well Declines of Shale Gas

A review of type decline curves for five shale gas plays constituting 80 percent of U.S. shale gas production is illustrated in Figure 1. The average decline over the first three years of well life for these plays averages 84 percent and ranges between 77% and 89%.

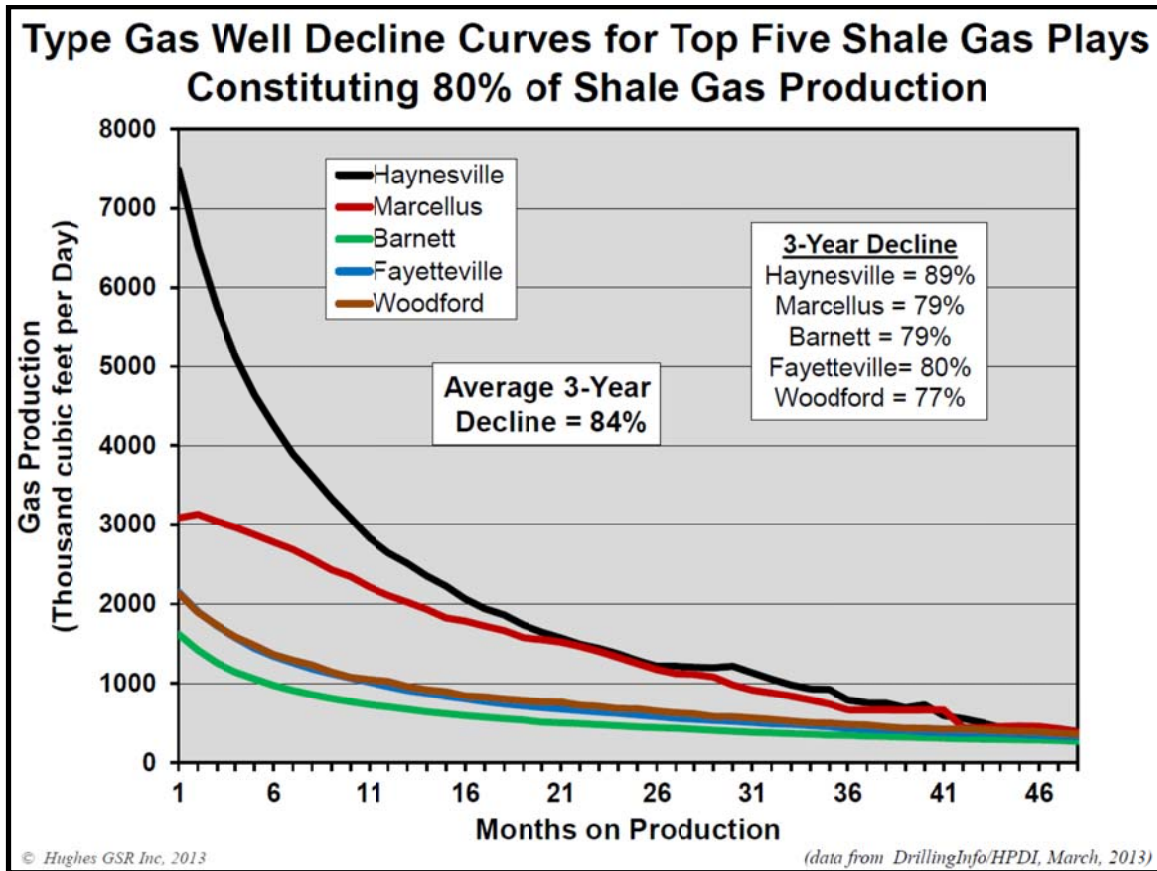


Figure 1 – Type well decline curves for five shale plays constituting 80% of U.S. shale gas production. Three year decline rates range between 77% and 89%, illustrating the need for continual drilling to maintain production.

Field Declines of Shale Gas

Given that the production decline in a shale gas well is typically steepest in its first year and is progressively shallower in its second and subsequent years, annual field production declines are less than first year well declines, but are still very steep. Figure 2 illustrates the yearly field decline in five shale gas plays that collectively make up 80 percent of U.S. shale gas production. Field decline is determined from the production profile of all wells drilled prior to 2012.

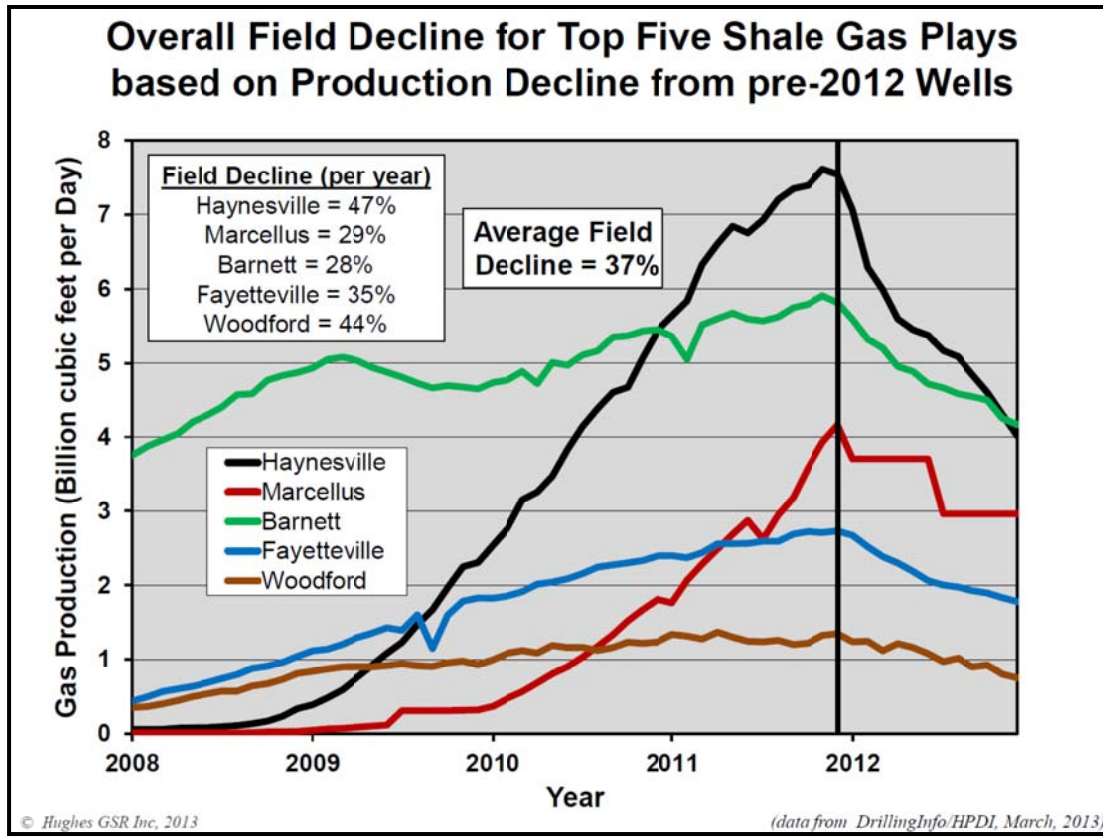


Figure 2 – Field decline curves for five shale plays constituting 80% of U.S. shale gas production determined using production from all wells drilled prior to 2012. Annual field decline rates range between 28% and 47%, and average 37%, illustrating the need for continual drilling to maintain production.

Sweet Spots within Shale Plays

Shale plays are not homogenous and inevitably sweet spots are defined that are the most productive and therefore most economic portions of plays. These sweet spots typically comprise 5-10 percent of a play’s total area and are drilled first. Saturating sweet spots with wells has contributed to low natural gas prices in the U.S. Current natural gas prices, which are in the \$3.75-\$4.25/GJ range, are roughly double the lows observed in mid-2012, although they are still much lower than the recent high of \$13/GJ in mid-2008 (Henry Hub prices). Figure 3 illustrates an example of a sweet spot, in this case within the Barnett Shale, which is the oldest shale play in the U.S. This sweet spot has become nearly saturated with wells and drilling has been moving into less productive areas resulting in a decline in the productivity of new wells and a decline in overall field production.

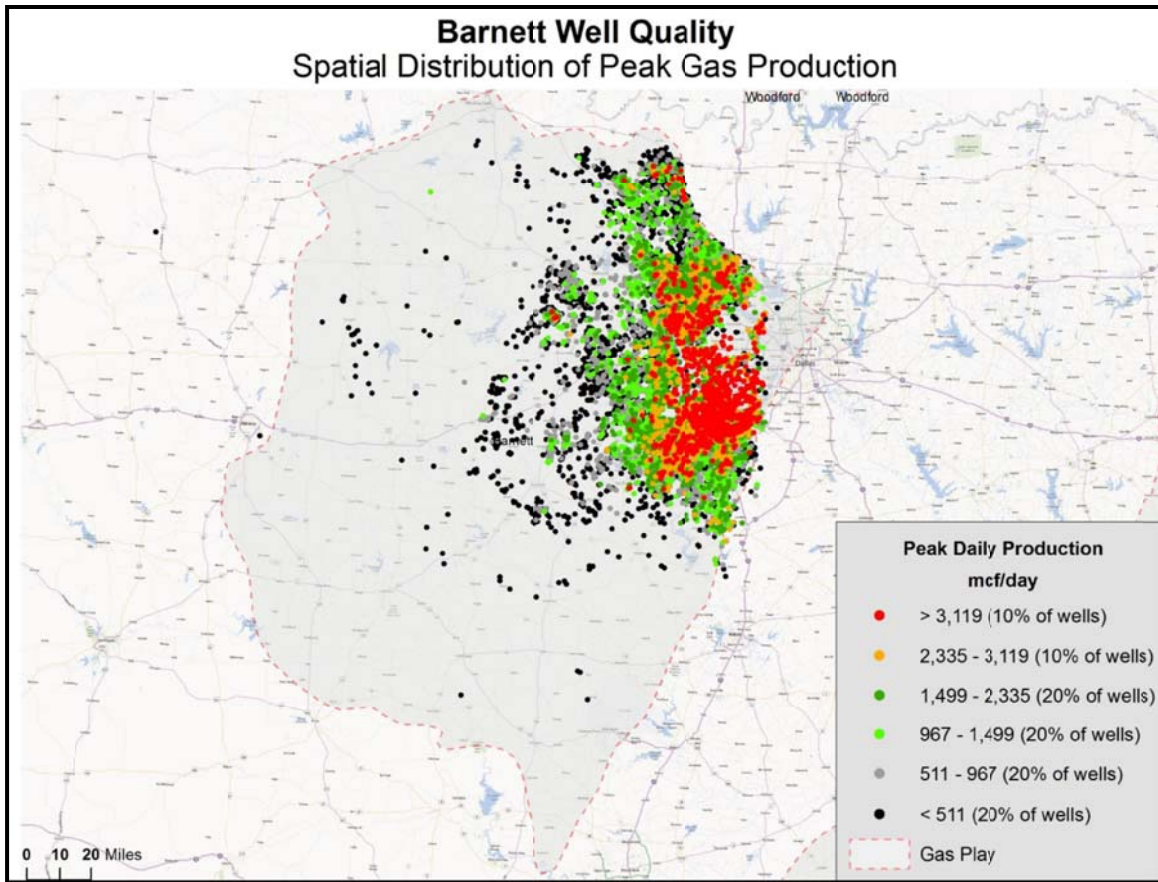


Figure 3 – Example of a sweet spot within the Barnett play – wells are colored by productivity. The highest productivity wells are located in a small portion of the total play extent (in light grey) – less than 10%. The highest productivity wells are in red and orange.

The pattern of first defining sweet spots, and then concentrating drilling within them, also characterizes the Marcellus play, which is a major focus of the Enbridge and Union applications. Ninety percent of Marcellus production is from Pennsylvania with the remainder from West Virginia (New York State currently has a moratorium on fracking). A sweet spot for dry natural gas has been identified within the Marcellus of northeastern Pennsylvania, and a sweet spot with lesser natural gas but more liquids production has been defined in the southwest corner of Pennsylvania. Figure 4 illustrates natural gas production by county in Pennsylvania showing just how much more productive the top six counties are than the rest, all of which are included in the large resource estimates touted for the Marcellus. Although the Marcellus underlies 33 counties in Pennsylvania, just two, Bradford and Susquehanna, produce 46 percent of the natural gas, and the top six counties produce 85 percent.

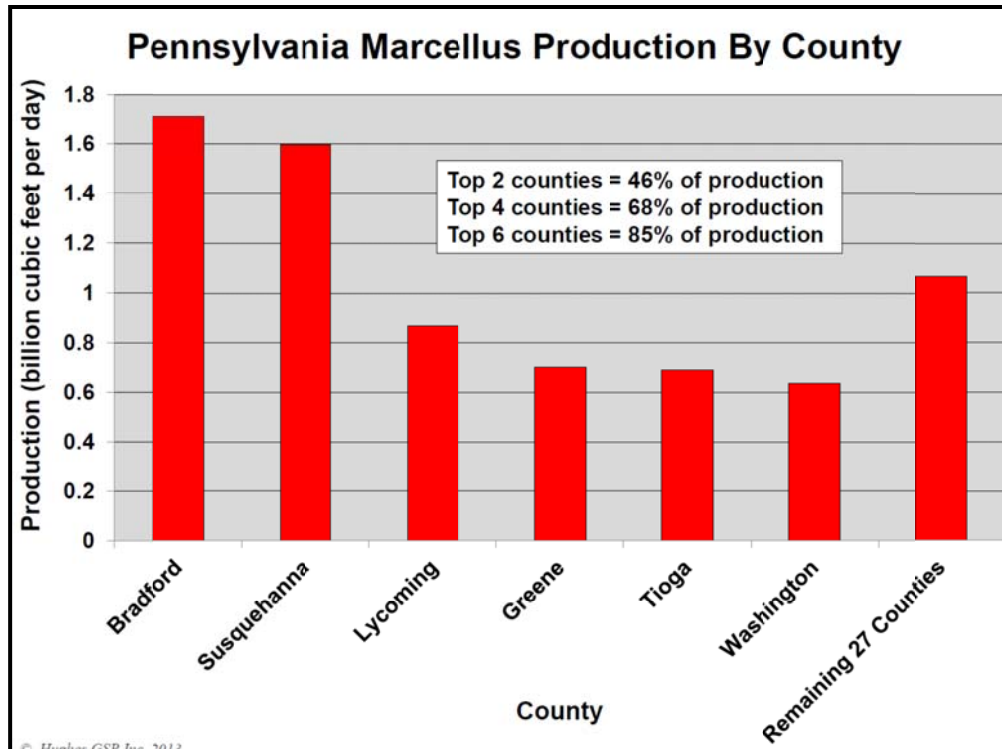


Figure 4 – Of the 33 Pennsylvania counties underlain by Marcellus shale 68% of production comes from just four, and 46% from two, illustrating the fact that sweet spots comprise a small part of the total area purported to be economically productive. The economics of the top two counties likely work at current natural gas prices, but the remaining counties will require considerably higher natural gas prices to be economic.

How much better the top counties are than the rest is illustrated in Figure 5 by the average “estimated ultimate recoverable” natural gas per well (EUR) for these counties (these EURs are developed from the type decline curves of wells in each county using data from the Drillinginfo/HPDI database). Each well in the best county, Susquehanna, will on average recover three times as much natural gas as the 27 least productive counties. Hence Susquehanna County, along with adjacent Bradford County, is being saturated with wells and has been a focal point of protests by environmental groups. The town of Dimock, in Susquehanna County, was central to the anti-fracking movie Gasland, which dealt with the environmental effects of fracking across the U.S.⁷ The extent to which these sweet spots can continue to produce cheap natural gas depends on the number of available drilling locations, which are running out. Figure 6 illustrates the current infrastructure and well pad footprint in the vicinity of Dimock, which is nearly saturated. This means that as drilling moves into lower productivity areas natural gas prices must rise in order to justify an ever increasing number of ever lower productivity wells, in order to maintain production.

⁷ Fox, Josh, 2010, Gasland documentary film, <http://en.wikipedia.org/wiki/Gasland> .

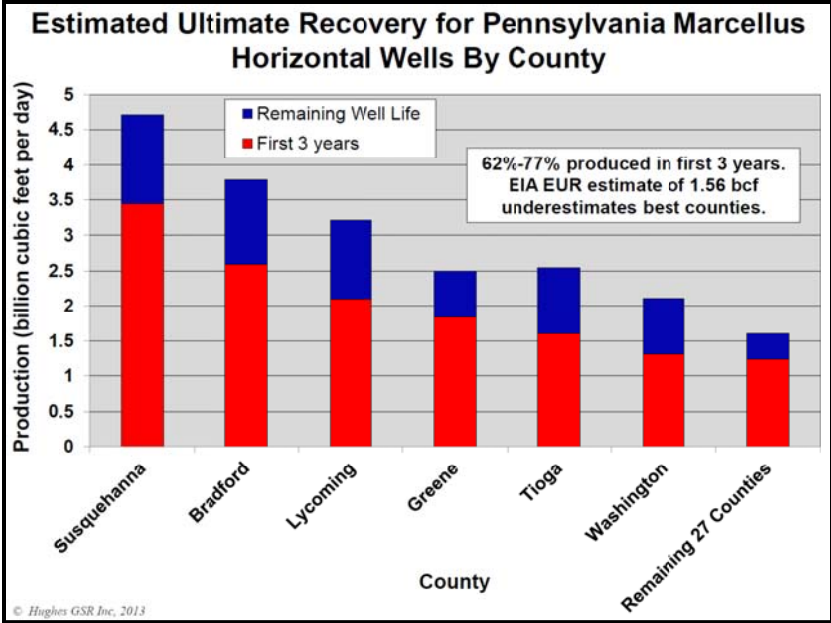


Figure 5 – Estimated ultimate natural gas recovery by county showing that the sweet spots in the top counties are two to three times as productive as the remaining 27 counties. Although the top counties are economic at current prices the bulk of Marcellus natural gas will require considerably higher prices

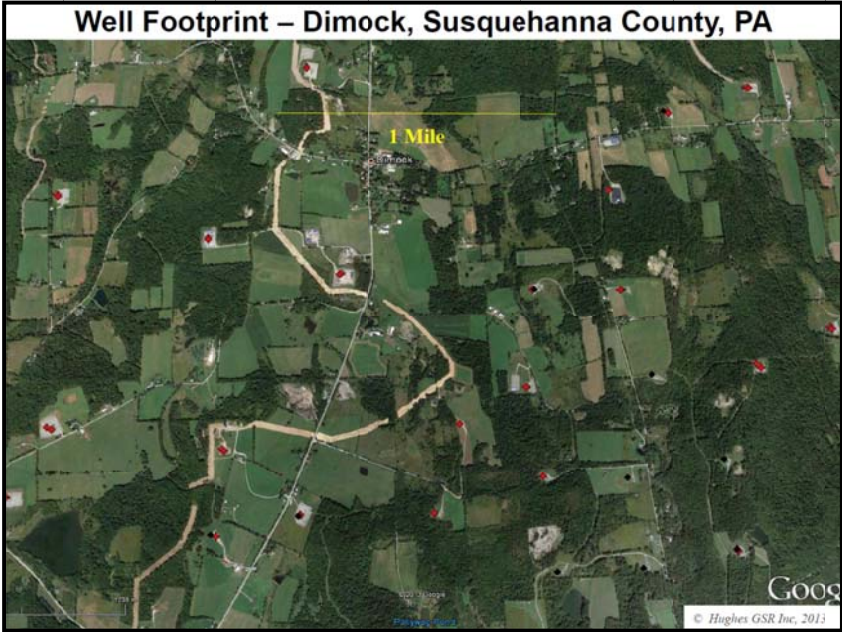


Figure 6 – The surface well pad footprint in the highest productivity “sweet spot” in Susquehanna County of the Marcellus play. Each well pad is roughly 4-5 acres and may contain several horizontal wells which cover much of the reservoir area between pads. There are more than 25 wells in this picture which covers about 8 square miles (some pads have several wells).

Aging of Top U.S. Shale Plays

Four of five shale plays, which account for 80 percent of U.S. shale gas production, are in decline or flat. The Haynesville shale play, which in 2012 was the largest shale play in the U.S., peaked in 2011 and is now down 20 percent from its peak (see Figure 7).

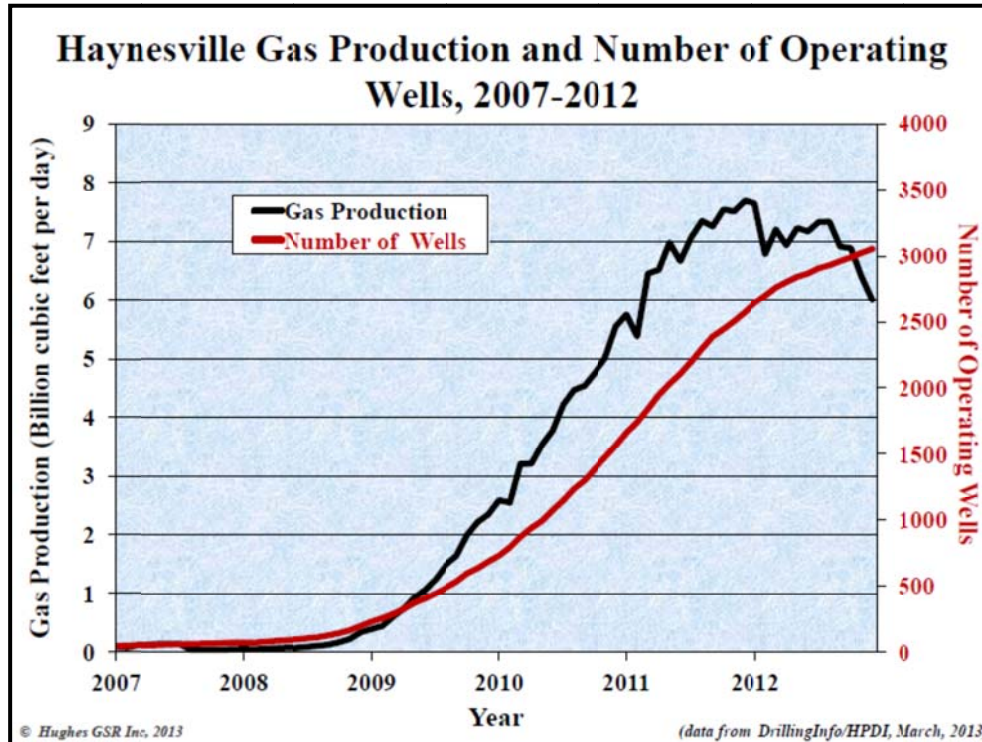


Figure 7 – Natural gas production and number of operating wells in the Haynesville play over its life cycle. Although well count is still rising the play peaked in 2011 and has since declined by 20%.

The initial productivity of a well when it is first connected to a collection system provides an indication of the overall amount of natural gas that well will produce over its lifetime, and hence indicates well quality. Early in the life of a shale play average well quality generally increases as the sweet spots are defined and better technology is applied (longer horizontal laterals, more fracking stages etc.). Once sweet spots are drilled off well quality declines, as drilling moves into less prospective areas, regardless of the application of better technology.

Four of five top shale plays are now in middle- or old-age, despite the fact that most are only about five years old (with the exception of the Barnett which is somewhat older). The progression of well quality with time, from youth to old age, is illustrated for five shale plays, accounting for 80 percent of U.S. production, in Figure 8.

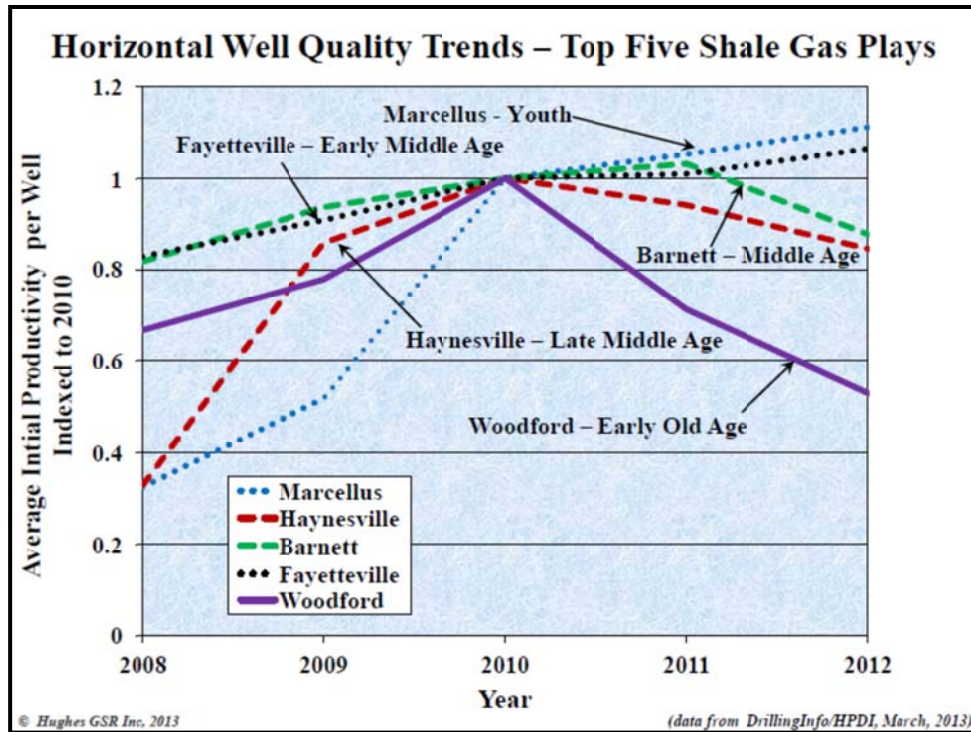


Figure 8 – Classification of five shale plays accounting for 80% of U.S. shale gas production according to the “shale play life-cycle”. Three of these plays have advanced into middle age and one, the Woodford, into old age. Only the Marcellus is in relative youth with strong growth in production.

The Marcellus is very unlikely to be exempt from the progression through the shale play life cycle even though it is in its youth now and production is rising. The highest producing counties in the Marcellus, Bradford and Susquehanna, are already showing signs of middle age as new well productivities are flat or declining. It is only a matter of time before the Marcellus follows the pattern of the other large shale plays and production peaks and declines. This will likely occur within five years or less.

The Utica shale, another supply focus of the Enbridge and Union applications, has so far proven to be much less productive on average than the best counties in the Marcellus.⁸

Environmental Issues Which Limit Shale Gas Production

The environmental issues which have caused such a public outcry against fracking in many areas have been dealt with in reports prepared for these proceedings by Ms. Lisa Sumi, and Dr. Anthony Ingraffea. If addressed by effective government measures, the cost of shale gas production is likely to greatly increase. If left unaddressed, opposition is likely to become even more intense as the evidence of adverse impacts continues to grow. These issues are, and will

⁸ State of Ohio, 2012, 2012 Utica Shale production report, <http://oilandgas.ohiodnr.gov/portals/oilgas/shale-activity/2012/FINAL-Utica-2012-Production.xls>

continue to be, an impediment to accessing the large number of drilling sites that are required to offset the high field declines experienced with all shale plays. In short they include:

- High levels of water consumption – 2 to 8 million gallons per well.
- Methane contamination of groundwater.⁹
- Disposal of produced fracture fluid potentially contaminating groundwater and inducing earthquakes.
- Industrial footprint – well pads, truck traffic, air emissions, etc.
- Full cycle greenhouse gas emissions which may be greater than coal.¹⁰

Lack of Growth in U.S. Natural Gas Production

The U.S. is still a net importer of natural gas from Canada and of LNG from offshore, despite the pervasive hype surrounding shale gas. U.S. natural gas production has remained flat for the past six months, even as natural gas prices rose from historical lows (Figure 9).

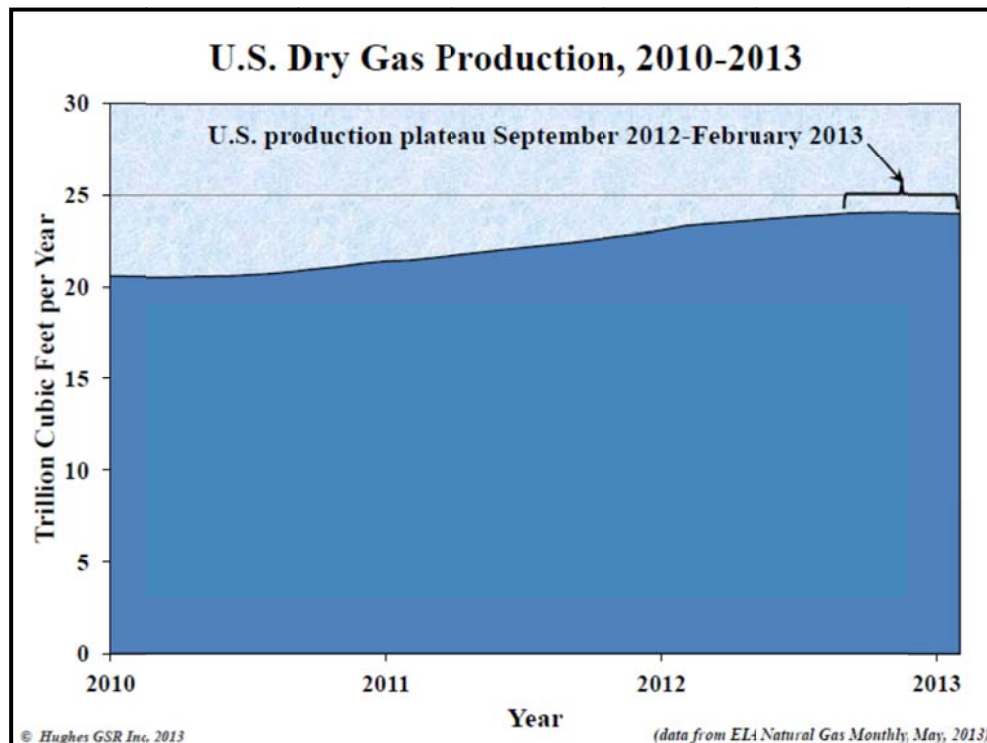


Figure 9 – U.S. dry natural gas production smoothed with a 12 month trailing moving average showing that natural gas production has been essentially flat over the most recent six months (EIA data through February 2013).

⁹ Jackson, R, et al, 2013, Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction, Proceedings of the National Academy of Sciences, June, 2013.

¹⁰ Howarth, R.W., et al., 2011, Methane and the greenhouse-gas footprint of natural gas from shale formations, Climatic Change DOI 10.1007/s10584-011-0061-5 <http://graphics8.nytimes.com/images/blogs/greeninc/Howarth2011.pdf>

Shale gas production is also declining in aggregate from four of five plays comprising 80 percent of U.S. shale gas production (Figure 10). Only the Marcellus, which is in its youth as discussed above, is serving to offset these declines and maintain a shale gas production plateau. Higher prices, in the \$6-8/GJ range, would likely allow production growth to resume for a few years until exhaustion of higher quality drilling locations inevitably increased the capital and number of wells required to offset field declines to uneconomic levels. At this stage prices would have to escalate further to maintain production.

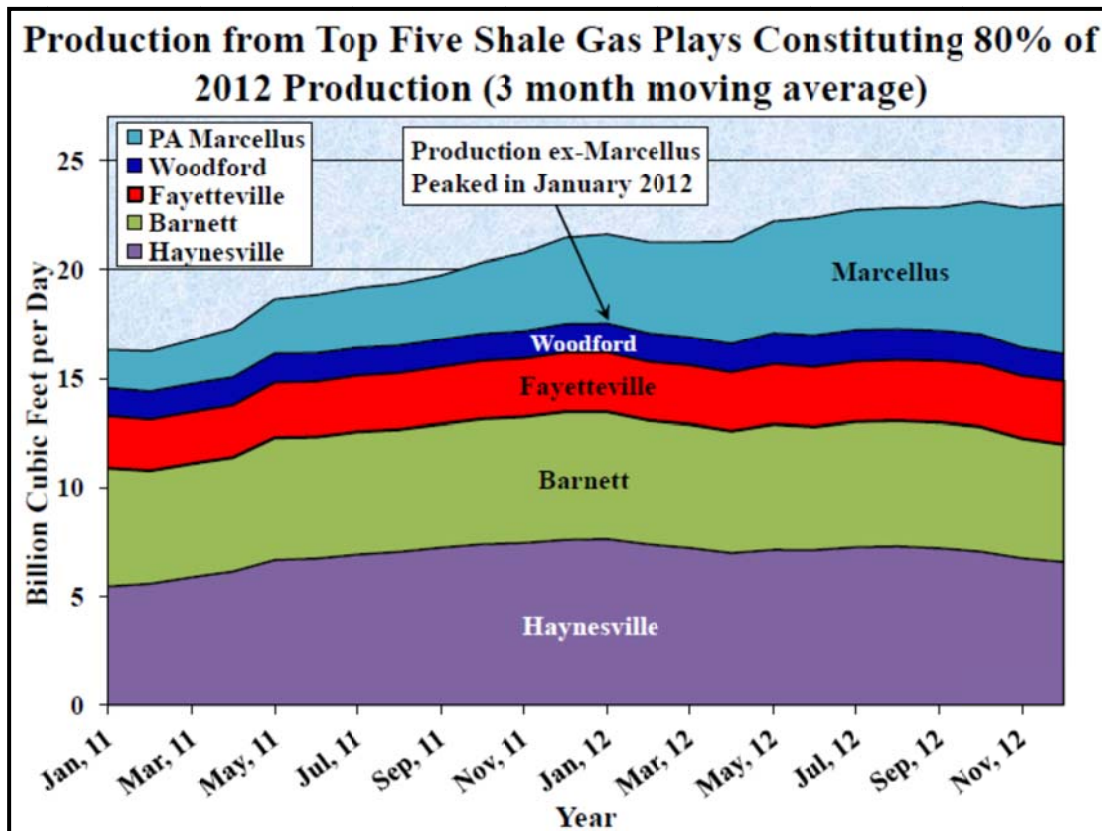


Figure 10 – Most recent two years of production for five shale gas plays constituting 80% of U.S. shale gas production. Four of the five plays have collectively peaked in January 2012 and gas production is being maintained on a plateau only through growth in the Marcellus. Data is from the Drillinginfo/HPDI database.

Conclusion

This analysis suggests that U.S. supply growth assumptions made by Enbridge¹¹ and Union Gas¹² are overly optimistic at the natural gas prices assumed.

On the supply side, given the nature and life cycle of shale plays explained above, the price of natural gas required to maintain production is likely to be considerably higher over the medium- and longer-term than that commonly assumed¹³. The environmental impacts of shale gas production are becoming an increasingly high-profile public concern, and are likely to lead to greater regulation of the industry, which in turn will generate further price pressures.

On the demand side, the U.S. is considering LNG exports of natural gas, based on projections of future growth in shale gas production, although it is currently a net natural gas importer. Furthermore, considerable amounts of new domestic U.S. natural gas demand have arisen due to the recent low prices (coal-to-gas switching, petrochemicals, etc.). U.S. LNG exports and rising domestic consumption will put further upward pressure on prices, including prices of exports to Canada.

¹¹ Exhibit A, Tab 3, Schedule 5, Paragraph 31, in Enbridge application

¹² EB-2012-0433, Section 23, pages 27-28 of 121 in Union application

¹³ Energy Information Administration, 2013, Annual Energy Outlook 2013, <http://www.eia.gov/forecasts/aeo/> .

John David Hughes

David Hughes is a geoscientist who has studied the energy resources of Canada for nearly four decades, including 32 years with the Geological Survey of Canada as a scientist and research manager, where he coordinating a team of 15 scientists and support staff. He developed the National Coal Inventory to determine the availability and environmental constraints associated with Canada's coal resources as well as their potential for coalbed methane production and CO₂ sequestration. As Team Leader for Unconventional Gas on the Canadian Gas Potential Committee, he coordinated the publication of a comprehensive assessment of Canada's unconventional natural gas potential. Hughes authored more than 350 papers, government and industry reports during his career with the Geological Survey of Canada.

Over the past decade, he has researched, published and lectured widely on global energy and sustainability issues in North America and internationally. His research on specific aspects of energy include shale gas, tight oil, coalbed methane, scaling issues with alternatives and considerations for long term energy security and sustainability. He is a Fellow of the Post Carbon Institute and his work has been featured in the popular press, radio, television and other public media. In recent years he has addressed more than 200 venues on these issues ranging from municipal-, provincial/state- and Federal-governments, through scientific conferences, universities, environmental groups and industry associations.

After leaving the Geological Survey of Canada in 2008 he founded Global Sustainability Research Inc., a consultancy dedicated to research on energy and sustainability issues. Clients have covered the ideological spectrum from multinational energy companies, including Imperial Oil and Forbes Energy Group, municipal governments, including the City of Edmonton, the Canadian Federal Government and environmental groups. Two recent reports commissioned by the Post Carbon Institute relate specifically to shale gas and its prospects in America's energy future: [Will Natural Gas Fuel America in the 21st Century?](#) and [Life Cycle Greenhouse Gas Emissions of Shale Gas Compared to Coal: An Analysis of Two Conflicting Studies](#) .

Hughes recently authored a [major study](#) of the latest drilling and production data for shale gas and tight oil in the United States which was published by Post Carbon in February 2013. This study, prepared from a database of production data widely used by industry, provides an objective assessment of the potential of unconventional energy resources such as shale gas and tight oil to fuel America's energy future.

Hughes holds a First Class Honours BSc degree and an MSc degree, both in geology, from the University of Alberta.