The Brattle Group

PARTNERING NATURAL GAS AND RENEWABLES IN ERCOT

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I. EXECUTIVE SUMMARY

Within the past decade ERCOT has seen the arrival of abundant, cheap natural gas resources and increasing levels of wind generation capacity. New shale supplies and drilling techniques have doubled Texas' natural gas supplies which are now projected to last through 2030 or even 2050.[1] In addition, a well-functioning competitive market, ample and excellent wind resources combined with the Federal Production Tax Incentive for wind (PTC) and Texas' Renewable Portfolio Standards have made Texas the national leader installed wind capacity. Texas is now facing a new set of challenges in the face of rapidly changing economics for electricity generation and the need for more coordinated development of its resources.

Low natural gas prices have fueled concerns that natural gas will soon crowd out renewable resources, undermining Texas' progress towards the development of a thriving wind industry and towards reducing emissions. At the same time, recent ERCOT analysis found wind and solar resources to be competitive with natural gas over the next 20 years under a number of plausible scenarios. This white paper therefore analyzes the interactions between gas and renewables in ERCOT, both in the short and in the long term.

The main conclusions of this white paper are that in the short run low gas prices are extremely unlikely to change the fact that existing renewables will nearly always have priority over gas-fired plants since, due to the absence of fuel costs, their variable costs are lower than those of essentially all other resources. Over the long term, as new plants are planned and built, it is possible that new gas-fired plants will compete with new sources solar and wind generation. Which source is cheaper will depend on the levels of gas prices, the existence (or lack thereof) of continued federal (and perhaps state) support and the technological progress of both wind and solar resources. In addition, it is possible that in the long run some combination of renewables and gas will displace existing coal-fired generation.

This is possible because, despite this competition, there is a strong complimentary relationship between natural gas and renewables. Not only may increasing concerns about air pollution and associated health and environmental consequences create additional costs for coal-fired generation, but gas-fired generation also matches much better with intermittent renewable generation from solar and wind projects than do coal-fired power plants. The path to low-carbon generation in Texas will therefore likely require the co-development and integration of both gas and renewable resources.

Low natural gas prices also facilitate Texas' continued transition towards a low-carbon emissions electricity sector by dampening any potential additional costs of renewable over conventional power generation sources. The cost of both wind and solar power has decreased significantly, but they are still not necessarily the lowest cost options, at least not without some explicit consideration of greenhouse gas emissions or continued federal subsidies such as the PTC. However, due to low natural gas prices, electricity bills, as a percentage of household income, are near their historical lows. Consequently, increased levels of a combination of renewable energy and new lower-cost gas power can likely be accomplished without materially increasing the share of income Texans have to dedicate to paying for electricity relative to the past.

How the precise interaction of natural-gas fired and renewable electricity generation plays out in ERCOT over the coming decades depends on several factors, including the price trajectory for both coal and gas, state and federal energy policies, transmission development, market design choices and environmental regulations. While making precise predictions about the future interactions between renewables and natural gas is therefore beyond the scope of this paper, we demonstrate that the two are not necessarily in competition and could both see significant growth in Texas over the next decade or so.

II. INTRODUCTION

Over the past few years, the story of falling natural gas prices has made major headlines in the press and has also raised questions about the future of renewable energy development. In May of 2012 the International Energy Agency (IEA) warned: "Golden Age of Gas Threatens Renewable Energy."[2] A recent blog post in the New York Times explained "…more and cheaper natural gas does not help our prospects for bolstering renewable sources of energy, including solar, wind and biomass. History has shown repeatedly that nothing is worse for renewable energy…"[3] The belief that natural gas competes with renewable energy in power markets is also evident from discussions specific to the Texas Market. In 2011 a Texas NPR member station, *State Impact*, reported that "the low price of natural gas has an automatic negative impact on the development of renewable energy sources…"[4]

At the same time, national labs, energy technology companies, trade associations and think tanks across the U.S. have documented natural synergies between the two resources. As a fast ramping resource that is relatively easily turned on and off, natural gas-fired power plants (in particular combustion turbines) are well- suited for backing up and smoothing out intermittent renewables and providing capacity. Stakeholders in the Texas market ask themselves how two such conflicting views can co-exist and what the net impact is of bringing both high levels of natural gas and renewable energy in the Texas market. This paper describes the nature of both competition and complementarity of natural gas fired and renewable electricity generation and under what conditions both might thrive together in Texas in the future.

NATURAL GAS AND RENEWABLE ENERGY; FRIENDS OR FOES?

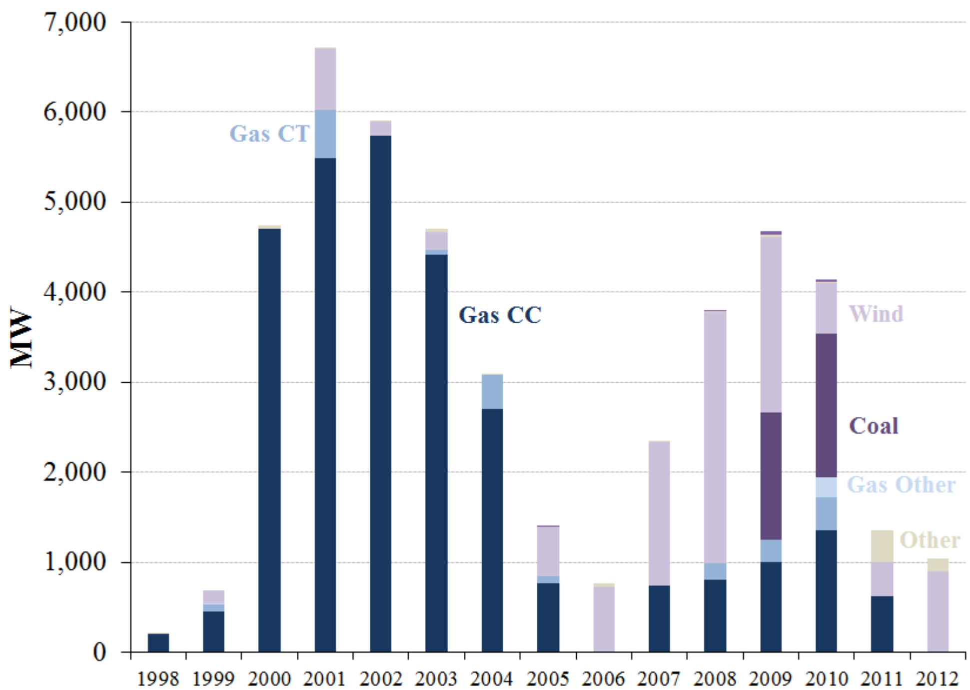
Two contrasting views of the relationship between natural gas and renewables currently frame the discussion across the U.S. and in Texas. The first view worries that they are competing with and displacing each other in power markets; the second sees both resources as natural complements that fit well together in a power system. In this paper we explain that the full relationship involves elements of both views and how electric sector policies can improve the complementarity between these two "fuels."

Recognizing that the fastest way to a low carbon future in the next few decades may be the coordinated development of both gas and renewables, The Mitchell Foundation asked *The Brattle Group* to explore the relationship between these resources and to identify ways to strengthen and improve policies that maximize the complementary relationship between natural gas and renewables in Texas. While primarily focused on the Texas/ERCOT gas and power markets, much of the discussion also provides insights useful in other states and countries.

THE CHALLENGE IN TEXAS

Today Texas has almost 69 GW[5] of natural gas-fired power capacity, most of which came online between 2000 and 2005. After a period of investment in coal and then nuclear generation, capacity investments shifted toward new, efficient gas-fired combined cycle (CC) plants. Texas had just deregulated its market and new CC plants provided significant cost savings over older less efficient plants. Policy supports also favored gas at this time and the 1999 Natural Gas Goal for Texas was established, although market conditions were sufficient to drive investment and its provisions were never needed. By mid-decade gas prices rose again and capacity investment shifted back towards coal. Between 2007-2009, a large amount of new wind capacity was built in response to high gas prices and renewable policy supports.[6] Increased natural gas production and reserves over recent years have pushed gas prices lower again. From 2009 to 2011 Texas gas prices have dropped from a little over $6.00/MMBtu to just over $4.00 MMBtu. This has led to high levels of coal to gas switching in existing plants across much of the U.S. and a resurgence in gas generator construction in 2007-2011, though not nearly at the levels seen in the early 2000's.

Figure 1: ERCOT Capacity Additions 1998-2012



Source: Ventyx (2013). Wind investments reported at nameplate capacity. Total quantities may not exactly match those reported in ERCOT sources because we rely on a separate data source for unit capacities.

Today natural gas prices remain close to their lowest levels over the past decade,[7] and are expected to stay low for the foreseeable future. Consequently, electricity markets are naturally experiencing a shift away from coal and towards natural gas. In the short run, this shift takes the form of generating more electricity from existing natural gas plants.[8] Persistent low natural gas prices will likely also lead more coal plants to retire in the future, many of which will likely be replaced by gas plants. This trend could well be reinforced by the fact that the costs of coal-fired generation may well be rising due to a number of potential new environmental regulations.[9] At the same time, thanks to federal tax supports, state Renewable Portfolio Standards (RPS) and substantial cost declines due to technological progress, many power markets are experiencing a significant influx of renewable energy and consequently face the need to integrate these resources. The shift towards cleaner energy supply will require a higher degree of coordination between abundant, cheap natural gas and variable renewable resources.

This challenge is most pressing in Texas, where the ERCOT electricity market is characterized by high levels of both natural gas and wind resources. Boosted by new unconventional gas resources, Texas is the leading U.S. producer of natural gas, providing 28% of all U.S. marketed natural gas production in 2011.[10] Texas is also the leading state for installed wind generation capacity and has the potential to further develop wind resources equal to twice the state's total annual peak electric demand.[11] No other State comes close to Texas' more than 12 GW of installed wind capacity.[12] The two leading wind states after Texas, California and Iowa, each have less than half of Texas' installed wind capacity.[13] While Texas currently ranks 13th among states for cumulative installed solar capacity, deployment of solar resources could increase because of their high complementary with peak demand.[14] Texas is considered to have the highest solar energy potential in the nation because of its large size and abundant sunshine.[15]
The need for energy policies that will guide efficient and complementary development of both natural gas and renewable resources will require a strong understanding of how they interact in the ERCOT market, both in the short and long-term.

In the remainder of this report we examine the complex and dynamic relationship between natural gas and renewable power generation, with a primary focus on the ERCOT market. We begin by examining the basic mechanisms by which gas and renewable power sometimes displace each other in the supply mix and other mechanisms that add both forms of generation together. We explain that the specific impact of these mechanisms on future ERCOT markets depends critically on price and cost trajectories for these resources -- which are difficult or impossible to control – and a variety of federal and state policies and market rules. These factors interact in complex ways, foreclosing simple answers as to who will "win".

Section III summarizes *current* state, federal, and ERCOT policies having the greatest effect on gas and renewable generation. Section IV builds on this discussion to examine additional policies that might be considered in ERCOT or other power markets to improve gas-renewables complementarity. Section V offers brief concluding thoughts.

This report is not intended to be a comprehensive examination of the issues and tradeoffs inherent in natural gas and renewable generation, nor does it offer a complete catalog of policy options available to ERCOT and other electricity markets. It is intended to be one contribution to a multi-faceted discussion of low-carbon energy futures and to provide suggestions as to the circumstances under which, and time frames over which renewables and natural gas act primarily as complements, and when they might compete.

Nevertheless, there are many ways that state and federal policymakers can guide ERCOT and other markets towards a low-carbon future in which gas and renewables both play a major part, especially in the next few decades.

III. AN OVERVIEW OF GAS AND RENWABLES INTERACTIONS

Gas and renewable energy sources interact in power systems in a number of ways. Their relative importance differs in the short-term and in the longer-term. For purposes of our discussion we define the short term as the one to two years, *i.e.* the time frame during which very little new equipment can be added to a power grid. Conversely, the long term is defined as the time frame, during which one expects that new generation, transmission, or distribution equipment may come on line or retire, changing the configuration of the system. This distinction is particularly important in the electric power sector since grid operators manage the grid in the short run very intensively, using both direct control and daily, hourly, or even sub-hourly markets, while these same operators have much less control over additions and retirements of generating plants in the long run.

As a result, we divide our discussion of interaction mechanisms into short and long-term effects. We recognize that this division is somewhat arbitrary and that some mechanisms will affect both time frames, perhaps in subtle and complex ways. In addition, we note that these interactions may involve specific technologies or segments of the industry, that they may largely have economic and financial rather than electro-physical effects, or both.

THE SHORT RUN: RENEWABLES WIN ON VARIABLE COSTS ALONE

Since, as per our definition there is no entry or exit by new power generation sources over the short-term, the interaction between gas and renewables is determined by which existing resources get deployed to meet electric demand – dispatch - and natural gas almost certainly does not displace renewable power. This is because ERCOT and other power markets typically select resources in merit order, *i.e.,* using as much as possible of the available supply resource with lowest variable cost, followed by the resource with the next lowest variable cost, and so on. No matter how cheap natural gas becomes, renewable energy sources, such as wind and solar PV, are almost always the resource with the lowest variable cost because they have no fuel cost.[16] In addition, at least as of today, wind generators receive a federal production tax credit typically if and only if they generate. These conditions mean that wind generators are willing to bid their generation into the ERCOT market at a price of zero or even lower to retain the production tax credit. On the other hand, the variable cost of natural gas fired generation remains significantly above zero even at very low gas prices – at or above $30/MWh even for the most efficient plants at gas prices of $4/MMBtu. As a consequence, renewable resources are always cheaper, and will be chosen to sell all their power whenever the wind blows or the sun shines regardless of the current price of gas. They will not be displaced by gas power generation unless very specific system conditions require the system operator to curtail them for reliability reasons.[17]

These reliability problems are quite rare, but they do occur in Texas from time to time, as they do in other grids. Renewables pose a reliability threat when there is simply too much local renewable generation relative to total demand to be able to use all the renewable energy without causing the local grid to destabilize or transmission constraints prevent wind from being able to be delivered to load centers. These situations occur most often in areas where wind resources are dense, such as West Texas. In 2011 ERCOT curtailed 2,622 GWh of wind power, about 8.5 % of wind available to the grid. This level is only half of what it was two years earlier but still remains much higher than in other regions in the U.S.[18] Some proponents of renewable energy claim that grid operators could do more to reduce periods when renewable power loses its priority and must be "curtailed." However, reliability-driven curtailments are not commonly seen as "gas backing out renewables," and renewable generators aren't the only ones urging grid operators to change their procedures to enable greater use of their power.

While gas does not displace renewables in the short-run, the opposite does happen. In the short-run, more renewable generation tends to means less generation from natural gas, even though some important caveats are required. In most electricity markets, including ERCOT, natural-gas fired power tends to be the marginal type of capacity during the majority of hours. This is partly because large coal-fired power plants tend to be cheaper than typical gas-fired power plants, at least with historic gas prices. When renewable power is injected into the grid, it displaces the most expensive power that would otherwise be supplying load and in many cases this power would be produced by gas. Hence, in the short run more renewable power likely means at least some reduction in natural gas-powered generation.[19]

TWO IMPORTANT CAVEATS

There are two reasons why the relatively simple assumption that renewable energy displaces whatever fuel would otherwise be at the margin needs to be made with great caution. Both have to do with relatively detailed operational issues of power markets and power plants. Because these caveats have some short-run impacts we mention them now, but it is important to note that these caveats are predominantly long-term interactions.

First, unlike fossil-fired power generation, most renewable energy sources cannot be dispatched, *i.e.,* they cannot increase or decrease production at will and in response to market prices.[20] Rather, renewables are "must-take generation" and feed electricity into the grid when the wind blows and the sun shines regardless of demand levels. Since the wind doesn't blow and the sun doesn't shine all the time, the injections of power from renewable sources vary, sometimes a lot and sometimes over very short time frames. Since there are currently very few buffers such as storage or price responsive demand in the electricity system,[21] system operators have to ensure that the sum of all generation matches load instantaneously. This requires balancing fluctuating renewable energy sources with other resources in real time. The services required to reliably transport electric power from seller to purchaser, given the requirements of the interconnected transmission system, are referred to as "ancillary services" and include scheduling and dispatch, reactive power and voltage control, resource reserves, and non-spinning reserves.[22]

In theory, many resources can be used to do this. They include all coal and gas generation as well as various demand resources (in essence consumers of power voluntarily curbing their electricity consumption). Since the fluctuations of power generation from wind and solar resources can occur very rapidly, the resources best suited to balance renewable energy tend to be gas-fired power generators and, increasingly, demand resources. Various forms of energy storage, such as compressed air or battery technologies, will likely also become increasingly available for balancing renewables, but still require substantial cost decreases to be competitive on a large scale. As a general rule, larger and older coal fired power plants tend not to have the operational characteristics that permit them to increase or decrease production very rapidly, and hence system operators tend to use them less for this purpose.

The result of this is that as renewable energy production increases, so does the short-run demand for various kinds of balancing services to compensate for the intermittency of renewable power generation. Since this demand is more cheaply and effectively supplied by natural gas fired power generation, it likely increases the demand for gas-fired generation at least relative to the case where no such "ancillary services" are considered.

A second caveat is very similar to the curtailment issue above and has to do with another operational inflexibility of large and older coal-fired power plants. To function properly, many of these plants, once started, have to run for a certain number of hours or days before they can be turned off again. Not observing these minimum run times leads both to less efficient, and therefore more costly, operation and higher maintenance costs. Because they have to be turned on sometimes for several days, many such inflexible units are producing power at the times of highest production from wind resources, which tends to result in a lot of supply precisely during times (at night) when demand is relatively low. The net effect is low, sometimes negative prices for power during such periods.

One would generally assume that a power plant would not generate power if the market price it receives for its power is lower than the cost of generating this power. However, with coal plants that have to keep operating because they have been turned on and cannot be turned off, or have certain types of PPAs for their output, this is not the case. As a result, many inflexible power plants, not covered by such PPAs or hedges, will increasingly see their profit margins decline as the operational inflexibility forces them to sell power at a loss.

Under these conditions, it is quite conceivable that some older and inflexible coal-fired power plants will not commit to operate for the required longer periods when low prices loom, but rather decide to remain idle until periods when the risk of losing money by generating are much lower. If this occurs, more renewable energy in fact displaces coal-fired plants (for a different reason than the one described above) and it is likely that gas-fired generation picks up the slack. How much of this occurs is very much a function of the specific mix of existing resources including wind, gas and coal plants, their operational characteristics, the profile of demand and the behavior of the local wind resource.

It is likely that the two caveats described above at least partially mitigate the short-term crowding out of gas by renewables described above. Whether they can entirely offset this effect even in the short run likely depends on the specific circumstances. The latter effect also increases the chance that some older, inflexible coal plants will retire in response to higher renewable penetrations, an issue we address below.

THE LONG RUN: AS NEW PLANTS ARE PLANNED AND BUILT, DISPLACEMENT IS POSSIBLE

So far we have only discussed the costs of generation technologies in the short-term, based on their variable costs, which determine what existing resources are placed onto the grid on a minute-by-minute basis. However, a different set of considerations dictate long-term generation planning.

When electricity demand is growing, electricity system planners and private electric generating companies perform economic forecasting studies to decide what type of generating plant to build next. In some areas this is handled as a state level planning process known as Integrated Resource Planning, which is managed by the Public Utility Commission and carried out by utilities. In areas without a centralized resource planning process, the Public Utility Commission will typically make information on capacity, demand, reserves, system constraints and transmission available to market participants to help them perform their own market-driven investment plans.

Regardless of which approach is used, power plant developers typically use the same investment criteria to decide the type of plant they build. In simplest terms, plant developers ask, "can I make money by entering this market, and if so what plant can I build that will be most profitable, considering what power prices are likely to be?" To answer this, they forecast how much it will cost to generate power from a natural gas plant versus a wind or solar plant with about the same output.[23] These studies are obviously very situation and market-specific, depending on the proposed location of the plants, local grid conditions, and how much each particular type of power plant must pay to become integrated into the grid.

When natural gas supplies are available at low cost, and predicted to remain so in the long run, these studies tend to show that the life cycle costs of a gas-fired plant are cheaper than a renewable-only plant. The life cycle cost analysis for new plants considers the variable costs of running the plant, such as fuel costs, the fixed costs of keeping a plant in operating, as well as the capital costs of building the plant, including upfront investment in engineering, construction, and equipment. Even with zero fuel costs, renewables still tend to be less attractive investments when the full costs and technical difficulties of building new resources are considered in a long-term, forecasted low gas market.[24] If power plant developers see natural gas plants as cheaper and more profitable than renewable plants, and choose not to build renewable plants, then it is fair to say that "cheap natural gas has backed out renewables". What this means is simply that it has become cheaper to build a new gas power plant than to build a renewable plant.

In an unregulated, unplanned market, power plant developers decide what plants to build. With no policy constraints, they choose what at the time appears to be the most profitable option. So far, renewable power plants have typically not been profitable to build without specific mandates or subsidies as the current market construct is less favorable for projects with high upfront capital costs and low variable costs. This means that, so far, nearly all renewable power plants were built not because they were cheapest by themselves, but rather because they were required and/or made to be cheaper by specific policies.[25] However, for any given set of market rules and government policy, the price of natural gas and the cost of new wind or solar plants have a huge impact on the size of this displacement effect.[26] We discuss this further in Section III.

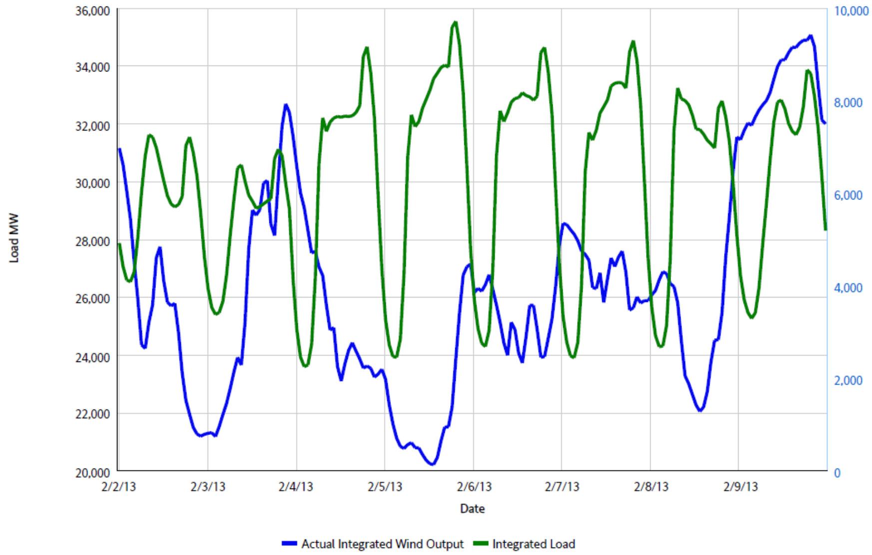
There is a small but possibly potent overlap between the debate over the environmental regulation of shale gas production and the question of how plant developers choose which types of plants are cheapest. Both environmentalists and economists agree that current shale gas production leads to "externalities", which in turn cause gas to be cheaper than its true social cost.[27] Some environmentalists might use this point to argue that gas is unfairly backing out renewables in the long run because "gas isn't paying its true cost" and that if it was, developers would not build as many gas plants. In the abstract this may be true, but there are two countervailing points to keep in mind. First, many cost estimates of regulations needed to bring hydraulic fracturing up to very high standards would not change the price of gas very much.[28] If this is true, then a lack of regulations to reflect the full cost of shale gas would have a relatively small impact on the long-term displacement of renewables. Second, the carbon externality affects all fossil fuels, so the net effect on gas plants is uncertain since fully reflecting carbon externalities in fuel choices would likely lead to at least some gas displacing coal-fired power. The exact impact of internalizing the climate externality on the evolution of the power generation mix over time is complex, and therefore beyond the scope of this report.

THE LONG-RUN TECHNICAL COMPLEMENTARITY OF NATURAL GAS AND RENEWABLES

There are technical reasons why gas and renewables also complement each other in the long-run. Adding controllable gas-fired plants hand-in-hand with wind and solar plants produces benefits for the entire grid because the latter's output is not dispatchable and the grid operators have little control over their output.

As already described above, the intermittent and still largely uncontrollable nature of renewable resources[29] in Texas creates significant challenges for grid operators who must balance the flow of power across the grid, especially if the share of such resources continues to grow. Of Texas' 11,585 MW of renewable electric capacity, an overwhelming 96% comes from wind generation.[30] At times wind power generation can already reach close to 30% of total demand, but these spikes in production are both uncontrollable[31] and are ill-matched with the time pattern of ERCOT's load, as Figure 2 below illustrates. Solar output, while still subject to weather conditions, tends to produce electricity in a more easily forecast manner if diversified geographically.

Figure 2: ERCOT Load vs. Actual Wind Output (02/02/2013 – 02/09/2013)[32]



Source: "ERCOT Grid Operations Wind Integration Report 02/09/2013," The Electric Reliability Council of Texas, February 9, 2013, p 3.

Typically, power generation from wind resources drops sharply during morning hours when load is on the rise. They pick up again in the evening as load begins to drop and blow the strongest during the night. The mismatch between typical wind generation and load makes it necessary for the system operator to ramp other resources up and down rapidly as the portion of power needed to meet demand that is not produced by wind resources increases and decreases. Beyond the typical pattern of wind generation, it is also the case that actual wind production varies significantly day by day and season by season, creating a wide range of mismatches between wind and demand in any given year. In ERCOT, the ramping requirements due to wind resources being mismatched with demand can be substantial. In 2009, ramping events lasted five hours on average and ramped up as high as 4,613 MW or ramped down as low as -4,788 MW.[33] Since natural gas resources are more flexible than nuclear and coal plants and can ramp up and down to complement wind output without incurring huge costs, they are very well suited for smoothing out spikes and dips caused by the mismatch between wind generation and demand. Solar output is also intermittent, but is far more aligned with peak demand than wind resources. In Texas, this especially important as the hottest, sunniest times tend to coincide with peaks in electricity usage for air conditioning.[34]

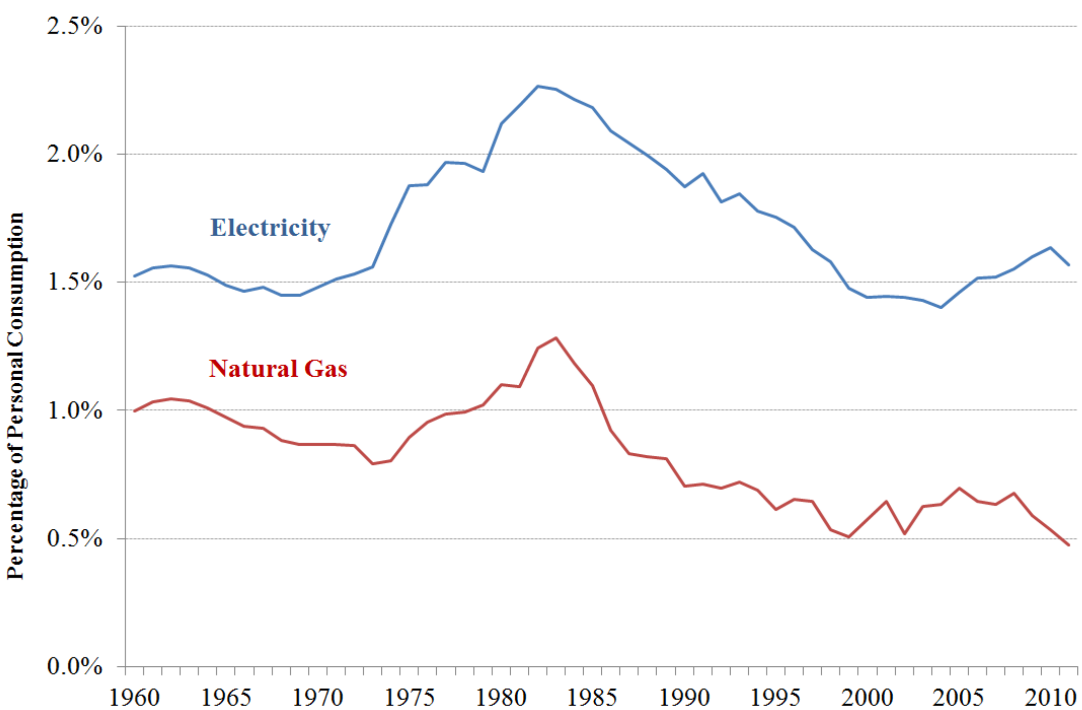
"Rate Headroom" Complementarity

Finally, it is also the case that cheap natural gas helps renewable energy in a certain forward-looking political-economic sense. On a forward-looking basis, as long as the cost of renewables exceeds the cost of alternative power generation technologies,[35] adding higher levels of renewables to the grid raises power costs to consumers at today's renewable energy costs. When regulators and policymakers look at long-term projections of the total price of producing electricity with more renewables added in the future versus projected prices using only additions of natural gas plants, average projected prices are usually higher with more renewables. The lower the price of natural gas power relative to renewables, the more pronounced the price difference. This may lead to pressure on policymakers to reduce mandates or policy support for renewables in order to limit projected increases in future electric prices.

On the other hand, projected low future gas prices may lead policymakers to a different conclusion if they adopt a different sort of reasoning. For example, policymakers might support a steadily increasing renewable portfolio standard as long as the projected total price of electricity does not increase more than a certain amount, such as 1% a year. If policymakers view is to support as much renewable energy as can be built within this limit on overall price increases, then lower natural gas prices increase the level of renewables that can be mandated under this approach because lower gas prices increase the amount of above-average-cost renewable megawatts that can be added to the system before the overall average impact of all new generators on price reaches the 1% threshold. In short, it is possible that lower long-term gas prices allow policymakers to adopt stronger policies supporting renewable energy additions.

Another way of thinking about the same issue is to recognize that low gas prices are leading to consumers having to dedicate a smaller share of their disposable income to the purchase of electricity and gas. As Figure 3 below shows, at the national level the portion of disposable income that needs to be spent on electricity and gas is at a 40 year low, almost entirely due to low natural gas prices. This suggests that even if new renewable resources remain somewhat more expensive than conventional generation sources, there is substantial "headroom" before total household spending on electricity and gas would reach the levels experienced over the last half century or so.

Figure 3: Share of Electricity/Natural Gas in Total Household Consumption Expenditure



Source: "Table 2.4.5U. Personal Consumption Expenditures by Type of Product," Bureau of Economic Analysis.

These politico-economic mechanisms are exceedingly fluid and informal to the point where it may not even be possible to determine whether or under what circumstances they apply to ERCOT or any other power market. Nevertheless, to the extent that either of these mechanisms do operate, they can represent a potentially important interaction between natural gas prices, renewable policy support and gas-renewables complementarity. In addition, the extra cost of adding more renewables to the system may also be justified because it provides long term insurance against the risk of both future gas price increases[36] and the introduction of greenhouse gas emissions limits. Historically, the price of natural gas has been quite volatile. While there is some discussion about whether or not shale gas may have an impact on the volatility of natural gas price going forward, the price of gas over the long-term remains uncertain. The variable cost of renewables, on the other hand, is relatively well known (and very low), since most of the cost of renewable power is associated with the upfront cost of constructing the wind or solar farms.
Some stakeholders in Texas are aware of this risk and some have warned against over-reliance on natural gas resources. The National Electric Reliability Corporation (NERC) has warned increased dependence on natural gas for generating capacity can amplify the bulk power system's exposure to interruptions in natural gas fuel supply and delivery," and has specifically cited Texas as an area where overreliance may be a concern.[37] Experts at the Union of Concerned Scientists have also warned against potential price spikes related to reliance on gas citing wind power as an important method to balancing supply prices.

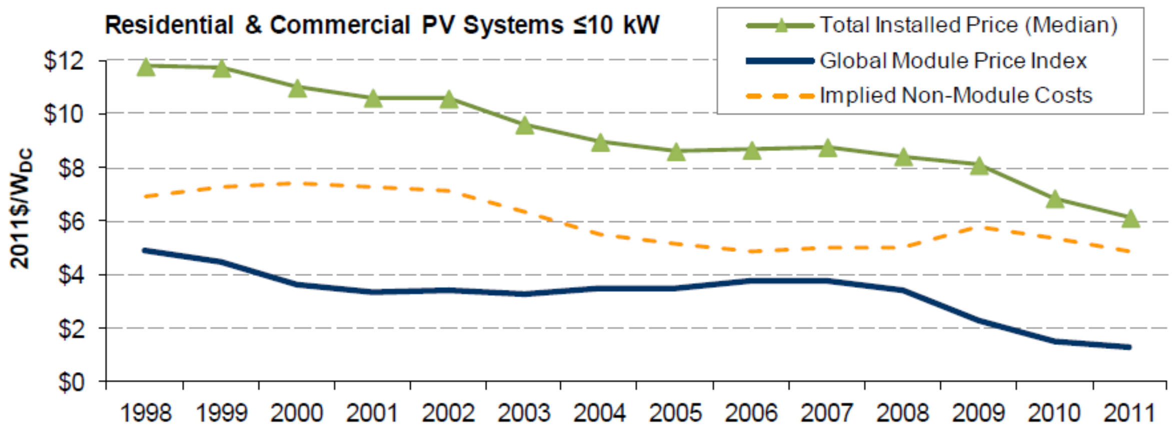
IV. PRICE MATTERS: FUEL PRICE TRAJECTORIES AND THEIR EFFECTS

RENEWABLE PLANT COST TRENDS

Throughout this report, we emphasize that gas-renewables complementarity is a function of *both* relative fuel prices and the totality of policies applying to each type of generation. In this section we review the recent history of generation fuel prices and illustrate the effects of the sequence of price shifts that have occurred in the last decade. While electric policies have also shifted during this period, we defer our discussion of the policy landscape for the following chapter.

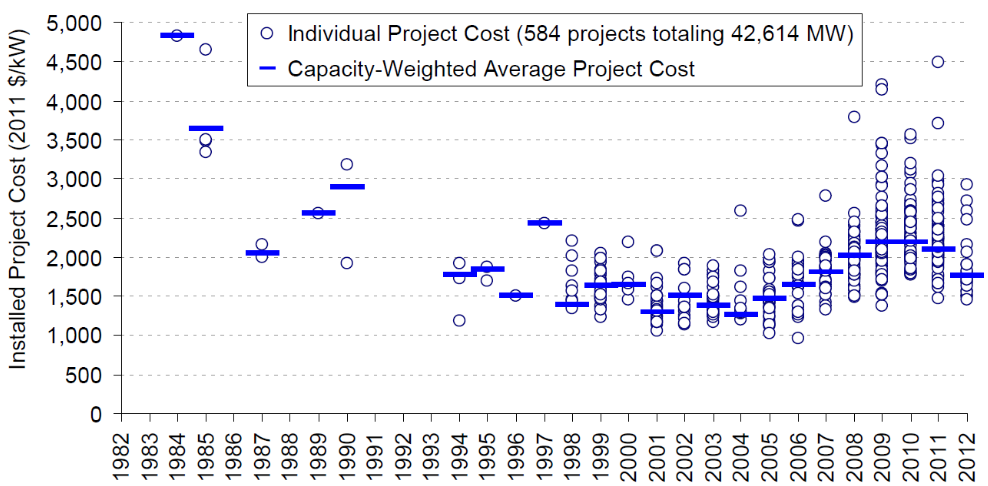
As seen in Figure 4 and 5 below, the costs for utilities or developers to build renewable generation plants have dropped rapidly and are projected to continue falling. Solar PV continues to see the most rapid declines and has reached retail rate parity in several U.S. retail electricity markets on a net-consumer cost basis.[38] While less steep than solar cost reductions, cost reductions for wind have also been substantial and are predicted to continue in the future, as seen in Figures 6 and 7 below. Regardless of the policy and market rules framework, the price of natural gas will have a profound effect on gas-renewables tradeoffs. Looking forward and ignoring the issue of integrating renewables onto the grid, which we discuss in more detail below, the relative roles renewables and natural gas might play in supplying electric power in Texas in the future will depend primarily on the costs of potentially competing resources.

Figure 4: Historic Installed Solar Costs



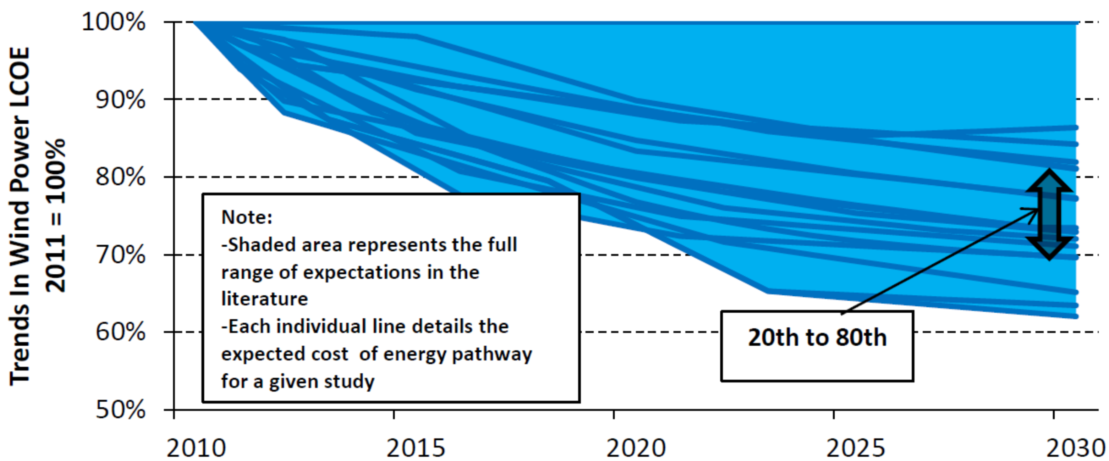
Source: Galen Barbose, Naïm Darghouth, and Ryan Wiser, "Tracking the Sun V," Lawrence Berkeley National Laboratory, p. 14.

Figure 5: Historic Installed Wind Costs



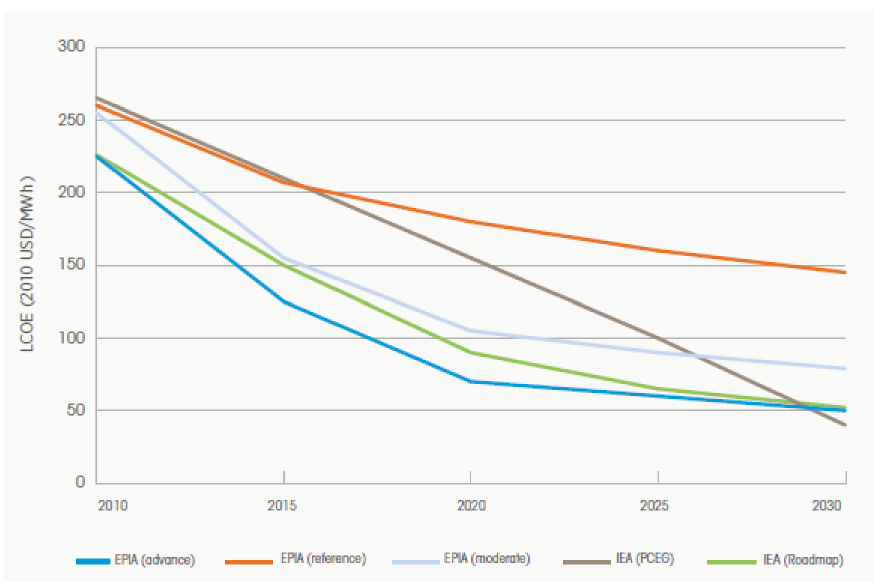
Source: "2011 Wind Technologies Market Report," DOE office of Energy Efficiency and Renewable Energy, August 2012, p. 34.

Figure 6: Estimated Range of Wind LCOE Projections Across 18 Scenarios



Source: Eric Lantz, et al. "IEA Wind Task 26: The Past and Future Cost Of Wind Energy," The International Energy Association, May 2012.

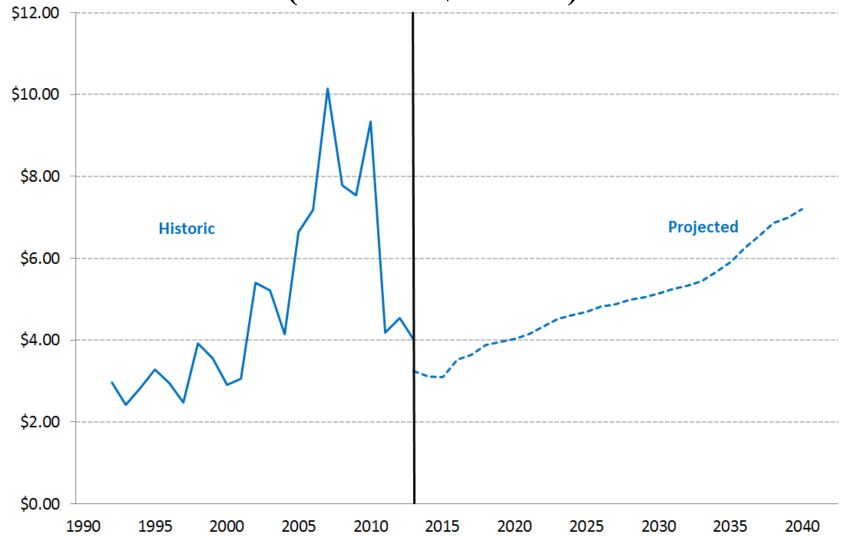
Figure 7: Estimated Range of Solar PV LCOE Projections Across 5 Scenarios



Source: "Solar Photovoltaics," Renewable Energy Technologies: Cost Analysis Series, Volume 1, The International Renewable Energy Agency (IRENA), p. 39.

As Figure 8 below shows, natural gas prices rose through the 90's and early 2000's, peaking in 2005. By 2008 prices began to drop in response to the recession and increased supply from shale resources. The most recent official U.S. forecast from EIA projects that base case prices will remain low through 2018. EIA also predicts that, through the following decades, gas prices are expected to increase moderately as demand for natural gas increases and shale production shifts to more expensive sources.

Figure 8: Historic and Projected Natural Gas Prices (Real 2011 $/mmBtu)

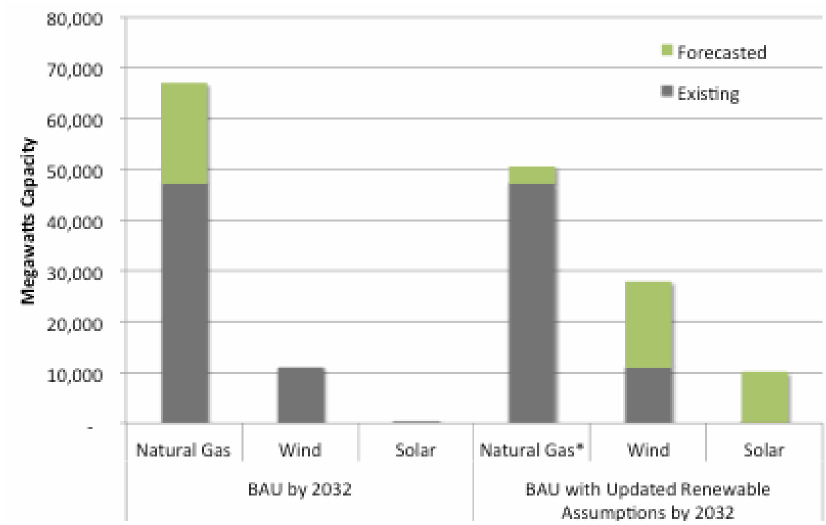


Source: "Annual Energy Outlook 2013- Early Release," Energy Information Administration, December 5, 2012.

With the prices shown in Figures 4-7, and current policies, it appears that natural-gas fired plants may still generally have a cost advantage over renewables, especially if natural gas prices remain low. However, renewable power costs are expected to decline over the coming decades, while gas prices are likely to increase, shifting this balance towards renewables.

The degree to which the relative attractiveness of gas and renewables depends on these factors is illustrated by the recently completed Long-Term System Assessment (LTSA) for the ERCOT Region.[39] The report highlights the fact that increased information about the economics (both cost and performance) of wind and solar resources over the course of the planning exercise significantly impacted the modeled optimal evolution of the generation mix in ERCOT. For example, as shown in Figure 9 below, incorporating new information about wind shapes, obtained in 2011, into the forecast results in a significant shift away from natural gas and towards wind and solar resources. A Business As Usual Case (BAU) with older wind shape information led to assumed 20,600 MW of new gas added little additional wind or solar resources by 2032. Incorporating new wind shapes led to a revised forecast that resulted in a reduction of the assumed need for new gas-fired generation of almost 10,000 MW to the benefit of both wind and solar PV resources.[40] As these Scenarios show, the relative role of renewables and gas depend significantly on the evolution of their relative costs and performance.

Figure 9: ERCOT 2012 LTSA Capacity Results[41]



Source: Colin Meehan, "New ERCOT Report Shows Texas Wind and Solar are Highly Competitive with Natural Gas," ThinkProgress.com, January 29, 2013.

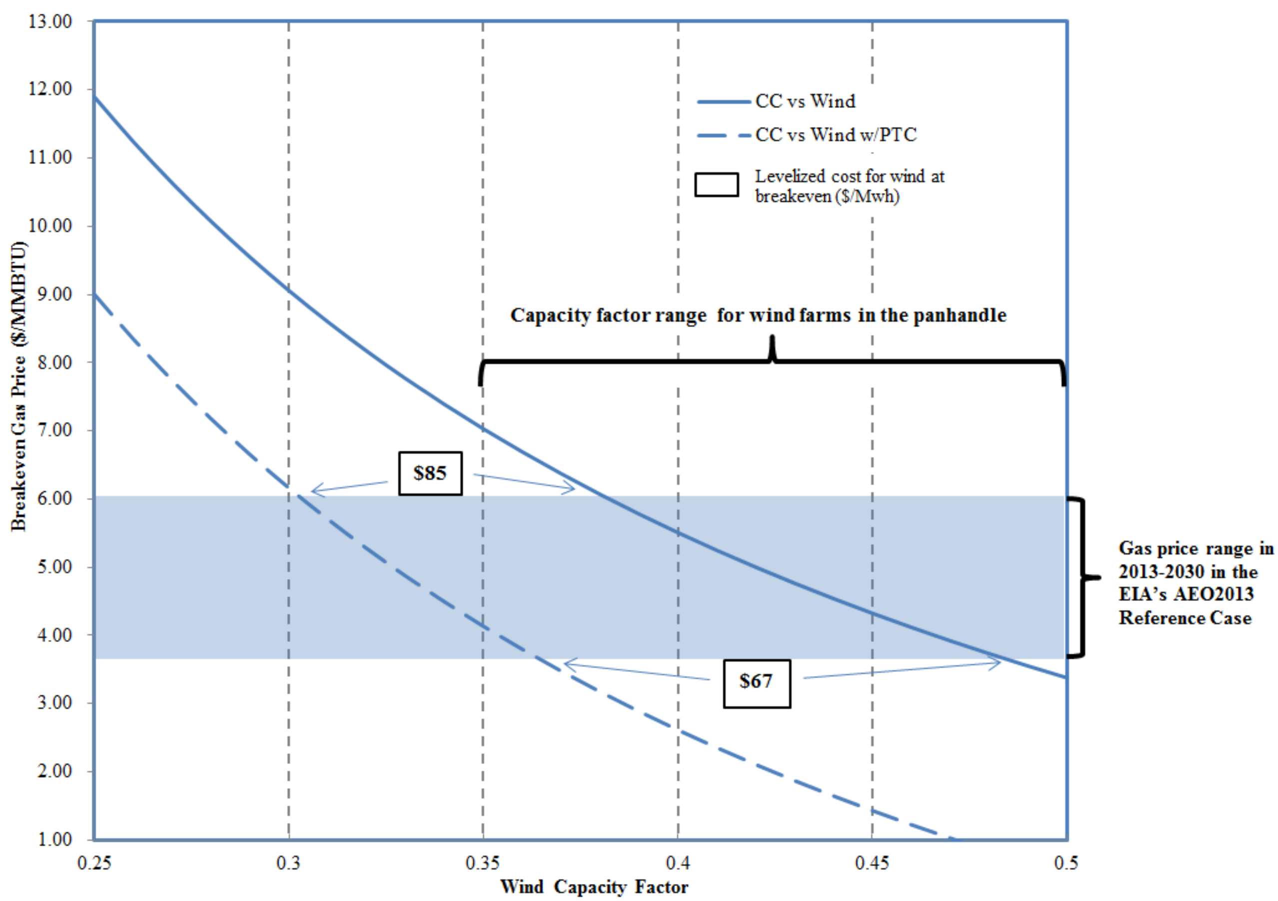
OTHER FUEL PRICES MATTER, TOO

While this discussion has focused primarily on the costs of renewables and natural gas, it is important to understand the economics of all actually or potentially competing resources. This is because new resources will not only be needed to meet projected increases in electric demand, but also to replace the output from power plants that may retire in the future. Some retirement occurs naturally and based primarily on plants reaching the end of their useful lives, or in response to environmental compliance mandates requiring either significant investment or retirement. But part of the retirement decision is also the expected profits from continued operation relative to the costs of remaining online. The expected profits in turn depend on the evolution of the same factors that drive the economics of natural gas and renewables, namely factors such as the price of natural gas, the existence (or not) of some price on emissions such as greenhouse gases, and the technology costs of renewables.

As an illustration of this point, a 2011 coal-plant retirement screening analysis by *The Brattle Group* estimates that a combined 5,000 MW of coal plants in ERCOT may be under threat of economic retirement due to a combination of EPA regulations, low gas prices and assumed environmental regulations in the future.[42] As cited above, a 2012 update to the same analysis came to the conclusion that in part as a result of less stringent regulation of coal-fired plants only 400 MW of coal plants in ERCOT would retire. This shows the sensitivity of the evolution of the future retirements and additions to the power generation mix to a variety of additional factors. While we have not analyzed in detail the impact such coal retirements might have, it is reasonable to assume, based on the scenarios modeled by the LTSA, that some of any retiring coal capacity would be replaced by both new gas-fired generation and a combination of wind and PV.

Wind farms in excellent wind regions such as the Texas panhandle may be able to compete with new combined cycle units even without the production tax credit. Figure 10 shows breakeven natural gas prices and wind farm capacity factors with and without the Production Tax Credit (PTC). As can be seen, over the Energy Information Administration's range of Reference Case natural gas prices between now and 2030 and wind farm capacity factors, wind is competitive with natural gas on a levelized cost of energy basis at many locations in the Panhandle.[43] With the PTC (2.2¢/kWh), wind farms can compete even at lower capacity factors such as those in eastern and central Texas closer to load centers[44].

Figure 10: Breakeven Frontier between Gas and Wind



Source: *The Brattle Group*, 2013.

V. CURRENT POLICIES AFFECTING THE GAS-RENEWABLES RELATIONSHIP

In this section, we describe a number of policies that currently affect the mix of gas and renewable resources used in the power sector in Texas. Broadly speaking, these policies fall into the categories of fuel specific programs (such as gas, coal or renewable power related policies) and general market related policies. Rather than comment on the relative merit of any specific policy, we merely outline current drivers before addressing in more detail how policies might be altered in the future in ways that affect natural gas and renewable development in the future.

NATURAL GAS DEVELOPMENT IN TEXAS

Over the past decade, new horizontal drilling and fracking have doubled Texas's proven natural gas reserves and natural gas exports to other states. As the natural gas regulator in Texas, the three-member Texas Railroad Commission (TRRC) is highly supportive of increasing production of shale resources through responsible fracking techniques. In recent years the TRRC has implemented some of the first frac fluid disclosure requirements, updated well integrity rules, and is developing rules to encourage oil and gas operations to do more recycling. In 2011 Commissioner David Porter created a Task Force designed to facilitate the development of the Eagle Ford Shale formation by increasing communication among stakeholders and addressing issues related to the development, such as water quality, landowner rights, and infrastructure issues.

To meet increased transport needs, gas pipeline infrastructure has grown both within the state and for export to other markets.[45] In Texas, development of new lines is uncomplicated as pipeline companies are given statutory right of eminent domain and are not required to obtain permits from the TRRC. Involvement from the TRRC is only needed if the project encounters problems requiring their assistance. Interstate lines follow the federal process and involve FERC approval as do all interstate lines.[46] As dependence on natural gas increases, ERCOT has identified the understanding of the impacts of pipeline system operations on the electric grid as a priority.[47]

The development of the Eagle Ford Shale formation has also required additional electric transmission lines to support production. Texas natural gas developers have been constructing facilities to serve their load faster than new transmission can be built, requiring many to turn to self-supply. ERCOT is focused on meeting this new demand and approved five sets of transmission projects in 2012 totaling $152.4 million.[48]

The Texas Legislature is also supportive of natural gas development, not only passing the Texas Law for Disclosure of Hydraulic Fracturing Additives (House Bill 3328) in 2011 but also the Texas Clean Transportation Triangle (Senate Bill 20). Senate Bill 20 will use funds from the Texas Emissions Reduction Plan (TERP) to develop a Texas Clean Transportation Triangle (TCTT) by building natural gas refueling stations on interstate highways connecting Houston, Dallas–Fort Worth, and San Antonio and converting heavy-duty fleet vehicles to natural gas vehicles (NGVs).[49]

To better manage the physical integration of natural gas resources onto the grid, ERCOT commissioned a study in 2012 to identify operational issues leading to of natural gas curtailment. The study concluded that pipeline infrastructure is sufficient to meet needs and the greatest risk came from weather concerns.[50]

The future of natural gas development in Texas and its impact on other resources will depend on production levels from shale reserves and natural gas price trends. This supply shift is expected to continue, reflected by natural gas futures. Recent studies of available gas reserves are reinforcing this belief, projecting Barnett Shale gas reserves can be drilled profitably for the next three decades or longer.[51] As a result, it is reasonable to expect that natural gas prices will remain relatively low for the foreseeable future.

FEDERAL RENEWABLE SUPPORT

Texas' high level of renewable capacity is not just a product of strong renewable resource potentials in the state, but also an outcome of successful state and federal policies to foster these resources. Financial incentives at the federal and state level combined with a Renewable Portfolio Standard (RPS) and aggressive action to overcome transmission barriers have allowed Texas to rapidly develop its considerable wind resource potential.

At the federal level, the Production Tax Credit (PTC) and Investment Tax Credit (ITC) in combination with advantageous depreciation allowances have perhaps been the biggest drivers of renewable energy development. The PTC applies only to onshore wind power; the ITC applies to all other approved renewables. Since enacted in 1992, the PTC has been renewed several times, most recently for one more year in 2013. The credit has allowed wind developers to secure private financing for projects by providing wind resources a 2.2¢/kWh credit for power generated in the first 10 years of operation.[52] As of this writing, proponents for renewables in Texas are seeking continued renewal of the credit or at least a controlled ramp-down to maintain stability in the industry. The American Wind Energy Association (AWEA) has endorsed a plan for a PTC ramp down involving 90% of the current credit available in 2014, 80% in 2015, and further annual declines to an eventual phase out in 2019.[53] The Texas renewable market has also benefited from the federal Investment Tax Credit (ITC), although to a lesser degree. The ITC has been a major driver particularly of solar development in selected states with complementary state policies and is currently expected to expire in 2016.

STATE POLICY SUPPORTS

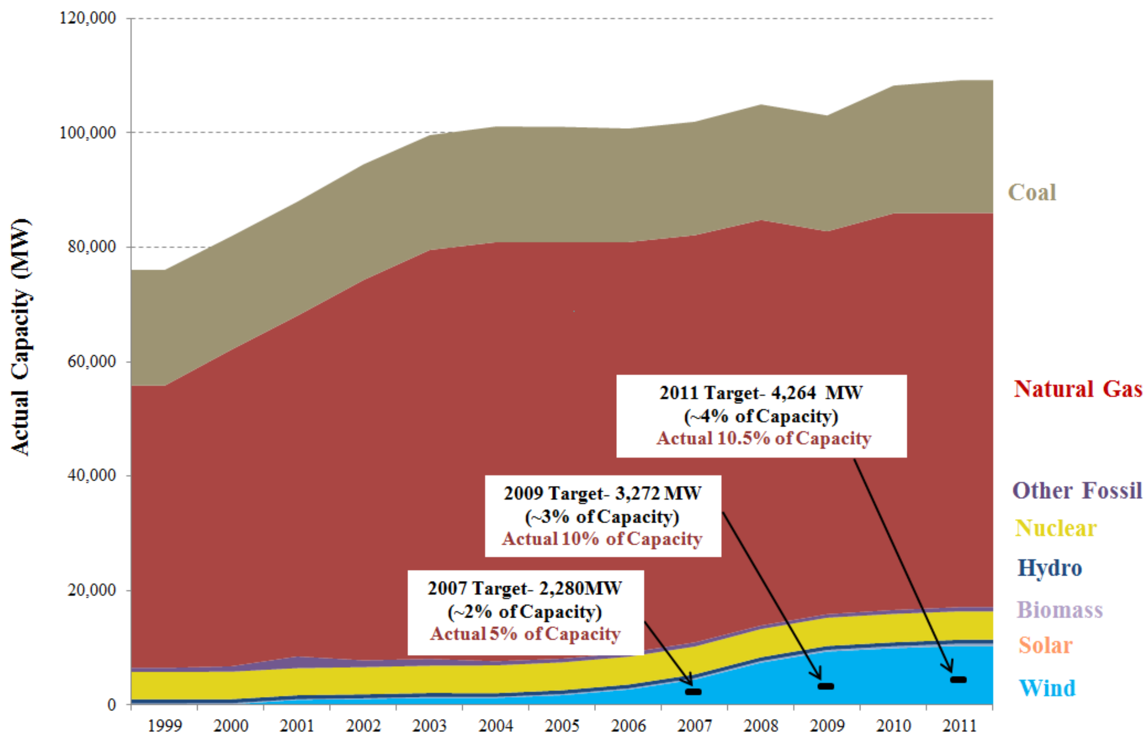
At the state level, several grants and tax exemptions exist for renewable energy. Both the Texas Enterprise Fund (TEF)[54], and the Texas Emerging Technology Fund (TETF) support solar and wind technology development. Recently the TETF funded the creation of the National Institute for Renewable Energy at Texas TechUniversity to examine challenges facing the Renewable Energy Industry.[55] The Solar and Wind Energy Business Franchise Tax Exemption has also supported the renewable industry by offering companies that manufacture, selling, or install solar energy devices an exemption from Texas franchise tax.[56] Renewable energy projects are also supported by the Texas Department of Rural Affairs (TDRA) which offers grants to local governments from the Renewable Energy Demonstration Pilot Program (REDPP).

Property related incentives have also driven renewable development in Texas. The state's Chapter 313 capital investment law allows projects to negotiate with a school district to receive temporary tax abatement. Recently the law has allowed wind farms to temporarily reduce their property tax bills but is now under attack by those seeking to end all renewable subsidies in Texas.[57] At the same time, proposed legislation to revamp Texas' Property Assessed Clean Energy (PACE) program could also benefit the renewable industry, particularly roof-top PV.

PACE programs allow homes and businesses to obtain long-term loans to improve buildings using property assessments.[58]

Since the 1990's state level Renewable Portfolio Standards (RPS) have likely been an important driver of renewable development in many states. An RPS requires states to obtain a minimum percentage of electricity supplies from renewable sources through state law or public utility regulation. Currently twenty nine states, including Texas, have enforceable RPS or other renewable capacity requirements with still more establishing voluntary goals.[59] The Texas legislature established its first RPS in 1999, targeting 2,000 MW of additional renewable energy by 2009 (approximately 3% of total capacity) and by 2001 established the ERCOT-managed Renewable Energy Credit (REC) market for generators and retailers to buy and sell energy credits. By 2005 it was clear Texas could achieve the set RPS easily and the level was raised to 5,880 MW by 2015 and 10,000 MW by 2025 in Senate Bill 20, this time including a 500 MW target for non-wind resources. Texas reached this goal in 2010 - fifteen years ahead of schedule.[60] Overall Texas renewable resources now total 11,436 MW and are well above current RPS mandates as seen in Figure 11 below:

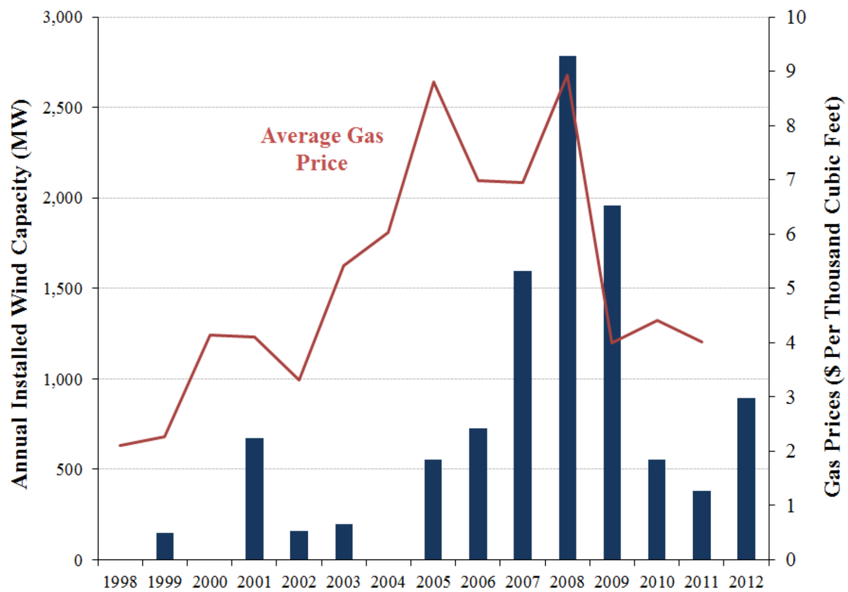
Figure 11: Total Texas Capacity vs. RPS



Source: *The Brattle Group*, 2013. Based on "State Renewable Electricity Profiles," Energy Information Administration, March 2012.

This suggests that while the RPS was likely an important catalyst in particular for wind development in Texas in the early years, the combination of excellent wind resources, PTC, and relatively high natural gas prices during much of the 2000s were also important factors in the rapid growth of wind energy in Texas, as illustrated in Figure 12 below.

Figure 12: Gas Prices and Wind Development in ERCOT



Source: Ventyx (2013), *The Brattle Group*. Wind investments reported at nameplate capacity. Texas Natural Gas Wellhead Prices from EIA (2013).

Net metering is another renewables policy used by many states and has been instrumental in particular for the development of distributed renewable energy resources such as residential soar PV and small-scale wind. Under net metering, a retail customer who generates their own power is effectively paid their current retail electronic price for this generation by their local utility. Texas currently does not have a net metering policy, though utilities may voluntarily implement their own programs. Current utilities programs include those offered by Austin Energy, the City of Brenham, and Green Mountain Energy Renewable Rewards Program. Even though Texas has excellent solar resources, historically the cost of solar PV has been significantly higher than the cost of wind (in areas with good wind resources such as Texas) and some other renewables. Thus, the absence of a state-wide net metering policy and relatively modest retail electricity rates in Texas likely explain why, unlike wind, solar resources have not been growing nearly as much as wind resources in the state.

TRANSMISSION AND RENEWABLES INTEGRATION

Setting renewable goals and providing financing have been a successful strategy for scaling up renewable energy capacity quickly, but by themselves were not enough to ensure that these resources are integrated onto the Texas grid efficiently. In recent years Texas has made several steps to address renewable integration and overcome barriers such as transmission development and energy storage. To fully integrate wind resources Texas is also beginning to make changes to its market rules.

The need for more transmission lines to connect areas of high wind development with demand became apparent very soon after the Texas RPS was established. The same Senate Bill that increased RPS levels in 2005 required ERCOT to designate Competitive Renewables Energy

Zones (CREZ) with potential for renewables development and then develop plans for cost-effective transmission lines to transport the power. By the time ERCOT began its study in 2006, annual congestion costs on the Texas grid had already reached $400 million.[61] Once CREZ lines were identified, the CREZ program used a competitive bid solicitation process to identify projects and allow both incumbent and non-incumbent utilities to win the rights to build, own and operate them.[62] Total investment in CREZ lines rose to $7 billion by 2012, above the original estimate of approximately $5 billion, and almost 3,600 miles of transmission are now planned or under development.[63] The final CREZ lines are projected to be complete and energized this year. Studies indicate new the new lines should remove West-to-North stability limits as a transmission constraint.[64] In addition to completed CREZ, ERCOT has another $2.7 billion in transmission improvements planned out to 2018.[65]

ERCOT Rules

As wind resources have continued to grow on the grid, so has ERCOT's attention to integration issues. In 2008 ERCOT commissioned a study of the impact of wind generation on ancillary services that projected the variability introduced by wind would be minimal at less than 5 GW, noticeable at 10 GW, and significant at 15 GW.[66] Shortly after, ERCOT established the Wind Operations Task Force, the Renewable Technologies Working Group (RTWG), and the Wind Cost Allocation Task Force (WCATF) to analyze strategies to better integrate wind resources including reactive power standards, low-voltage ride through, and improved wind forecasting tools. The Renewable Technologies Working Group (TRWG) produced ERCOT's Emerging Technologies Integration Plan to address needed changes to ERCOT's planning models and assumptions, operational capabilities and procedures, and elements of the nodal market design to meet Texas RPS and CREZ goals.[67]

As wind increases on a grid it becomes more difficult to maintain adequate dynamic reactive power capability to respond to voltage events. Reactive power – which is the power needed to support voltage levels- had not previously been required of wind generators, leaving this balancing function to transmission providers. In 2009 the working group considered a requirement that older turbines be retrofitted to provide reactive power or to pay a fee to transmission providers if they fulfilled the reactive power requirement for them.[68] Ultimately this measure was not adopted and additional reactive power requirements were not required for turbines built before 2008.[69] Ultimately, low voltage ride through requirements were established for all new units but found unnecessary for older units. Large, central solar inverters, however, are now equipped (and currently deployed) to provide reactive power control.

ERCOT has also developed new processes for wind data collection and tools for wind forecasting, covering a variety of data types and time frames. Wind generators are required to update their current operating plan every time the capacity or status of a resource changes. ERCOT incorporates this and other data into three forecasts that look out over the next 48 hours.[70] The Total ERCOT Wind Power Forecast (TEWPF) provides the probability distribution for total wind production in ERCOT and is the basis for the Short Term Wind Power Forecast (STWPF) which estimates the most probable output level from this information. Wind resources use the STWPF to set their Generation Resource Limits used in ERCOT's Current Operating Plan. ERCOT incorporates this wind generator output behavior and historical wind power forecast error into its Ancillary Service requirements as well. Finally, the Wind Generation

Resource Production Potential (WGRPP) forecasts the production potential for each wind generator individually and will soon be used in determining whether a generator is capacity-short

ERCOT uses this information to publish a Wind Generation Resources Production Potential (WGRPP) and a Short-Term Wind Power Forecast (STWPF) for every generator. Requirements for wind data inform ERCOT's decisions when setting resource limits in current operating plans and determining capacity value in Reliability Unit Commitments. In addition to wind generation forecasts, ERCOT has developed the ERCOT Large Ramp Alert System (ELRAS) to specifically calculate the risk of a large increase or decrease in wind. The model provides planners with the probability and scale of potential large ramps six hours in advance.[71] Like ERCOT, other grid operators are using multiple wind forecasts and some are considering establishing their own versions of ELRAS.[72]

Today the TRWG has evolved into the Emerging Technologies Working Group (ETWG) which continues to provide input and recommendations on protocols to integrate emerging technologies.[73]

Carbon and Environmental Regulation

The future generation mix in Texas will at least partially depend on pending new EPA rules targeting emissions. The Environmental Protection Agency's (EPA) Mercury Air Toxics Standards (MATS) has been finalized and includes less restrictive requirements on compliance deadlines and equipment than expected. In addition, EPA's proposed rules on cooling water intake structures were also more lenient than predicted and will not require universal requirements to install cooling towers. The Cross-State Air Pollution Rule (CSAPR), which was designed to control SO_2 and NO_X, was vacated by the DC Circuit Court adding uncertainty around future proposals by the EPA. These factors have reduced the pressure on coal plants. At the same time, lower natural gas prices have put coal plants under economic pressure. On balance, lower gas prices have put so much economic pressure on coal plants that retirement projections have increased even though environmental compliance costs are lower. In the ERCOT market, however, control equipment has held expected coal retirements to less than one GW through 2016. Coal Combustion Residuals (ash) regulations and Texas' State Implementation Plan (SIP) for revised SO_2 standard may have further impacts once developed.[74]

Directly, natural gas-fired generation would be minimally affected by these rules as such plants do not emit significant sulfur dioxides, particulates, or mercury. Of potentially affected gas generation, 3,500 MW have already installed selective catalytic reduction (SCR). Regulations on Water Intake Structures (316b), if they had more stringent closed-loop cooling tower system requirements, would have had a far greater impact on natural-gas fired units.[75] However, to the extent these rules lead to more coal plant retirements, the resulting indirect impact on gas plants, which would likely fill a large part of the resulting resource gap, could be significant.

The future of natural gas development in Texas may also depend on the development of environmental rules governing shale gas production in Texas. Strong opposition to hydraulic fracturing due to pollution concerns isn't seen in Texas as it is in other states, such as New York. However, Texas passed legislation in 2011 requiring developers to disclose their fracturing fluids; since then, legislation has turned its focus on gas development incentives.[76] In a water constrained state, shale gas production also poses long-term concerns, as each well requires approximately 4 to 6 million gallons of water over its lifetime. Texas water use for hydraulic fracturing has more than doubled since 2008 and is expected to increase through the 2020's.[77] While water constraints have not slowed development yet, they may become a concern in the future.

VI. TEXAS AS A TEST-BED FOR NATIONAL RENWABLES DEVELOPMENT

BUILDING ON TEXAS' SUCCESS

Texas' experience with renewable energy, both past and future, has potential relevance for the rest of the United States (and perhaps other parts of the world) for a number of reasons. Having ramped up in particular wind generation faster than any other state, Texas' ability to integrate this renewable resource into its existing power system has the potential to be a model for other states as they see the share of wind in their electricity supply increase.

Unlike other parts of the U.S. or the world with very sizable amounts of wind capacity, Texas also represents an important example because of the relative isolation of the ERCOT system from the surrounding markets. This means that – at least for now and unlike other high wind regions such as Denmark or Germany – Texas cannot rely on surrounding markets to help manage the effects of high levels of electricity generation from intermittent renewable energy. The Texas experience will therefore become immediately relevant to other relatively isolated energy markets with increasing renewable energy production and for markets that have reached high levels of renewable penetration across larger market areas and have to manage its effects largely within their geographical area. The latter may become particularly relevant for Europe, where Texas provides a useful case study for another reason.

This reason is that Western Europe is like ERCOT in having retail choice and an energy-only market, *i.e.,* it does not have a formal capacity market. There is currently a significant discussion in the EU about the need to implement some form of capacity payment mechanism to allow electricity markets to function properly in the presence of ever increasing amounts of intermittent generation from renewable sources. ERCOT's solutions and success will therefore be followed with heightened attention. In addition, as a deregulated market, the Texas experience will provide insights into the interaction of market forces and regulation.

Texas is a useful state to closely study the co-development of natural gas and renewable resources in search of strategies that are mutually beneficial to both and maximize their complementarities. As seen so far, for both natural gas and renewables, the state has ample natural resources, established infrastructure, an industry-friendly environment, and momentum for further growth. Growing electricity demand and related need for capacity additions also make Texas an ideal state to study development of new resources. With this in mind, however, it is important to keep some key differences in mind when contemplating how these lessons may translate to other states or regions.

Similarities and Differences between ERCOT and Other Markets

ERCOT is unique among U.S. regional power markets in that it is a market with full retail choice, but without a formal capacity mechanism. As just mentioned, in that sense it resembles Western European markets more than it does other U.S. markets, which tend to be characterized either by retail choice and formal capacity mechanisms (such as PJM, New York and New England) or by limited or no retail choice (SERC, SPP, WECC). However, even though the combination of retail choice and energy-only markets in Texas is a somewhat unique case in the United States, many of the strategies that can be used to deal with increased levels of renewable generation can potentially be applied in other U.S. markets.

Another difference between Texas and other parts of the country is its historic endowment with natural gas.[78] This has led to a large share of natural gas fired generation in Texas at a time when other parts of the United States have relied more on coal, or have at least increasingly gotten worried about "over-reliance" on natural gas. For example, in much of the Southeast and Midwest, coal remains a much more dominant source of electric power than it does in Texas, and in the Northeast, where until recently local natural gas supplies were non-existent, concerns about gas supply bottlenecks have created concerns about further increasing the use of natural gas. By contrast, the gas supply and related infrastructure in Texas are relatively robust and associated concerns about gas supply bottlenecks for electric power generation limited to relatively rare extreme weather events.[79]

Finally, in spite of its competitive electricity market, Texas is a pioneer in developing a coordinated approach to fostering the development of renewable energy. Recognizing the critical and complex link between renewable energy development and the transmission necessary to deliver renewable power to demand centers, Texas' CREZ approach is both relatively unique and likely a promising model for others to follow. California is already moving in this direction, and others may follow [need to check status in CA and in other parts of the country].

VII. POLICY OPTIONS FOR ENHANCING GAS-RENEWABLES COMPLEMENTARITY

In this section, we highlight a number of areas where changes to existing policies could have a meaningful impact on the relative role of renewables and gas in Texas in the next few years. Without exhaustively listing all potential areas for policy change, we focus on those areas where there is a sound rationale for changing existing policies or for introducing new policies. They include transmission and linkages to other markets, evolving the design of ancillary services markets, net metering, regulations of coal-fired power plants, and perhaps a strengthening of the State RPS. We also briefly discuss the potential impact of either a federal or state-level carbon pricing regimen.

New Transmission Build

Transmission capacity is likely to remain a limiting factor in the development of further renewable resources. Even as new CREZ lines come online, Texas is still looking for additional new lines to transport wind to load. For example, if approved, the proposed "Southern Cross"

400-mile, 500 KV HVDC line between the Southeast and ERCOT could make Texas a wind exporter.[80] Similarly, the Tres Amigas project to interconnect ERCOT, the WSCC and the Eastern Interconnection could provide an opportunity to make use of significant additional amounts of renewables. Clearly, linking the ERCOT system to other US power markets would facilitate the task of integrating larger amounts of renewable energy. It would likely also improve the economics for wind in the long run, especially as long as the ability to absorb additional amounts of wind generation into the existing Texas market becomes more challenging and exporting wind from Texas to other regions of the U.S. could lead to additional revenues for wind projects.

However, while probably helpful for renewables and in particular wind resources, the impact of connecting ERCOT to other power markets on natural gas resources is less clear. Given Texas' abundant gas resources and infrastructure, a Texas market more closely integrated with other U.S. power markets may result in additional export potential for gas-fired power generation. On the other hand, transmission links to other markets may also provide an alternative to gas with respect to smoothing out the intermittent electricity production from wind. Perhaps most importantly, whether the interconnections themselves make economic sense requires a careful benefit cost analysis beyond the scope of this report.

MARKET DESIGN/ANCILLARY SERVICES

By most measures the experience with integrating increasing amounts of intermittent renewable generation is still small and quite recent. Electricity markets have largely been designed within the paradigm of relatively predictable demand, fluctuating over the course of the day largely in response to weather and other relatively stable factors, and supplies from mostly controllable power plants. With the advent of large amounts of renewable generation sources, in particular wind and solar PV both at the utility scale and behind the meter, this paradigm is increasingly coming under pressure. Demand fluctuations become harder to predict as customers have more options (including generation and/storing their own power on their side of the meter, opting for time-sensitive retail rates, etc.) and supply sources become less controllable. While it is true that even with respect to controllability technological developments are leading to rapid change – wind can now provide partial regulation service – this means that there are likely adjustment and reforms to market rules that will be needed to improve the co-functioning of traditional and new elements on both sides of the market.

While the list of target reforms is long (and some perhaps not even invented at this point), we here point to only one aspect of market rules that impact both the ability to use large amounts of renewable electricity to meet demand and the mix of resources used to integrate those renewable sources of electricity.

Market rules with respect to the provision of various ancillary services and potentially capacity could have a significant impact on how increasing amounts of renewable power are handled. The details of how one specific ancillary service – primary regulation – is compensated may have a significant impact on the relative economics of storage, particularly battery storage, and natural gas fired generation. For example, to comply with FERC Order 755, the Pennsylvania New Jersey Maryland (PJM) Interconnection introduced a performance-based regulation service (PBR).[81] PBR provides two revenue streams for providers of regulation service, one of which rewards faster responses to regulation control signals. The effect of such an approach to compensating regulation service providers is to potentially provide additional revenues for very fast ramping resources. Since at least some storage technologies can ramp substantially more quickly than even the fastest ramping gas turbines, this type of market construct can impact the attractiveness of storage relative to natural gas. Market rule changes such as the one implemented for regulation service in PJM could therefore have an important impact on the optimal choice of resources in the future.

While the impact of redesigned or new ancillary services on the mix of natural gas and renewables (or the degree to which increases in ancillary services needs caused by increasing levels of intermittent renewable generation are met by natural gas as opposed to other technologies) very much depends on the precise market design of such services, it is likely that in general a strengthening of ancillary services and associated revenue streams will favor natural gas, in particular relative to coal fired power generation. This is because gas-fired power generation, due to their greater relative flexibility, can participate more fully in ancillary services markets than coal-fired generation can.

NET METERING

Another factor likely driving in particular the evolution of distributed renewable energy systems, such as solar PV, is the ability of system owners to capture the value of energy production from such systems. For the most part, especially residential retail rates for electricity don't reflect the full value of energy consumed (or produced) in the sense that rates tend to be relatively undifferentiated. The majority of rates involve a flat charger per kWh of electricity, in some cases a different one for the peak summer period and the rest of the year.

There is a vast literature on the inefficiencies caused by this type of retail pricing and a full discussion is beyond the scope of this white paper. While improving the incentives for consumers through better rate design remains important, net metering has emerged as one way to provide additional incentives for behind-the-meter generation sources, likely at least partially compensating such resources for benefits not captured through flat retail rates. Many states now have net metering policies in place. Several different designs are in place, but the basic principle is that a consumer with behind-the-meter resources gets credited for amounts generated in excess to their own demand. Since monthly bills are typically based on a monthly meter reading, the meter simply goes backwards during times when a customer produces more electricity than she consumes. Since in most states bills include volumetric charges for items other than electricity (distribution charges, transmission charges, various forms of system benefits charges), net metering allows the participating customer to avoid the full retail rate (and potentially get paid the full rate of electricity) rather than just the cost of electricity itself. Since the costs that can typically be avoided by the participating customer through net metering exceed the wholesale cost of power, net metering creates additional incentives for the installation of distributed renewable generation.[82] Since some of the items typically charged for on a volumetric basis are intended to cover fixed costs – such as the costs of the transmission and distribution system – net metering typically results in under-recovery of fixed costs from participating customers. Since the fixed costs remain the same, other customers in essence cross-subsidize net metering customers to some extent.

Net Metering has therefore been identified as a potential policy tool to drive development of non-wind renewables, in particular solar PV. If implemented, it would potentially compete with other renewables, but also likely displace some gas-fired generation (either existing or new) since solar PV generates substantial amounts of power on-peak, when generally gas-fired power generation sources are producing energy at the margin. Net metering itself typically leads to some inefficient shifting of fixed costs from net metering customers to the remaining customers, since it allows participating customers to avoid paying for some portion of fixed costs that consequently have to be paid by the remaining customers. In the short run, especially as long as there are relatively few participating customers, net metering may thus function as a relatively crude substitute for other policies creating more appropriate economic incentives for renewable technologies such as solar PV. In the long run however, either net metering rules will need to be reformed and/or more efficient policies towards renewable energy – such as providing distributed solar PV with pricing that reflects the value of generating power during times when demand for power is high – will need to be implemented. Proposals on how to improve the economic efficiency of net metering programs in Texas have been made relatively recently.[83] Since net metering provides incentives for behind the meter generation sources, it is very likely to lead to more renewable generation in from solar and perhaps small scale wind. It may also lead to more natural gas generation, in the form of evolving primarily natural-gas fired micro-generation options available both as back-up generation sources and as substitutes for grid-sourced power. It is likely that in the near future a more comprehensive net metering approach would likely most benefit the development of distributed solar PV resources.

Strengthening Environmental Rules

As mentioned above, various emissions-related federal policies, notably a number of potential measures by the EPA, would have a substantial impact on the economics and longevity in particular of coal-fired generation in Texas. More recently, the prospect of very significant federal action has diminished somewhat. Consequently, current estimates of likely near-term retirement by coal-fired power plants have also diminished. This does however not mean that the rationale for imposing legitimate environmental regulation on power plants either at the federal level or in Texas specifically has disappeared.

Many states impose environmental regulations on their power generators that are more stringent than federal standards. Some of these policies affect existing plants, others address new resources. States like California have categorically prohibited the construction of new coal-fired power plants. In many other cases, plants to build new coal plants have either been cancelled due to worsening economics or because key permits were denied under existing environmental regulations. Indicative of the potential dynamics is the very recent decision by White Stallion Energy LLC not to pursue further development of a 1,200 MW new coal-fired plant after the Texas Supreme Court rejected its appeal to reconsider a decision by a lower Court to send its air pollution permit back to regulators at the Texas Commission on Environmental Quality (TCEQ) based on the assertion that it had been improperly authorized.[84]

It is however at least possible that in several areas local considerations may merit more stringent environmental rules, at least some of which might affect coal plants more heavily than gas plants. For example, coal-fired power plants remain the highest sources of air pollution in the state. Emissions of several key pollutants such as mercury and sulfur dioxide from coal-fired power plants tend to be significantly higher than corresponding emissions from gas-fired plants. As a result, placing additional limits on such emissions at the state level would likely lead to either the early retirement of existing coal-fired plants or the lack of incentive to build new ones.

Also, water use is a key issue in Texas. The cooling of coal-fired power plants results in significant water use. In 2011 ERCOT experienced its worse drought in 50 years, lowering water levels at nearly every reservoir across the state, reducing the production capabilities of several plants and requiring ERCOT to start up mothballed generating units to meet high summer demand.[85] ERCOT is currently studying the potential impacts of continued droughts and developing a long-term drought scenario with several sensitivities.[86] Given the recent drought experience and the expected increase in future water demand in the state due to population and economic growth, it is entirely possible that grounds exist for imposing more serious regulations on water use by power plants. In response to similar concerns California has banned once-through cooling, the standard approach to using water for cooling purposes in fossil fired power plants, as of 2010.

In sum, based on the existing evidence concerning the health effects of various air pollutants as well as the pressure on water resources in Texas, it is at least possible that additional state-level regulation affecting all fossil power generation could be justified. It is likely that all such regulation would make all fossil-based power generation more costly and thus create a relative cost advantage for renewable power. It is however also likely that many of the reasonable environmental control policies would have a more significant impact on coal than on gas. If implemented, this could hasten the retirement of at least some of the remaining coal-fired power plants in Texas, with the effect of creating the need for capacity to replace retiring coal plants. For the reasons described throughout this report, it is relatively likely that the majority of this replacement capacity would be natural-gas fired.

CHANGING/INCREASING THE STATE RPS

Given that Texas quickly reached and overshot its RPS targets, it is worth assessing the potential benefit of further increasing or changing the RPS target as a tool for continued support of renewable energy development. With the 10,000 MW by 2025 standard already met, stakeholders and lawmakers have proposed raising this level to 13,000 MW by 2020,[87] 15,000 MW by 2020, and other targets.[88] As of the writing of this report there are several bills in the Texas Legislature targeting expanded renewable resources, one of which targets a new standard of 35% of generating capacity by 2020.[89]

Unlike almost every other state RPS, the existing Texas RPS is defined as a set MW amount instead of a percentage of the total capacity.[90] It has been proposed that the Texas RPS be restructured as a percentage of total demand and perhaps be revisited every five years. A ratio-based standard could better align renewable levels to total capacity- an element of RPS design that would be more important to markets with growing demand and capacity. ERCOT is currently one of the few growing markets and expects demand to grow 2% annually through 2022.[91] Most U.S. markets project demand growth between 0.5-1.0 % over the next few decades and markets such as NYISO and CAISO are predicting flat to negative demand growth.[92] TREIA, for example, has advocated for the establishment of a RPS target equal to 25% of demand by 2025, a common target for a state with high renewable potential.[93]

Another important design element of the Texas RPS is the new non-wind carve-out introduced in 2005. Unlike the first, the current RPS provisions specify that 500 MW of new capacity must come from non-wind resources by 2015 as an effort to diversify Texas' renewable portfolio. Texas has plentiful solar resources and tapping into these resources could potentially provide reliability benefits to the Texas grid. Solar resources have very different load profiles than wind and could potentially reduce the strain wind patterns place on the grid, or help meet peak load in the state. Some proposed RPS designs include a carve–out for solar, for as much as 2% of overall consumption by 2020.[94]

It is likely that strengthening the Texas RPS in the sense of setting targets beyond already installed capacity would create additional incentives for the deployment of renewables in the State, especially given that unlike in the mid-2000s the current forecast of natural gas prices is low so that even with ongoing technological progress wind resources may find it more difficult to compete with natural gas going forward, especially if/when the PTC disappears.

In sum, it is likely that some modifications to the RPS could have a near-term impact on the development of renewables in Texas. In particular, committing to or refining the carve-out for non-wind resources would potentially have an impact on the development of non-renewable resources, perhaps in particular solar generation. Texas has an excellent solar resource, yet, unlike wind, solar generation in the State is relatively small and creating solar-targeted incentives within the RPS could help change that. Other states with solar-specific RPS targets such as New Jersey or Massachusetts have seen significant growth in solar installations.

Beyond the carve-out, the effect of moving towards an RPS based a percentage of total sales rather than a set MW amount and/or increasing the level of the RPS especially in the short run is less clear. As Figure 10 above showed, due to the excellent quality of the wind resource base in Texas, wind is likely already competing with gas-fired generation even with current low gas prices, especially while the PTC remains in place and interest costs are low. It is therefore likely that as long as renewable energy can get to market – either as the CREZ lines are completed and/or opportunities to export energy into adjacent markets get created – Texas will see continued development of wind resources. Should the PTC go away and interest rates increase, it is however possible that in the longer term additional development of wind resources will slow, assuming gas prices stay low.

As the issue of how to reform the RPS is likely not currently on top of the list of potential measures to improve the market environment for renewables, but should be monitored over time. Moreover, any revision of the RPS should be integrated carefully with market design revisions to address resource adequacy and other dimensions of the Texas power markets so as to create an effective overall system.

PUTTING A PRICE ON CARBON

Finally, placing an explicit or implicit price on greenhouse gas emissions is a policy that would certainly influence the gas-renewables relationship. As many studies of climate policies have shown, carbon prices on the trajectories proposed in recent federal legislation, typically starting in the range of \$10 to \$20/ton CO2E, increase both natural gas and renewable generation over the coming decade. Renewables increase because the price of all carbon-emitting technologies increases and renewables become relatively more affordable; natural gas power increases because increased renewables create a larger demand for fast-adjusting gas-fired power plants and at some threshold carbon price natural gas power plants become cheaper than coal. As an example, EPA's analysis of the American Clean Energy and Security Act of 2009 (also known as the Waxman Markey Bill) showed that natural gas generation would have been expected to increase from 539 TWh to 544 TWh between 2015 and 2025 under this law, while renewable generation was expected to grow from 310 to 375 TWh.[95]

Obviously, Texas has only indirect influence on the implementation of a national carbon price. It does have the option of establishing a state-wide carbon price and would not be the first state or region to do so. California and the Regional Greenhouse Gas Initiative (RGGI) in the Northeast are two examples of carbon prices at the regional/state level. In the near future, a carbon price would put further strain on the economics of coal-fired power generation and thus could well lead to increased natural gas use in the short run – by using existing gas-fired plants relatively more often than coal-fired plants, and in the long run by accelerating the retirement of coal-fired plants and their replacement with gas-fired generation.

Assuming a carbon price regime is developed as the primary mechanism for eliminating (or strongly reducing) greenhouse gas emissions from the power sector over time, carbon prices would have to rise significantly in future decades, ultimately reaching levels where this complementarity comes to an end. Ultimately, the goal of a climate policy is to reduce GHGs to approximately 80% below 2005 levels by the middle of this century. To accomplish this goal, carbon emissions prices or other policy measures will have to constrain the growth of natural gas-fired power in Texas as well as other markets around the world. Nevertheless, in view of the compelling benefits of adopting sound policies to limit the damage from climate change, and the near term complementarity of these policies, we recommend some form of carbon pricing in all electric markets.

VIII. CONCLUSION

In this report we explored the multi-faceted relationship between gas and renewables in Texas. We explained that gas and renewables can be either complements or substitutes, depending on the time frame of analysis as well as a number of additional factors such as the long-run trajectory of gas prices, renewable technology costs, electricity market rules and complementary policies affecting all power generation technologies.

Given the current expectation of relatively low gas prices, it is likely undesirable to increase coal-fired generation in the long run, due to climate, air pollution, water and other considerations, and due to the ongoing improvements to the cost and performance of several renewable technologies it is quite possible and perhaps even likely that natural gas and renewable generation technologies will be the primary pillars of Texas' future electric grid in the near future.

Over the longer term, the majority of the factors driving the expansion of all forms of generation – such as carbon policies and market-based fuel prices – are beyond the exclusive control of Texas policy makers. The transition can be helped, however, with a mix of complementary state policy measures, from potential emission regulation to expanding the RPS to changing market rules for ancillary services in an effort to create the investment incentives to develop an electricity market capable of dealing with what will almost certainly be an increasing amount of intermittent generation from renewable resources over time.

We argue throughout this paper that natural gas and renewables are naturally matched and will likely both be needed in Texas for many years to come. As we have also shown in this report, the precise interaction between both as well as their relative importance in the electricity system over time depends on a myriad of uncertain forces and policies. Determining with some confidence how these factors will impact the interplay between renewables and gas in Texas over the coming decades requires a more analytical effort than possible here. Nonetheless, there is a clear set of challenges facing the Texas power market and an emerging set of policy options that merit more discussion and analysis on the path towards a clean energy future.

Endnotes

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[11] "Texas Renewable Energy Industry Report," Texas Renewable Energy Association, July 2012.

[12] "Renewable Energy Data Book," The Department of Energy, February 2013, p.30.

[13] "U.S. Wind Industry Fourth Quarter Market Report 2012," American Wind Energy Association, Released January 30, 2012, Slide 8. It is worth noting that as a percentage of total installed capacity several smaller states have a higher share of wind than Texas.

[14] "Texas Solar," The Solar Energy Industry Association Website. Available at: http://www.seia.org/state-solar-policy/Texas

[15] "Solar Energy Overview," Texas Wide Open For Business Website, August 2012. Available at: http://www.texaswideopenforbusiness.com/resources/files/solar-energy-overview.pdf

[16] Wind does have some variable operating and maintenance expenses, but these tend to be very small when compared to fuel costs for gas-fired power generators, which also have variable operating and maintenance expenses. In other markets, hydro power resources may have lower variable costs (due to perhaps even lower operating and maintenance expenses) and may need to be dispatched before wind or solar resources due to water flow management constraints.

[17] We use the term reliability broadly, representing a combination of lack of transmission capacity, the need to operate larger fossil (and nuclear) plants at minimum output levels and inflexible demand, resulting in challenges to maintaining an instantaneous balance between supply and demand, which in turn results in risks of collapse of the grid, black outs, etc.

[18] Ryan Wiser and Mark Bolinger, " 2011 Wind Technologies Report," U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, August 2012, p. 43.

[19] It is also likely that during some periods and in some regions more renewable power displaces coal-fired generation. This would typically be the case in the parts of the U.S. relying most heavily on coal-fired generation (Midwest) and during time periods when demand is low and wind generation high such as night time or potentially weekends. Therefore, renewables generally reduce natural gas generation but it is not the case that one additional MWh of renewable energy necessarily displaces exactly one MWh of gas generation.

[20] This statement needs further clarification. In particular, wind generators can adjust production levels downwards when the wind is blowing, *i.e*. when they are generating electricity. In a typical case this is not desirable since, as discussed above, the variable cost of wind is very low – and thus it is often not appealing to curtail very cheap energy when the capital cost, which may be relatively high, has already been incurred. Nonetheless, there are increasingly situations when wind generators are prepared to reduce production and in essence participate in an ancillary services market.

[21] As noted, ERCOT is making great strides in the addition of storage but even with current levels of storage, natural gas performs the vast majority of balancing energy today.

[22] E. Hirst and B. Kirby, "Ancillary Services," Oak Ridge National Laboratory, Technical Report ORNL/CON 310, February 1996.

[23] In reality, the analysis is more complex and requires a detailed estimation of likely future hourly prices since wind and solar PV tend to generate more power during certain times of the day, while fossil-fired power plants can generally be run whenever expected power prices exceed their variable costs.

[24] The availability of state and federal renewable supports has been used in the past to overcome or soften this cost disadvantage, especially when combined with higher gas prices, as they existed in the mid-2000s, when Texas experienced its initial burst of wind development. However, it is both questionable to what extent public subsidies should be included in cost comparisons when making investment decisions for the ultimate benefit of rate payers (since they indirectly pay at least part of such subsidies) and likely that support levels will decrease and ultimately disappear.

[25] Renewable energy advocates argue that fossil and nuclear plants get many subsidies as well, and they are correct, but given that reality unregulated developers simply take all available subsidies into account when decided what is cheapest for them.

[26] Given that the expectations about the future price of natural gas were very different only a few years ago, i.e. before the discovery of shale gas, investments in wind may have been profitable in expectation.

[27] "The SEAB Shale Gas Production Subcommittee Second Ninety Day Report," Department of Energy, Secretary of Energy Advisory Board, Department of Energy, November 18, 2011.

[28] It is commonly estimated that the additional costs of sufficient environmental regulations of shale gas production are in the range of $0.50-$1.00/MMBtu or less. See "Natural Gas Update," presented to Hogan Lovells by *The Brattle Group*, September 6, 2012.

[29] There is some evolution in the technical capabilities of renewable generation sources. In particular, wind turbines are becoming increasingly sophisticated, leading to much improved control over their output. For example, it is now possible to use wind resources to provide "ramping down" ancillary services.

[30] "2011 Annual Report on the Texas Renewable Energy Credit Trading Program," The Electric Reliability Council of Texas, 2012, p.2.

[31] It is possible to "control" wind production by curtailing it. However, given the goal of using renewable energy due its environmental benefits and the fact that its variable cost is close to zero, curtailing wind production as a means of managing its intermittent and "uncontrollable" nature is typically not a desirable outcome.

[32] "ERCOT Grid Operations Wind Integration Report 02/09/2013," The Electric Reliability Council of Texas, February 9, 2013, p 3.

[33] Yih-huei Wan, "Analysis of Wind Power Ramping Behavior in ERCOT," National Renewable Energy Laboratory, March 2011, p 5.

[34] "Reaching for the Sun," Environment Texas Research & Policy Center, February 2013, p. 11.

[35] As illustrated below, the cost gap between renewable and fossil generation technologies has been shrinking as a result of both technological progress and the scaling up of renewable energy technologies. It is therefore possible that this gap will disappear in the next few years, at least with respect to certain renewable technologies and in certain areas.

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[37] "Emerging Issue #RAS-3: Gas-Electric Interdependency," 2012 LTRA Emerging and Standing Issues Templates, NERC, p.1.

[38] Peter Kind, "Disruptive Challenges: Financial Implications and Strategic Responses to a Changing Retail Electric Business," Edison Electric Institute, January 2013.

[39] Long-Term System Assessment for the ERCOT Region, ERCOT, December 2012.

[40] *Ibid*, pp. 19-20.

[41] Colin Meehan, "New ERCOT Report Shows Texas Wind and Solar are Highly Competitive with Natural Gas," ThinkProgress.com, January 29, 2013. Accessed January 29, 2013 at http://thinkprogress.org/climate/2013/01/29/1509551/new-ercot-report-shows-texas-wind-and-solar-are-highly-competitive-with-natural-gas/.

[42] Metin Celebi, "Potential Coal Plant Retirements in ERCOT Under Emerging Environmental Regulations – Update," *The Brattle Group*, June 22, 2011, p.15. This screening did not consider some of the operational impacts of more intermittent renewable generation on the economics of coal-fired generation discussed above. It is likely that adding such considerations would put more coal-fired power generation at risk of retirement.

[43] Capital cost, fixed O&M, variable O&M and heat rate estimates come from http://www.ercot.com/content/committees/other/lts/keydocs/2011/Long_Term_Study_Interim_Report_Volume_2.pdf. The 2007-2011 ERCOT average combined cycle capacity factor of 38.5% was used (source: Energy Velocity).

[44] Levelized costs are a crude measure of the relative costs of various technologies and therefore only provide a partial view of the relative attractiveness of various technologies. In particular, this analysis treats the value of electricity generated in all hours as equal when in reality power production during peak demand periods is more valuable than power produced at other times. Since natural gas fired plants can choose when to produce when wind cannot, it is likely that the value of electricity produced by natural gas plants exceeds, on average, the value of electricity produced from wind power. Also, this analysis assumes a certain capacity factor for gas combined cycle plants. The levelized cost of plants decreases as the capacity factor increases. A higher capacity factor would therefore also shift the economics in favor of natural gas combined cycle plants.

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[46] Frank Russo, "Pipeline Permitting: Interstate and Intrastate Natural Gas Permitting Processes Include Multiple Steps, and Time Frames Vary," Government Accountability Office, February 15, 2013, p. 24.

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[48] "Report on Existing and Potential Electric System Constraints and Needs," ERCOT, December 2012, p. 24.

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[50] "Gas Curtailment Risk Study," Prepared for the Electric Reliability Council of Texas by Black and Veatch, March 2012.

[51] Mike W. Thomas, "Study Predicts Natural Gas Boom To Last For Decades," *San Antonio Business Journal*, February 28, 2013.

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