Northwest Power and Conservation Council

MARGINAL CARBON DIOXIDE PRODUCTION RATES OF THE NORTHWEST POWER SYSTEM

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SUMMARY

The cost of future carbon dioxide (CO_2) regulation is a significant factor in utility resource planning in the Pacific Northwest. Failure to properly account for this risk when evaluating resources can result in poor resource decisions and higher costs for the region's ratepayers.

One of the benefits of conservation is that it avoids CO_2 emissions.[1] The benefit it provides depends on what generating resources would be replaced and how much CO_2 they produce. This requires understanding what generating resources are on the margin; that is, the generation that could be displaced by the conservation. The marginal resource is the last resource brought on-line to supply power during a given time period (i.e., the highest variable cost resource available and needed during the period). In the Northwest, the average marginal CO_2 production is substantially higher than the average CO_2 production from all electricity generation. This is because hydroelectricity and wind, which have low operating costs and no CO_2 emissions are brought on-line before coal-fired or natural gas-fired generating units. Because only the marginal plants would be displaced by conservation, it would not be proper to use the average of CO_2 emissions from all power generation to estimate the CO_2 saved through conservation.

This paper evaluates what resources are on the margin in every hour and what the CO_2 reduction would be as a result of conservation. The analysis is an extension of the Council's recent interim wholesale power market price forecasts.[2] In the base case for that analysis, natural gas-fired combined-cycle plants are on the margin most of the time so conservation would avoid the CO_2 emission of a gas-fired combined-cycle power plant for most of the hours in a year. When the marginal CO_2 emissions for each hour are averaged over all of the hours in a year, the average of these hourly CO_2 emissions is about 0.8 pounds per kilowatt-hour. This increases the value of conservation by up to $5.60 per megawatt-hour (in constant 2006 dollars) under the base case CO_2 price assumption of $14 per ton in 2025.

The value of conservation can be significantly higher for measures, such as city street-lighting programs, that target load reduction during weekend nighttime hours. This is because coal-fired generation is typically the region's marginal resource during these low load hours. Since coal-fired generation has higher CO_2 emissions than natural gas combined-cycle plants, more CO_2 is displaced by each unit of conservation.

In addition to the Interim Base Case, this analysis tests two alternative assumptions about future resource costs. First it looks at a case of higher capital costs for generating resources, similar to recent experience. This case produced no change in the resources that were expected to be developed in the Northwest, but it did eliminate significant coal development in other parts of the West. Fewer coal resources reduce Westwide annual CO_2 production. Interestingly, the annual

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[1] Similarly, the value of other low-CO_2 resources including many types of demand response and most renewable resources should include the value of the CO_2 production displaced by the resource.
[2] The "Interim Wholesale Power Price Forecast" paper is available at: http://www.nwcouncil.org/library/2008/2008-05.pdf

CO_2 emissions in the Northwest increase since Northwest resources run more frequently to meet regional and Western loads. This is because fewer new resources are constructed in this high capital cost case. The increased use of Northwest resources means that coal-fired generation is used less often as the region's marginal resource. So, even though the region's annual CO_2 emissions increase, its marginal CO_2 production rate decreases to about 0.7 pounds of CO_2 per kilowatt-hour.

The second case adds higher CO_2 allowance prices (the possible future costs of CO_2 emissions) of $43 per ton of CO_2 beginning in 2012 to the high capital cost case. This results in much higher average marginal CO_2 emissions, up to 1.8 pounds per kilowatt-hour, and raises the value of conservation to as high as $38.00 per megawatt-hour. The high CO_2 prices increase the operating cost of coal plants more than they increase the operating cost of natural gas combined-cycle plants. This differential is enough to cause natural gas plants to be dispatched before coal-fired plants. With natural gas plants now operating first, coal plants are forced to the margin. This increases the region's average marginal CO_2 production rate and, therefore, the value of conservation to lower CO_2 emissions.

The other side of this change is that with higher CO_2 prices, natural gas-fired plants provide more baseload generation and therefore reduce the use of coal-fired generation as a share of total electricity production. As a result, total CO_2 emissions in this case are greatly reduced. Whereas, total CO_2 emissions in the region continued to grow in the Interim Base Case and the High Capital Cost Case, total CO_2 emissions are reduced to near or below 1990 levels in the High CO_2 Price Case. This is a direct result of the reduction in generation from existing coal-fired plants.

The effectiveness of the higher CO_2 prices in reducing CO_2 emissions appears to be very sensitive to fuel costs. At $43 per ton of CO_2, the variable cost of most existing coal plants is slightly higher than the variable cost of gas combined-cycle plants. However, any increase in the cost of natural gas would favor the dispatch of coal and return combined-cycle plants to the margin. A higher CO_2 price would be needed to restore coal to the margin. The Council intends to further explore this issue during development of the Sixth Power Plan.

Marginal Carbon Dioxide Production Rates of the Northwest Power System

INTRODUCTION

During any given hour of the year, there are numerous generating units supplying power to the Pacific Northwest power system. Some of these units will be hydroelectric units or wind generating units that do not emit CO_2 into the atmosphere. At the same time, some of these units will likely be coal-fired or natural gas-fired generating units that do emit CO_2 into the atmosphere. Each type of generating unit has a distinct rate at which it emits CO2. For example, a contemporary natural gas-fired combined cycle unit emits roughly 0.8 pounds (lbs.) of CO_2 per kilowatt-hour. A typical conventional coal-fired steam unit emits roughly 2.3 lbs. of CO_2 per kilowatt-hour.

One way to measure the CO_2 production rate of the Northwest Power system is to average the rates of all the generating units operating during a given time period. In this paper, we use the term, *average CO_2 production rate*, to refer to an average across *all resources* operating during a given time period.

Another way to measure the CO_2 production rate of a power system is to determine the CO_2 emissions rate of the last resource (or marginal resource) brought on-line to supply power during a given time period. In wholesale power markets, generating resources are typically brought on-line in the order of their operating costs. In other words, resources with low operating costs are used before resources with higher costs. In general, hydroelectric, nuclear and wind generating units will be brought on-line before coal-fired or natural gas-fired generating units. It is the CO_2 emissions of the marginal resource that can be avoided by adding energy-efficiency measures to the system.

This paper estimates the Pacific Northwest power system's marginal resource, and its CO_2 production rate, during each hour for four separate years: 2010, 2015, 2020, and 2025. Because there are typically 8,760 hours during a year, we summarize our results by providing *average marginal CO_2 production rates* for each year. In this paper, we use the term *average marginal CO_2 production rate* to refer to an average across *only the marginal resources* operating during a given time period.

The major findings and conclusions of this new analysis are:

- For the Northwest power system, with its large amount of hydroelectric, nuclear and wind generating resources, the *marginal CO_2 production rate* is considerably higher than the *average CO_2 production rate*. Power system planners and resource analysts should use the marginal CO_2 production rate to quantify and evaluate the ability of energy-efficiency and other resources with low CO_2 emissions to reduce emissions.

- Marginal CO_2 production rates for the Northwest power system, under our Interim Base Case assumptions, are forecast to range between 0.7 lbs. of CO_2 per kilowatt-hour (kWh) and 0.9 lbs. of CO_2 per kWh over the period 2010 through 2025.

- The region's average marginal rate of CO_2 production and its overall level of CO_2 production tend to move together, but in opposite directions. For example, under our combined High Capital Cost and High CO_2 Price Case assumptions, the region's marginal CO_2 production rate is forecast to jump as high as 1.8 lbs. of CO_2 per kWh. Carbon regulation, while decreasing overall CO_2 emissions, also increases the region's marginal CO_2 production rate since coal plants become the marginal resource.

- The type and amount of generating resources added to the Western power system outside our region influence the Pacific Northwest's CO_2 production. For example, although the Interim Base Case and the High Capital Cost Case forecasts have essentially the same resource mix for the Pacific Northwest, the High Capital Cost Case forecasts less overall new plant development, and no new conventional coal-fired plant development, in the Western power system over the planning period. This results in lower annual CO_2 emissions for the Western power system. At the same time, however, annual CO_2 production increases in the Pacific Northwest (and marginal CO_2 production rates decline) as Northwest resources are operated more intensely to meet loads both inside and outside the region.

METHODOLOGY

The methodology we use to estimate the Pacific Northwest power system's marginal resource is an extension of the modeling described in the Council's recent Interim Wholesale Power Price Forecast paper.[3] In this paper, we provide further analysis of two scenarios presented in the interim forecast paper: the Interim Base Case and the High Capital Cost Case. Each of these cases incorporates the same fuel price forecasts, estimates of the future costs of CO_2 allowance prices, and schedule of renewable resource additions to achieve state renewable portfolio standards. The only difference between these cases is the estimated costs of constructing new generating resources.[4] The Interim Base Case assumes construction costs from the "2006 Biennial Monitoring Report of the Fifth Power Plan." Since the release of the monitoring report, construction costs have increased significantly. The High Capital Cost Case was developed to better reflect current estimates of the future cost of building new generating resources and is being used in the preliminary studies for the Sixth Power Plan. We also present new results for a combined High Capital Cost/High CO_2 Price Case. The resource mix underlying each of these forecasts affects the choice of the marginal resource, and therefore, the marginal CO_2 production rate for the Pacific Northwest power system. These effects are discussed in the results section of this paper.

Council staff uses the AURORA$^{xmp®}$ Electric Market Model to develop its wholesale power price forecasts.[5] This model simulates hourly supply and demand to determine a marginal resource and market-clearing price for every hour of the simulation period for each of the load-resource zones in the model. The Council's configuration of AURORA^{xmp} uses 18 load-resource zones to represent the Western power system. The Pacific Northwest power system is

[3] The "Interim Wholesale Power Price Forecast" paper is available at: http://www.nwcouncil.org/library/2008/2008-05.pdf
[4] For a description of our current estimates of new resource capital costs see the "Interim Wholesale Power Price Forecast" paper (pp. 10-13).
[5] Available from EPIS, Inc. (www.epis.com).

represented by 6 of these zones.[6] Therefore, for each hour of a simulation period, AURORA^{xmp} identifies 6 marginal resources for the Pacific Northwest, one for each zone.[7]

In order to identify a single Pacific Northwest marginal resource, and marginal CO_2 production rate, for each hour of the simulation period, Council staff conducted additional analysis on the AURORA^{xmp} hourly output databases. The hourly output databases contain statistics summarizing the simulated operation of each generating unit located in the Pacific Northwest.[8] Staff performed a series of filtering steps to arrive at a single marginal resource for each hour. First, staff removed any units considered to be must-run resources. Must-run resources are those that are operated regardless of wholesale power market prices. For the Northwest, must-run resources include: wind plants, municipal solid waste facilities, industrial co-generation facilities, geothermal steam plants, and landfill gas energy recovery and other biogas facilities. Second, for each hour, any unit that did not generate electricity was removed from consideration. Finally, of the remaining units, the unit with the highest dispatch cost was selected as the region's marginal resource for each hour.[9] This process resulted in a single marginal resource for the Pacific Northwest for each hour of the simulation period.[10]

This methodology for identifying the region's marginal resource is analogous to the resource stacking approach depicted in Figure 1. The figure is a snapshot of our forecast of the region's supply and demand during the peak hour of demand in 2020.[11] The vertical axis of the figure is dispatch cost--the cost that can be avoided by curtailing operation of a resource. For any resource, the dispatch cost comprises the variable operating and maintenance costs (including integration costs for intermittent resources), variable fuel cost, CO_2 allowance cost, any unit cycling premium, and a dispatch premium representing the "profit" over cost demanded by a plant owner to dispatch the resource.

The horizontal axis represents cumulative generating capability for the hour. The supply curve for this hour starts with the region's lowest-cost resource, hydroelectric generation, and adds supply in order of increasing dispatch cost. The forecast demand for electricity in this hour is 38,081 megawatts, shown as the vertical black line. The region's marginal resource for this hour is the generating unit that is situated at the intersection of the region's supply and demand curves.

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[6] The Pacific Northwest zones are identified as PNW Westside North, PNW Westside South, PNW Eastside North, PNW Eastside South, Idaho South, and Montana East.

[7] This is equivalent to 52,560 marginal resources in the Pacific Northwest on an annual basis (8,760 hours * 6 load-resource zones = 52,560 marginal resources).

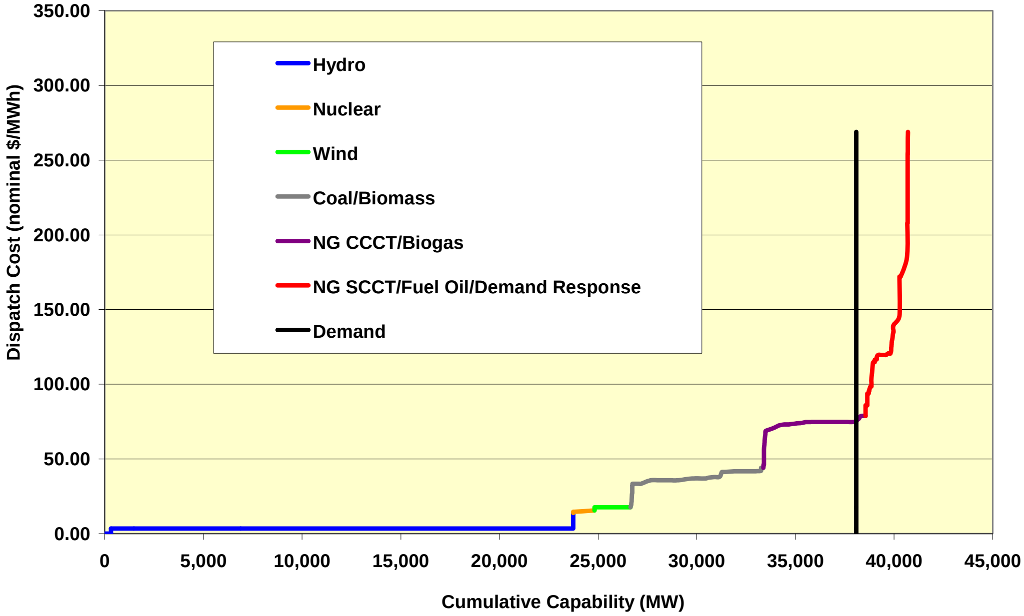
[8] The annual databases contain roughly 7.4 million records (844 generating units * 8,760 hours = 7.4 million records)

[9] If two or more units tied for the highest dispatch cost in an hour, the unit operating farthest from its maximum capability (or closest to its minimum capacity) was chosen as the marginal resource.

[10] For an annual simulation period, this results 8,760 marginal resources in the Pacific Northwest.

[11] The snapshot shown is for hour ending 7:00 P.M. on January 15, 2020.

Figure 1: Illustration of the marginal resource selection methodology (High Capital Cost Case)



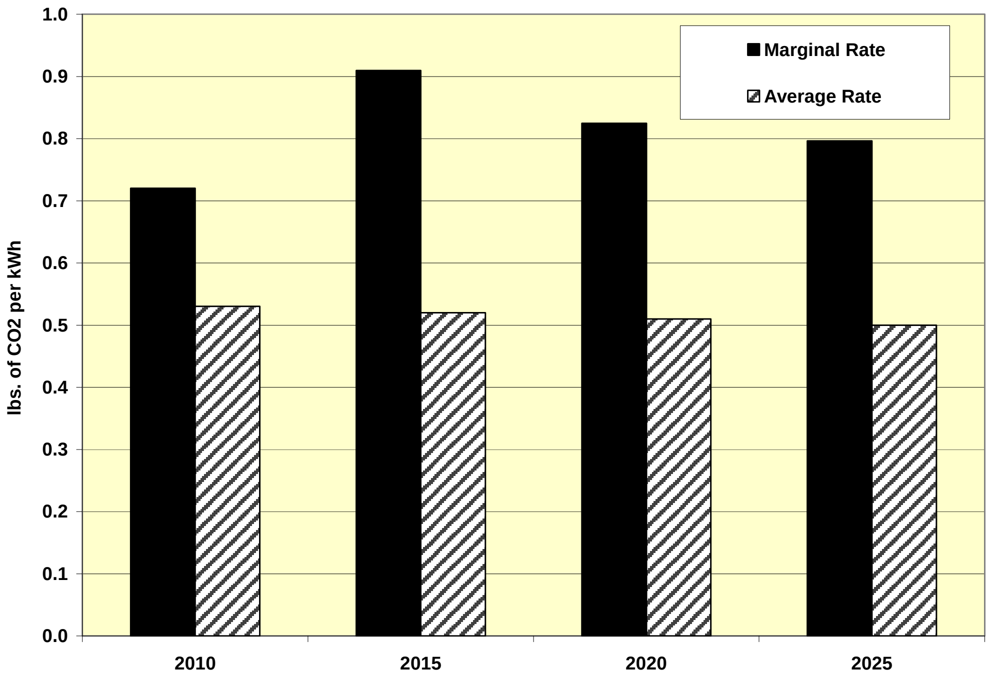
The region's marginal resource will change not only from season to season as the region's water supply, loads, fuel prices, and resource availability varies, but also from hour to hour as demand changes. The filtering methodology described in the previous paragraph is roughly analogous to performing this resources stacking for each hour of the forecast year.

RESULTS

Interim Base Case

For the Northwest power system, with its large amount of hydroelectric, nuclear and wind generating resources, the *marginal CO_2 production rate* is considerably higher than the *average CO_2 production rate*. Figure 2 compares these two rates for the Interim Base Case.

Figure 2: Northwest marginal and average CO_2 production rates (Interim Base Case)



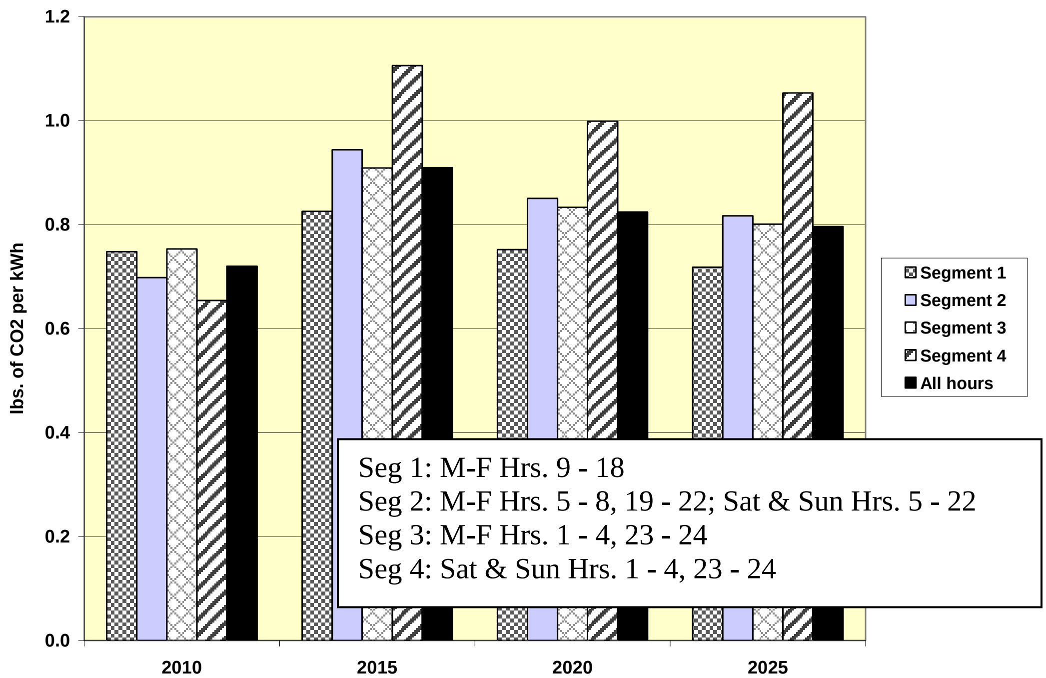
Power system planners and resource analysts should use the marginal CO_2 production rates to evaluate the CO_2 cost associated with future purchases of power from the wholesale power market and the relative benefits of energy-efficiency measures and other resources with lower CO_2 emissions. For example, given the Council's current interim forecast of future CO_2 emissions prices (i.e., \$11.12 per ton in 2015, \$12.55 per ton in 2020, and \$14.15 per ton in 2025), the estimated CO_2 cost included in future purchases from the wholesale power market would be \$5.06 per megawatt-hour (MWh) in 2015, \$5.17 per MWh in 2020, and \$5.63 per MWh in 2025.[12]

Marginal CO_2 emission rates (pounds of CO_2 per kWh) vary by time of day and day of week because the marginal generating resource changes with load. Gas-fired power plants with relatively high variable costs are typically on the margin during heavier load hours, whereas coal-fired plants with lower variable costs can be on the margin during nighttime and weekend light load hours. Therefore, both the physical quantity, and dollar value, of avoided CO_2 emissions vary with time. The Council and the Regional Technical Forum use four load

[12] The calculation of the market CO_2 cost in 2015 is: (0.9 lbs. of CO_2 per kWh) / (2000 lbs. per ton) * (1000 kWh per MWh) * (\$11.12 per ton of CO_2).

segments to assess the cost-effectiveness of conservation measures. Figure 3 shows the average marginal CO_2 emission rates for the four segments for the four future years.

Figure 3: Northwest marginal CO_2 production rates by load segment (Interim Base Case)

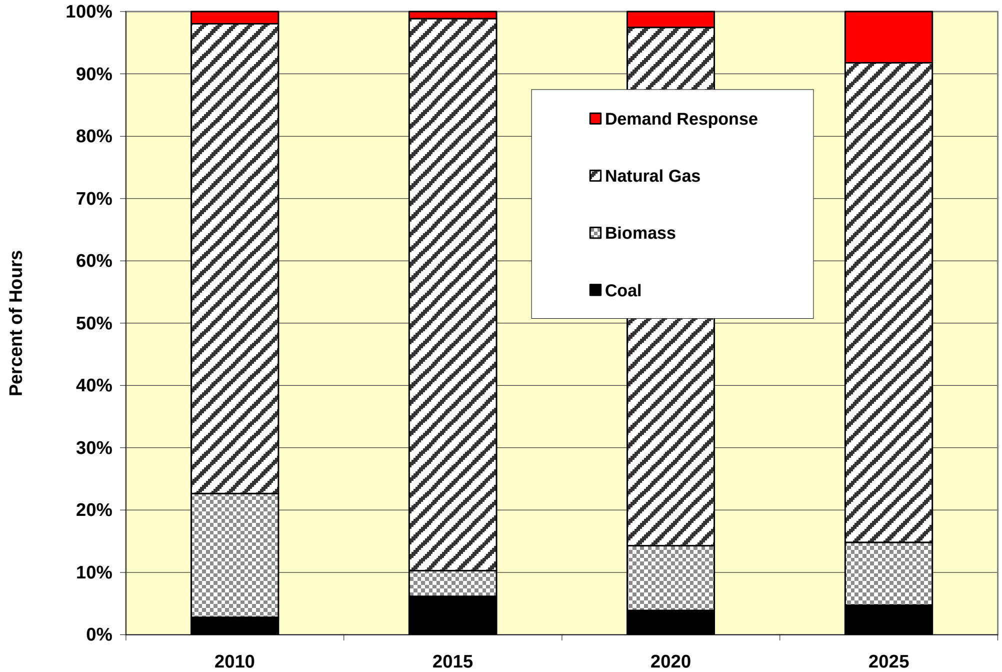


The pronounced increase in the marginal CO_2 production rate during weekend nighttime hours (i.e., during Segment 4 hours) is due to coal-fired units being the marginal resource during these low-load hours. This is consistent with the recent and expected addition of significant amounts of wind generation to the Northwest power system, which pushes coal-fired resources up toward the margin.[13] After 2015, there is a slight downward trend in the Northwest's marginal CO_2 production rates. This downward trend reflects the changing fuel mix of the region's marginal resources over time.

Figure 4 shows the percentage of hours in each year that resources of various fuel types are on the margin. The percentage of hours that coal-fired resources are the marginal resource declines from 6.2 percent in 2015 to 4.7 percent in 2025. As regional loads continue to grow, there is also an increase in the number of high load hours during which demand response is the region's marginal resource. Both of these changes have the effect of lowering the region's marginal CO_2 production rates.

[13] An open issue at this time is whether the coal-fired resources operating at the margin during these light load hours can provide the operational flexibility needed to integrate intermittent resources into the power system.

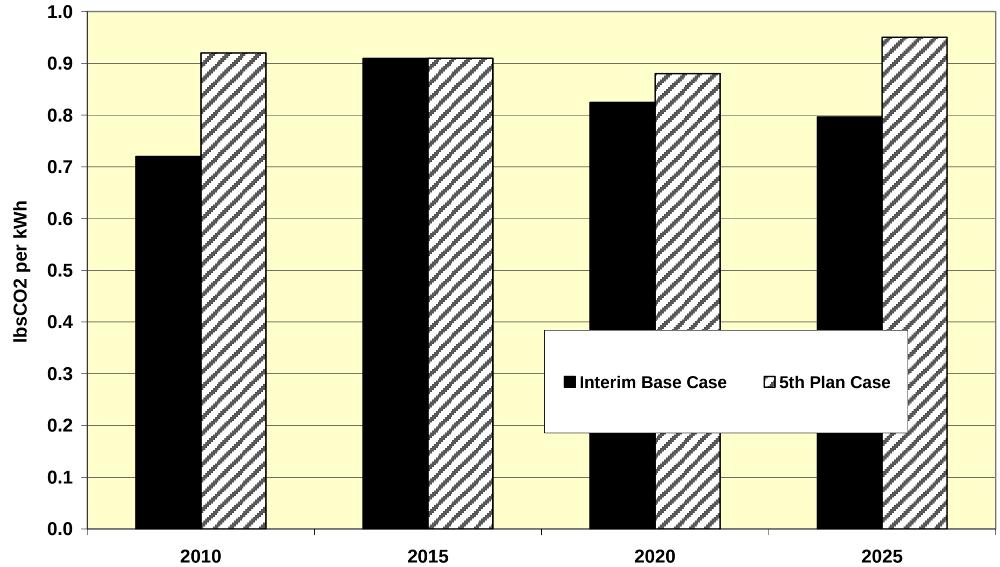
Figure 4: Percentage of hours resources of various fuel types are the marginal resource (Interim Base Case)



The low percentage of hours that coal-fired resources are the region's marginal resource is a significant change from the Council's previous forecast of the marginal rate of CO_2 production in April, 2006.[14] At that time, coal-fired resources were forecast to be the marginal resource in 16 percent of the hours in 2010, declining to 12 percent of the hours in 2025. This difference in marginal resource mix is evident in a comparison of the two forecasts of marginal CO_2 production rates (see Figure 5).

[14] Staff presented, "Power System Marginal CO_2 Production Factors" to the Council's Power Committee on April 11, 2006, in Whitefish, Montana.

Figure 5: Comparison of marginal CO_2 production rates (Interim Base Case vs. 5th Plan Case)



The decrease in coal-fired generation on the margin can be partly attributed to the improved methodology for selecting the region's marginal resource.[15] However, this difference is also partly explained by differences in forecast assumptions and the forecast, or recommended, resource mix for the Pacific Northwest. For example, the Interim Base Case uses higher CO_2 allowance prices than the 5th Plan Case.

It is important to place the declining trend in the Northwest power system's marginal CO_2 production rates, and the underlying changes in its marginal resource mix, within the wider context of the overall power system CO_2 production. In the Interim Base Case, Northwest power system CO_2 emissions are forecast to total 57 million tons in 2010, and to increase to 61 million tons in 2025. For comparison, we previously estimated that the Northwest power system's CO_2 production was 44 million tons in 1990 and that it would have been 57 million tons in 2005 (had normal hydro conditions prevailed).[16] Figure 6 shows our CO_2 emissions forecasts for the Northwest power system under the three future scenarios discussed in this paper.

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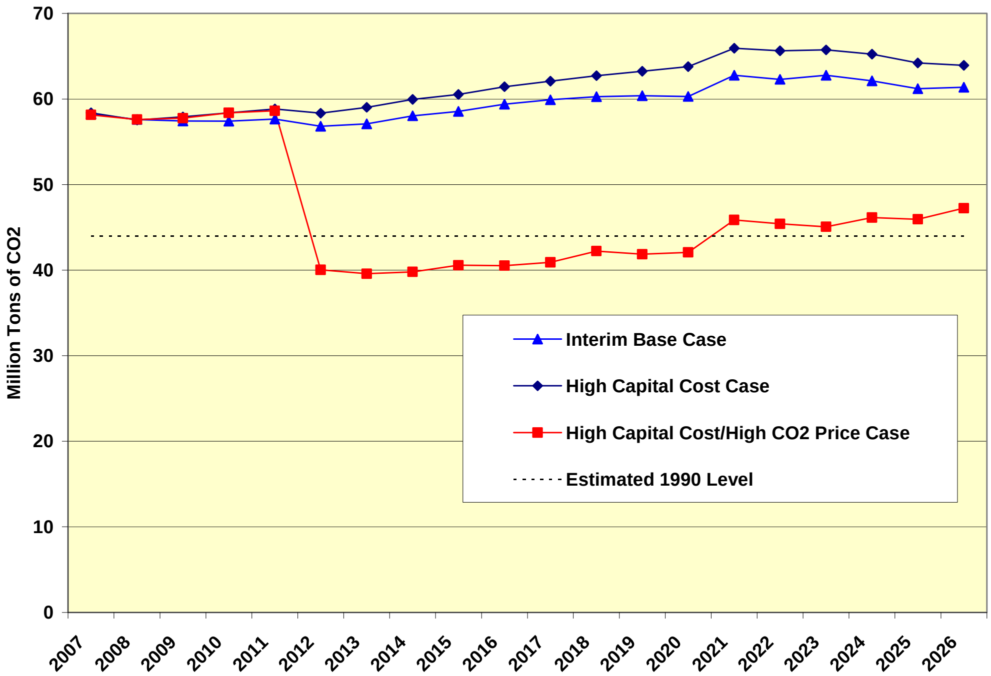
[15] The previous methodology selected a single regional marginal resource during each hour of the year by starting with the units that AURORA[xmp] identified as the marginal resource in each of the six Northwest load-resource zones. Starting with only one resource in a load-resource zone, and then removing it from further consideration if it is a must-run resource, has the effect of removing all the resources in that zone from consideration as the region's marginal resource. In some hours, this method could erroneously select an intra-marginal resource as the region's marginal resource. The prior method had the potential to overstate the occurrence of coal-fired units and hydroelectric units as the region's marginal resource. The methodology presented in this paper avoids this problem by starting with all of the generating units dedicated to serving loads in the Pacific Northwest.

[16] We also estimated that with implementation of the recommended resource portfolio of the 5th Power Plan, CO_2 emissions would total 67 million tons in 2024. These estimates are from the Council's paper titled, "Carbon Dioxide Footprint of the Northwest Power System." This paper is available at: http://www.nwcouncil.org/library/2007/2007-15.htm

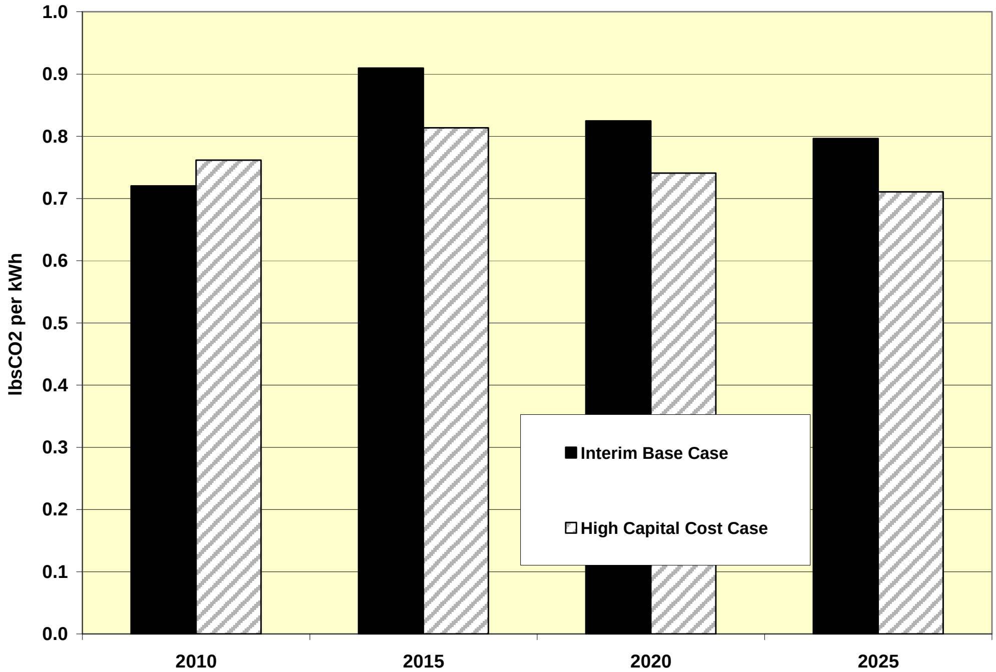
Figure 6: Forecasts of the Northwest power system's CO_2 emissions



High Capital Cost Case

It is also important to describe the sensitivity of our results to changes in key input assumptions. Figure 7 shows the effect of our revised forecast construction costs for new generating resources on marginal CO_2 production rates. The higher construction costs in the High Capital Cost case reduce the level of forecast resource additions in other regions of the West. This leads to more intense use of power resources in the Pacific Northwest, and to lower marginal CO_2 production rates.

Figure 7: Comparison of marginal CO_2 production rates (High Capital Cost Case and Interim Base Case)



The portfolio of Northwest generating resources is essentially the same in both the High Capital Cost Case and Interim Base Case. In both cases, Northwest generating resources consist of existing resources and the forecast addition of renewable resources to meet state renewable portfolio standards. The reduction in marginal CO_2 production in the Northwest is primarily driven by a change in the amount and type of new resources added to meet load in areas outside of the Northwest. The High Capital Cost Case results in more new natural gas-fired resources and fewer new coal-fired resources being added to the Western power system over the planning period.[17] This change in incremental resource mix results in Northwest resources being dispatched more often to serve loads, both inside and outside the region. This increase in the dispatch of regional resources increases the occurrence of natural gas-fired resources on the margin and reduces the Northwest's marginal CO_2 production rates.

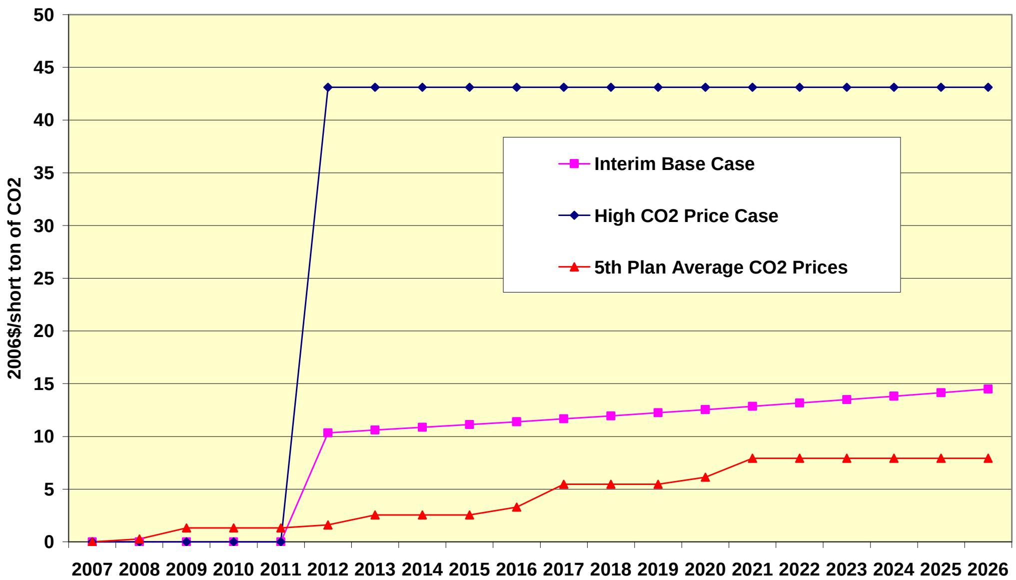
The increased utilization of the Northwest's resources also leads to higher total CO_2 production in the Northwest (see Figure 6). For example, total Northwest CO_2 production is 64 million tons in 2025 in the High Capital Cost Case compared to 61 million tons in 2025 in the Interim Base Case. However, from the perspective of the interconnected-West, the higher resource use in the Northwest contributes to the reduction in total Western CO_2 production to 461 million tons in 2025 in the High Capital Cost Case from 519 million tons in the Interim Base Case.[18]

[17] See "Interim Wholesale Power Price Forecast" paper, p. 26, for a detail description of this change in incremental resource mix.
[18] See "Interim Wholesale Power Price Forecast" paper, p. 24, for a detail description of annual Western Electricity Coordinating Council (WECC) CO_2 production.

Combined High Capital Cost and High CO_2 Price Case

The following figure shows the difference between the CO_2 allowance prices used in the Interim Base Case (and High Capital Cost Case), and the higher CO_2 allowance prices used in the High Capital Cost/High CO_2 Price case.[19] It also shows the average of the 750 possible future trajectories of CO_2 emissions prices used in the Fifth Power Plan.

Figure 8: Base and high CO_2 emission prices

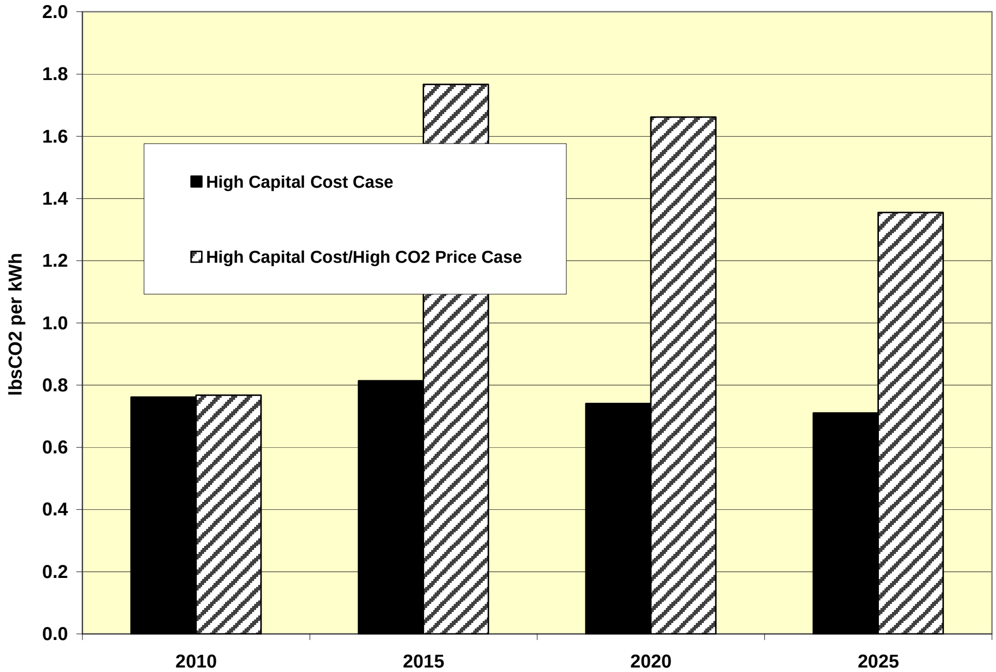


The higher CO_2 emissions prices used in the High Capital Cost/High CO_2 Price Case significantly reduce the forecast annual CO_2 production of the Western power system. Forecast Westwide CO_2 production drops from 461 million tons in the High Capital Cost Case to 384 million tons in the High Capital Cost/High CO_2 Price Case. The higher CO_2 emissions prices also drive a dramatic decline in the forecast of annual CO_2 production from the Northwest power system (see Figure 6).[20]

The higher CO_2 prices also have a significant effect on the forecast of the Northwest's marginal CO_2 production rates. These marginal rates are dramatically higher (see Figure 8). This increase occurs because the higher CO_2 prices drive heavy CO_2 producing resources to the less frequently dispatched end of the region's supply curve and puts them on the margin during more hours of the year.

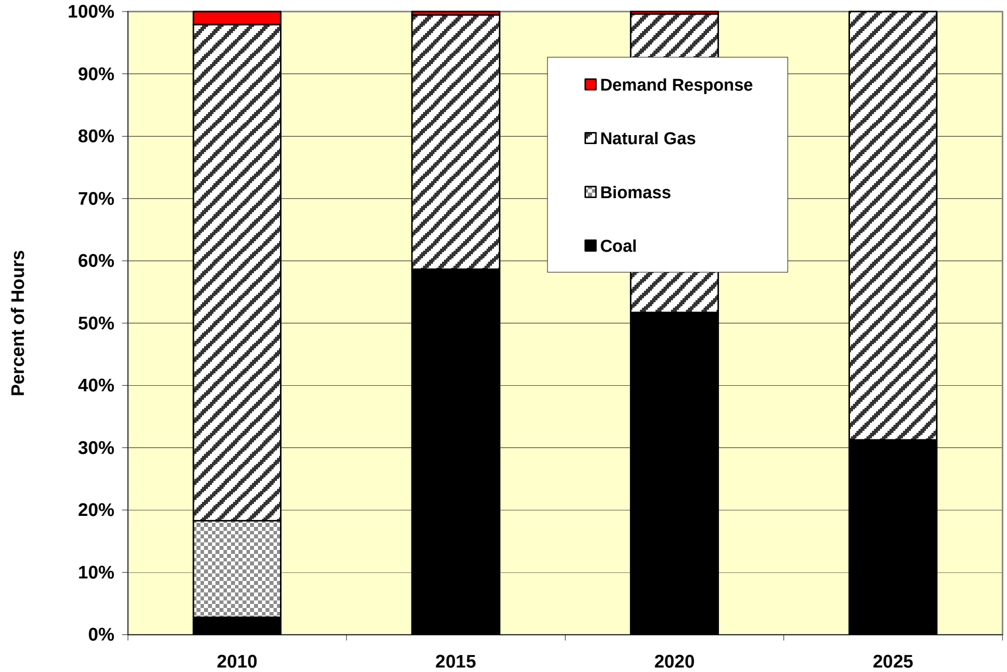
[19] For a description of the rationale underlying our CO_2 emission price assumptions see the "Interim Wholesale Power Price Forecast" paper (pp. 8-10).
[20] The higher CO_2 emissions prices result in 1,200 megawatts (MW) of new wind resources being added to the Northwest power system over the planning period (i.e., 500 MW in 2016, 200 MW in 2024, and 500 MW in 2025). This is installed wind capacity above the amount forecast to be added to meet state renewable portfolio standards.

Figure 8: Comparison of marginal CO_2 production rates (High Capital Cost Case vs. High Capital Cost/High CO_2 Price Case)



Under the High Capital Cost/High CO_2 Price Case assumptions, coal-fired resources are the marginal resource during 59 percent of the hours in 2010, 52 percent of the hours in 2015, and 31 percent of the hours during 2025. Figure 9 shows the increased role of coal as a marginal resource mix for this sensitivity case, compared to the base case shown in Figure 4.

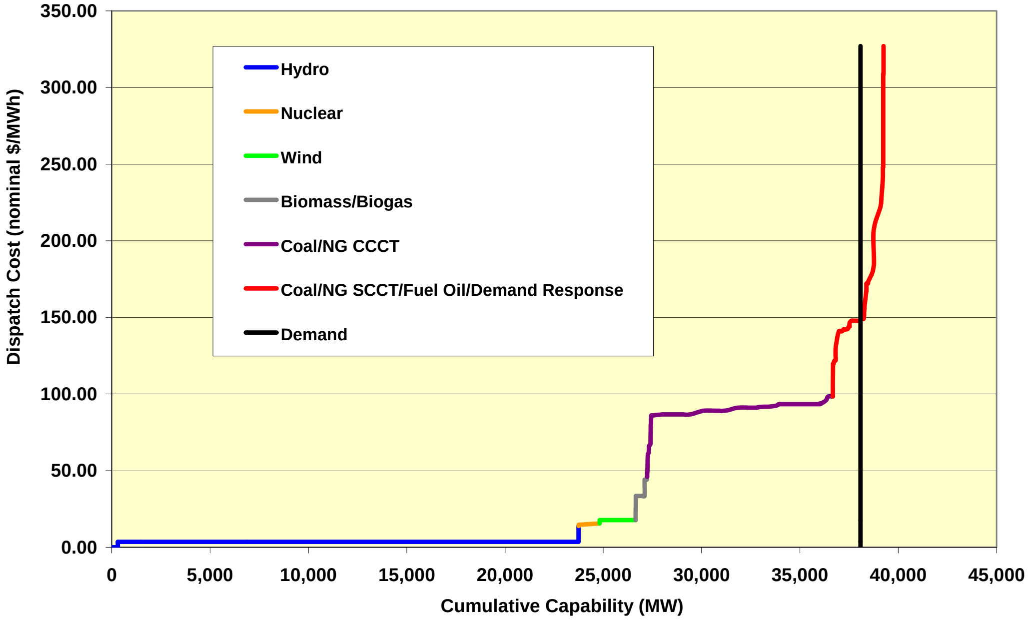
Figure 9: Percentage of hours resources of various fuel types are the marginal resource (High Capital Cost/High CO_2 Price Case)



Again, stated differently, the increase in the percentage of hours that the Northwest's coal-fired resources are on the margin is due to their higher dispatch cost because of emission charges. Their dispatch cost increases to, and in some cases surpasses, the dispatch cost of the Northwest's natural gas-fired combined cycle units. This "leveling" effect of the higher CO_2 emission prices is illustrated in the following snapshot of the region's supply and demand during the peak hour of demand in 2020.[21]

[21] The snapshot shown is for hour ending 7:00 P.M. on January 15, 2020.

Figure 10: Illustration of the change in the regional supply curve (High Capital Cost/High CO_2 Price Case)[22]



With high CO_2 emissions prices, most of the region's coal-fired units move up to share the same relative position on the region's supply curve with natural gas-fired combined cycle units (some of the less efficient coal-fired units move beyond this level to mix with natural gas-fired simple cycle units and other "peaking" resources). This leveling of the costs of coal-fired generation and natural gas-fired generation creates a "high plateau" in the region's supply curve near $90 per MWh. A quick comparison of Figure 10 and Figure 1 also highlights this effect. The resources lying along this plateau would likely clear the market during many hours of the year.

This analysis confirms that high CO_2 emission prices can drive significant reductions in total CO_2 emissions, both Westwide and in the Pacific Northwest. The analysis also shows that high CO_2 emissions prices increase the region's marginal rate of CO_2 production, and therefore, likely increase the value of energy-efficiency measures that reduce CO_2 emissions.

CONCLUSION

This paper forecasts the marginal CO_2 production rates for the Pacific Northwest power system to be between 0.7 lbs. per kilowatt-hour and 0.9 lbs. per kilowatt-hour for the period 2010 through 2025, under interim base case assumptions. The Council and the Regional Technical Forum can use these marginal CO_2 production rates to quantify the value of CO_2 emissions avoided by conservation and to evaluate the cost-effectiveness of energy-efficiency measures and other resources with lower CO_2 emission rates. These marginal CO_2 production rates are

[22] Coal purposefully appears in two places on the legend. With high CO_2 emissions prices most of the Northwest's coal units have dispatch costs similar to natural gas-fired combined cycle combustion turbines (NG CCCT), however, some of the less efficient coal units have even higher dispatch costs, similar to natural gas-fired simple cycle combustion turbines (NG SCCT) and other peaking resources.

very sensitive to changes in the future regulation, and cost, of CO_2 emissions. Because of this sensitivity, the marginal CO_2 production rates may change significantly if the assumptions regarding CO_2 allowance prices change during development of the Sixth Power Plan.

The effectiveness of the higher CO_2 prices in reducing CO_2 emissions also appears to be very sensitive to fuel costs. At $43 per ton of CO_2, the variable cost of most existing coal plants is slightly higher than the variable cost of gas combined-cycle plants. However, any increase in the cost of natural gas would favor the dispatch of coal and return combined-cycle plants to the margin. A higher CO_2 price would be needed to restore coal to the margin. The Council intends to further explore this issue during development of the Sixth Power Plan.

Sensitivity to Higher Natural Gas Price Assumptions

Addendum to Marginal Carbon Dioxide Production Rates of the Northwest Power System

SUMMARY

An important result presented in the Council's paper, "Marginal Carbon Dioxide Production Rates of the Northwest Power System," indicated that with carbon dioxide (CO_2) allowance prices of $43 per ton the Northwest power system's annual CO_2 emissions could be reduced to its1990 level. This result was achieved at the Council's medium fuel price forecast.

Results presented in this addendum indicate that:

- With the Council's high fuel price forecast the $43 per ton CO_2 allowance price assumption fails to produce the same dramatic reduction in annual CO_2 emissions that were shown for the medium fuel price forecast.

- With the Council's high fuel price forecast CO_2 allowance prices would need to increase to nearly $70 per ton in order to achieve annual reductions in CO_2 emissions similar to those achieved under the medium fuel price forecast.

INTRODUCTION

An important modeling result presented in the Council's paper, "Marginal Carbon Dioxide Production Rates of the Northwest Power System," is that the Northwest power system's annual carbon dioxide (CO_2) emissions can be driven below its 1990 level with CO_2 allowance prices of $43 per ton of CO_2 (in constant 2006 dollars). This CO_2 allowance cost would bring about a significant reduction in annual emissions by changing the dispatch order of coal-fired and natural gas-fired generating units. Coal-fired units would become more costly to operate than natural gas-fired units and would dispatch to meet load less often. The reduced operation of coal-fired units would lower the Northwest power system's annual CO_2 emissions.

The result presented in the marginal CO_2 assessment was achieved at the Council's medium fuel price forecast. Higher natural gas prices would be expected to increase the CO_2 allowance prices required to change the dispatch order of coal-fired and natural gas-fired plants. This addendum examines how higher fuel prices might affect this result. How sensitive is the modeled reduction in annual CO_2 emissions to increased natural gas prices? With high fuel prices how high would CO_2 allowance prices need to climb in order to reduce the Northwest power system's annual CO_2 emission to its 1990 level?

METHODOLOGY

The High Capital Cost/High CO_2 Price Case presented in the "Marginal Carbon Dioxide Production Rates of the Northwest Power System" paper serves as the reference case for the analysis presented in this addendum. This case serves as the point of reference because it showed that with CO_2 allowance prices of $43 per ton the region's annual total CO_2 emissions could be reduced to its 1990 level. For ease of reference, we refer to this case as the Medium Fuel/$43 CO_2 Price Case in this addendum.

In this addendum, we also model three high fuel price sensitivity cases. This modeling is an extension of the modeling presented in the Council's recent "Interim Wholesale Power Price Forecast" paper.[23]

The first sensitivity case is a combined high fuel price and $43 per ton CO_2 allowance price case (referred to as the High Fuel/$43 CO_2 Price Case). This case is designed to test the sensitivity of the modeled reduction in the Northwest power system's annual total CO_2 emissions to high fuel prices.

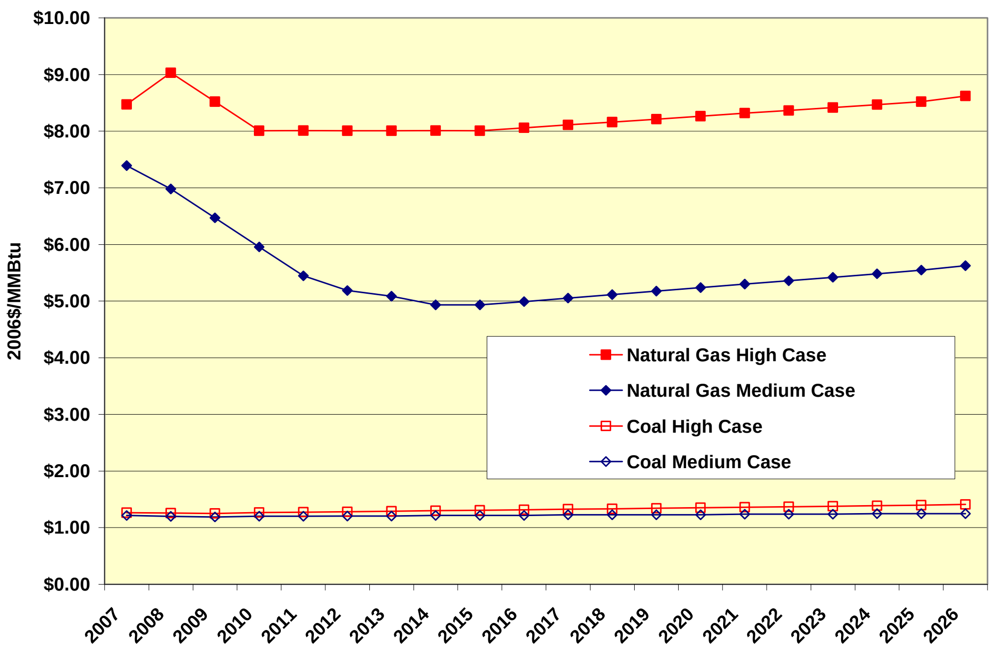
The second sensitivity case is a combined high fuel price and $70 per ton CO_2 allowance price case. This is an intermediate case. The only difference between this case and the first sensitivity case is that the CO_2 allowances prices are increased to $70 per ton (in 2006 dollars). Importantly, the forecast resource mix of the Western power system is held constant in this sensitivity case. The $70 per ton CO_2 allowance price was determined to be the level needed to drive the forecast of the Northwest power system's annual CO_2 emissions below its 1990 level. We refer to this case as the High Fuel/$70 CO_2 Price/Fixed Mix Case.

The third sensitivity case expands on the second sensitivity case by using the AURORA^{xmp} model to forecast a new incremental resource expansion for the Western power system under the $70 per ton CO_2 allowance price assumption. In other words, the underlying resource mix is allowed to change in response to the increased forecast of CO_2 emissions costs. We refer to this case as the High Fuel/$70 CO_2 Price/New Mix Case.

The Council's current set of fuel price forecasts were developed in the summer of 2007.[24] The low, medium-low, medium, medium-high, and high fuel price forecasts cover a wide range of possible future price trends. Figure 1 compares the medium and high price forecasts for natural gas and coal delivered to electricity generators located in the western load-resource zones of the Pacific Northwest. For natural gas, the high price forecast is approximately $3 per million British thermal units (MMBtu) higher than the medium price forecast over most of the planning period.

[23] The "Interim Wholesale Power Price Forecast" paper available at: http://www.nwcouncil.org/library/2008/2008-05.htm
[24] The "Revised Fuel Price Forecasts" paper is available at: http://www.nwcouncil.org/library/2007/2007-14.htm

Figure 1: Comparison of medium and high fuel price forecasts



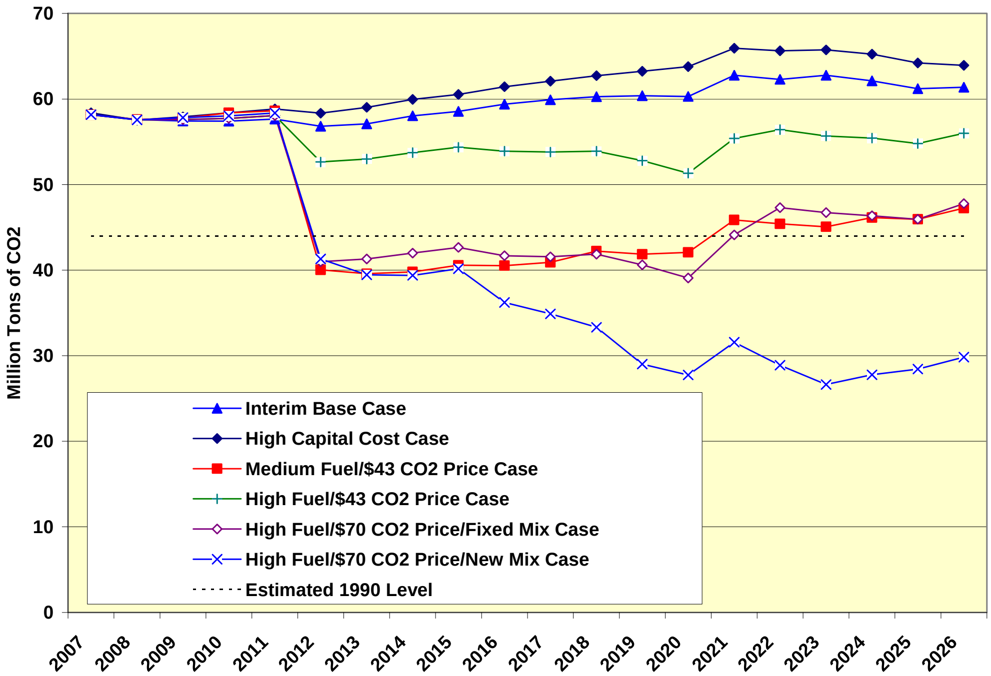
RESULTS

Figure 2 shows the Northwest power system's annual total CO_2 emissions for the reference case and the three high fuel price sensitivity cases. For continuity with the "Marginal Carbon Dioxide Production Rates of the Northwest Power System" paper, it also shows the annual total CO_2 emissions for the Interim Base Case and High Capital Cost Case of that paper.[25]

In the reference case the significant reduction in annual total CO_2 emissions is driven by a switch in the dispatch order of coal-fired and natural gas-fired resources.[26] The results of the High Fuel/$43 CO_2 Price Case show that this reduction in total emissions is sensitive to high natural gas prices. While some reduction in CO_2 emissions is achieved, with natural gas prices in the $8 to $9 per MMBtu range the $43 per ton CO_2 allowance price fails to reduce CO_2 emissions to the 1990 level. This is because the higher cost of natural gas favors the dispatch of coal-fired generating resources. With the higher natural gas prices the $43 per ton CO_2 emission cost is not sufficient to move coal-fired generation to the margin during a significant number of hours each year.

[25] See Figure 6, p. 11, in the "Marginal Carbon Dioxide Production Rates of the Northwest Power System" paper.
[26] See the "Marginal Carbon Dioxide Production Rates of the Northwest Power System" paper (pp. 7 - 16).

Figure 2: Forecasts of the Northwest power system's total CO_2 emissions

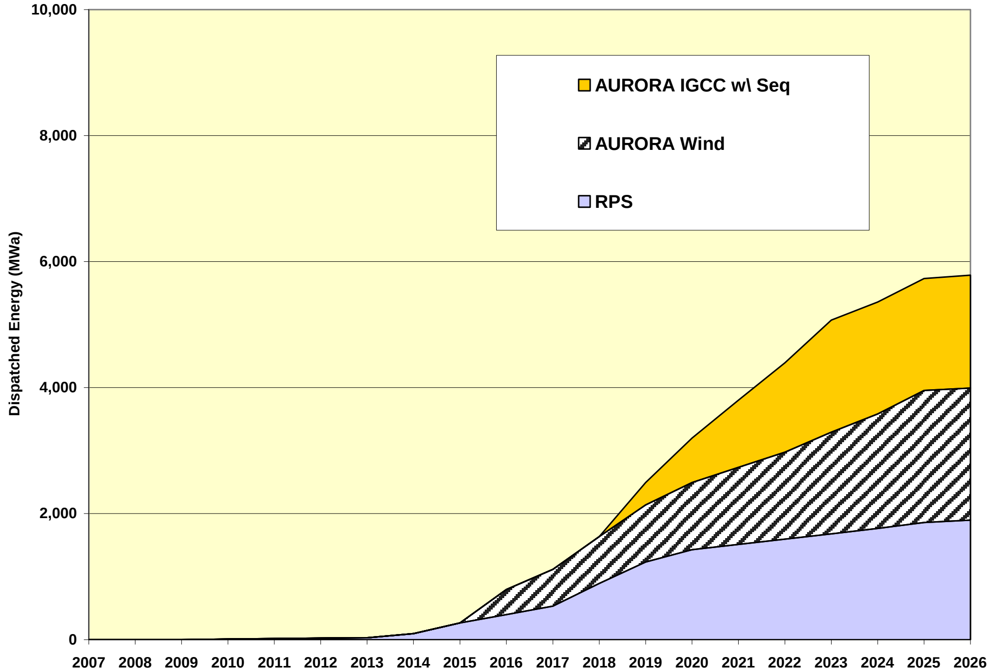


The results for the High Fuel/$70 CO_2 Price /Fixed Mix Case show that under the Council's high fuel price assumptions the price of CO_2 emissions allowances would need to climb to as high as $70 per ton of CO_2 in order for the Northwest power system to reach its 1990 level of CO_2 production with the resource mix of the reference case. The high natural gas prices work against efforts to reduce Northwest CO_2 emissions by forcing the cost of CO_2 allowance prices to climb in order to achieve the same targeted reduction in emissions.

The results for the High Fuel/$70 CO_2 Price /New Mix Case easily achieve 1990 levels of CO_2 emissions and show a continued decline in annual total CO_2 emissions after 2015. This is because additional wind generation (beyond Renewable Portfolio Standard requirements) and integrated gasification combined cycle (IGCC) generation with carbon capture and sequestration become economic additions to the power system. In addition, two large coal-fired generating units, Boardman and Valmy 1, become uneconomic to operate under these assumptions and are and retired in 2013 and 2020 respectively.[27] Figure 3 shows the energy output of the incremental resources added to the Northwest power system over the planning period. The continuing decline of CO_2 emissions observed in this case suggest that over the long-term, CO_2 allowance prices of less than $70 per ton of CO_2 may be sufficient to maintain emissions below 1990 levels, even with high natural gas prices.

[27] The Boardman unit is also retired in the reference case in 2012.

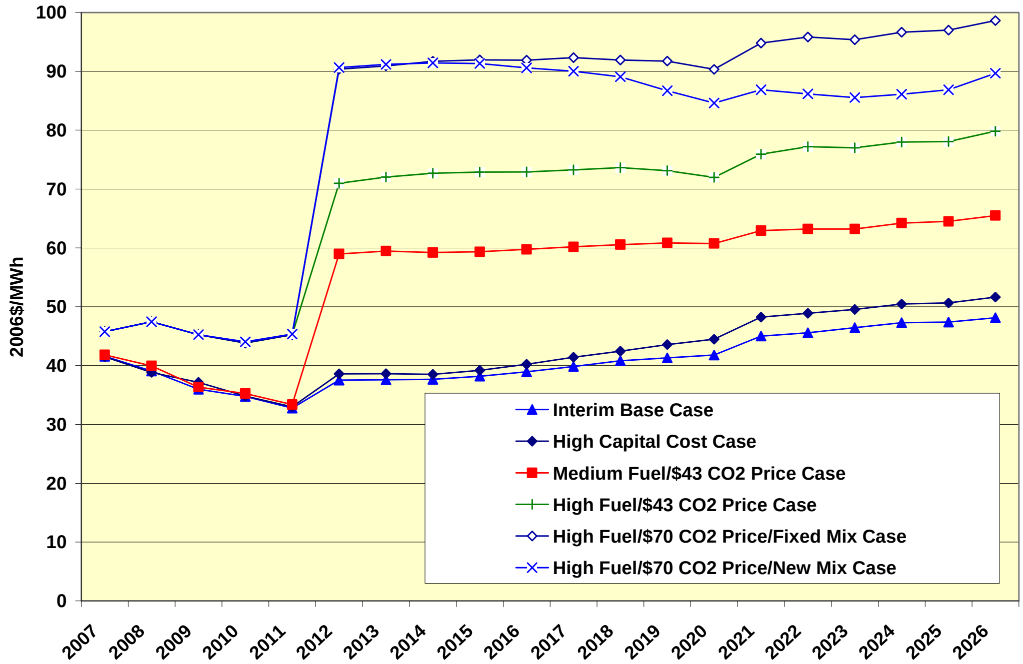
Figure 3: Forecast Pacific Northwest incremental resource mix based on dispatch energy (High Fuel/$70 CO_2 Price/New Mix Case)



In its Fifth Power Plan the Council assumed that IGCC plants with CO_2 capture and sequestration using unconventional sequestration media (i.e., other than enhanced oil or gas recovery) could be in service in the region in the 2015 - 2020 period. Because of disappointingly slow development of the technologies involved it is uncertain whether five IGCC plants with carbon capture and sequestration could be built in the Northwest between 2019 and 2026. Moreover, because of the absence of relevant plant construction experience, the cost and risk of carbon sequestration is difficult to estimate. The Council will continue to improve its assumptions regarding this technology as it develops the Sixth Power Plan.

Whether CO_2 allowance prices of $70 per ton of CO_2 would be politically sustainable for a prolonged period of time is also an open question. Many of the cap-and-trade proposals introduced in the 110th Congress call for “safety valve” options designed to release the CO_2 emissions cap if the cost of compliance becomes unacceptably high. Figure 4 shows the forecast wholesale power prices for each of the scenarios studied. The high fuel price sensitivity cases with $70 per ton CO_2 allowance prices have the highest forecast power prices. For example, the High Fuel/$70 CO_2 Price/New Mix Case had a levelized wholesale power price of $73.70 per megawatt-hour (MWh). This is $20.90 per MWh higher than the levelized price of the reference case. The High Capital Cost Case presented in the Council’s “Interim Wholesale Power Price Forecast” paper had a levelized wholesale power price of $41.30 per MWh. However, a $70 per ton of CO2 allowance price appears to be more than sufficient to reduce CO2 emissions to 1990 levels, raising the possibility that somewhat lower allowance prices may suffice to achieve this objective, even with high natural gas prices. Moreover, a portion of the allowance revenues would likely be redirected to energy efficiency measures and low carbon generation, partly offsetting the overall cost of power system operation.

Figure 4: Forecasts of Northwest wholesale power prices



CONCLUSION

An important modeling result presented in the Council's paper, "Marginal Carbon Dioxide Production Rates of the Northwest Power System," is that the Northwest power system's annual CO_2 emissions can be driven below its1990 level with CO_2 allowance prices of $43 per ton. This result was achieved at the Council's medium fuel price forecast.

The findings presented in this addendum demonstrate that this modeling result is sensitive to higher natural gas price forecasts. At the Council's high fuel price forecast the $43 per ton CO_2 emission cost is insufficient to achieve the same dramatic reduction in the total annual emissions of the Northwest power system.

The higher natural gas prices tend to work against efforts to achieve significant reductions in total CO_2 emissions. This is because higher natural gas prices favor coal-fired generation by making natural gas-fired units more costly to operate. Our modeling indicates that with the Council's high fuel price forecast, CO_2 allowance prices would need to climb to a level between $43 and $70 per ton of CO_2 in order to reduce the Northwest power system's annual total emissions to its 1990 level.

The Council will continue to explore these issues as it develops its Sixth Power Plan. While a wide range of uncertainties regarding both fuel prices and CO_2 allowance prices will be incorporated in the Sixth Power Plan portfolio risk analysis, CO_2 reduction objectives can only be indirectly considered by subsequent examination of the CO_2 production implied by the resulting preferred resource portfolio.