Fuel Switching Potential of Electric Generators: A Case Study

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Summary

There has been much debate about electricity generator's capability to respond to high natural gas prices by switching to petroleum when market conditions dictate. This study addresses that question by using historic performance data during a period of rapidly changing fuel prices (year 2000 through 2001) to analyze the actual behavior of existing electric generators. By using performance data, the study circumvents the issue of potential to switch and determines the extent to which electricity generators did switch from natural gas to petroleum when market conditions warranted.

The study found that about 29 gigawatts (GW) of electricity generating capacity actually switched between natural gas and petroleum as prices changed. Approximately, 40% of this capacity fired residual fuel oil/natural gas with the remainder firing distillate/natural gas. This generating capacity when firing natural gas consumed on average 2.7 BCFD.

Furthermore, there is about 4.3 GW of electricity generating capacity, which switches from natural gas to petroleum during the winter regardless of relative petroleum/natural gas prices.

Finally, the study found that during the winter months of some years, 20-60 GW of low cost non-fossil electricity generation capacity supplanted a like amount of electricity generation from natural gas fired units. This decline in the use of natural gas did not appear related to high natural gas prices.

Introduction

For many years, steam boilers capable of firing either natural gas or residual fuel oil were considered a backstop to rising natural gas prices. However, during the past ten years the introduction of new environmental regulations that discourage the use of petroleum, changes in power generation technology, and the structural changes in the electric utility industry have resulted in a reduction in fuel switching capacity for electric generators. The question that arises is: How much fuel switching capacity still exists today?

The Energy Information Agency (EIA) previously estimated the physical capacity held by electric utilities, which nominally is capable of switching between petroleum and natural gas. In its publication, "Inventory of Electric Utility Power Plants in the United States 2000", EIA estimated 100 GW of fuel switching (petroleum/natural gas) capacity owned and operated by then electric utilities. Of these units about 72 GW fired residual fuel oil/natural gas and 35 GW fired distillate/natural gas. However, the actual amount that fuel switched when market conditions warrant was thought to be quite a bit less than their "advertised" potential capacity. Possibly, environmental regulations, infrastructure constraints, changing economics have created institutional barriers that limit the number of units that can switch in response to changing pricing signals.

Fortunately, the radical swings in the natural gas prices during the past several years presented an excellent opportunity to measure the extent of actual fuel switching capacity. From the second half of 1999 through the first half of 2000, petroleum prices were high relative to natural gas favoring the use of natural gas. However, everything changed during the second half of 2000 and into 2001. Oil prices remained steady, weather became more severe and natural gas storage was at very low levels going into the winter. The high natural gas prices that resulted during the winter of 2000-2001 created a strong economic incentive for natural gas consumers to switch to other fuels whenever possible. This sharp contrast in market conditions allows the opportunity to study the behavior of electric generators during each of these time periods and deduce from their choice of fuel during these time periods, the extent of fuel switching capacity that actually responds to changing relative prices.

The objective of this study is to estimate, based upon actual behavior, the capacity of electricity generators to switch between natural gas and other fuels in response to changing market conditions. By studying the "willingness" of electric generators to switch as determined by their actual behavior versus the "advertised" physical capacity to switch one can determine more realistically the actual level of fuel switching capacity that responds to changes in relative fuel prices. By comparing the actual fuel switching capacity with the "advertised" physical capacity, one can quantify the importance of institutional barriers in retarding flexibility in the market place.

Consequently, this study focused upon the decision making by existing generators, using actual field experience to evaluate behavior. It did not consider the influence of relative fossil fuel prices on selection of technology for building new plants. Although the study primarily focused on competition between petroleum and natural gas, other means of power generation were also considered. Because studying an issue from different perspectives often sheds new insights into a problem and serves a means of cross checking results, the problem was analyzed using data sets at a national, regional, and individual unit level.

It was recognized that some seasonal fuel switching occurs regardless of relative fuel prices. The study also estimated the degree of this phenomenon and separated it from the overall effects. The study also considered indirect fuel switching, which is defined as turning down one unit and replacing its generation with that from another unit. The study assessed the extent of indirect switching and how much of indirect fuel switching is driven by relative fuel prices versus seasonality.

The study also segmented the petroleum/natural gas fuel switching capability into distillate and residual fuel oil components, since the two petroleum products have significantly different pricing and either may be from time to time the price setting mechanism for natural gas.

Finally, based upon the findings of the study a set of recommendations were made to those who operate mathematical models of natural gas demand concerning the treatment of electricity generator fuel switching.

Methodology

This study was an analysis of historic performance. Consequently, it was important for the study to use a consistent set of historic data for electricity generation, fuel consumption, fuel prices and electric generator characteristics. Fuel prices can be volatile and change daily. Pricing on fuel supply contracts is based often upon spot prices either related to daily or monthly pricing. Fuel price data for natural gas and petroleum products are available on a daily basis from public sources. However, fuel consumption and electric generation data is available only on a monthly basis. Thus the consumption and generations data limited the degree of data disaggregation and the study relied upon monthly datasets for analyzing market behavior.

The study relied upon data collected by the Energy Information Agency (EIA). For electric generators, EIA publishes monthly fuel consumption and generation data on a national and regional level in its Monthly Electricity Review. EIA also maintains a series of databases, which contain individual plant data at a monthly level. All these datasets are available online through the EIA website. EIA also collects fuel-pricing data and the study relied upon their data for petroleum product prices. For natural gas, the most referenced pricing point is Henry Hub, which the study used.

The study needed a parameter (i.e. metric) in order to measure whether an electricity generation unit should burn petroleum or natural gas. The decision to burn a particular fossil fuel is dependent upon relative pricing at the burner tip and burner tip pricing will vary by location throughout the United States. Since it was beyond the scope of this study to determine relative burner tip pricing at each unit, it was necessary to use a single parameter (i.e. metric) to measure when natural gas or petroleum was the favored fuel. It was decided to use the difference in price between the Henry Hub natural gas price and the price of residual fuel oil delivered to the Gulf Coast as the metric. When the natural gas price at Henry Hub was greater than the residual fuel oil price delivered to the Gulf Coast, residual fuel oil became the preferred fuel. When pricing relationship was reversed, then natural gas was preferred. Fortunately, regional differences became a mute point because during the time period of investigation the natural gas price volatility was so extreme.

The initial period of investigation extended from January 2000 through December 2001. This period was chosen because the differential between natural gas prices and petroleum prices was widely fluctuating. During some months pricing favored the use of natural gas and in other months pricing favored the use of petroleum. Later when analyzing seasonal switching not related to the difference between natural gas and petroleum prices, we expanded the period to include the years 1999 and 2002 because we needed a period when natural gas and petroleum price differentials were more stable.

The analysis used a top down approach. The study first analyzed energy switching behavior at a national level. Then the study used more disaggregate data to determine the nature of energy switching behavior on a regional and individual plant level.

Non-utility generators became a more prominent component of power generation during this period because of the restructuring of the electric utility industry. Industrial cogeneration has been an important component of power generation since the late 1970s. As a result, it was important for the datasets used in the study to encompass all three classes of electricity generators: utilities, non-utility generators and cogenerators.

National Level

In order to study fuel-switching behavior at the national level, three months of extreme price differentials were selected. In the first month, the extreme prices favored the use of natural gas. In the second month, the extreme prices favored substitution of petroleum for natural gas. In the third month, the prices reverted back and again favored the use of natural gas.

The months chosen for investigation were based upon two criteria; the metric of the difference in price between natural gas and residual fuel oil and the total level of electricity produced during the month.

Figure 1 illustrates the price relationship between natural gas and residual fuel oil during the period of investigation. First, in order to assess the level of switching a month was chosen in which natural gas prices were favored relative to petroleum to serve as a basis. Next, a month was selected in which relative pricing turned in favor of petroleum. By calculating the changes between the two months, it was possible to estimate the extent of fuel switching. Finally, a third month was chosen in which relative pricing again favored natural gas. By calculating the change in generation between the third month and the second month the degree of reversibility in switching could also be determined. This third month essentially served as a check upon the earlier analysis. Since the study was effectively analyzing changes in share by fuel it was necessary to ensure that none of these changes could be associated with a change in the total level of generation. Therefore it was important to normalize the generation in each month to a base value. In order to minimize the extent of extrapolation, months were chosen which had about the same level of total generation. Figure 2 illustrates the total electricity produced by month.

Based upon these two criteria, June 2000 was chosen as a base month, and January 2001 as the month in which relative prices switched in favor of petroleum. September 2001 was chosen as the third month to determine if the fuel switching, which occurred during the first two months reversed itself.

For the three months of interest, data was gathered on electricity generation and fuel consumption. The monthly electricity generation data was disaggregated by fuel type. Relying upon electricity generation data is important because it allows the elimination of any bias in the fuel data resulting from different efficiency of electricity generation. The data collected was then compared for each of the three months selected to determine the actual degree of fuel switching that occurred.

This analysis included all major electricity generation technologies. As such, both direct and indirect switching was measured. Direct switching is when an individual plant is capable of burning more than one fuel. As fuel prices dictate, that individual plant will switch back and forth between fuels in order to minimize its fuel cost. Indirect switching occurs between multiple plants, when one plant stops generating, a second plant takes it place. For instance, consider two plants, the first plant can only burn natural gas and the second plant can only burn residual fuel oil. When pricing favors natural gas the first plant operates; however, when relative pricing changes in favor of petroleum the first plant shuts down and the second plant goes online and replaces it.

Individual Plant Performance and Regional Analysis

The study next analyzed individual plants advertised as capable of burning either petroleum or natural gas in order to determine their historic fuel-switching behavior. For this analysis, individual units were characterized by their electricity generation patterns for the same three months used in the previous piece of analysis. Each unit was characterized by its capacity, location, versatility in burning different fuels, and actual electricity generated by fuel.

The analysis consisted of observing the behavior of each unit during the particular study months and categorizing the plants by their behavior. For this analysis, a plant was designated as "fuel switching" if during the first month it burned primarily natural gas, during the second month primarily petroleum and the third month primarily natural gas. Conversely, a plant was classified as "natural gas burning" if it burned primarily natural gas during the three months of interest. Likewise, a plant was classified as "oil burning" if it burned primarily petroleum during the same three months.

The study considered only direct fuel switching because it looked at the behavior of single plants. The data did not lend itself to determining when one plant turned off which other plant may have turned on.

The individual plant data was aggregated by location to determine regional distribution.

Seasonal Fuel Switching

For some electric generators, it is necessary to switch from natural gas to petroleum or other fuels during winter months regardless of relative prices. Infrastructure restrictions, contractual arrangements, the timing of shutdowns may all contribute to this phenomenon. This study wanted to quantify the significance of seasonal fuel switching and to separate seasonal fuel switching from total fuel switching.

Seasonal switching was estimated by selecting two recent years in which relative fuel prices favored natural gas, both in the fall and during the winter months. The study then compared the degree of fuel switching which occurred during this period to that which occurred between June 2000 to January 2001. The difference in fuel switching between the periods of comparison is attributable to changes in relative fuel prices. The study analyzed the seasonal switching issue from two different perspectives using both national level data and individual plant data.

Split Between Heavy and Light Oil

An ability to disaggregate fuel switching into light and heavy oil is important to modelers. Petroleum represents a form of substitution for natural gas demand. The price at which this substitution occurs and the volume of demand shed is important to understanding how changes in natural gas demand can affect price volatility. Since distillate is much more highly valued than heavy oil, the split between distillate and residual fuel oil determines the extent of the ability of this substitution to moderate swings in natural gas prices

The national level data for Non Utility Generators ("NUGS") does not disaggregate petroleum consumption. Therefore, the study used the individual plant database to determine the number of plants and their capacity that switched to either residual fuel oil or distillate.

Results

National Level

The national level analysis focused upon the changes in electricity generation mix between June 2000 and January 2001. Unlike laboratory experiments, where one can control for a single variable, the historic data used in this analysis reflected multiple effects that were occurring simultaneously. As shown in Figure 3, about 14 billion kw-hrs of electricity shifted away from natural gas. Simultaneously, generation from hydropower dropped by almost 6.9 billion kw-hrs. These declines in electricity generation were offset by increases in nuclear, coal, petroleum and to a small extent renewables. Trying to sort out the multiple effects can be challenging. If one assumes that the hydropower, nuclear, coal are used primarily to meet base load, then one can net out their individual changes. Using this methodology, the 6.9 billion kw-hr decline in hydropower is partially offset by the 3.3 billion kw-hr increase in nuclear. The remainder of the drop in hydropower (3.6 billion kw-hr) can be thought of as being offset by an equivalent increase in coal-fired generation. With those calculations complete, it appears that the 14 billion kw-hr drop in natural gas fired generation is about 60 % offset by 8.6 billion kw-hr increase in petroleum fired generation and 40% offset by a 5.4 billion kw-hr increase in coal fired generation. Since dual fired units are generally thought of as being oil/natural gas capable, the introduction of coal implies that a sizeable portion of the fuel switching may have been in the category of indirect switching (i.e. when one unit is turned down and another unit replaces it).

The study analyzed the reversibility of fuel switching by comparing January 2001 (when petroleum prices were lower than natural gas prices) to September 2001 (when natural gas prices were lower than petroleum prices). As shown in Figure 4, from January 2001 to September 2001 natural gas fired generation increased by 21 billion kw-hrs. Allowing for the further decline in hydropower (2.2 billion kw-hr), the remaining 19 billion kw-hrs increase in natural gas offsets the declines in coal and petroleum usage. The increased use of natural gas in the January 2001 to September 2001 period is greater than decline in natural gas from the June 2000 to January 2001 period. This result is consistent with the wide spread construction of natural gas fired units that occurred during the years being investigated and represents a structural changes in the generation mix.

The data clearly shows that two types of switching were occurring during this period. The first type is the direct fuel switching between natural gas and petroleum and the second type is the indirect switching between natural gas and coal.

Direct Switching

Direct switching is defined as an individual unit that can switch between two fuels (i.e. petroleum and natural gas) without any capital investment. In order to analyze the degree of direct fuel switching, the study relied upon EIA databases that characterized generation at individual electricity generation plants throughout the United States. A subset of the database was created which contained only those units, which were advertised as being capable of firing petroleum and natural gas. The dataset contained 1069 units of which 427 units had either incomplete or inconsistent data and 45 units were classified as standby units. The remainder, 597 units served as the basis for the analysis.

Total Direct Switching

Using the criteria for fuel switching discussed in the methodology section, about 1/3 of the units (215 units) exhibited fuel switching behavior for the three months analyzed (June 2000, January 2001, September 2001) (Figure 5). These plants fired primarily natural gas in June 2000, petroleum in January 2001, and natural gas again in September 2001. Of the remaining units, 328 units, which comprise 55% of the total units, fired primarily natural gas during the three months studied. The remaining 54 units or 9% of the total units fired primarily petroleum during the three months studied.

The 215 units that exhibited fuel switching represented about 30% (33 GW) of the total capacity of the 597 units. Natural gas only units represented 57% (64 GW) of the total capacity, and the petroleum only units represented about 13% (15 GW). However, the fuel-switching units generated only about 17% of the electricity produced. Both the petroleum only and natural gas only units generated larger shares of the electricity generated in proportion to their capacity.

Direct Seasonal Switching

Direct seasonal switching refers to individual units that switch from natural gas in the fall to petroleum in the winter regardless of price signals. We used the methodology explained before were used to estimate the size of this fraction of the total direct fuel switching. We analyzed the behavior of the 215 units that did exhibit fuel switching during the months of October 1999 and February 2000 were analyzed to determine the number of those units that switched regardless of relative price. Results indicate that 27 units or about 13% of the total, fuel switched in this earlier time period even though the relative fuel prices created an incentive to continue to burn natural gas (Figure 6). These seasonal switching units represented about 12% of capacity (4 GW) and about 6% of generation (0.3 billion kw-hrs).

Direct Switching: Distillate/Residual Oil Split

There are two important segments to the distillate/residual oil split. The first is the units, which switch seasonally. Although this segment constitutes only 4 GW, it is important in order to analyze seasonal demand and the associated price swings. Seasonal switching will tend to moderate seasonal price changes. The second segment of importance is fuel price sensitive switching units. This segment is important because it acts as a dampening mechanism on fuel price volatility. Traditionally it has been the principal backstop to rising natural gas prices. However, the results of this study indicate that the size of this segment is about 29 GW, much smaller than the advertised physical capacity.

The geographic distribution of seasonal switching capacity is presented in Figure 7. Capacity is a very relevant parameter for modelers because they need to know how much potential generation is available. Their modeling logic will make decisions about how to dispatch or utilize the capacity and how much fuel will be consumed in the process.

Figure 7 shows that the heavy oil seasonal switching capacity is located along the east coast with about 70% of the capacity situated in the Northeast. This is consistent with a view that in the northeast (particularly New England) limited natural gas pipeline capacity has historically forced utilities to switch away from natural gas in the winter months as residential/commercial heating load grew. Industrials tended to be on the margin, with some industrials capable of burning both natural gas and other fossil fuels. Older electricity generators (steam boilers) would switch to residual oil during these high demand periods. The remaining heavy oil capacity is situated in the southeast and Texas region.

The distillate seasonal switching capacity has a different distribution. About 50% of the capacity is located in the southeast with an additional 33% located in the east south central region. There was no seasonal switching to distillate in the northeast.

Figure 8 shows the distribution of the heavy oil price sensitive switching capacity. A majority of this capacity is situated on the east coast, about 60% of the nation wide total capacity. An additional 16% of the national total is located in the Texas region.

The distribution of distillate price sensitive switching capacity is more evenly distributed than that for the seasonal distillate switching capacity. About 34% of the capacity is located in the southeast region with additional significant amounts in other southern and mid-west regions. The northeast exhibits some switching, about 11% of the total.

This distribution indicates that the ability to respond to the extreme high prices varies from region to region. This is important from the perspective of basis differentials and how they might increase or decrease with changes in regional demand.

Indirect Switching

Due of its nature, indirect switching is a more difficult phenomenon to analyze. It is very difficult to identify the direct correspondence between the unit that is turned down and the unit that replaces it. As a result, the study looked at this phenomenon from a national level.

Total Indirect Switching

From Figure 3, we estimated that the amount of indirect switching which occurred during the 2000-2001 period was 5 billion kw-hrs. The indirect switching in this case consisted of switching from natural gas and hydropower to nuclear and coal.

Seasonal Indirect Switching

The study estimated the extent of seasonal indirect switching by analyzing the generation patterns in both the prior and later years. The analysis used the same months (October, February) as was used in the direct seasonal switching analysis.

The results were unexpected. During the 1999-2000 period, about 14 billion kw-hrs of indirect switching occurred (Figure 9). During the period 2001-2002, seasonal indirect switching represented about 9 billion kw-hrs of electricity generation (Figure 10). This was almost 2-3 times the amount for the 2000-2001 period.

This analysis indicates that seasonal indirect switching is an important phenomenon. Converting generation to a capacity equivalent indicates that between 20-60 GW converts on a seasonal basis independent of natural gas or petroleum prices. This is the same order and potentially larger than both the amount of seasonal and fuel price sensitive direct switching that occurred.

Conclusions

Based upon our analysis, approximately 29 GW of electricity generating capacity practices price sensitive direct switching between petroleum and natural gas. These units are capable of burning either fuel in the same units. The 17 GW of this capacity which fires distillate or natural gas, is primarily turbine-based technology. It is likely used for peaking and intermediate dispatch. The remaining 12 GW fires either residual fuel oil or natural gas. These units are steam boilers and some are advertised as also capable of burning distillate.

The 29 GW represents about 1/3 of the total number of units, which includes utility, non-utility generators and cogenerators that are nameplate advertised as capable of firing multiple fuels. The advertised units have a total nameplate capacity of 155 GW.

During the months studied, approximately 2.7 BCFD of natural gas demanded by these units switched to petroleum. This measure of loss in natural gas demand is very dependent upon the utilization of the units. The 2.7 BCFD is based upon actual historic monthly data. If one were to calculate the maximum potential daily demand for natural gas from 29 GW of capacity, the number would be much higher. For instance, assuming a heating rate of 10,000 Btu/kw-hr and 100% utilization, the maximum daily gas consumption yields about 7 BCFD.

In addition to the 29 GW, about 4 GW of capacity appears to switch seasonally between petroleum and natural gas. This seasonal switching occurs independent of price signals.

In addition, a segment of the electricity generation capacity exhibits indirect seasonal switching. This segment switches away from natural gas to either coal, nuclear, of hydropower during the winter season. Indirect switching appears driven by the availability of low variable cost power generation. For instance, in the case of hydropower drought is an important consideration. The extent of this indirect seasonal switching can vary from year to year based upon; extent of forced outages, routine maintenance schedules, and other factors. Indirect seasonal switching does not appear to be driven by relative oil/natural gas prices or absolute level of natural gas prices. The extent of indirect seasonal switching is significant. Our preliminary estimate is 20-60 GW of capacity. On the upper end, this represents twice the fuel price sensitive switching capacity. However the extent of indirect seasonal switching varies from year to year. Nevertheless, this indirect switching may have a larger impact on natural gas price volatility than direct switching between petroleum/natural gas.

Recommendations for Modelers

Modelers should allow for 29 GW of petroleum/natural gas fuel switching capacity. The regional and petroleum product breakout of this capacity is provided in Figure 8. In addition, for models with seasonal or monthly forecasting ability, allowances should be made for winter season switching regardless of relative petroleum/natural gas prices. Modelers should include allowances for 4 GW of oil/natural gas fired capacity to switch away from natural gas to petroleum in the winter season and build logic in their model which forces this switching to occur independent of pricing.

Also, for those models with seasonal or monthly forecasting capability, it is important to include logic, which varies the availability of non-petroleum/natural gas by season. It is important to allow a move away from petroleum/natural gas to other power generation technologies during the winter months independent of natural gas prices. This capacity should be between 20-60 GW.

Figure 1
Petroleum Natural Gas Price Differentials Indicate Alternating Periods When Petroleum or Natural Gas are Cost Advantaged

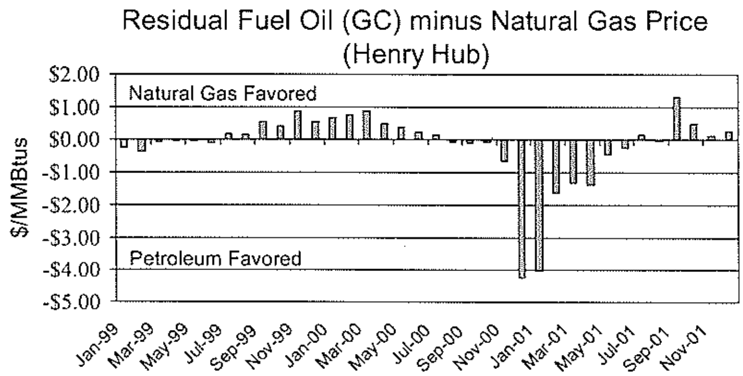

Figure 2
Important to Select Months in which Total Generation is about the Same

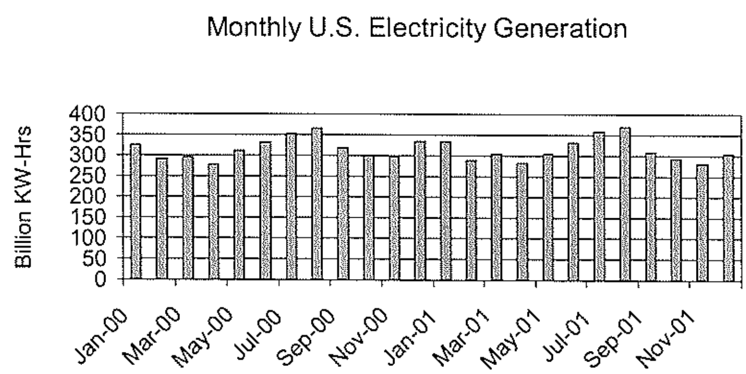

Figure 3
As Natural Gas Prices Increased, Generation Shifted Away from Natural Gas to Petroleum and Coal (Jun00 to Jan01)

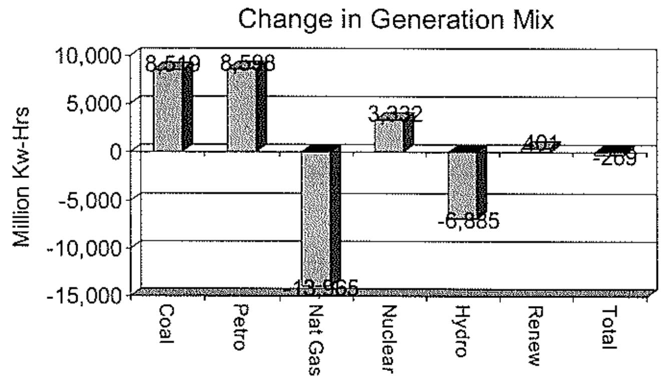

Figure 4
When Natural Gas Prices Fell, The Generation Returned to Natural Gas at the Expense of Petroleum and Coal (Jan01 to Sept01)

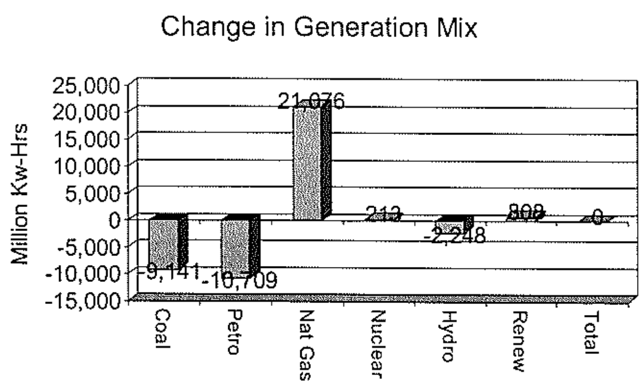

Figure 5
In Jan01 Only about 1/3 of the Units Designated Dual Fuel Capable Actually Switched from Natural Gas to Petroleum

Distribution of Dual Fuel Capable Units
(# of Units)

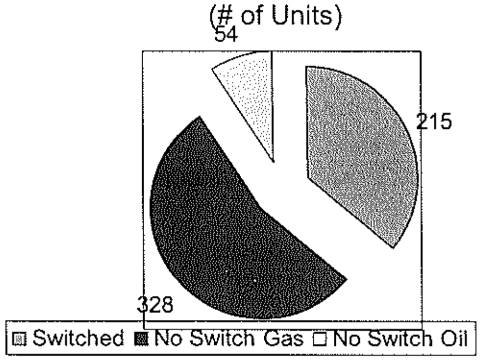

Figure 6
About 10% of the Dual Fuel Units Switched Seasonally Independent of Fuel Prices

Distribution of Units Exhibiting
Fuel Switching Behavior
(# of Units)

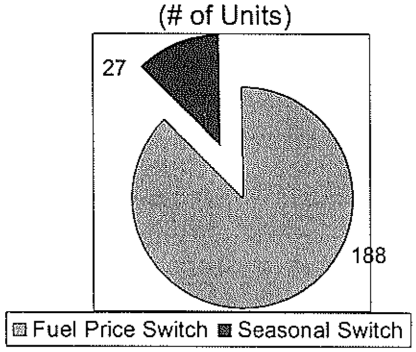

Figure 7
Regional Distribution for Seasonal Switching Oil/Natural Gas Units

	Light	Heavy
ME,VT,NH,MA,CT,RI	0%	16%
PA,NY,NJ	0%	52%
IL,IN,MI,OH,WI	10%	0%
IO,KN,MN,NE MO,ND,SD	2%	0%
DE,DC,GA,FL,MD NC,SC,VA,WV	54%	21%
AL,KN,MS,TN	33%	0%
AK,LA,OK,TX	0%	11%
AZ,ID,MT,NM UT,WY,NV	0%	0%
CA,OR,WA	0%	0%
Total GW	2.6	1.7

Figure 8
Regional Distribution for Fuel Price Sensitive Switching Oil/Natural Gas Units

	Light	Heavy
ME,VT,NH,MA,CT,RI	2%	2%
PA,NY,NJ	9%	34%
IL,IN,MI,OH,WI	11%	10%
IO,KN,MN,NE MO,ND,SD	12%	4%
DE,DC,GA,FL,MD NC,SC,VA,WV	34%	25%
AL,KN,MS,TN	14%	9%
AK,LA,OK,TX	16%	16%
AZ,ID,MT,NM UT,WY,NV	1%	0%
CA,OR,WA	2%	0%
Total GW	17	12

Figure 9
During 1999-2000, about 14 Billion Kw-Hrs Seasonally Switched (Oct99 to Feb00)

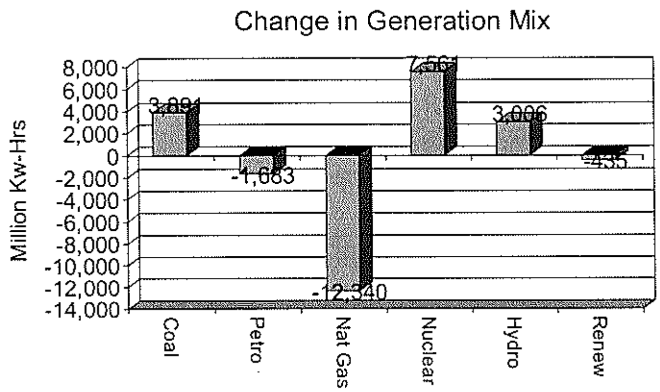

Figure 10
During 2001-2002, about 9 Billion Kw-Hrs Seasonally Switched (Oct01 to Feb02)