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Marcellus Shale: Through A Glass, Darkly

Mar. 31, 2014 12:06 PM ET | 139 comments | Includes: APC, BOIL, CHK, COG, DGAZ, GAZ, KOLD, NAGS, RRC, SWN, UGAZ, UNG, UNL, XOM

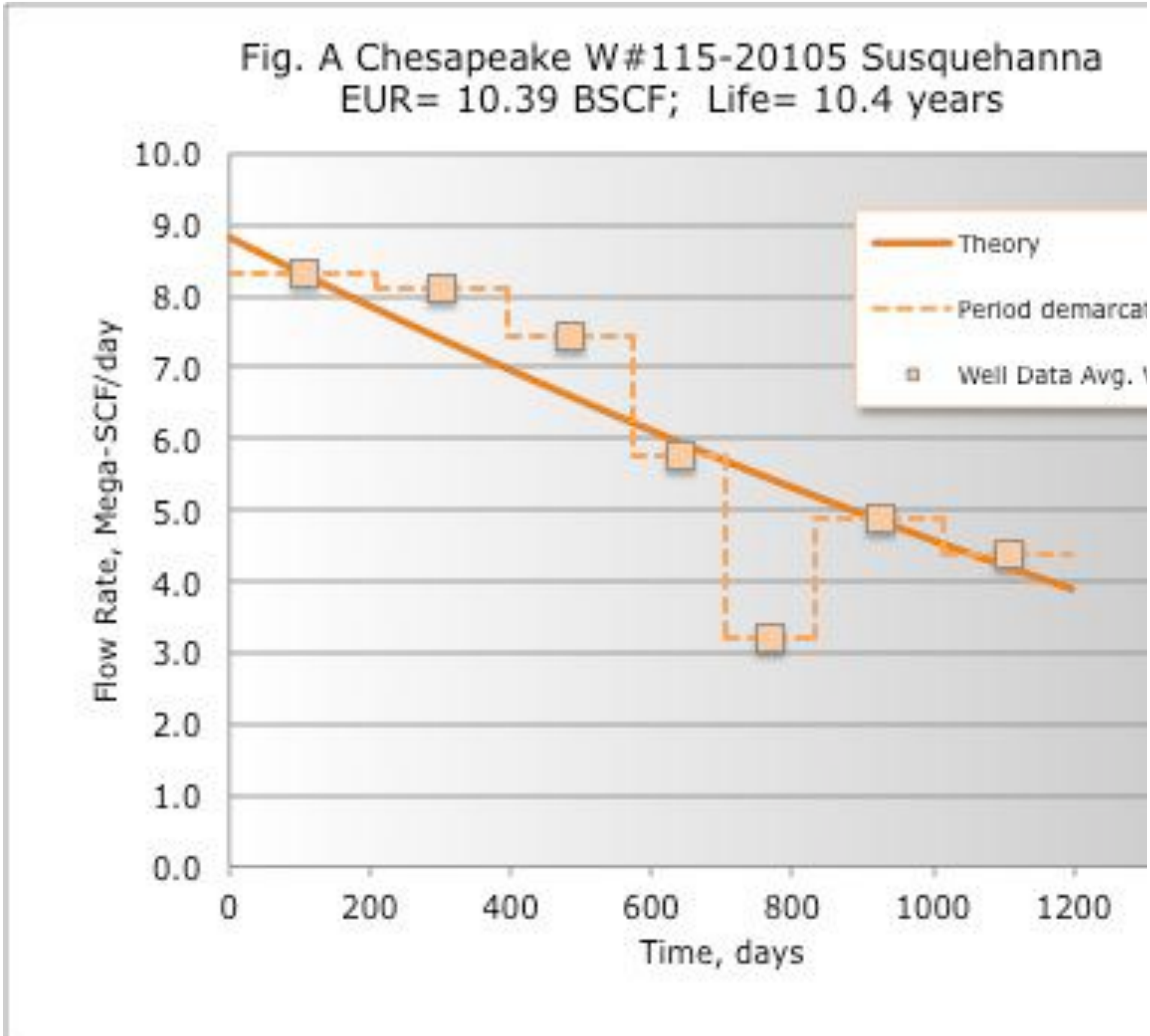
Disclosure: I am long XOM, APC, CVX, APA, RDS.A. **(More...)**

Summary

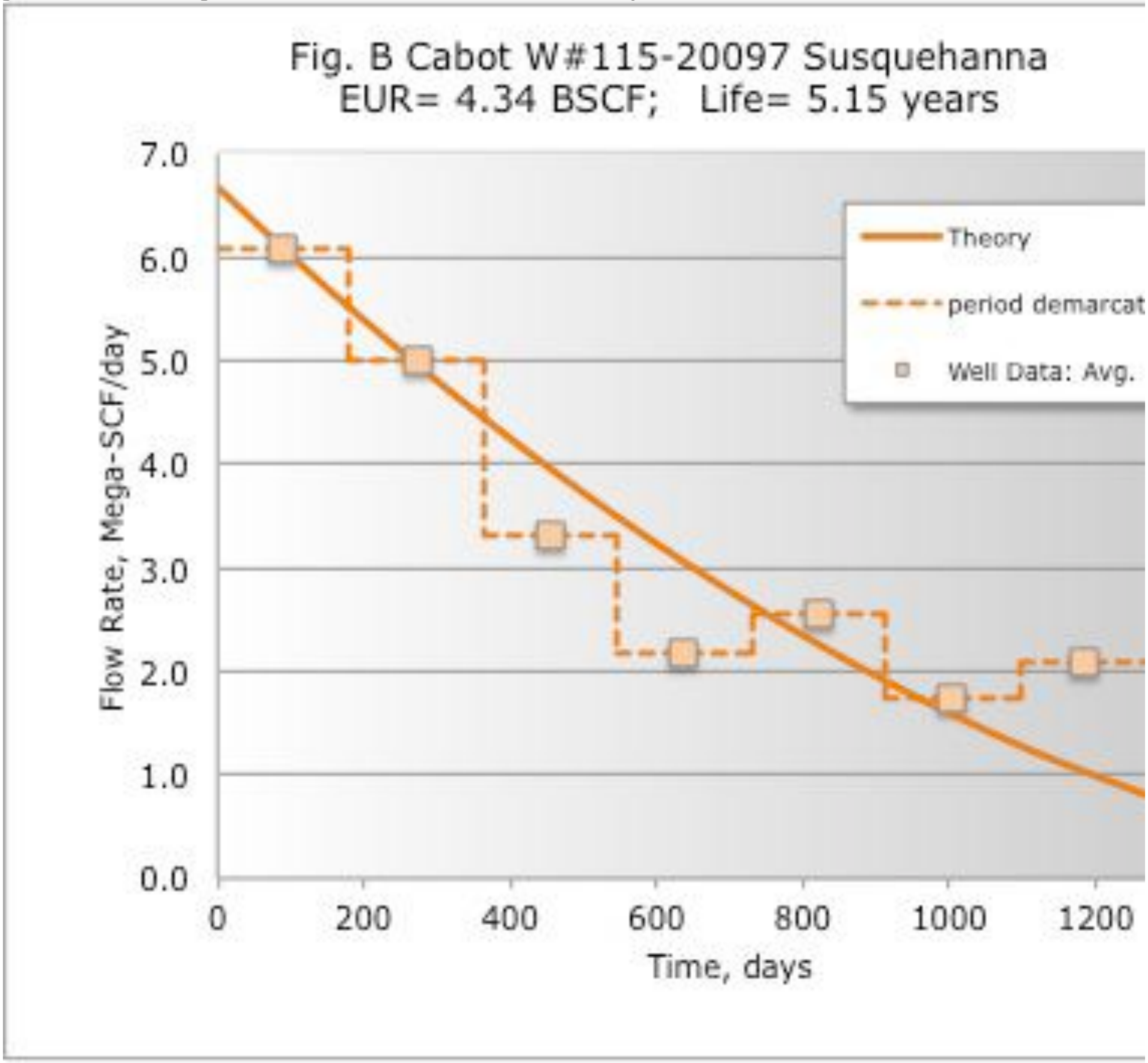
- Marcellus shale dry-gas production rates and well number evolution are analyzed to understand overall productivity. A precise linear dependence between production rate and well numbers is demonstrated.
- Marcellus proved reserves, along with production rate, allow projection of life span, which is shown far less than the 100 years, closer to 10 years.
- The closeness to complete depletion of any domestic reservoir should lead to pricing escalation. An enhanced Hotelling model is derived, based on the entire US NG reserves, demand, and GDP.
- With EIA (2013) Proved Reserves of Marcellus NG, with the escalated price model above, profitability should be impressive, but drop to zero by 2019 -- per our pro forma.

- In the race to sustainability, one must escalate the use of NG in the short term: replacing coal for power generation and synthetic liquid transportation gasoline. Must regulate properly.

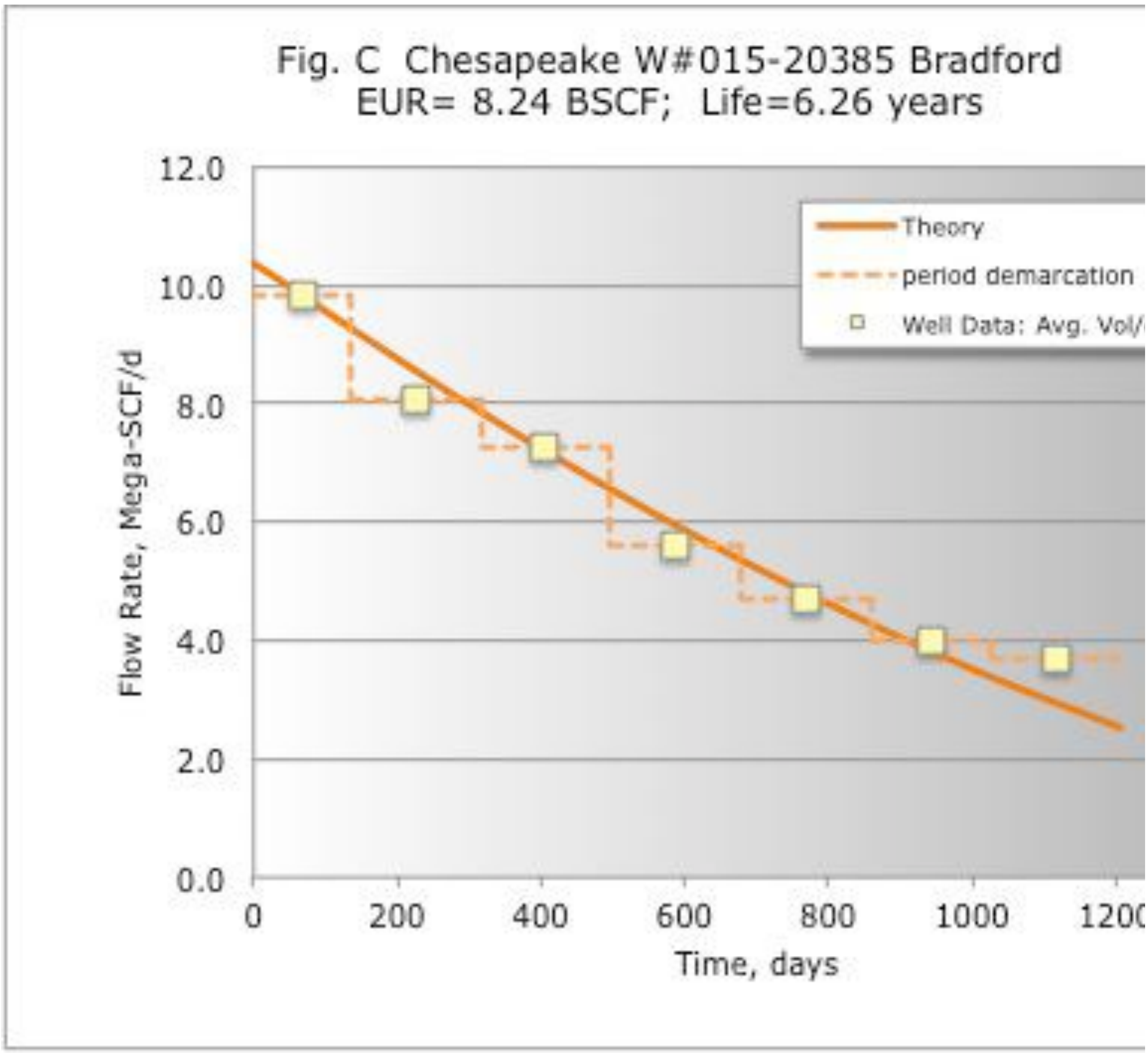
1. Background: The Marcellus has become the wonder child of US energy, a natural gas holy grail. We hear of "100 years-plus of reserves", and witness a wild drive for Marcellus drilling leases and permits, which seems to have momentarily driven down the price of US natural gas. In parallel, re-opening US crude reservoirs (plus some new Gulf of Mexico discoveries) has brought about a feeling of energy independence and sustainable abundance. We hear about a drive to export natural gas by relaxing export restriction, building LNG export terminals, conversion of existing LNG import terminals to export (Cheniere, LA), even export of US crude petroleum. Are these for real? We started our critical look at the Marcellus in December 2013. One way to get an idea of proved reserves is through EUR (economical ultimate recovery), based on well flow-rate data, we thought, naively. If you sum up (i.e., integrate) projected production rate over time, you can calculate EUR, as well as the life span of any well. The available PA-DEP data, starting 2010, is provided in semi-annual intervals. So, 7 points (max.) could serve as a crude start.



1.1 Daily Production Rate vs. Time? Amazingly, we could not find any published physics-based formulation. Operators seem to use "decline curves", which amount to pure empirical representation, sometimes without even attempting correlation. A "3.75 BSCF (EUR) type curve" (a Chesapeake pro forma favorite) is an exponential decay, which has 71% of its production rate depleted in the first year, then much slower decline to some later date. This curve's correspondence to reality is similar to a stopped clock. It may be right twice during the well's lifetime. After reading some Truly Discouraging papers by respected geological scientists, and a brief discussion with Prof. TerryEngelder of Penn State, I gave up the search, and decided to derive our own formulation based on discharge/recharge thermodynamics of a dry shale-gas reservoir. The formulation uses 3 data pairs, (Production; Time) to calculate 3 coefficients: A time scale, EUR, and a desorption factor. Life span is defined when a well's production rate drops to near-zero, or the reservoir pressure drops below some minimal pipeline requirement. Defining the coefficients is iterative, since the formulation is nonlinear and requires convergence. Since our formulation requires specific well's data, it can predict nicely this particular well's performance. Of course, this calculation process must be repeated for each well, and the results, they differ.



Three distinct well examples are provided to conclude this brief introduction. The PA-registered well serial numbers are shown in the headers, as well as the converged EUR in Billion Std. Cubic Feet (BSCF), and the Life Span, in years. These simulations may miss the initial pulse, as it occurred during the first year (2010), but the overall fidelity to the later recorded data is quite satisfactory. Of course, for any particular operator, processing this information for few, or for hundreds of wells, is needed. Thus, one may calculate the operator's productive wells' actual (as opposed to speculative) EUR and Life Span. We intend to return to the subject of simulation of well performance in a subsequent article.



The Marcellus dry gas plays offer two puzzles, or challenges. One, can money be made on the underlying asset, and if so, how much and for how long? The present article will try to provide some answers. Two, how to distinguish the better operators? The second subject will be taken up by a third article in this series.

We are thankful to the PA-DEP for providing all the Marcellus data to the public in downloadable form. With the mandatory semi-annual operator reports, we have a reasonable database to start from. Marcellus is, therefore, fully quantifiable, and one does not need to infer from the older Barnett, TX shale play and its 17,000 well history. Yet, the lessons learned there seem to be repeated in the Marcellus. This indicates that the same physics apply to both, a disturbing thought.

We should also acknowledge the old Danish proverb, "it is very difficult to predict, especially the future." In the end, this article provides a series of insights based on the available data and use of logic; necessarily, these insights are conjectural. All of the data are as referenced. The graphics and ideas presented are our own. We also own all the mistakes that might have been made herein, endorse no operator or stock, and make no explicit or implicit buy or sell recommendation. This article can best serve those wise investors among us seeking a fundamental physical understanding of the asset underlying their investment. It is dedicated to those who drive policy (until now) without use of a map.

2. Marcellus in a Nutshell. The Marcellus shale extends over six states in the Appalachian basin in the USA. The size of the shale core is 16-32 million acres, mostly in Pennsylvania (PA), where, in particular, it has seen significant development starting in 2009, which continues today. In PA, the Marcellus shale is at a depth of 2 kilometers, and has a thickness of about 20 meters. In comparison, the Neuquén shale in Argentina is at the same depth, but its thickness is about 240 meters. The shale is horizontally layered like tile stacks, and has the consistency of good countertop granite slab. Its permeability and porosity are low, and its occluded water content high. The methane (natural gas) within the rock is thermogenic (as opposed to biogenic), its discrete sites are on 10-100 micron scale (not interconnected), and collocated with and highly adsorbed to clay micro-sites. A good description of dry gas shale physical properties (and an introduction to its problematic nature) can be found in Daniel Soeder's 1988 article.

This shale rock does not give off the methane readily, and has to be stimulated. The current fashionable way of stimulation is hydro-fracturing, "fracking". Wells are drilled vertically 2 km, then turn horizontal for about 2 km, typically in the lower half of the shale layer. Fracking is done in stages (18 is state-of-the-art today) and usually in the horizontal leg only. Holes are blasted through the sides of the casing, using a retractable "gun" holding shaped charges; then, a section of the pipe with the holes is closed, and high-pressure water and additives are injected into it.

Hydro-fracking involves injection of about 5-6 million gallons of water (19,000 to 23,000 cubic meters) per well, at very high pressure, to cause fracture of the shale layer. The water is laden with sand proppant, as well as other chemicals to facilitate smooth flow and penetration. Typical solids loading in the water is 10% by weight, and typical fracking pressures are 10,000-15,000 psi (680--1,000 atmospheres). Once fracked, the well starts production at a high rate, then undergoes a rapid decay, followed by a gradual decline in production rate over time. The flow rate from a fracked well is not controllable. A good geological description of gas shale reservoirs, their characteristic discharge, and the problems associated with physical modeling of their performance is given in Charles Vanorsdale's 1987 paper.
Per Cabot O&G, modern horizontal wells are drilled ten (10) or so per well pad, which saves a lot of time and money on moving rigs around. The arrangement in PA would be 5 horizontal wells going to northeast, and 5 going opposite, to southwest. The spacing between the parallel fingers can be as low as 500 ft. (150 m) without any crossover effects. A well pad footprint for 10 wells as above is shown to require some 170 hectares (420 acres). More typical well pad area is about 80 acres (32.4 hectares). Although the lower half of the Marcellus shale layer is normally drilled, it was found (Cabot O&G 2013 Update) that the upper half was not less productive.

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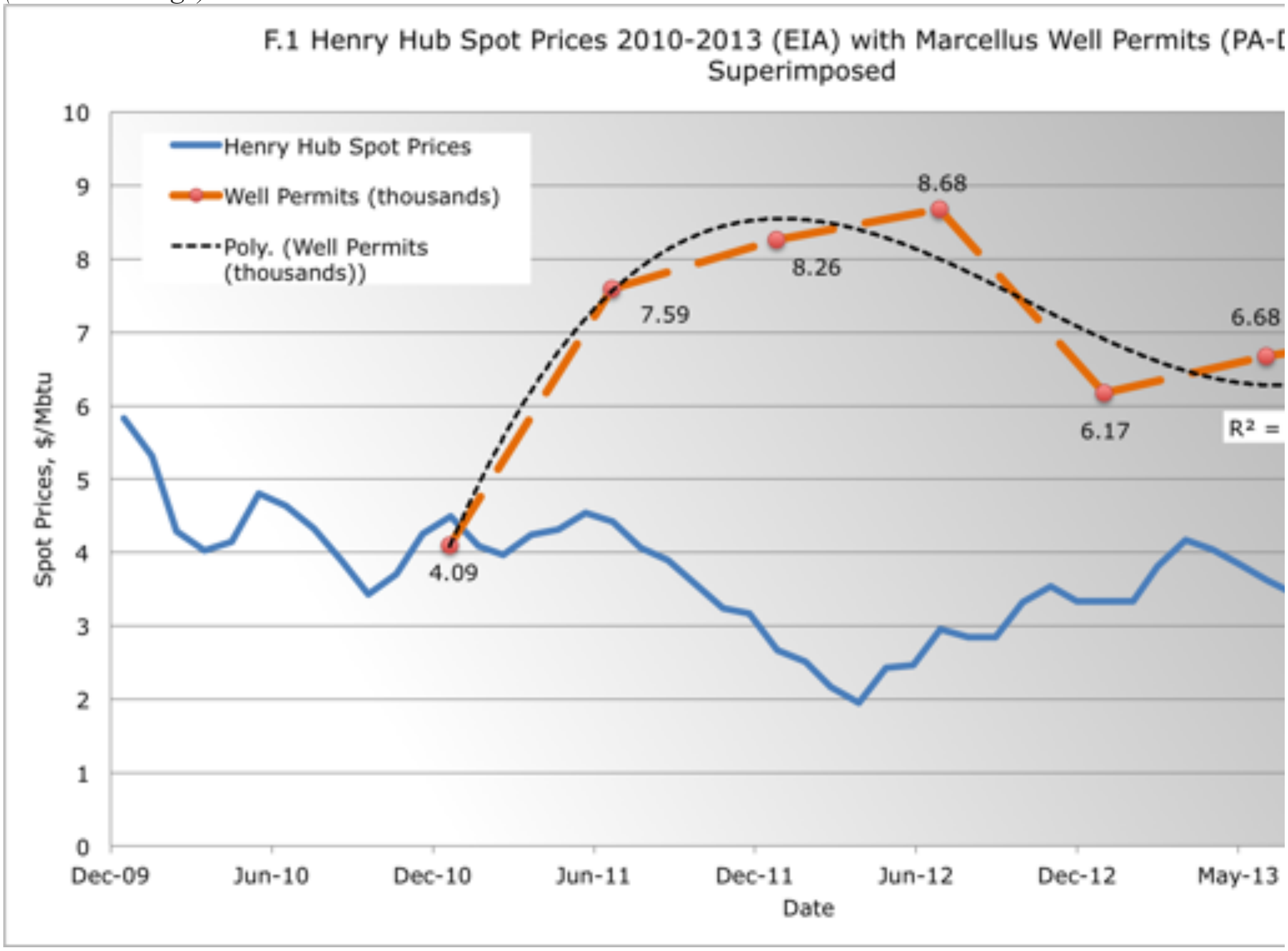

3. The Ecstasy: According to the EIA (Aug. 2013 Report), the Marcellus "proved reserves" as of 2011 were 31.9 Trillion Std. Cubic Feet (TSCF). The total shale-based proved reserves in the entire US were 131.6 TSCF, and the total NG, including conventional and wet sources, were 348.8 TSCF. Thus, Marcellus reserves represent just 9.2% of the total US proved reserves. Yet, the Marcellus seems to have ignited the recent exuberance regarding natural gas (NG) abundance in the US, leading to a feeling of glut: NG was produced, with nowhere to go, especially at the Marcellus. Arguably, exuberance can be measured by virtue of the following conjecture. A counter-correlation is offered between Henry Hub (HH) natural gas spot prices and the number of drawn permits for Marcellus wells, as shown in Fig.1. Between Dec. 2010 and Dec. 2012, the number of permits is increasing, peaking, and decreasing, as slightly later, the HH spot prices are doing the exact opposite, with a phase-lead by the permits. This is called "out of phase" in dynamics, and is highly significant. We have used a fourth-order polynomial correlation for the permits, as the available PA-DEP data is very sparse. Whereas causality is strongly inferred, it is not proven.

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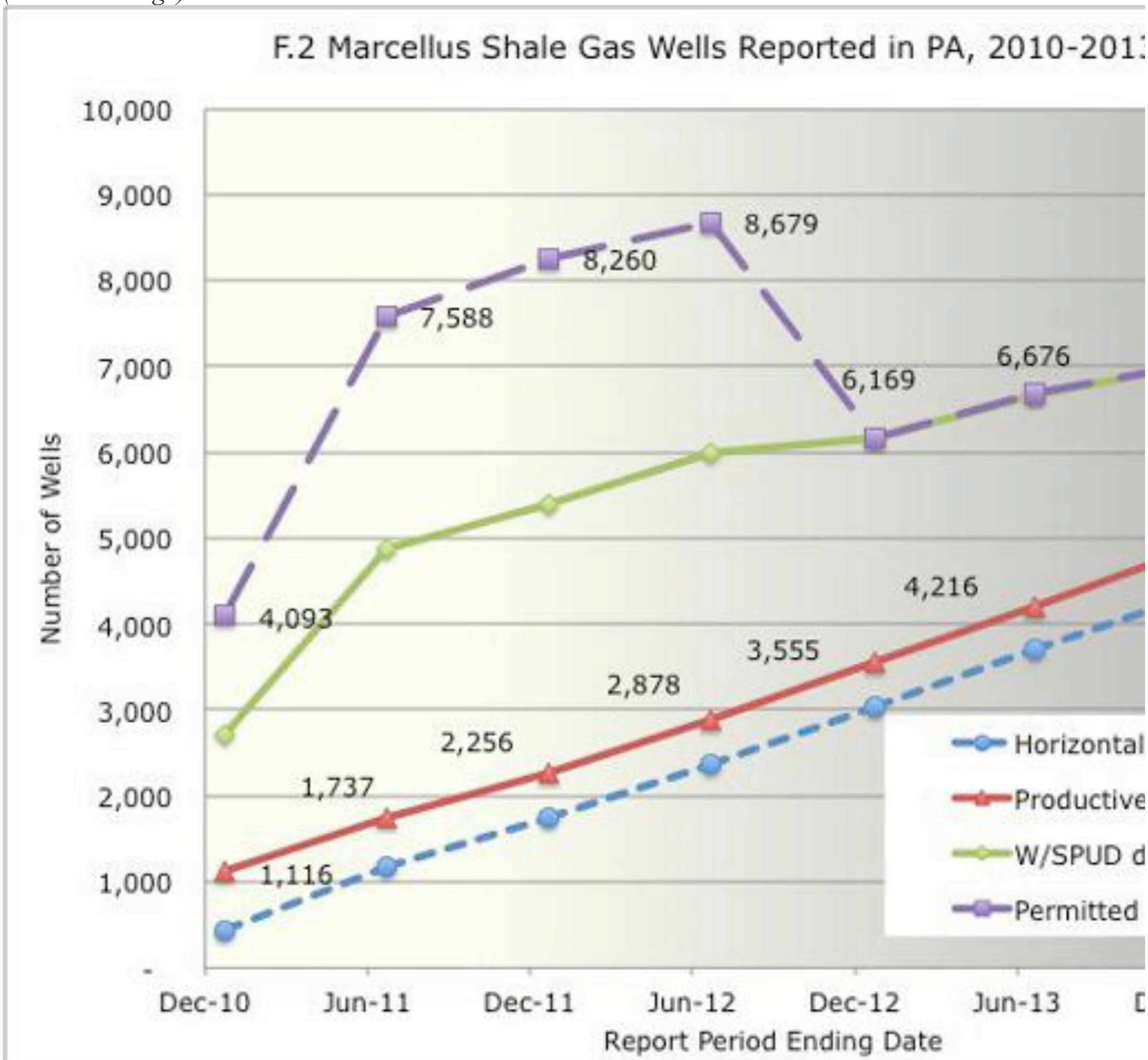
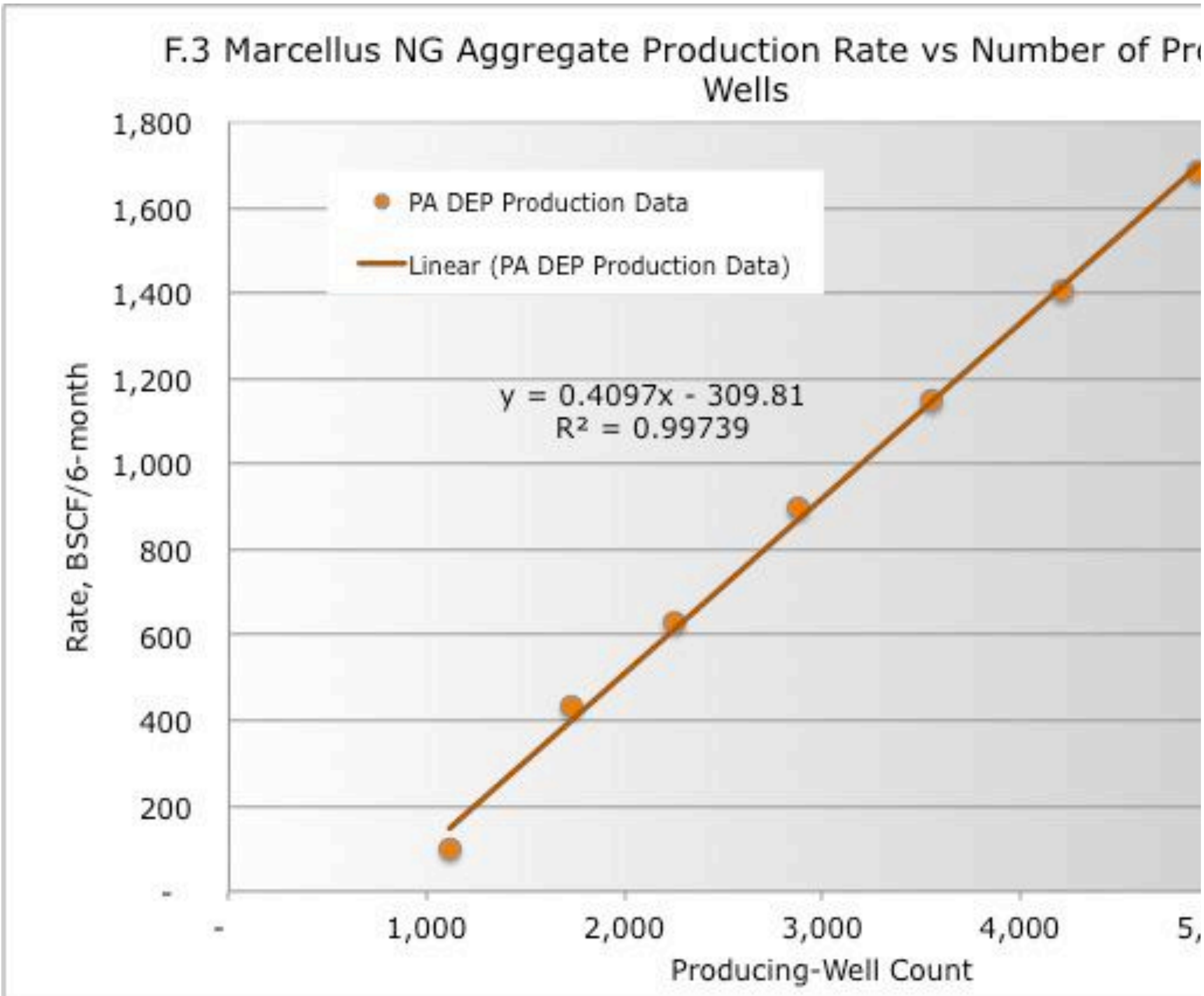
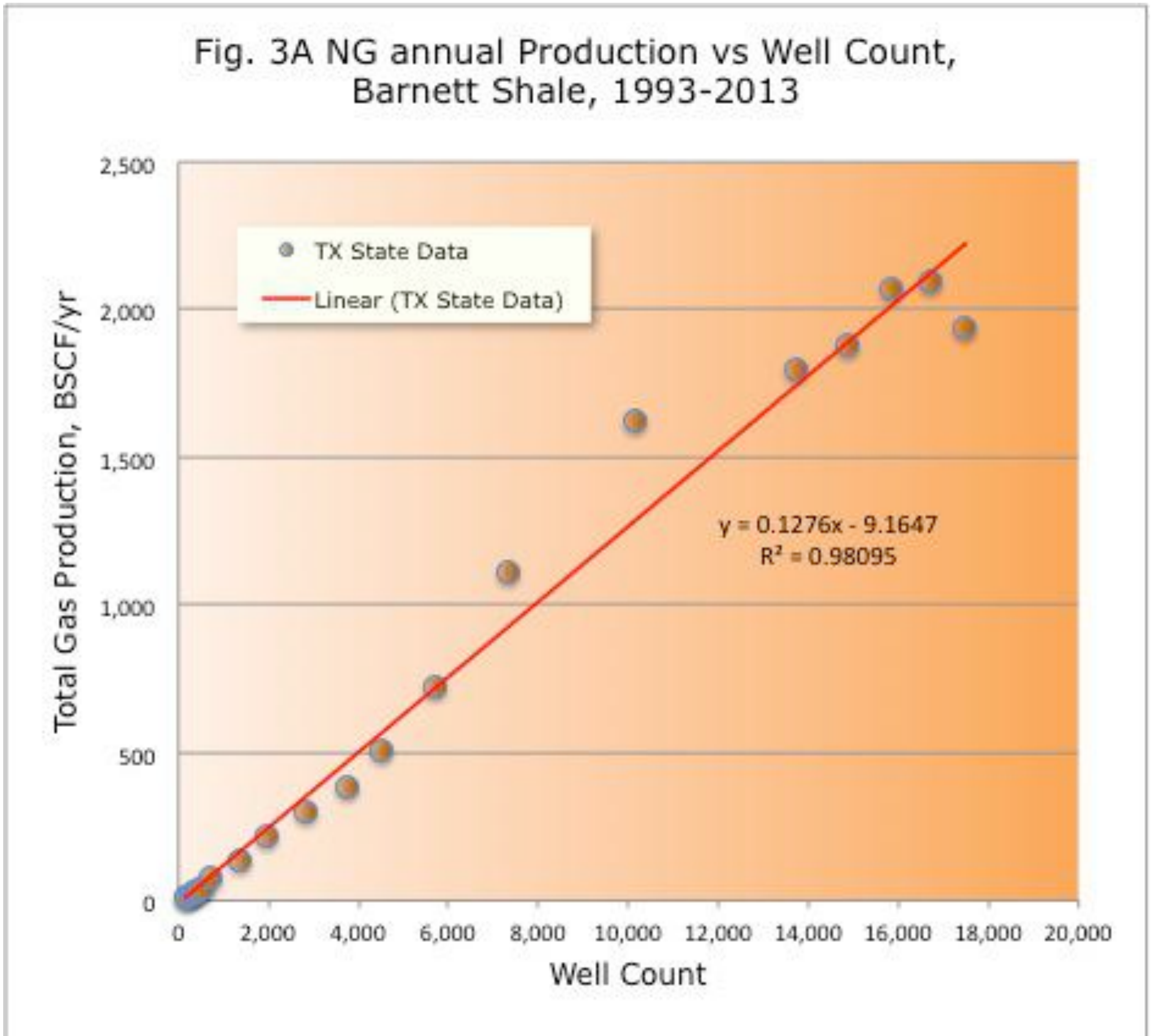


In the period 2010-2012, there was a significant gap (about 2,500 units) between Marcellus-drawn permits and actual SPUDs, and further about 6,000 units' difference between the number of permits and that of productive wells. This is shown in Fig. 2, a summary of all PA Marcellus unconventional wells. (SPUD is defined as the date when the drill is inserted into the ground.) This indicates significant unproductive spending.



3.1 Production Rate and Well Numbers: As shown in Fig. 2, the number of productive Marcellus wells (red line) increased linearly time-wise, from 521 at the end of 2009 to 4,900 by the end of 2013. This represents a significant capital investment, about $8 billion/year in 2013 dollars in aggregate. We assumed roughly $6.5 million per productive well, on average (explained later). In comparison, the horizontal shale gas wells in the Barnett, TX play increased exponentially during 2003-2009, from zero to 9,000 in about 7 years (Arthur Berman, 2012). A strong similarity is therefore inferred between the developments of Barnett and Marcellus. Indeed, the shale structures are also quite similar. Perhaps more alarming, after an apparent stop to new wells in the Barnett in 2009, the total production rate has declined quite sharply by 36% in the next 12 months.

In Fig. 3, we plot the total Marcellus production rate vs. the number of productive wells reported for the same period. Remarkably, there is a linear correlation between the aggregate rate of NG production and the number of productive wells. The production rate is as reported per each 6-month period. The units: 1,000 SCF (Std. cubic feet) = 1.023 Mega-Btu (MBtu). Thus, 1 Billion-SCF is equal to 1.023 millions of MBtu. Again, MBtu herein is Mega-Btu, one million British thermal units. Thus, it should be simple to convert volume to energy, and hence, to monetary value. The linear correlation is of high fidelity, as the correlation coefficient R2 closeness to unity indicates. What can be inferred from the linearity in Fig. 3 is that the time-wise variation of production is proportional to well numbers, and they are at a constant ratio.



In comparison, the Barnett (TX) shale performance has a longer history and over 3X the well number to 17,500 wells at the end of 2013, yet, far fewer horizontal fracked wells in comparison. Barnett production rate vs. well numbers are shown in Fig. 3A, with a near linear correlation, ending with decline. Note that wells are still being added in 2013, only fewer than the original rate, which still resulted in production decline.

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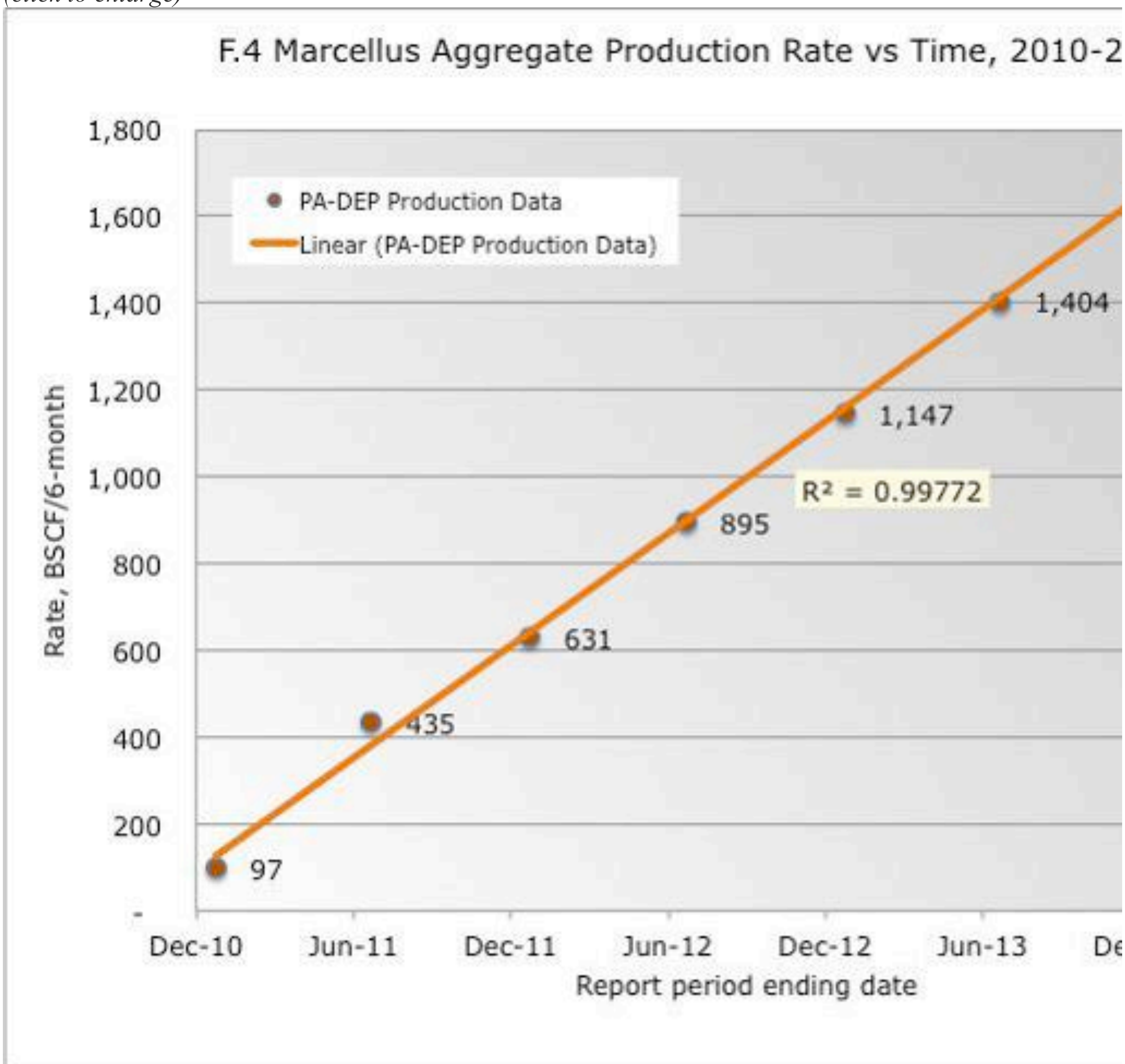
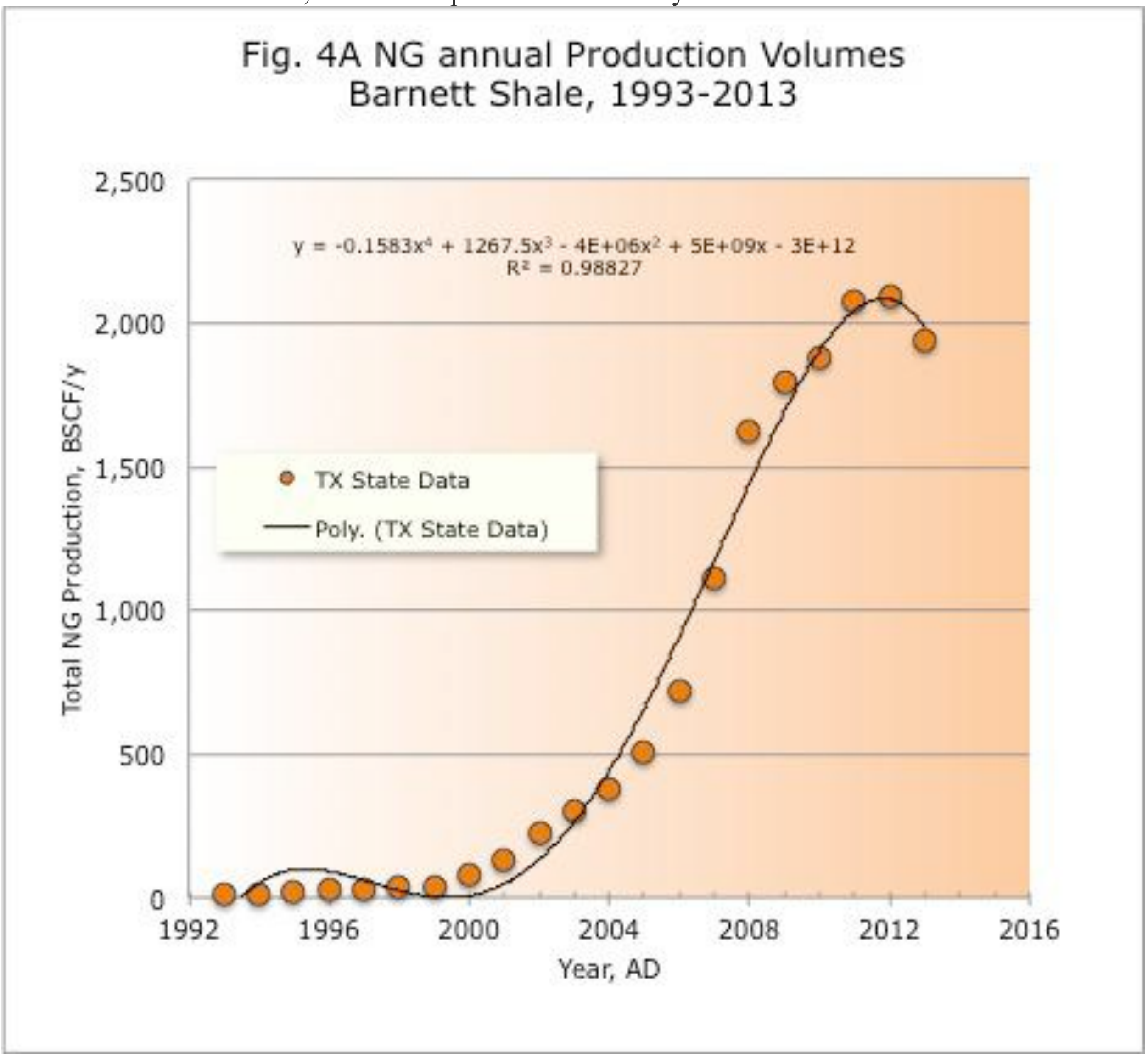
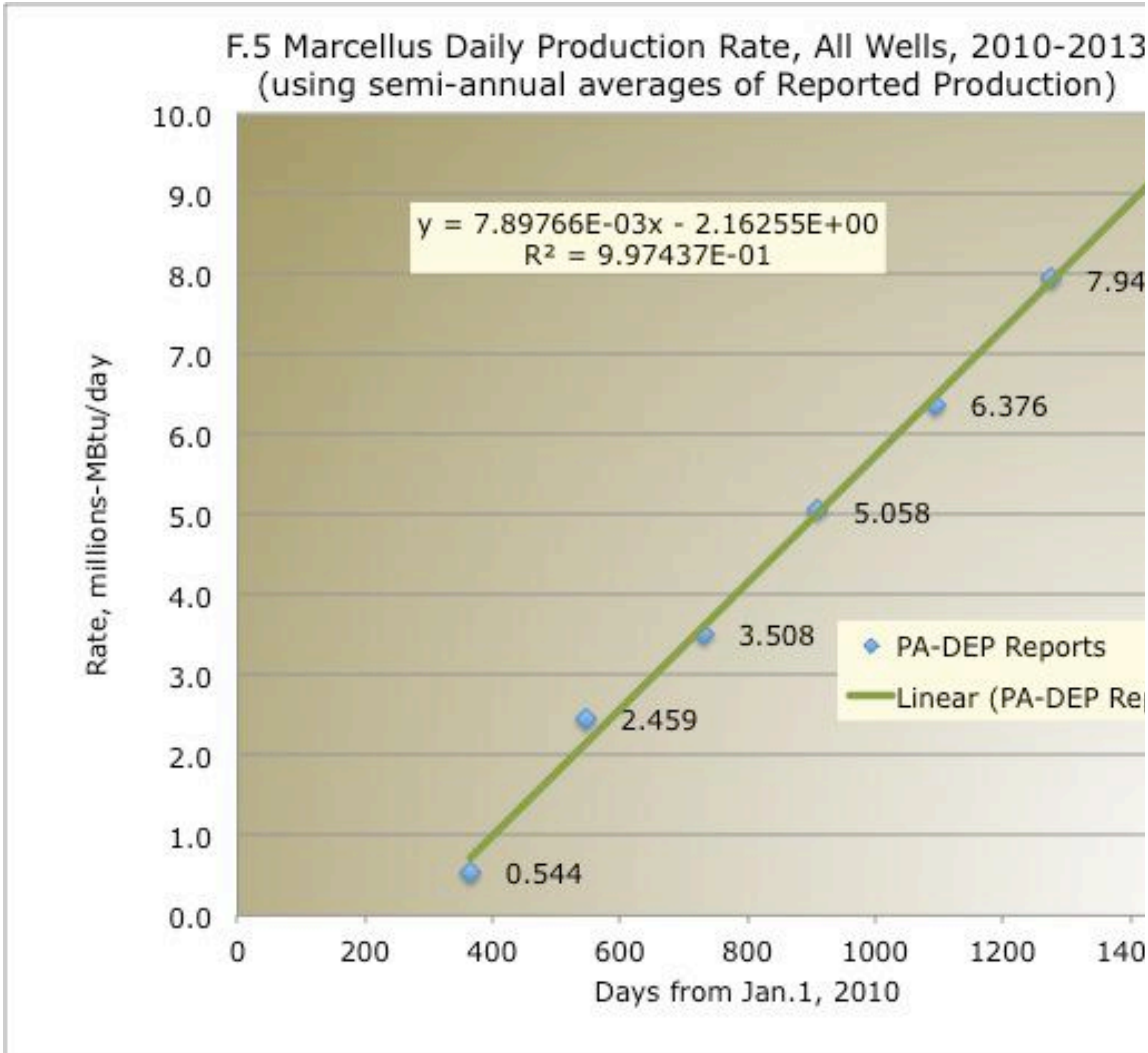


3.2. Total Production Rate vs. Time: Figure 4 shows time-wise variation of the aggregate production rate. Not surprisingly, from the linear time-wise productive well count in Fig. 2, the aggregate production rate in Fig. 4 indeed increases linearly with time. Barnett shale production rate vs. time is shown in Fig. 4A for comparison. Barnett shows the nonlinear accelerated production increase due to new wells, with subsequent decline -- very different from current Marcellus.



The Marcellus linearity is quite non-obvious, since, as we know, production comes from a series of wells with distinct, nonlinear declining production rates, started at irregular time intervals by many independent operators. This is analogous to the miracle of an ant swarm, each individual apparently pulling in its own direction, yet actually carrying an outsized edible object (in our case, Wall Street) directly to their colony.



To become useful for income calculations, we need the average Marcellus (all wells) daily production rate, time-wise. The data for Fig. 4 can be easily converted to total daily energy production. For each given reporting period, this number is obtained by dividing the sum of all wells' production by the number of days in the period (181 days or 184 days). This is **not** the sum of all wells' actual days online reported. The reported volumes in BSCF were then converted to millions of Mega-Btu (MBtu), after multiplying by 1.023. The results are shown in Fig. 5. It provides a linear correlation for the period 2010-2013, which we intend to extrapolate.

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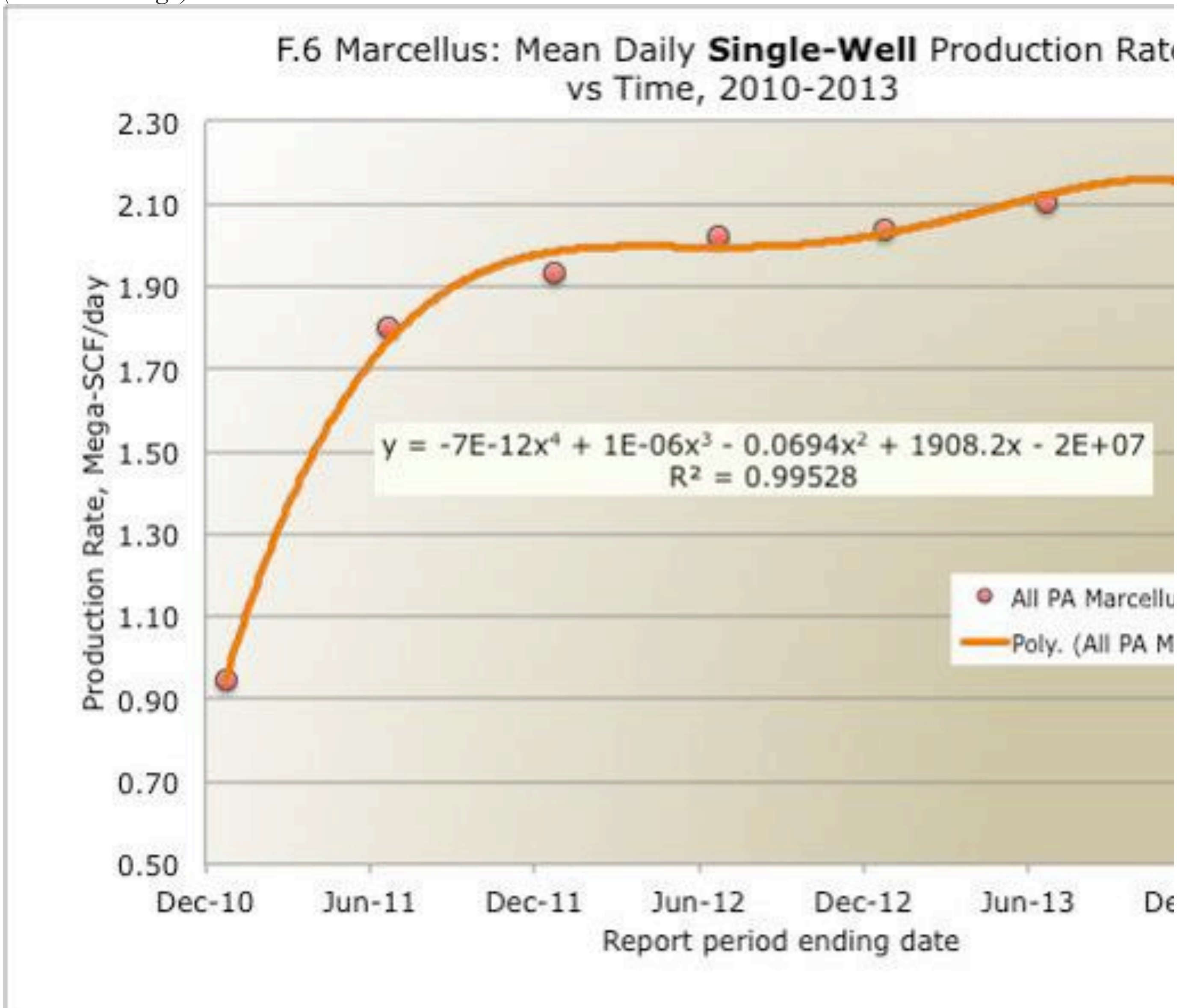
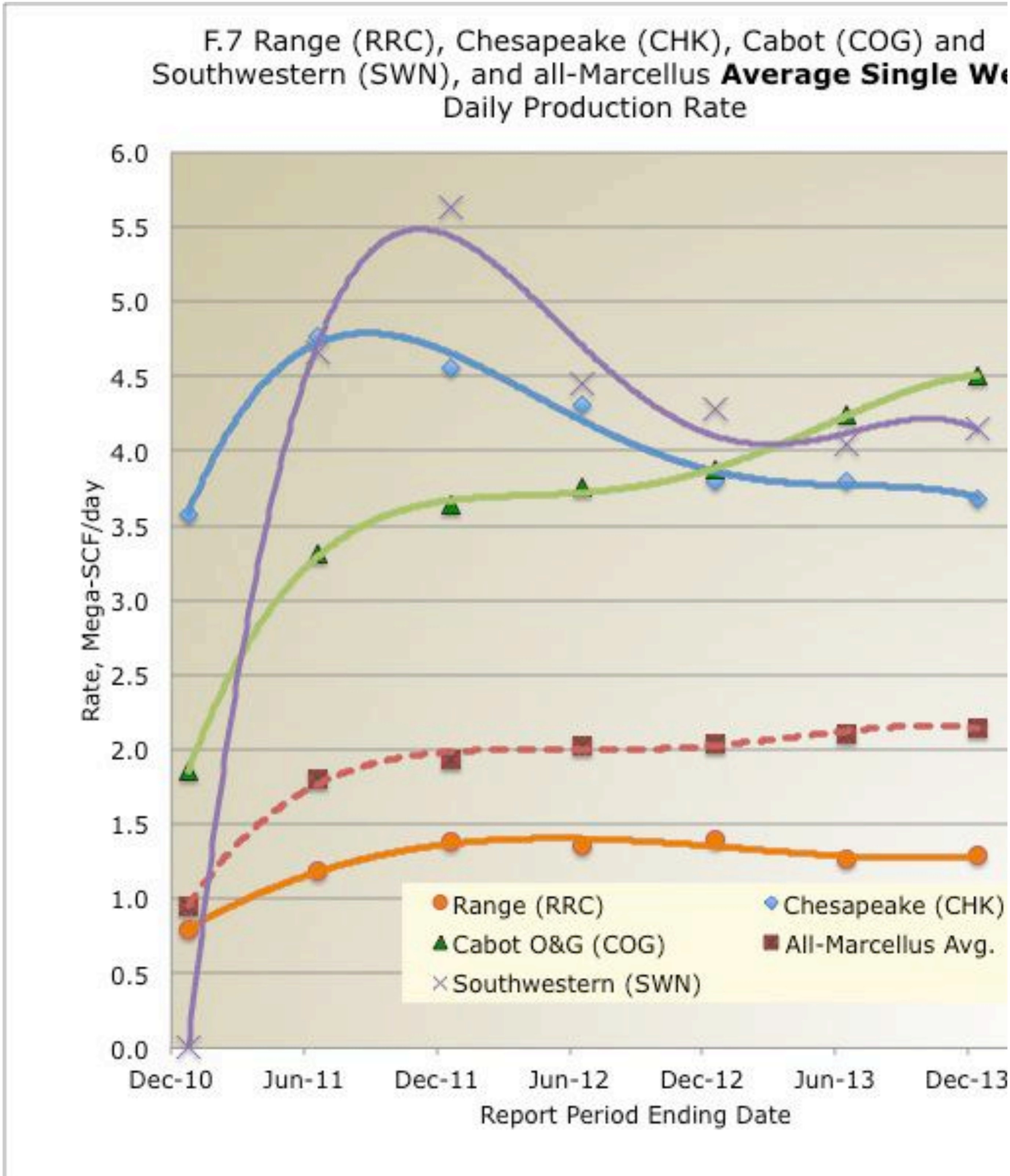


How does this compare to the average daily production per well? This is obtained as above, dividing the reported total semi-annual volumes by the sum of **actual** reported days of operation in the same period. This strips off the well-number multiplier, so that a very different picture emerges, see Fig.6 and Fig. 7.



F.7 Range (RRC), Chesapeake (CHK), Cabot (COG) and
Southwestern (SWN), and all-Marcellus **Average Single We**
Daily Production Rate
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Rate, Mega-SCF/day
Range (RRC)
Chesapeake (CHK)
Cabot O&G (COG)
All-Marcellus Avg.
Southwestern (SWN)
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13
Dec-13
Report Period Ending Date

We emphasize that these are very different from individual well production profiles, since the averages in Figs. 6, 7 contain a variable mixture of new and old wells. There are differences in the mean per-well daily production rate vs. time profiles of different operators, as shown in Fig. 7, where daily production rates from 4 distinct operators, Chesapeake (CHK), Range Resources Corp. (RRC), Cabot O&G Corp. (COG), and Southwestern (SWN) are superimposed over the mean Marcellus performance. For CHK, RRC [as well as for Anadarko (APC), XTO Energy, Inc. (now Exxon, XOM) and many others], production has peaked during the last half of 2011, leaving a shallow decline or near-constant rate. Only Cabot is rising monotonously. As shown in Fig.7, there must be a considerable number of wells underperforming the mean, like RRC, such that the mean total production rate per well comes lower than CHK, COG, SWN, and APC (not shown) profiles. The Marcellus mean shows a rise to December 2011, likely driven by a large number of start-ups, then taper off to nearly constant daily production rate of about 2,200 MBtu/day.

4. How Significant, Marcellus? If we sum up the last 2 Marcellus reporting periods of 2013, we get an annual aggregate rate of 3.09 Trillion-SCF per year (TSCF/y), or 3.16 billion MBtu/y. At the end of 2012, this figure was 2.09 billion MBtu/y, representing an increment of 1 TSCF/y per year. How significant is this production rate in the overall US energy picture?

According to the EIA 2013 Energy Report, NG production and consumption in the US were quite close over the last two decades. Latest available numbers are for 2012: total US consumption was 25.53 TSCF/y, while production was 25.31 TSCF/y. Thus, the Marcellus part of total 2012 US production was 2.09/25.31 = 8.3%. Whereas total US production increased by 10% from 2011 to 2012, the Marcellus aggregate output has increased some 50% over the same period. So, if the current productive-well expansion rate continues in the Marcellus (1,262 wells per year, on average), it can be expected to play a more prominent part in the total US production in the near term. Or would it?

With the above 2012 observation, it may be concluded that while the Marcellus shares of total US production and proved reserves, 8.3% and 9.2% respectively, are not negligible, they should not be considered significant.

Now we all know that economical ultimate recovery (EUR) is but a fraction of Proven Reserves, and thus, should expect recovery to be less than the proved reserves. Nevertheless, let us pretend for the moment that 100% of proved reserves are recoverable, and remain as stated.

Thus, assuming that proved Marcellus reserves remain at 31.9 TSCF, and**production remained constant** at its December 2013 level, namely 3.09 TSCF/y, the entire play would last about 31.9/3.09 = 10 years.

However, if we keep increasing the number of new Marcellus wells at the current rate of 1,262/year, and thus, increase production rate by the current 1.0 TSCF/y each year, as seen in Fig. 4, while the proved reserves remained constant at 31.9 TSCF - then, we are left with only 7 years of Marcellus production from 2011. This brings us to the year 2018, which has its own significance: This is the Chinese Year Of The Dog, in which Chinese GDP, rising exponentially since year 2000, is projected to overtake the US GDP, rising linearly. But wait, what if the actual proven reserves of the Marcellus were twice larger, or 64 TSCF? Keeping the current linear expansion rate, the Marcellus will last 10.3 years to about mid-year 2021, not much longer than the current EIA 2011 proved reserve would provide.

In summary, our last two calculated observations are: (1) Marcellus proved reserves and its production rate are insignificant relative to the total US market, and (2) Marcellus, at the current expansion rate, even with double the proved reserves, will last just 10 years.

5. A Black Swan (or Two): In light of the above, and accepting for the moment the conjecture in Fig.1, with the large increase in well permits affecting the Henry Hub cost decline, this seems like a case of the exuberant tail wagging the dog. Put another way, we are witnessing a nonlinear market mechanism, in which a physically small item leads a very significant effect. Typical to systems of this nature, a black swan (channelingNassim Taleb) is awaiting us just around the corner. A black swan is a widely unexpected event, not necessarily bad in general. For the US natural gas (indeed, energy) market, however, the outcome could be ominous. Exuberance has two dangerous daughters.

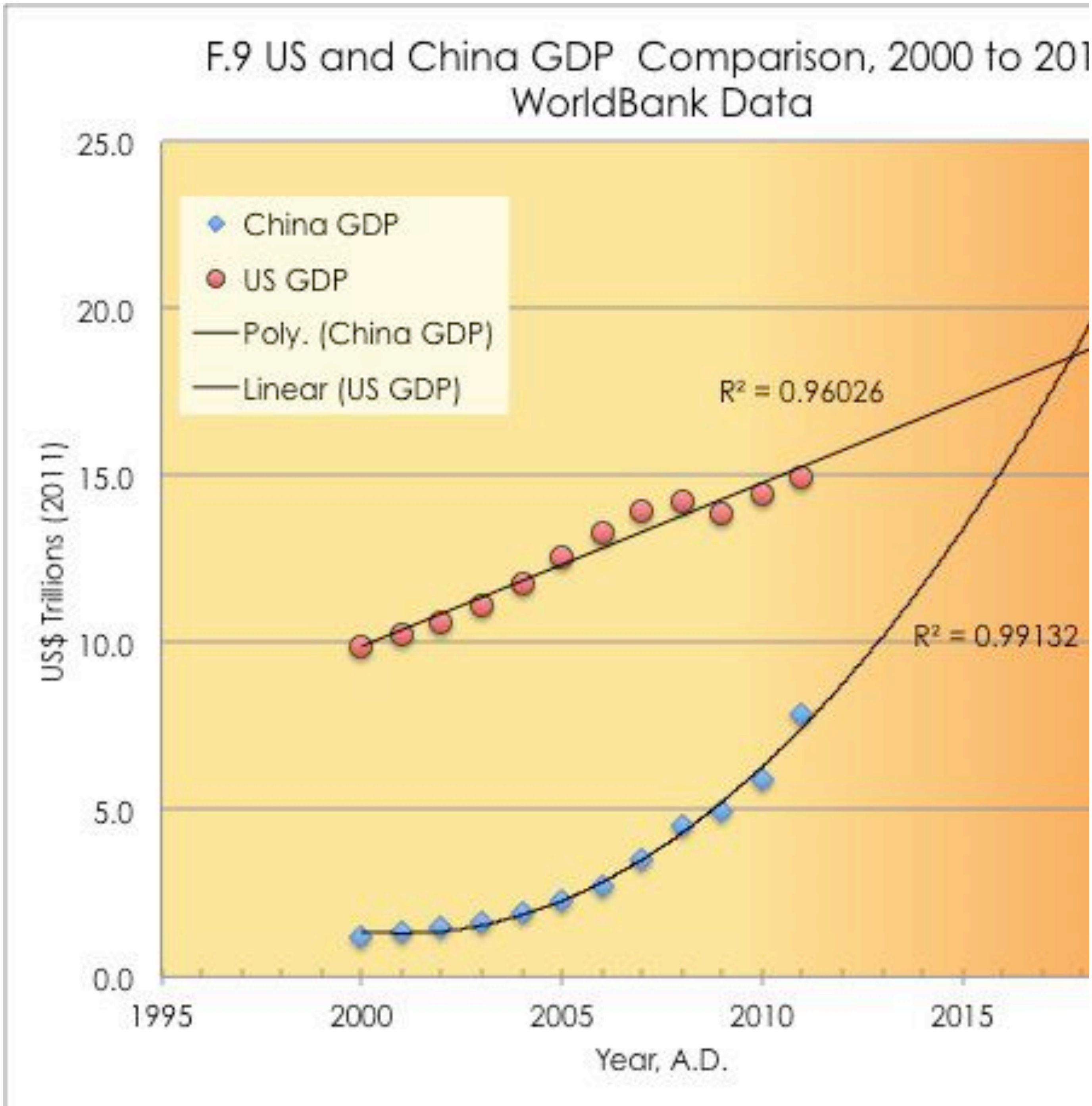
The first dangerous aspect is low vigilance. A perception of limitless abundance of NG allows one to throw caution to the wind, and any opportunity in renewable energy to the dustbin. Indeed, we have virtually stopped the development of biomass-based renewable transportation fuels (corn ethanol is the opposite of this solution). And with our current crude oil proved reserves (25.54 billion barrels, per EIA 2013) and consumption rate, (6.89 billion barrels/year, same source), we have less than 4 years of in-ground reserves, in case imports stopped. Thus, no alternative synthetic transportation fuels, and increased, not decreased, future dependence on OPEC. We will revisit this troubling subject later on. It has serious balance of trade, energy security, and national security ramifications.

The second dangerous aspect of exuberance is low NG prices. This virtually assures a very risky future to the Marcellus enterprise. Indeed, to the whole energy future of the US. How? Lack of investment attraction to (1) expanding the inadequate pipeline network for a product with low present value, and (2) building new NG-based power generation, in anticipation of NG price instability. As strange as it may sound, low NG prices, lacking any regulatory support, cause aversion to new power generation. We have seen in the recent past (2005), NG prices spiking to $14/MBtu and more. NG availability may be in question due to Item (1) above, and coal-based power generation may rebound if a new administration relaxed the relevant severe environmental restrictions. Under these circumstances, investment in NG infrastructure and large-scale NGCC power plants is not attractive.

In summary, the dual dangers of exuberance await: (1) Neglecting the development of renewable alternatives on a large scale, and (2) Low NG prices impede development of NG infrastructure and sustainable expansion of its use in the near term, especially, replacement of coal in power generation.

6. Marcellus Pro Forma. It seems that there may be a buck to be made, yet. We should thus ask a Warren Buffett question: Is the underlying asset healthy? So we set out to check the viability of the Marcellus enterprise, as if it were a single entity. The objective is to see whether it makes sense commercially, in the aggregate, regardless of how better off, or worse, are the actual operators' respective performances. This simplification has but limited merit, in providing a foundation for a further look at individual operators' stock or options. Ultimately, one must evaluate each of the operators' distinct positions. The following assumptions are made.

6.1 Income Past: The aggregate daily production shown in Fig. 5 is used to generate time-wise monthly production figures, which are matched with the corresponding Henry Hub monthly spot prices, the same as shown in Fig.1. This is done by the linear correlation, shown in Fig. 5, for production through 2013. The resulting income for this initial period is shown in Fig. 8. As a footnote, we know full well that Marcellus NG is sold lower than HH because of inadequacy of pipeline networks. We use HH nevertheless for pro forma calculations, to compare to other available sources.



6.2 Income Future: After December 31, 2013 there is no further production data available, so we will have to extrapolate our linear production vs. time. The following derivation is offered for predicting the future.

As discussed above, the total US Proven Reserves (EIA, 2013) for NG are 334 TSCF (2011 figure), while US consumption closely matches production; at the end of 2011, consumption was 24.47 TSCF/year. The ratio of these two numbers, if held constant time-wise, gives less than 15 years of production. Although we can anticipate availability of LNG in world markets, we must also anticipate increasing demand by buyers richer and more powerful than the US. In particular, China, expected to dominate world economy after 2018. See Fig. 9.

6.3 The economy of an exhaustible mineral resource (such as NG, in our case) has been studied by Howard Hotelling in his 1931 paper, famously ignored today. The formulation that we have derived for future pricing of NG in the US is based on Hotelling's approach, (for a particular case where interest rates are very low), with two major modifications, as follows.

1. Upon approaching the event of total resource depletion, the price of the commodity must be affected by the diminishing amount remaining in the ground. The less that remains, the higher the price. So, in the denominator, we should have the difference between the initial reserve and the total amount produced or extracted to-date. The initial reserve is denoted A_o = 334.07 TSCF, as set in 2011.
2. The numerator of the pricing should be driven by the instantaneous demand, as per the following formula. The projected time-wise demand (or production rate) should escalate in a compounded way under the force of GDP, namely, at time t, consumption is expressed as,

$Q(t) = Q_o * \exp(G * t)$ (1)

where Q_o is the initial consumption quantity (e.g., 24.47 TSCF/year) at time t = 0, which we set at 2011. G = the US GDP annual variation. US GDP varies linearly since year 2000, with a calculated mean slope of 4.94% per year, see Fig. 9. So, we use the dynamics of an exhaustible resource coming close to full depletion for the entire US reserves to calculate a conservative price projection for the near term. The future pricing formula is, therefore, the ratio of "demand" to "remaining resource", as above, multiplied by the initial (2011) price factor, P_o = 3.17 $/MBtu, compounded by the interest rate, "α",(using the 10-year Treasury Note yield, e.g., a= 2.726% per year currently). Thus,

$P(t) = [P_o*\exp(\alpha*t)] *\exp(G*t)/[1-(Q_o/A_o)*(\exp(G*t) -1)/G]$ (2)

The first term in Eq. (2) is the original Hotelling future value. Our projected pricing for NG, using Eq. (2) above, is shown in Fig. 10, together with the initial Henry Hub data available to early 2014. Note the effect of the severe winter in February 2014, where HH spot price shot up to $6.00. Of course, we expect actual prices to fluctuate about the mean line shown in Fig. 10, similar to the HH behavior, previous. Of course this is entirely speculative, and done only for the purpose of obtaining some pro-forma income for the total Marcellus NG sales. It should be interesting to compare with actual Henry Hub prices, 2014-2018, when available.

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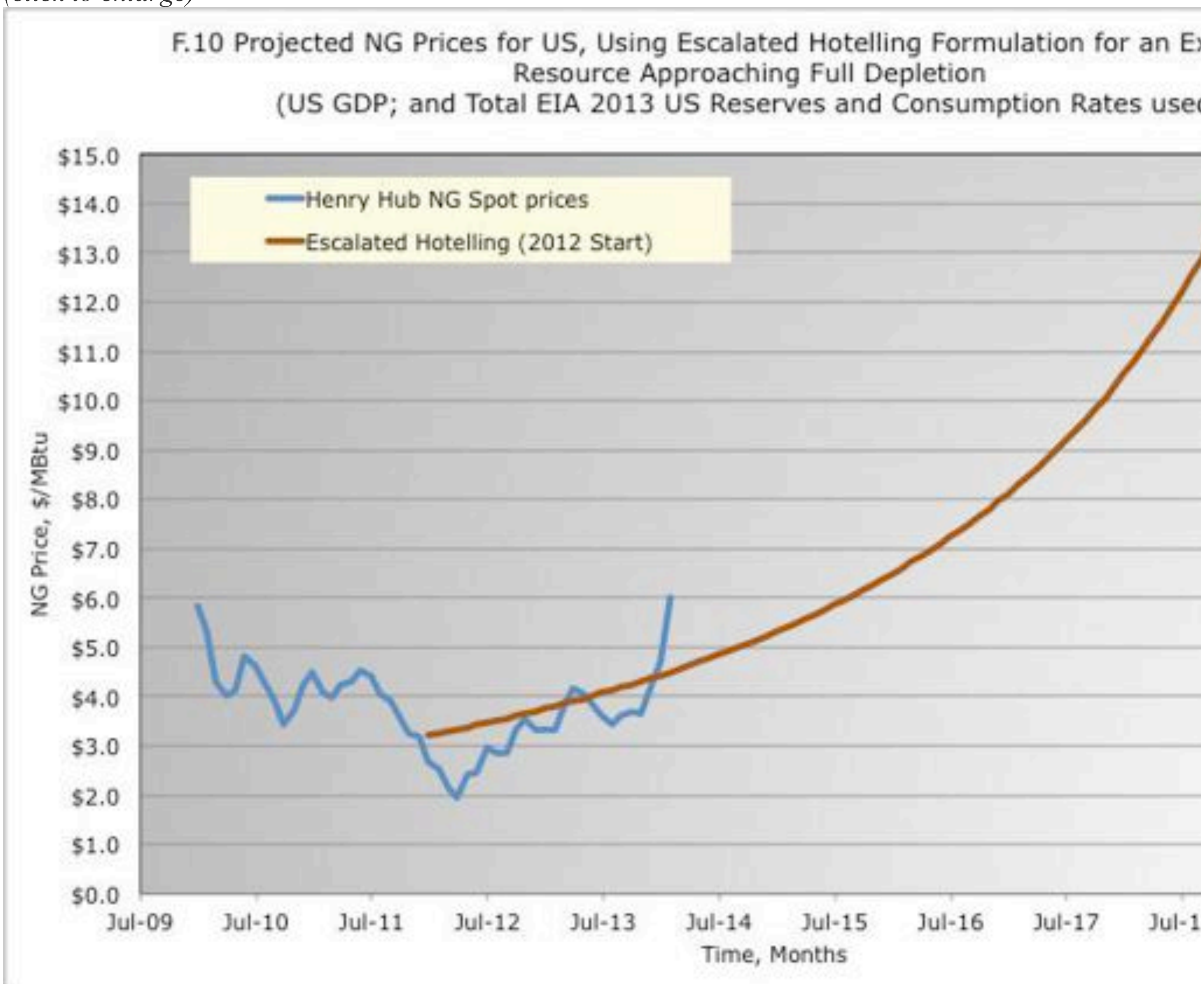
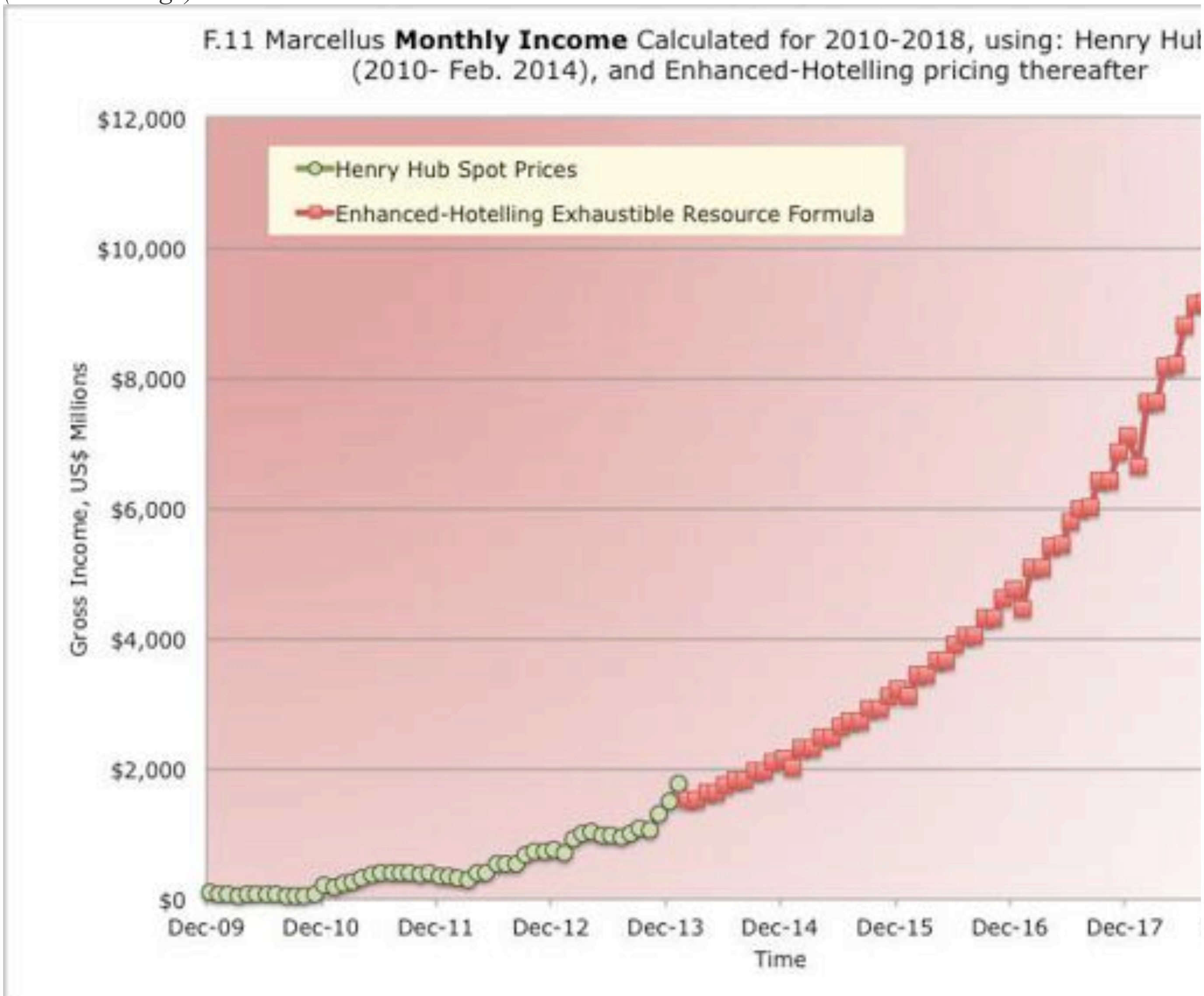


How much time remains for the entire US reserve above if consumption followed the moderate GDP-driven Q(t) exponential escalation described in Eq. (1) above? Ten (actually 10.3) years to complete depletion. An interesting closeness to the remaining time on the Marcellus clock (7-10 years), calculated in the previous section.

The foregoing analysis is highly simplistic, yet should be considered conservative. Three major effects should drive demand, and, hence, price in the US much higher, and quite dramatically. These are,

(1) Large-scale NG use for electric generation. Assuming coal-based generation in 2011 was 1,560 Terra-Watt-hours, to be replaced entirely by clean-burning NG Combined Cycle (NGCC), at 50% thermal efficiency. Add 10 TSCF/year.
(2) Large-scale use for synthetic liquid transportation fuel, namely, high-octane gasoline. Use NG to generate 20% of US gasoline consumption, i.e., 640 million barrels/year of high-octane gasoline (plus some LPG), using theExxonMobil MTG method. Add 5 TSCF/year to NG consumption. And,
(3) Severe weather due to climate change will further add to heating and cooling NG usage.
Returning to the Marcellus now, we use the same linear expansion in overall production shown in Fig. 5, in combination with the monthly price projections from our enhanced Hotelling analysis derived here, see Fig. 10, to get a calculated future gross income. The monthly income for Marcellus (PA only) is shown in Fig. 11, with projection to 2018. Since we expect that by the end of 2018 the current Marcellus proved reserves would be depleted, the income curve indeed looks like a supernova.

(click to enlarge)



6.4 Capital expense: Fracking is an expensive proposition. It uses 5-6 million gallons of water per well, and costs (per Cabot O&G, 2013 Company Update) $6.4 million per well in a 2-well pad, with 18 fracking stages. More stages are currently contemplated, so costs will become higher. We use this cost/well both forward and retroactively. It is recognized that earlier wells might have been cheaper to complete, but non-productive permits and SPUD sites, and re-stimulation of poorly performing wells indicate significant expense beyond the productive well count, which would be compensated by this high "constant" well completion cost. We take the annual increment of 1,262 wells/y and apply the capital expense fraction, at the above constant completion cost. Our pro forma assumption is that 10% of each well is financed. Thus, the annual CAPEX is 90% of $8.08 billion, and is presented as an expense. The financed 10% we assumed payable in 10 years at APR =

LIBOR + 2.8% added to represent inherent risk. At the time of this writing, LIBOR current week Red Book rate was 4.47%. Cumulative debt service is, therefore, adding to the expenses each year.

6.5 Operating Expenses: Using Cabot's 2013 Update, total expenses, including tax, without debt service, was reported $1.67 per MBtu in 2012 (1.023 Mega-Btu = 1,000 SCF). We have adopted this figure, although it seems low. The pro forma is calculated from 2010 as start year. The first 6 years are shown in Table 1.

There are additional potential "operating costs" in waste disposal, which were excluded. The Marcellus shale rock is rich with occluded ancient water. Actually, when examining core samples, the Marcellus shale layers top and bottom are sometimes identified by running a Geiger counter in parallel to the core axis; the shale radiation levels are typically 100 times the normal background. This water comes to the surface during the early stages of recovery, and has high radioactivity due to dissolved Radium 226, Uranium 238, and radioactive potassium salts. (See radioactivity discussion in Terry Engelder's presentation.) Thus, water recovery in conventional settling lagoons, and sludge separation pose serious problems. Fracking waste water, declared "for reuse" should actually be quite unusable.

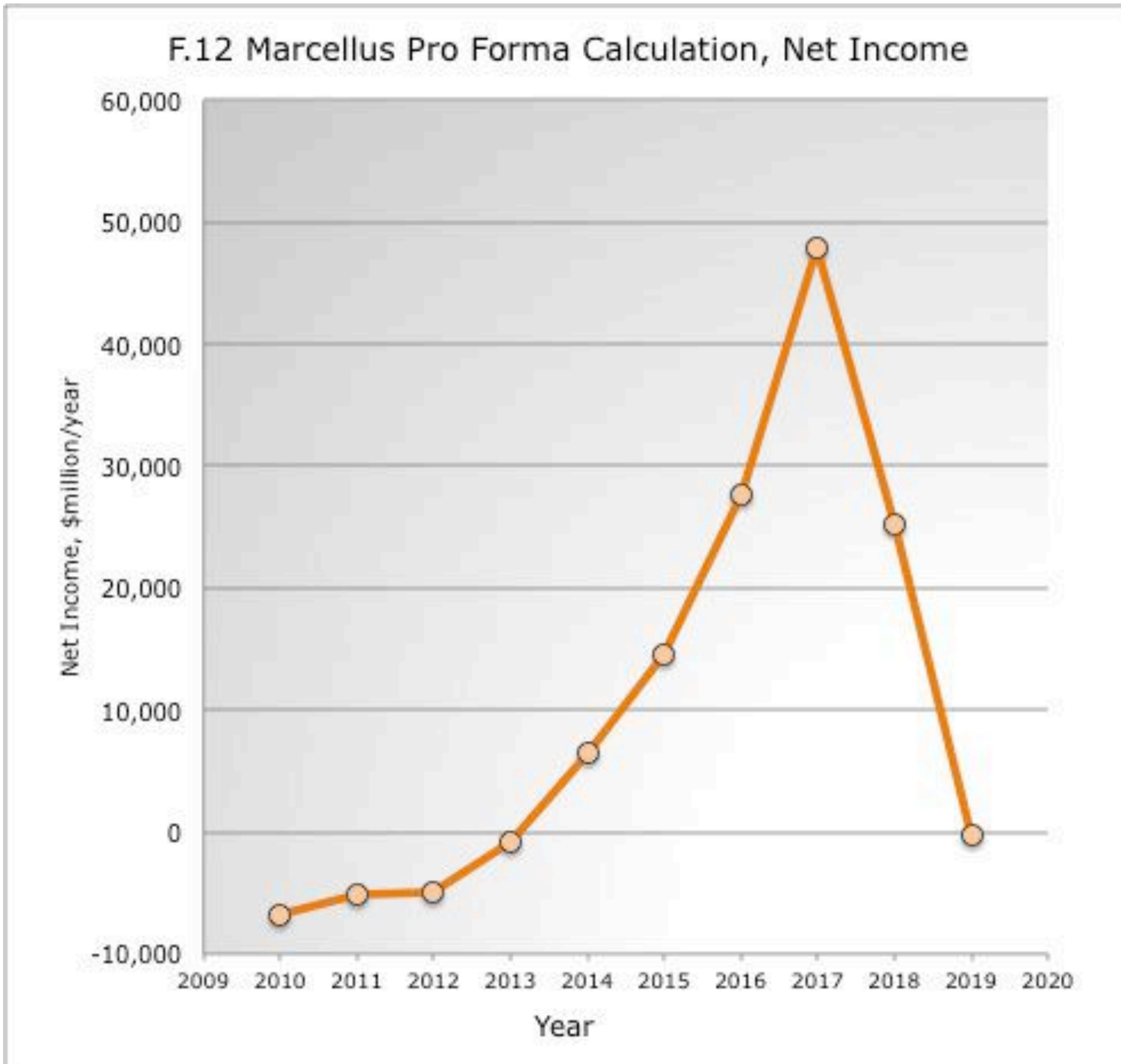
(click to enlarge)

Table 1:Total Marcellus Dry-Gas Pro forma:

Assumptions:				2010	2011	2012	2013	2014	2015
			Year No. =	1	2	3	4	5	6
Derived LNG Price			$/MBTU =	$4.38	$3.73	$2.85	$3.76	$4.96	$5.84
NG Sales Volume, Linear Correlation			millions MBTU/Y=	198	1,091	2,089	3,165	4,241	5,291
	Equity	New/year	$million/well			$ million/year			
NG Production Income	90%			$870	$4,064	$5,952	$11,912	$21,041	$30,908
CAPEX New Wells	$7,269	1,262	$6.40	($7,269)	($7,269)	($7,269)	($7,269)	($7,269)	($7,269)
Total OPEX Other (Cabot, 2012)	$/MBTU=	$1.67		($331)	($1,821)	($3,488)	($5,285)	($7,083)	($8,836)
EBITDA				($6,731)	($5,026)	($4,805)	($642)	$6,689	$14,804
	%APR	PV, $million	Years						
New Wells Debt Interest	7.27%	$808	10	($58.7)	($113.2)	($163.3)	($208.5)	($248.5)	($282.9)
Wells Amortization	SL	$0	10	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Tax	0.00%			$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
NG Production Net Income				($6,790)	($5,139)	($4,968)	($851)	$6,440	$14,521
		$millions							
	PV-10 =	$44,501	IRR=	41.8%					

6.6 Summary: The calculated PV-10 and IRR are based on the net income over a period of 10 years, as shown (in part) in Table 1. The figures for PV-10 and IRR, $44.5 billion and 41.8%, shown at the bottom of T.1, are quite impressive. Please note that there is no way to infer NPV or IRR of any individual operator, past or future, from these calculations. The net income is plotted vs. time in Fig. 12, showing the crossing over to profitability in 2014. Note that the calculations were limited to the 10-year period, because the extrapolated rate of production would have exhausted the Marcellus proved reserve in 2018. Regarding the net present value (assuming 10% interest rate), we

note that the expense on new wells during the 5 years 2010-2014 would be equivalent to $40.4 billion, close to the PV-10 calculated here.
Of course, at a more moderate price increase, without the radical price escalation projected above, there would be a far lower profitability for the enterprise.



7. Possible Remedy: Replace Fracking. The limited life expectancy of the Marcellus enterprise is troubling. One way to improve on the proved reserves is through improved recovery technology. The porosity of the Marcellus shale suggests a far higher NG/shale-volume ratio than the current

proved reserves. Proved reserves, as well as EUR stand to improve greatly if we switch from fracking to a better recovery technology. Just by observing the volumes of shale adjacent to the horizontal bore, which are not addressed by the fracking process, one may expect a 4X improvement over the current ultimate recovery, or higher.
The attributes of this new technology are,

(1) Minimal water use (orders of magnitude lower) compared to fracking,

(2) Enable gas extraction on micro-scale, unlike fracking's macro-scale. Translation: far larger volumes of natural gas extracted per unit shale-volume stimulated, without affecting underground tectonics,

(3) Controllable extraction, namely the rate of gas production in the well would be tunable, at will, by the operator. The initial discharge pulse would be avoided, and

(4) Cost, and energy spent, comparable to current well completion, or lower - without the environmental issues. Such technology could be developed within a time frame of 6-8 years.

Now, even though we may increase reserves by an appreciable factor, the total life span of the Marcellus will improve just incrementally, possibly by 10 additional years, due to the expanding production rate. Since the Marcellus (and overall, shale) is but a small part of the overall US NG Proved Reserves, the supply-limited price projections in Fig. 10 above are still expected to hold. Any significant increase in the interest rate will further drive NG prices up exponentially, as per Hotelling.

8. The Agony, in Conclusion. The foregoing analysis indicates that a significant change of perception of NG and of energy policy are necessary, and urgently. We seem to have an abundance of neither natural gas, nor crude oil. Our proved NG reserves will last less than 10 years, if imports stopped, and those of crude oil, less than 4 years. We are well underway to become much more dependent, not less dependent, on OPEC, which is poised to regain the top position in world energy supply (per Exxon projections, 2014). In this regard, how to explain the expanding popular sales of fuel-guzzling 3.5 ton SUVs and pickup trucks in the US 40 years after the warning of 1973? Easter Island, anyone?

We must make a serious commitment to renewable energy, and in the short term, drastically increase the use of NG for power generation and synthetic transportation fuels, replacing crude oil and coal. But is it sane to increase the consumption of NG in the face of low US reserves (and inevitable NG price escalation)? Indeed, it is. This is the only way to break out of our dependency on OPEC and on toxic coal, and lead into sustainability in the long term. Also, to avoid an undersea wonderland called New York City. It cannot be accomplished without new regulation.

We better stop dreaming of colonizing Mars and of huge LNG export terminals, and use our resources to get all the NG we can by long-term contracts and acquisitions. And get serious about new dry-gas shale technology to replace the inefficient fracking. In light of the projections herein, there is little wonder that Big Energy is making exactly such Large NG resource acquisitions. It is not gambling. It makes great business sense.

Summary of Key References:

1. *PA-DEP, source of reported Marcellus MG production data:https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/Welcome/Agreement.aspx*
2. *EIA, May 2013 US Oil and Gas Reserves, Production and Consumption:http://www.eia.gov/countries/country-data.cfm?fips=US*
3. *Berman, Arthur E, "US Shale Gas: Magical Thinking and the Denial of Uncertainty", Duke U., Jan. 2012 http://kansas.sierraclub.org/duke-university-u-s-shale-gas-magical-thinking-the-denial-of-uncertainty/*
4. *Barnett (Texas) Shale data: www.rrc.state.tx.us/barnettshale/index.php*
5. *EIA, Henry Hub NG Spot Prices:http://www.eia.gov/dnav/ng/hist/rngwhhdm.htm*
6. *Soeder, Daniel J. "Porosity and Permeability of Eastern Devonian Gas Shale" SPE Formation Evaluation, March 1988, pp. 116-124.http://www.pe.tamu.edu/wattenbarger/public_html/selected_papers/--shale%20gas/spe15213.pdf*
7. *Vanorsdale, Charles R. "Evaluation of Devonian Shale Gas Reservoirs" SPE Reservoir Engineering, May 1987, pp. 209-*

216.http://www.pe.tamu.edu/wattenbarger/public_html/selected_papers/--Shale%20Gas/SPE14446.pdf

8. *EIA: "US Crude Oil and Natural Gas Proved Reserves /With Data for 2011" Aug. 1, 2013 http://www.eia.gov/naturalgas/crudeoilreserves/*
9. *Hotelling, Harold, "The Economics of Exhaustible Resources" The Journal of Political Economy, Vol.39, No.2, April 1931, pp. 137-175.http://www.jstor.org/discover/10.2307/1822328?uid=3739808&uid=2129&uid=2&uid=70&uid=4&uid=3739256&sid=21103708378997*
10. *MTG: Mobil's methanol to gasoline technology:http://www.exxonmobil.com/Apps/RefiningTechnologies/files/sellsheet_09_mtg_brochure.pdf*
11. *Taleb, Nassim Nicholas, "Antifragile: Things that gain from Disorder" Random House, NY, 2012.*
12. *Diamond, Jared,"Collapse: How Societies Choose to Fail or Succeed", Penguin Books, 2005*

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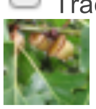
- 

  rlp2451 Comments (3630)

  If the price at Henry Hub goes to $1, our reserves will go to 0 years.

Proven reserves are price-driven, not geological, so as the price rises, more wells will be drilled (since the economics work).
The renewable crowd seems to always want to dismiss the wealth of fossil fuels available not only in the US but globally, but I have yet to see an automobile powered by a windmill.

31 Mar, 12:16 PMReply! Report AbuseLike16

- 

johnnyvolvoComments (291)

It will take some time to digest this article. I agree with you that proven reserves have a major, if not overriding price component that was not fully addressed by the author of this article.

Your "windmill" comment was a little disingenuous, as in the literal sense any pure EV could, indeed, be powered by a windmill, and the fact you have not "seen" and EV charging off of a windmill powered charging station is irrelevant. I have not actually "seen" our proven NG reserves either, but I do have "evidence" of them.

What I find most interesting about this article is that Warren Buffett recently purchased a huge stake in Exxon. Why would he do such a thing? Why not Chesapeake, or EOG, for example? I don't know, but I do know he is a master at front running trends. He is usually very early, not late, to an investment category or sector, sometime by years.
This article may provide a bit of a clue as to his thinking.

Interesting. This could be the basis for a series of pro and con articles. While the author appears to have laid out a more compelling argument on the surface than (what I shall call) the "100 years of reserve" crowd, this matter is far from settled, and really bears a very very thorough examination.

Perhaps the authors most important and timeley comment is this....

"We better.....get serious about new dry-gas shale technology to replace the inefficient fracking."

31 Mar, 12:53 PMReply! Report AbuseLike3

- 

TakeFiveComments (5096)

rip... Couple of things:

So once again we're gonna have to say goodbye to fossil fuels? Reminds me of one of my favs. http://bit.ly/1ggWTIJ

So far as wind powered autos, perhaps you're just not paying attention:http://bit.ly/1ggWVQI

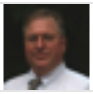
31 Mar, 01:10 PMReply! Report AbuseLike0

- 

  Randal James Comments (1961)

  Next time you are passed by a Tesla, rethink that notion.

  31 Mar, 04:22 PMReply! Report AbuseLike1

- 

  Dave Shafer Comments (281)

  Berkshire also is the largest owner of wind mills. They have also gotten into large solar arrays. Sounds like he is making several bets at the same time!

  31 Mar, 04:47 PMReply! Report AbuseLike2

- **tstreet**Comments (360)

  Depending on which part of the country you are talking about, or which country, if you have seen an electric car, you may have seen a car at least partly powered by a windmill, or more accurately, a wind generator. EVs are typically recharged at night which is typically the best time for wind generation.

  I gather that the author is part of the renewable crowd and it would appear he has made a rather good case that natural gas is less sustainable than many people have thought.

  1 Apr, 09:55 AMReply! Report AbuseLike1

- **Bruce Lingle**Comments (21)

  Berkshire has the political pull to make utilities buy their "sustainable" energy regardless of cost. That's the key for the "sustainable" "renewable" energy biz.

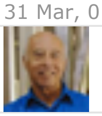
  1 Apr, 12:27 PMReply! Report AbuseLike0

- **Mark Tully**Comments (39)

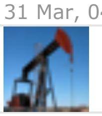
  rlp2451
  Your comment and this piece reminds me of a story from years ago, about a senior

engineer who had come to work for our engineering company from Washington, late Carter administration.
Carter energy policy was based on the opinion that we were running out of oil and natural gas. This engineer was asked to substantiate that for natural gas, but on studying the situation, determined that the natural gas was there, just not being produced because of regulation and price controls. Of course, writing it up this way did not do wonders for his Washington career, and he found his way to us.
He did not mention it, but I came upon his name in an article on the subject some months later (in New Republic, Atlantic Monthly, something in that line). When I asked, he said, yes, that was him and filled me in on some details.

31 Mar, 01:47 PMReply! Report AbuseLike3

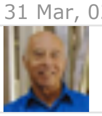
- 
Moshe Ben-Reuven
, Contributor
Comments (64)

Author’s reply » Dear Mark, thanks. We have nothing to fear but fear itself--
31 Mar, 04:02 PMReply! Report AbuseLike0

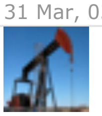
- 
okoilComments (63)

What abandonment pressure are you assuming? It is common practice to produce old wells nearly on a vacuum with booster compressors to get into the pipeline. Having all the wells on pads will make this easy to accomplish. Also, the pipelines are sized for huge flow rates. Once every well is tooling along at 100 MCF/D, the pipeline pressures required can be very low.

Gas wells are so cheap to operate, these wells will be around much longer than 10 years. A few thousand wells making 50-100 MCF/D isn't chop liver, but to your point it won't power the whole country either.
31 Mar, 02:53 PMReply! Report AbuseLike1

- 
Moshe Ben-Reuven
, Contributor
Comments (64)

Author’s reply » Zero Gage was assumed in my well calculations (i.e., 1 atm absolute.)
31 Mar, 03:58 PMReply! Report AbuseLike0

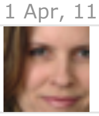
- 

okoilComments (63)

I think you should consider the comments by Wellsfargo and some others, proved reserves are probably much smaller than the total resource because they require an already producing well or a very close offset to be "proved".

Also, you renewables guys can keep wishing that we won't be able to find more oil and gas, but we consistently can over the years by improving our technology. If you guys want to big dog it and be a world scale industry like oil and gas you have a lot of work to do. We are able to power the world at an extremely (historically) cheap cost, using a small amount of skilled labor, with the rest of the labor usually being crackheads and criminals unemployable by most other industries. Until a meth head or 2 can install a solar panel by themselves and 1 engineer can supervise 20+ meth heads I think the economics will be tough. In the oil and gas industry each drilling engineer supervises about 60 meth heads and 3-6 non meth head high school graduates. The ratios are similar for completion engineers and slightly lower for production engineers. We aren't even a labor intensive industry but there just isn't enough skilled labor for a world scale industry like energy.

1 Apr, 11:21 PMReply! Report AbuseLike1

- 

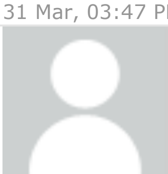
Jennifer Warren
, Contributor
Comments (333)

Amazing background and I too will be needing to re-read slowly at another date. I direct you to a physics-based analysis of the Barnett, from my Barnett piece, if of interest. You may find it interesting in light of the Marcellus-Barnett comparisons. A quote from it:

The Bureau of Economic Geology study uniquely uncovers well-by-well analysis of production and calculates estimated ultimate recovery (EUR) for all wells. The authors base their analysis from the development of a physics-based decline curve that closely describes Barnett well declines, also a novel contribution. Their methodology is based on the physics of the system rather than on mathematical decline-curve fitting. Importantly, this development "should offer a more accurate method of forecasting production declines in shale wells in other basins." Their contribution is a major advance in projecting the decline of shale gas wells.

BTW: I am interested in alternative ways to recover resources and renewables. The future is upon us...

31 Mar, 03:47 PMReply! Report AbuseLike4

- 

chazsf[Comments (568)]

"BTW: I am interested in alternative ways to recover resources"

http://bit.ly/1i8OnxK

31 Mar, 05:44 PM Reply ! Report Abuse Like 0

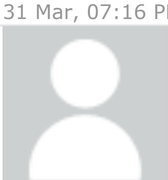
- 

Moshe Ben-Reuven
, Contributor
Comments (64)

Author's reply » Dear Jennifer; Chaz: Me too. We are working on a technology for shale recovery along the attributes given in the article.

Although the anaerobic digesters in the Ref. by Chaz could make a welcome contribution, (and in Holland, it is mandatory for pig farms)-- regrettably, this is too small compared with current NG consumption rates.

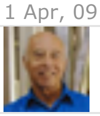
31 Mar, 07:16 PM Reply ! Report Abuse Like 1

- 

JimTwoComments (78)

Anaerobic digesters are very expensive.

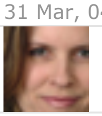
1 Apr, 09:55 AM Reply ! Report Abuse Like 0

- 

Moshe Ben-Reuven
, Contributor
Comments (64)

Author's reply » Thanks Jennifer, please send a link, I an curious-- unaware of any published formulation.

31 Mar, 04:00 PM Reply ! Report Abuse Like 0

- 

Jennifer Warren
, Contributor
Comments (333)

http://seekingalpha.co...

go to third paragraph, first sentence, highlighted as "study". It's in two parts. Part I is methodology focused; part II econ.

I met the lead author as he presented a week or so ago (more of a macro pres) not about Barnett, but perused their site as he referenced the study by his bureau.

31 Mar, 07:34 PM Reply ! Report Abuse Like 1

- 

Moshe Ben-Reuven
, Contributor
Comments (64)

Author's reply » Dear Jennifer,

Thanks for the reference to John Browning et al article on the Barnett, TX. The "well by well" data referred to there is based on "77 well-behaved wells" which go in productivity from 2 Mega-SCF/day to 0.25 Mega-SCF/day in 7 years (see Fig.6 of the unprintable O&G Journal). The theory of diffusion-controlled production from shale wells seems to me flawed, based on a uniform permeability coefficient (0.3 micro-Darcy) and a length scale, both undefinable. I believe their theory is explained by the Tad Patzek's (one of the authors) Paper, http://bit.ly/1heMw8l discussed below. It is mostly wrong, as admitted by the authors.

What is more worrying, however, is that most of the Marcellus wells I have simulated, went from about 2-10 Mega-SCF/d to fractional Mega-SCF/d in just 3-4 years, which means obviously that the wells are younger, and far more productive initially than the Barnett Magnificent-77, but their decay rate is also faster.

And yet, it seems that (a) a better well by well (not "average") calculation would bring a more realistic EUR and life-span calculation, and (b) I would still conclude, based on the data, far less than even 30 years on the production remaining.

Again, many thanks for your helpful references.

2 Apr, 02:20 PM Reply ! Report Abuse Like 0

- **rajprasad** Comments (229)

this is the first time I notice someone refers to gas prod rate in units of Mega-scf/d; thats funny; normally gas flow rate is reported in mcf/d m stands for thousand; this tells me all these analysis is done by some one not familiar with oil ind gas industry

2 Apr, 07:52 PM Reply ! Report Abuse Like 2

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DIA	-0.4%	5.2%	9.9%	-0.8%
XLE	0.5%	13.8%	18.2%	6.9%
IPW	0.2%	16.6%	16.1%	10.9%
SSO	-0.8%	12.3%	36.1%	3.2%
RWL	-0.2%	7.5%	18.6%	1.9%
SDY	-0.1%	7.2%	9.4%	2.4%
PRF	-0.3%	7.3%	17.7%	2.5%
EPS	-0.3%	6.8%	16.9%	1.9%

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