WORKING PAPER

Replacement of Coal by Fracgas in the Production of Electric Power

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Replacement of Coal by Fracgas in the Production of Electric Power

Yale Graduates in Energy[*]

Abstract

New well drilling technologies, when utilized to fracture common shale formations promise to provide access to very large volumes of gas. Indeed, the trade press and news media have generally taken the position that "fracgas" over the next decade can add up to 800 trillion cubic feet of reserves, four times the current level of reserves, almost equally spaced over the four quadrants of the country. But estimates of reserves are notably judgmental and with respect to new finds can be over optimistic.

The key issue however is not the size of the far future reserve base, but rather if fracgas production can replace coal in electricity generation in the next few years as limits on coal sulfur and carbon oxide emissions are phased into coal plant operations. Fracgas per KWH of produced electricity has an emissions rate one quarter that of coal. Then is it going to be used in gas engines to replace shutdown coal boilers to the extent required to sustain growing electricity supply?

The answer does not lie in detailed and controversial reserve estimates. Alternatively, there are two sources of data now extent that are relevant, (1) the estimated market price of natural gas and fracgas (and its relation to futures prices) and (2) the volumes of coal in power production. We use a range of values in these data series to estimate the cross elasticity of coal demand with respect to gas price, that is the percentage change in coal used in power production with respect to the percentage change in gas price. As a result also of reviewing a number of recent such estimates, as well as our own, we conclude that there is a determined limit on coal to gas substitution far short of driving coal out of the power market.

Introduction:

For fifty years we have tried to develop new fuels to replace inground reserves of crude oil and natural gas in the United States. Success has been limited to finds outside the boundaries of existing reserves–heavy oil in the sands of Western Canada, crude oil in deep offshore wells, where development would and has disrupted the environment. But what may not be just marginal has been the discovery of gas embedded in hard rock in deep underground formations along with development of horizontal drilling technologies that fracture the rock and emit large volumes of the gas. This new technology for producing "fracgas" is based on drilling deep wells (vertical

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and at the end then horizontal) that can be productively located in almost half of the territory of the northeast quadrant of the country, the Texas–Southwest quadrant, and in regions in Colorado and surrounding states.

The expectation of being able to develop fracgas reserves orders of magnitude greater than the 200 trillion cubic feet now in place from orthodox vertical well sources has set off a bonanza–like change in the energy outlook for this country. According to the General Electric Company "The energy America has been looking for is right here at home: natural gas. New superefficient gas turbines can turn that natural gas into enough electricity to power every home in the country for 70 years. The more energy we find at home the less we have to buy from abroad. And using more electric cars and trucks helps reduce our dependence on oil imports" ("Plug into the power of natural gas", the New York Times, June 14, 2011 page A 22)

Based on such an expansion of reserves a very large expansion of production would follow. For 50 years the ratio of production to reserves has been approximately 1-to-10, so that an increase of reserves from fracgas of 200 to 300 trillion cubic feet would expand production from the historic 20 to 30 trillion cubic feet (see Figure 1 a & b below for historical and forecast gas and coal production associated with electricity generation). To get this additional supply into power generation would require at least a one third increase in pipeline capacity for transmission to the power plants. Instead of coal piles, there would be gas inventory stored in the pipelines. And there would have to be new gas-fired power plants (as with General Electric's advanced gas turbines), given that the current capacity to generate power with gas would be insufficient to both displace a significant amount of coal and to account for the expansion of the system to meet growing demands for industrial commercial and household electricity. For this to take place in the coming decade an expansion of massive capital outlays in electric power would be required, making the new fracgas a game changing development.

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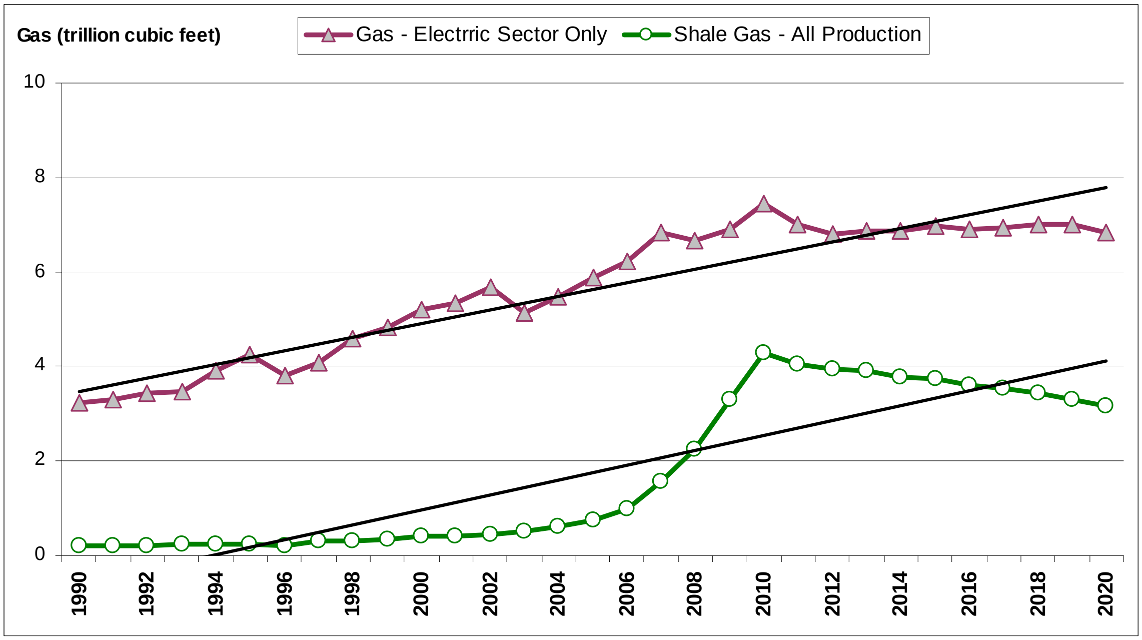
Figure 1a: Gas Production in Electricity Generation[1]



Note: that the level of production has been projected in the EIA database to 2020 as in decline from 2010 on

[1] Gas data from the electricity sector is taken from the following EIA website: http://www.eia.gov/forecasts/aeo/. Total shale production data is taken from the following EIA power point presentation: *Annual Energy Outlook 2011*, Reference Case The Paul H. Nitze School of Advanced International Studies December 16, 2010 Washington, DC Richard Newell, Administrator. Trend lines are linear based.

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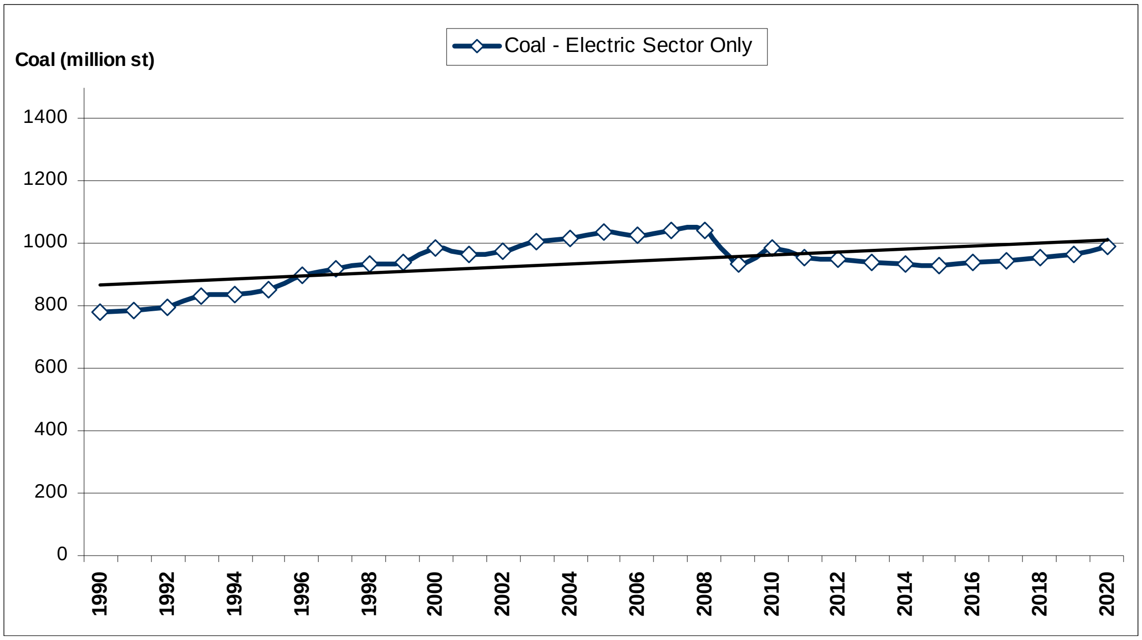
Figure 1b: Coal Production in Electricity Generation[2]



Note: in contrast to gas in Figure 1a that coal is not projected to decline in the 2011 to 2020 period

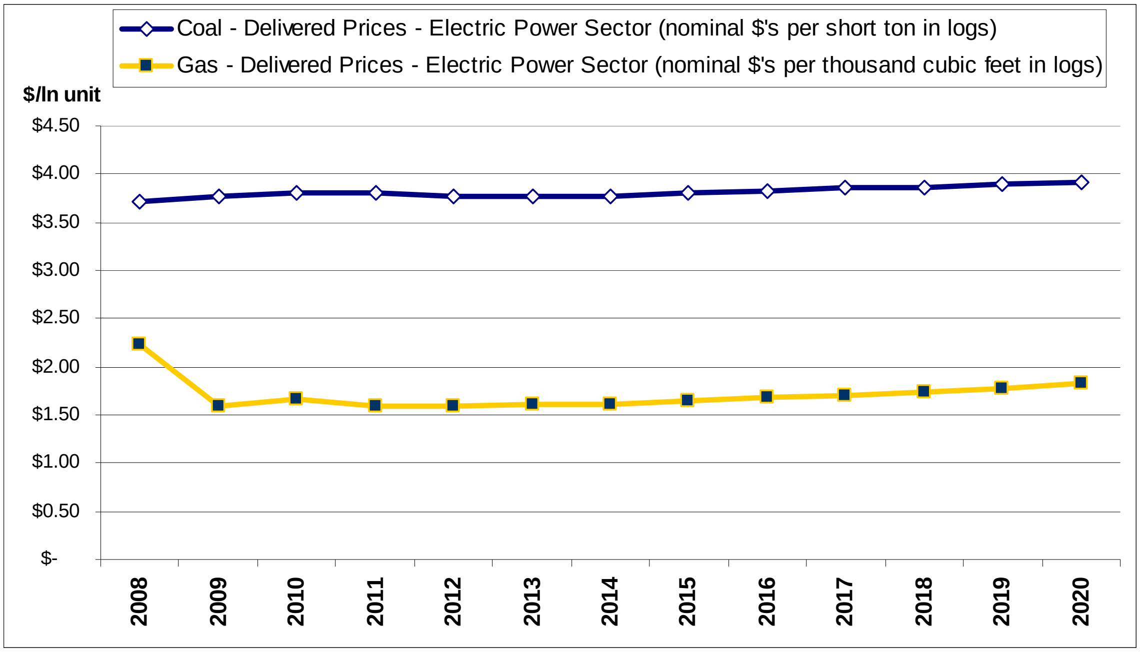
Industry spokesmen of note have taken the position that reserves discovered through the hydraulic fracturing process will exceed 800 trillion cubic feet (given that dry gas reserves are included, as listed in the Energy Information Administration Annual Energy Outlook 2011 at 245 trillion cubic feet). But geologists and gas experts within the industry have not been in universal agreement on reserves this large. The New York Times of June 27, 2011, compiled e-mails at EIA and gas producers to support the inference that "companies have exaggerated shale gas well profitability … using overly optimistic models for projecting well productivity over the next several decades" (page A12). The most pithy quote from an e-mail of an EIA administrator was "am I just totally crazy, or does it seem like everyone and their mothers are endorsing shale gas without getting a really good understanding of the economics at the business level?" (A 12 op cit).

[2] Coal data from the electricity sector is taken from the following EIA website: http://www.eia.gov/forecasts/aeo/.

The basis of bias in reported fracas reserves is that hundreds if not thousands of different geological estimates are alike in being excessively optimistic. But they come from widely different geological and economic conditions. The seven major shale deposits are all different in terms of taking production from shale formations; the Barnett shale, which is largest in historic production, has leveled off since 2008 while the Haynesville has rapidly increased from almost zero to one half the production level of Barnett in the same period. The three other more promising shale formations -- Marcellus in the Northeast, Fayetteville in Arizona, and Woodford in Oklahoma – are at a very early stage in what should be a two decade long period of productivity. How those estimating not only near future production but life of reserves from near to far in independent producing horizons could possibly come to a systematic overestimate is unknown.

The possibility exists that we can bypass the issue of "excessive optimism" by focusing on prices rather than quantities. EIA constructs a price index for fracgas that is the same as for dry gas produced and sold in wholesale/industrial retail markets since the Natural Gas Act of 1938. Only produced gas is priced on sale at the wellhead and then at points of pipeline intersections north from production locations on electronic bulletin board spot markets during the process of pipeline delivery. Projections of futures prices are based upon modeling exercises of demand at various points in the pipeline networks that treat future transactions "as if" they replicated that current spot price setting process. EIA future prices are approximations for market clearing prices so that any excess supply that consists of over estimation is eliminated (see figure 2 below, gas and coal future prices). That is, if excess future production (or reserves) are posted in biased reports to EIA data collectors, the impact on the sources would be reductions in future forecast prices, next period for example, a 10% overstatement of current reserves (based on current production) would generate a 10 to 20% reduction of the next period price forecast in the model depending on assumed demand elasticity ---- hardly a benefit for the collection of overly optimistic producers).

Figure 2: Gas and Coal Delivered Prices to the Electric Power Sector[3]



Finally, if there were a significant gas supply bubble in the forecasts (based on exaggerated reserve projections), as after price deregulation in the early 1980`s (see P.W. MacAvoy "The Natural Gas Market" Chapter One, Yale University Press, 2000) there would be a significant price increase embedded in the forecast. Producers, land owners, and brokers would only hold the excess newly discovered supplies for future sales at higher prices. In the last bubble, set in place by those in a frenzy to store and increase inventories while telling buyers of the abundance to come, the EIA price index increased by up to 500% in 1981-83 (see ibid Figure 1.2). But to the contrary the present EIA forecast projects the Henry Hub spot prices to be approximately the same as the current over 2010 to 2015 (see R. Newell, EIA "Annual Energy Outlook", also shown in figure 2 above). The gas market is acting as if there is not going to be a shortage or an excess of supply relative to demand in the next few years.

[3] Data taken from the following EIA website: http://www.eia.gov/forecasts/aeo/

Coal to Gas Cross Price Elasticity Academic Estimates:

Then how much replacement of coal by gas is likely to take place in power before 2020? That seems to be the core question, given that there are limited other uses for large amounts in chemical refinery operations or industrial heating that could absorb a large part of the current increase in supply. The first approach to answering the big question has been to estimate the cross elasticity of coal demand with respect to gas price.

To see how far into the power generation infrastructure the gas expansion has to go requires building plans for each new gas fired facility in the country. But before that undertaking there is an alternative approach for a first overall assessment of gas for coal substitution that does not require detailed plant by plant data. Rather than documenting planned responses of hundreds of specific corporate decision makers, an econometric design can be used that makes the assumption that the aggregate reduction of coal in power plants follows the pattern set out by shifts of coal to gas in relation to relative gas price decreases across the industry in the last 35 years.

Based on data compiled on "the cost of fossil fuel at (all) electricity generating plants" by the EIA, the University of Calgary and the World Bank have estimated numerous equations of average relationships including the "cross elasticity of coal with respect to gas from the relative price reduction in gas." Of interest as well are estimates of the "(Morishima) elasticity of substitution of gas for coal"

Given the dominance of gas as less costly to transport, store and combust, one could hypothesize that the exchange of gas for coal across the electricity generating industry would be quick and extensive as the relative price of gas has declined. Of course there would have to be costly restructuring of the burner tip technology in fuel boilers, and the turbine generator would have to be made compatible with the new gas driven steam temperatures and pressures. Even so, with the regulatory pressures favoring gas, in order to reduce sulfur and carbon emissions, the relative response in coal reduction to be equal to or in excess of the relative gas price reduction.

The Calgary equations, based on data for 1973 to 2007, (see "Interfuel Substitution in the United States" A. Serletis, et. al, Energy Economics, vol 32, pp 740 – 743, 2010) have a cross elasticity of coal to gas of 0.064, indicating that for every 10% reduction in gas price, holding coal price constant, there has to be 6/10ths of a percent shift to gas in the production of electric power. With gas prices from 2008 to 2009 falling by more than 50%, and with no prediction of return to previous price levels as fracgas increases, the forecast for interfuel substitutability, from coal to gas, from this source is little more than three per cent.

The econometric estimate for the elasticity of substitution appears to be more expansive, but not by that much. Estimated from the same database (Morishima) elasticity of substitution is 0.201, so that the ratio of coal to gas decreases by 2% for every 10% decrease in relative gas price. Recall, however, that the ratio to start is less than half, so that over that decade this larger response leaves gas with only slightly in excess of 15% of the electric power fuel source market. This result is difficult for the Calgary authors themselves to accept, for example, "interfuel elasticities of substitution are (in general) consistently below unity, revealing the limited ability to substitute one source of energy for another" (see pages 737-745). Another explanation is that these data, having a very limited range over this period had limited ability to reflect switching behavior over 50% price gas price reduction (see pages 738-739).

Consider that the cross elasticity is defined as the percentage reduction in coal per percentage reduction in gas price. The common sense of that ratio can be broken down into two further ratios, i.e. (%coal|%gas times %gas|% gas price). The first is the relative change in coal to gas volume; the second is the orthodox definition of the demand elasticity for gas alone. When volume changes were limited, as in the 1990s, and prices were high, due to small gains annually in reserves, both ratios would be expected to be less than one and the product less than one. But with the advent of fracgas, while the physical fuels change ratio could be less than one the gas demand elasticity would be far in excess of one. The cross elasticity on an annual basis should be larger in the recent years not included in the data bases of the econometric studies.

While we could find no other studies that examined interfuel substitution by sector, specifically in electricity generation, we were able to find additional studies that examined interfuel substitution possibilities in total energy demand. Serletis and Shahmoradi in Semi-Nonparametric Estimates of Interfuel Substitution in U.S Energy Demand (Energy Economics, Vol 30 pp 2123-2133, 2008) calculated (Morishima) elasticity of substitutions between .307 and

.480 based on EIA data from 1996 to 2004. Clifton T. Jones in “A Dynamic Analysis of Interfuel Substitution in U.S. Industrial Energy Demand” (Journal of Business & Economic Statistics, vol 13, No. 4 pp 459-465 1995) calculated linear logit coal to gas cross elasticities between .027 to .210 based on U.S. industrial energy consumption data from 1960 to 1992. These if used to project the hypothetical sweep of gas into coal markets for fuels in power generation would indicate again that less than 20 % of coal use capacity would move over to natural gas.

Coal to Gas Cross Price Elasticity Yale Graduates in Energy Estimate:

We made one additional hypothetical estimate of our own, using as much as possible the most recent data, on coal to gas which would be affected by the 50% reduction in 2008 to 09 in the price of gas. With coal and gas demand and price data (from EIA) for the electricity sector from 1990 to 2009 we calculated an OLS cross elasticity of coal demand to gas price of .2 (see Figure 3a & 3b). While the equation is simple and (most likely) the estimates are not efficient, it is most likely that there are not yet enough years of fracgas volume to be able to assess the impact on coal utilization.[4] The results in the summary regression table below indicate that the cross elasticity approximates 0.20, and a 50% reduction in gas price would generate a 10% reduction in coal demand.

[4] The Credit Suisse report, referenced later in the paper, suggests that generators are not responding to observed commodity prices today, but that this can be explained by operators dispatch patterns which are based on existing power and coal price hedges which buoy economics above break-even (effectively they are giving up the positive NPV of the “in the money” hedges) (see page 37)

Figure 3a: YGE Elasticity Data[5]

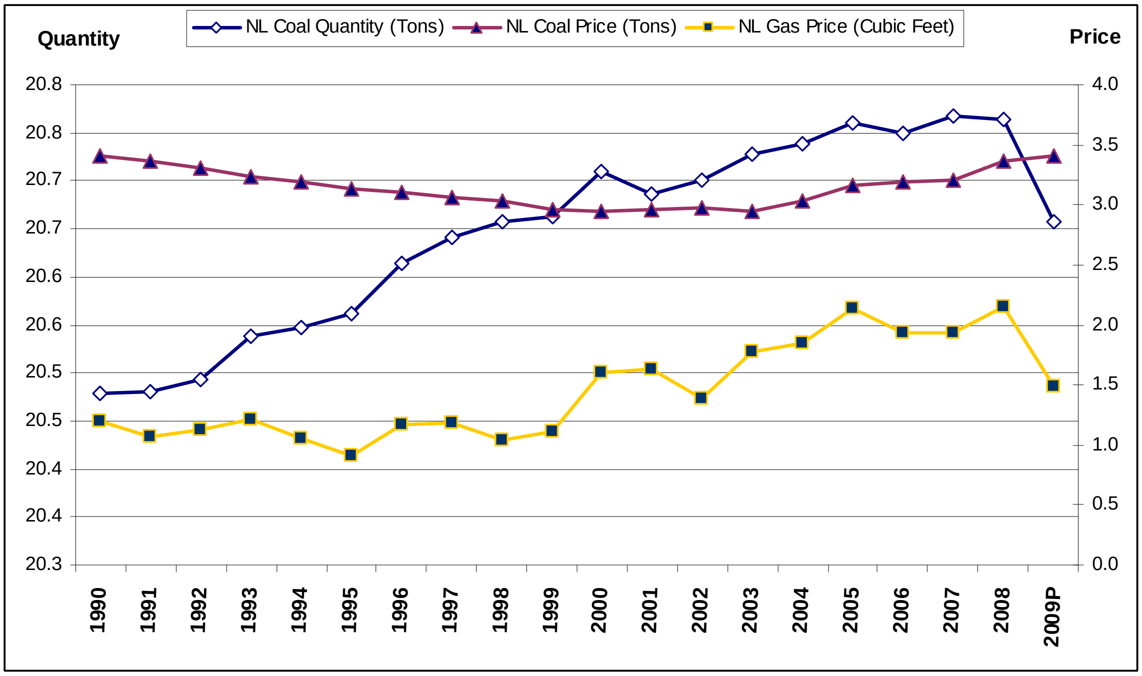


Figure 3b: YGE Regression Summary Results

Regression equation: NL(coal q) = a + b NL(gas P) + U

ANOVA

	df
Regression	2.00
Residual	17.00
Total	19.00

	Coefficients	*Standard Error*	*t Stat*
Intercept	21.19	0.18	117.17
NL Coal Price	-0.26	0.06	-4.71
NL Gas Price	0.20	0.02	8.83

A Field Survey of Impending Shift of Coal to Gas:

With such a narrow range of cross elasticity estimates, based on previous price and quantity behavior before fracgas came into the markets we have to turn to more “micro” and recent data. Credit Suisse’s equity research division’s September 2010 Electric Utilities report (Growth From Subtraction, Research, Analysts Dan Eggers, Kevin Cole, Yange Y. Song, & LinLin Sun) provides a perspective on the implications associated with shifts in current and near future

[5] Data set is chained (2005) dollars, calculated by using gross domestic product. Data is taken from the following EIA website: http://eia.gov/totalenergy/data/annual/#naturalgas.

changes in plant capacity to known coal. Upcoming EPA policy (CATR, CAIR NOx, CAIR Sox, Mercury MACT)[6] to limit coal plant emissions on the electricity generation will play a large role in any new cross elasticity. Specifically, the report provides an overview on plant closures, compliance timelines, capex & fuel demand implications. We will focus on summarizing their findings associated with plant closures and corresponding fuel shifts in order to provide a field survey perspective on cross elasticity.

The report estimates that out of the 340 GW coal plant capacity in the United States 50 GW (or 15% of capacity) will be forced to shut down with an additional 100 GW requiring significant investment to install emission control technologies (i.e. scrubbers, SCRs, Dry Sorbent Injection, SNCR, Baghouse with ACI, etc.)[7] to meet anticipated EPA limits on emissions (an additional 30% of capacity). Targeted compliance dates of late 2014/early 2015 are expected to be extended by 2 years to account for problems during implementation (i.e. logistics, system reliability, etc.). The 100 GW of capacity that requires investments is discretionary because the alternative option is to switch to gas generators. Coal generators are vulnerable where coal pricing is at a premium to natural gas (out the forward curve when the marginal costs including CAPEX are greater than forecast total costs of gas plus gas plant at $5/mcf). The portion of the coal fleet that is most at risk are the smaller units where the comparable cost of reaching environmental compliance is higher. Further 70% of the small coal plants (72 GW) were built over 40 years ago and fully depreciated.[8] As a result, coal generator owners, will review the economic implications of investing in emission control technology. [9]

With that said, as dire as the future of small old coal plants may seem they are significant contributors to electricity generation as they are dispatched at 48%, only 15% lower than the US average (63%). Therefore it is possible that the implementation of EPA policy slows down as

[6] CATR: Clean Air Transport Rule, CAIR: Clean Air Interstate Rule
[7] For a CAPEX, or capital expenditure, perspective, retrofitting a coal plant with FGD and SCR ($450 – 700/KW) is not much cheaper than constructing a brand new CCGT ($750 – 1000/KW). The CAPEX estimates associated with retrofitting all of the 128 GW of un-scrubbed coal plants is $38 to $89 Billion versus replacing all of them with CCGT's at a total investment cost of $96 to $127 Billion. Operating and Maintenance costs ("O&M") for gas plants can be as little as 10% of a coal plant: Table 1, Updated Estimates of Power Plant Capital and Operating Costs, EIA *Annual Energy Outlook 2011*.
[8] 70% of the total US coal fleet, regardless of size, is over 30 years old and 33% of the fleet over 40 years old.
[9] Below $6/mmbtu for gas and above $80/ton for CAPP coal revenue requirements for a new CCGT investment are lower than retrofit.

deadlines are extended. If community support for local jobs applies additional political pressure then the EPA would allow these small plants to run until they were decommissioned. The result of business as usual would be the 324M tons/yr of coal used to supply plants with no environmental controls (~100 GW) stays in place. The 157M tons/yr used to supply small coal plants (60 GW) that were expected to be shut down and replaced with CCGT/Natural gas continue to run. In total, the 1 billion tons of coal used annually to supply the utility industry would remain practically unchanged.

Credit Suisse projects much more of a shift to gas from these old coal plants. They focus on two extreme cases: one that 60 GW of coal (i.e. the small plates) is retired and the other that all the plants lacking both scrubbers and SCRs are closed (103 GW). The impact of either scenario (over the next 5 to 7 years) results in a significant redistribution in energy demand for coal and gas electricity generation. Specifically, coal demand would fall by 157 to 324 MM tons/yr (15% to 31% drop in steam coal demand) and natural gas demand would increase 1.8 to 3.7 TCF/yr (7.8% to 16% demand increase). But these figures do not account for future demand growth (up to 1.5% a year) which would require another 2.5 TCF/yr, subtracting 110M Tons/yr in coal's base generation fuel delivery, if natural gas was used to meet all the growth over the next 7 years.[10]

Conclusion:

No source in energy policy formation appears to have gone back behind the expansive statements on fracgas to determine whether it is the "discovery of the present century". If they had done so, then they would have started with survey work that specified when and to what extent the new fracgas supplies would replace coal as the preferred fuel in power plants. The new GE turbines would be shown as having been ordered for gas plants to be built in place of the coal plants that were without scrubbers or at the end of a forty year working life. Corporate plans would be documented for transfer of gas peaking plants to baseload. And industry wide plans for

[10] The 110M Tons in coal base displacement number was calculated using a 1.5% growth rate over 7 years and maintaining a .34 KW to Coal ratio (340KW/1000BCoal).

additional generating capacity would show the expanded future use of fracgas to meet new demand for electricity.

This, as said, has not been done to provide a sound basis for telling whether fracgas will drive coal wholly or even partly out of the fuel markets for generating electricity. But we have scavenged data and some relevant estimates from diverse sources of demand cross elasticities that support an assessment.

There are data and analysis sources that attempt to estimate the percentage changes in coal used in power production associated with percentage changes in prices of gas. These various estimates, all based on old data, do not exceed 0.20 except in elasticities of substitution outside our range of analysis; a simple linear regression based on more recent data also had an estimate of this cross elasticity of 0.20. With a gas price reduction of 50%, due to the arrival of large volumes of fracgas on the market, the replacement of coal by the fracgas in our judgment is going to be in the range of (0.20) X (50%) equal to 10% and is not going to exceed 20%. Turning to micro studies of these markets by Credit Suisse we find that the percentage could be as low as 15% and as high as 30% based on the opportunity to replace obsolete coal plants with new gas fired jet engines for the production of not only lower cost but also cleaner electric power. Our position is a judgment call that the limit will not exceed 20% based on the replacement process being determined by the Federal pollution control authorities—whoever that may be.

No case can be made for gas taking over and driving coal out of the markets for fuel to generate electricity. The most that can take expected in the next five to ten years—the years that count for corporate investment and Federal pollution abatement policy—is that fracgas will supplant 20% of coal otherwise used in power plants. That is not totally consistent with the hyperbole fracgas is this country's most important new energy source of this century.