Carbon Dioxide Footprint of the Northwest Power System

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This report summarizes the results of an analysis of CO_2 production from the Pacific Northwest power system. It compares 2005 CO_2 production to levels in 1990 and to forecast future levels. The analysis explores how future growth in CO_2 production would be affected by various resource development scenarios and other policies of interest.

Summary of Findings

Following a 2006 staff analysis of the marginal carbon dioxide (CO_2) effects of conservation called for in the Council's Fifth Power Plan, the Council requested additional analysis of the CO_2 production of the Northwest power system under various future resource development scenarios. The scenarios included the recommended resource portfolio of the Fifth Power Plan (the base case), a low-conservation scenario in which the conservation targets of the Fifth Power Plan are not achieved, and a high-renewables scenario based on state renewable energy portfolio standards. A scenario based on the resource acquisition recommendations of utilities' integrated resource plans (IRPs) was dropped following the release of several revised utility IRPs that closely matched the recommendations of the Fifth Power Plan. In addition, the Council asked for sensitivity analysis of several specific policies related to hydro system operations to understand how related scenarios could affect the CO_2 production of the power system. The analysis does not address CO_2 production from other sources such as transportation or industrial processes.

The actual CO_2 production of the Northwest power system in 1990 is estimated to have been about 44 million tons.[1] By 2005, production of CO_2 from the regional power system rose to an estimated 67 million tons. However, 2005, unlike 1990, was a poor water year, requiring more than normal operation of CO_2-producing fossil power generation. Under normal water conditions, the CO_2 production in 2005 would have been about 57 million tons, which is a 29 percent increase over the 1990 level. For perspective, the annual CO_2 output of a typical 400-megawatt coal-fired power plant is about 3 million tons, and the CO_2 output of a typical 400-megawatt gas-fired combined-cycle power plant is about 1.2 million tons.[2]

Factors contributing to the increase from 1990 to 2005 include economic growth, the addition of fossil-fueled generating units, lost hydropower production capability, and retirement of the Trojan nuclear plant. The year 1990 is used for comparison because 1990 has been adopted as a baseline by many climate-change policy proposals, including Washington Governor Gregoire's climate-change executive order, Oregon HB 3543, and national legislation proposed by Senators Lieberman and Warner.

Due to the large share of hydroelectric generation in the Pacific Northwest, CO_2 production here is much less than that of other regions when compared to electricity produced. For example, under normal water conditions, in 2005 the Pacific Northwest would have produced about 520 pounds of CO_2 for each megawatt-hour of electricity generated, compared to 900 pounds for the entire Western interconnected power system (WECC). However, because the Northwest has essentially the same set of future resource options available as other areas of WECC, it may be more difficult for the Northwest to maintain or reduce its average per-megawatt-hour CO_2 emission rate. In the base case of this study, which assumes implementation of the Council's Fifth Power Plan, the WECC CO_2 emission rate increases about 3 percent to about 920 pounds per megawatt-hour by 2024, whereas the Northwest rate, with aggressive development of conservation and renewables also increases 3 percent to about 530 pounds.

The future growth rate of annual regional CO_2 production would be even higher if the conservation, wind, and other resource development called for in the Council's Fifth Power Plan were not accomplished. With implementation of the Council's plan in the base case, the annual CO_2 production of the regional power system in 2024 under normal conditions would be about 67 million tons, an 18 percent increase over normal 2005 levels.

This paper explores the difficulty of reducing CO_2 production from electricity generation by assessing the effects of several scenarios on CO_2 production. The scenarios include some that would increase CO_2 production and some that would decrease it. These

[1] Unless otherwise noted, quantities are expressed as short tons (2,000 pounds) of carbon dioxide.
[2] A 400-megawatt pulverized coal-fired plant of 10,000 Btu/kWh heat rate operating at 80 percent capacity factor will produce about 3 million tons per year of carbon dioxide. A 400-megawatt combined-cycle plant fueled by natural gas of 7,000 Btu/kWh heat rate operating at 80 percent capacity will produce about 1.2 million tons per year of carbon dioxide.

scenarios were selected to develop a "scale-of-effects" sensitivity analysis that includes alternative resource development scenarios and hypothetical changes to the hydroelectric system. The hydroelectric sensitivity analyses address two hypothetical river condition alternatives: "no summer spill" and breaching the four lower Snake River dams. The controversial nature of these two scenarios is recognized, but has no relevance in this paper other than the CO2-related data the alternatives generate as a result of their respective scenario parameters.

An important finding of the analysis is that achieving the renewable portfolio standard goals and eliminating all summer spill would reduce the region's projected growth in power system CO2 production by only 75 percent, even if counting the resulting net CO2 reduction for the entire WECC. Failure to achieve the conservation targets in the Fifth Power Plan, or removing the lower Snake River dams and replacing the power in a manner consistent with the Fifth Power Plan could more than offset the potential savings from the scenarios that reduce CO2 production. The effects of these scenarios, positive or negative, on CO2 production are the equivalent of only one or two coal-fired plants, whereas the forecast regional CO2 production for 2024 in the Fifth Power Plan case exceeds 1990 levels by an amount equivalent to eight typical coal-fired plants.

The findings of this study are depicted in Figure 1 and compiled in Table 1. Figure 1 depicts changes from base case projected CO2 emissions from WECC power systems for each of the scenarios. Table 1 shows the CO2 emissions in 1990, 2005, and projections for 2024 in each scenario, both for the Pacific Northwest and the WECC as a whole. Changes to the 2024 levels are shown in parentheses for each scenario.

These results illustrate the difficulty of actually reducing CO2 production with policies that affect only new sources of electric generation. CO2 production from electricity generation is dominated by existing coal-fired generating plants. To stabilize CO2 production at 2005 levels or to reduce CO2 production to 1990 levels would require substituting low CO2-producing resources or additional conservation for some of these existing coal-fired power plants. In addition, the scenario analysis shows that policy choices that are made for purposes other than CO2 reduction (in this case fish and wildlife policy) can also have significant effects on CO2 production; enough effect to negate policies such as renewable portfolio standards. Such unintended effects often go unexplored in important policy debates that focus narrowly on only one objective.

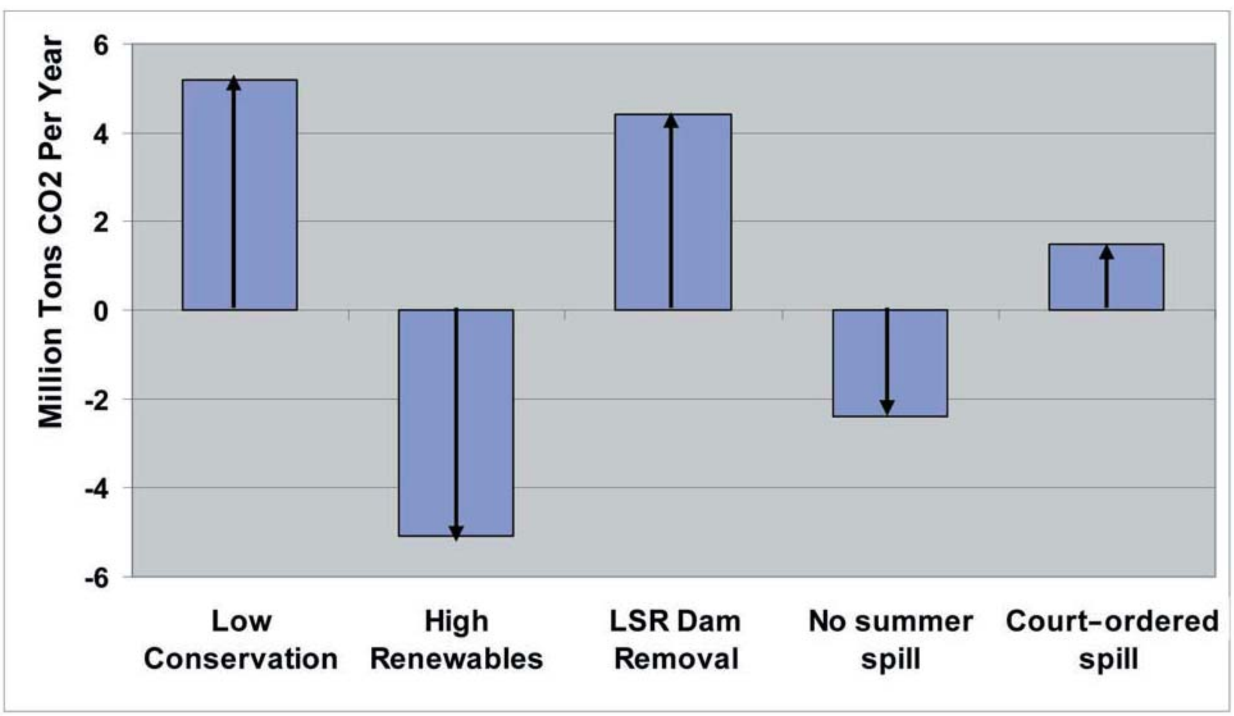

Figure 1: Changes from the base case projected CO2 production in alternative scenarios (WECC)

	Northwest Sources	WECC Sources
Historical values		
Actual 1990	44	Not estimated
Actual 2005	67	Not estimated
Simulated 2005 w/average hydro	57	378
Forecast 2024 rates and change from base case		
Base Case (5^{th} Plan Portfolio)	67	531
Low Conservation	71 (+4.4)	536 (+5.2)
High Renewables	63 (-4.2)	526 (-5.1)
Remove LSR Projects, Replace w/Gas Generation	70 (+3.6)	536 (+4.4)
No Summer Spill	66 (-1.1)	529 (-2.4)
Court-ordered Spill	67 (+0.5)	533 (+1.5)

Table 1: Historical and projected CO_2 production and effects of alternative scenarios

As perspective, it is useful to understand regional CO2 emissions in a global context. In 2005, the world production of CO2 from the consumption and flaring of fossil fuels is estimated to have been about 28,000 million metric tons (30.8 billon short tons). The United States accounted for 21 percent of these emissions. The U.S. production of CO2 per capita is about 5 times the world average, largely reflecting its advanced state of development. However, the U.S. production of CO2 relative to its state of development as measured by Gross Domestic Product is substantially lower than the world average; about 70 percent of the world average.[3]

Electric power generation accounts for about 40 percent of the U.S. production of CO2. The electric power share is much lower in the Western U.S., however, at about 31 percent, and even lower for the Pacific Northwest where the 2004 (a fairly normal water year) share was 23 percent.

Greenhouse gas reduction targets, such as the Western Climate Initiative, typically target all sources of greenhouse gas emissions. Carbon dioxide is the dominant greenhouse gas. It accounted for 84 percent of all greenhouse gas emissions in 2005.[4] Sources of CO2 emissions other than electricity generation will need to be reduced to meet greenhouse gas reduction targets. For the U.S. as a whole, electricity generation is the largest producer of CO2. It is followed closely by the transportation sector, which accounts for one-third of emissions, and then by the industrial sector contributing 18 percent. The residential and commercial sectors combine to account for 10 percent.

Although electricity generation is the largest source of CO2 emissions in the U.S., in the West transportation is the largest. Transportation accounts for 43 percent of the CO2 emission in the West compared to 33 percent in the U.S. as a whole. In the Pacific Northwest, the transportation share is even larger at 46 percent.

The diversity of CO2 emission shares should be an important consideration in structuring CO2 reduction policies. In the West, with a smaller contribution to CO2 emission coming from electricity production, other sectors will need to carry a larger burden in reaching overall CO2 reduction targets. In addition, as discussed later in this paper, the CO2 production for electricity generation in the Pacific Northwest can vary significantly with changing hydroelectric supplies. This variability will need to be accounted for in setting CO2 reduction targets and in any cap and trade allocation system.

Background

Increasing concerns regarding the impact of CO2 production from the electric power system on global climate and heightened prospects of mandatory

[3]Data on CO2 emission from energy are from the U.S. Energy Information Administration.
[4]U.S. Environmental Protection Agency. EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005.

controls on the production of CO2, led the Council in the summer of 2006 to request a forecast of the CO2 produced from alternative future resource portfolios. Four scenarios were identified: the recommended resource portfolio of the Fifth Power Plan (the base case), a low-conservation scenario in which the conservation targets of the Fifth Power Plan are not achieved, a high-renewables scenario based on state renewable energy portfolio standards, and a scenario based on the resource acquisition recommendations of utilities' integrated resource plans (IRPs). The utility plans scenario was removed from the final paper following the release of several revised utility IRPs that closely matched the recommendations of the Fifth Power Plan. Two additional sets of studies were subsequently requested: 1) the CO2 effects of removing the federal dams on the lower Snake River; and 2) the CO2 effects of summer spill at the lower Snake River and lower Columbia River dams.

The purpose of these alternative scenarios is to quantify the sensitivity of results to plausible changes in the power system and to some related policies that have received attention. No new Council position on any of these policies is intended by this analysis, nor should any be inferred.

Historical Carbon Dioxide Production of the Northwest Power System

The year 1990 is frequently used as a benchmark in policies for the control of greenhouse gases.[5] The 1990 production of carbon dioxide from the Pacific Northwest power system is estimated to have been about 44 million tons, based on electricity production records of that year. Load growth, the addition of fossil-fuel generating units, the loss of hydropower production capability, and the retirement of the Trojan nuclear plant resulted in growing CO2 production over the next 15 years. By 2005, the most recent year for which electricity production or fuel consumption data are available, CO2 production increased 52 percent to 67 million tons (Figure 2). This is approximately the CO2 output of 23 400-megawatt conventional coal-fired power plants, 56 400-megawatt gas-fired combined-cycle plants or about 11.7 million average U.S. passenger vehicles.

The regional CO2 production estimates from 1995 through 2005 shown in Figure 2 are based on the fuel consumption of Northwest power plants as reported to the Energy Information Administration (EIA). Because fuel consumption data were not available before 1995, estimates for 1990 through 1995 are based on plant electrical output as reported to EIA and staff assumptions regarding plant heat rate and fuel type. Estimates based on plant electrical production are likely somewhat less accurate than estimates based on fuel consumption because of multi-fuel plants and uncertainties regarding plant heat rates. However, the two series of estimates are within 2 percent in the "overlap" year of 1995.

[5]For example, California Assembly Bill (AB) 32, passed by the legislature and signed by the governor in 2006, calls for enforceable emission limits to achieve a reduction in CO2 emissions to the 1990 rate by 2020. Washington Governor Gregoire's climate-change executive order includes the same target for CO2 reductions. Oregon House Bill 3543, passed by the legislature and signed by Governor Kulongoski in August, declares that it is state policy to stabilize CO2 emissions by 2010, reduce them 10 percent below 1990 levels by 2020, and 75 percent below 1990 levels by 2050.

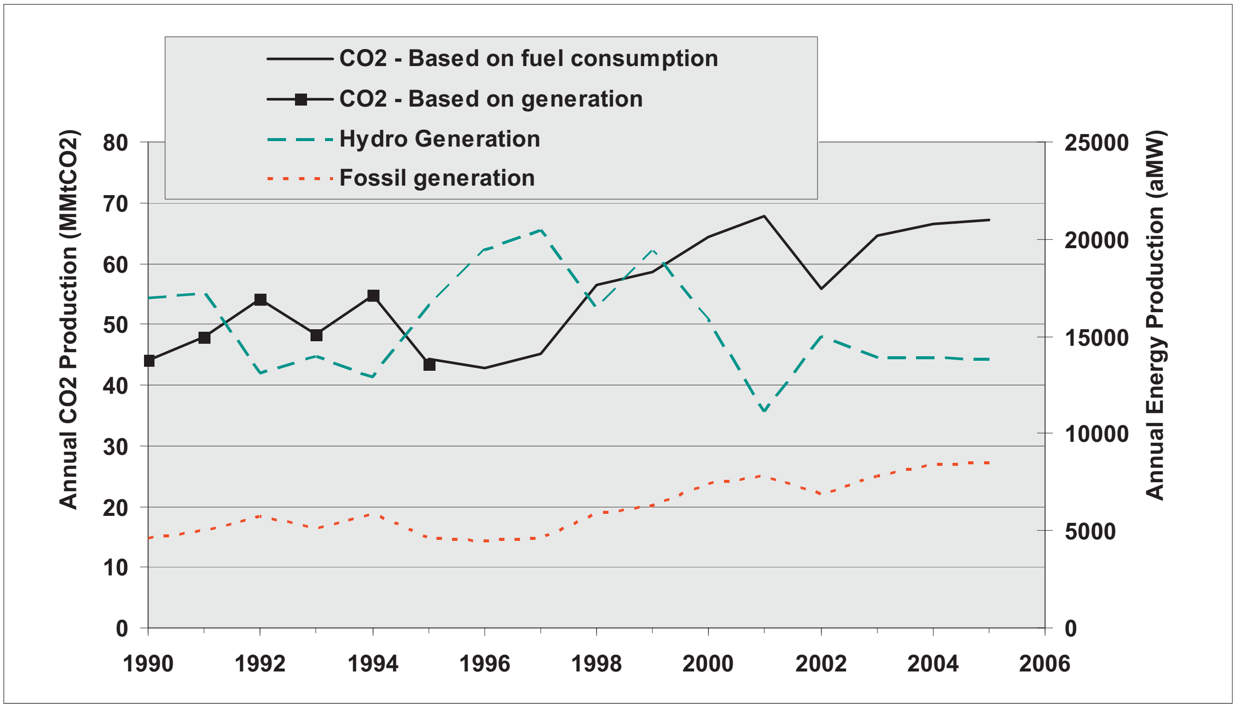

Figure 2: Historical CO2 and energy production of the Northwest power system[6]

Annual hydropower conditions can greatly affect power system CO2 production. Average hydropower production in the Northwest is about 16,400 average megawatts. As shown by the plot of Northwest hydropower production in Figure 2, the 1990 water year was nearly 17,000 average megawatts, slightly better than average. Other factors being equal, this would have slightly reduced CO2 production that year by curtailing thermal plant operation. Conversely, hydro production in 2005 was about 13,800 average megawatts, a poor water year. Other factors being equal, this would have increased thermal plant dispatch, raising CO2 production. The effect of hydropower generation on thermal plant generation and CO2 production is shown in Figure 2.[7]

If normalized to average hydropower conditions, actual generating capacity, and the medium case loads and fuel prices of the Fifth Power Plan, the estimated CO2 production in 2005 would have been 57 million tons, a 29 percent increase over the 1990 rate. This is the value used for comparison in this paper.

The Base Case - The Fifth Power Plan's Portfolio

The recommended resource portfolio of the Fifth Power Plan was used as the base case for all studies. Because the recommended resource portfolio of the Fifth Power Plan is defined in terms of "option by" dates rather than in-service dates, assumptions must be made to translate the portfolio into the fixed resource schedule needed for the AURORA™ model.[8] For this work, the "mean value resource development" schedule of the preferred resource portfolio of the Fifth Power Plan was represented in AURORA. The resulting resource development schedule was then tested against the Resource Adequacy Forum's recently proposed pilot capacity adequacy standard, using the capacity addition mode of the AURORA model. The resulting resource development schedule, illustrated in Figure 3 and enumer-

[6]Estimated CO2 production from 1995 through 2005 is based on power plant fuel consumption as reported to the U.S. Energy Information Administration (EIA). Fuel consumption information before 1995 is not readily available. CO2 production for these years was based on reported generation and estimated plant heat rates. As evident in Figure 1, the two methods result in reasonably consistent estimates for the overlap year of 1995. Incomplete reporting of generation for the increasing amount of non-utility power plant capacity makes comparisons less reliable for subsequent years. Estimates are based on all utility-owned power plants and non-utility plants selling under contract to utilities. Included in the definition of "Northwest" are the Jim Bridger plant in Wyoming and the Idaho Power share of the North Valmy plant in Nevada. The output of this capacity is dedicated to Northwest loads.

[7]In Figure 1, it is evident that Northwest thermal generation does not decline as much as Northwest hydro generation increases in above average water years, e.g. 1994 - 1997. This is likely due to the fact that the abundant hydropower of good water years creates a regional energy surplus that can be sold out of the region where it displaces thermal generation, which often consists of older, less efficient gas-fired units.

[8]The use of the AURORA model in preparing these forecasts is described in the Appendix A of this paper.

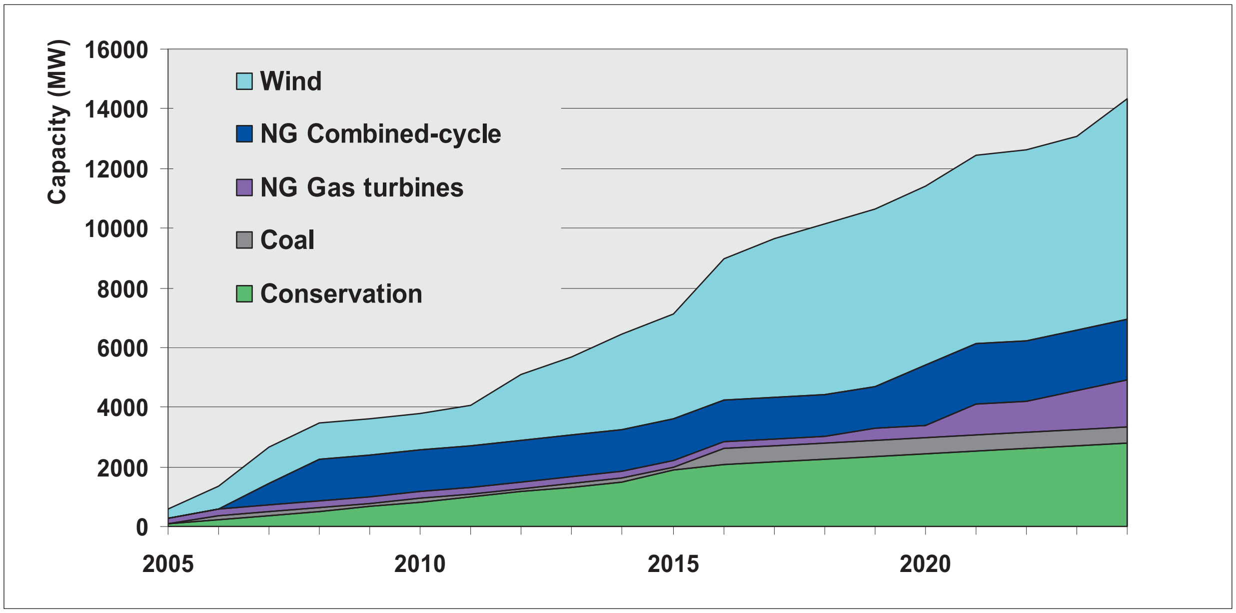

Figure 3: Base case Northwest resource development

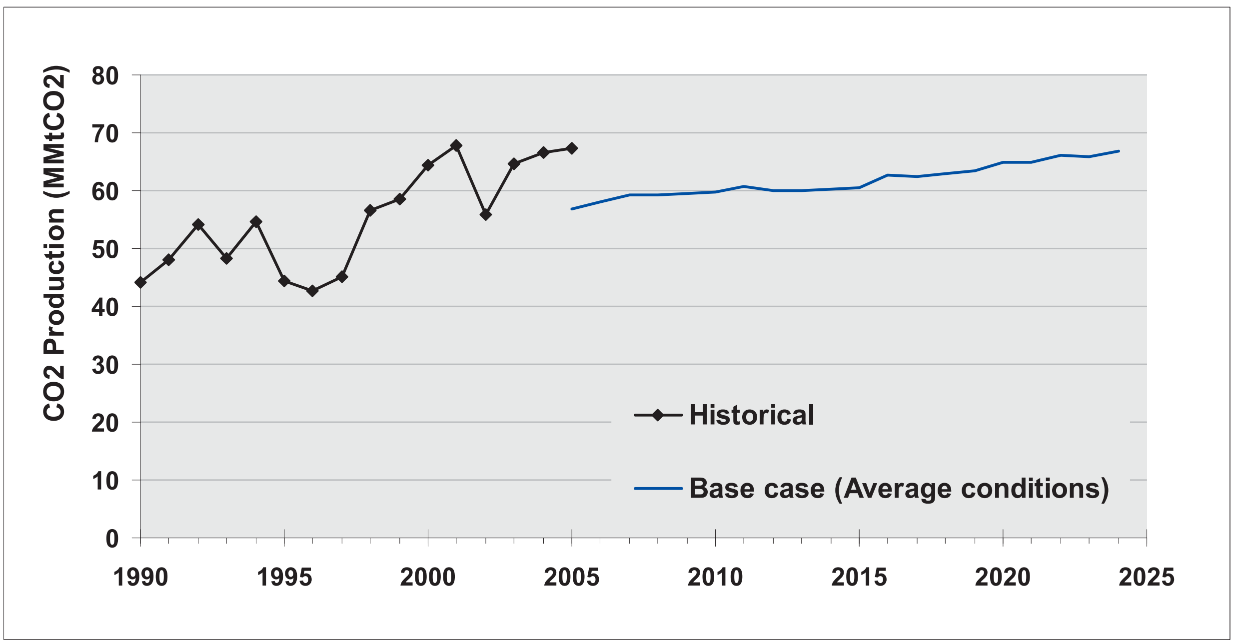

Figure 4: Forecast and historical CO2 production of the Northwest power system

ated in Appendix B, contains additional simple-cycle gas turbine capacity needed to maintain the proposed Northwest pilot capacity reserve standards. The schedule also contains several recently constructed wind projects not included in the resource portfolio of the Fifth Power Plan, so it includes a somewhat larger amount of wind capacity by 2024 than the original Fifth Plan portfolio. The AURORA capacity expansion run was also used to define resource additions and retirements for WECC areas outside the Northwest.

Forecast CO2 production of the Northwest power system for 2005-24 is compared to historical production in Figure 4. The forecast is normalized to average hydro, fuel prices, and loads, leading to the difference between actual and forecast values for the low water year 2005. Annual CO2 production under average conditions is forecast to increase from 57 million tons in 2005 to 67 million tons in 2024. This represents an 18 percent increase over the planning period of the Fifth Power Plan, an average annual rate increase of 0.8 percent. The forecast annual rate

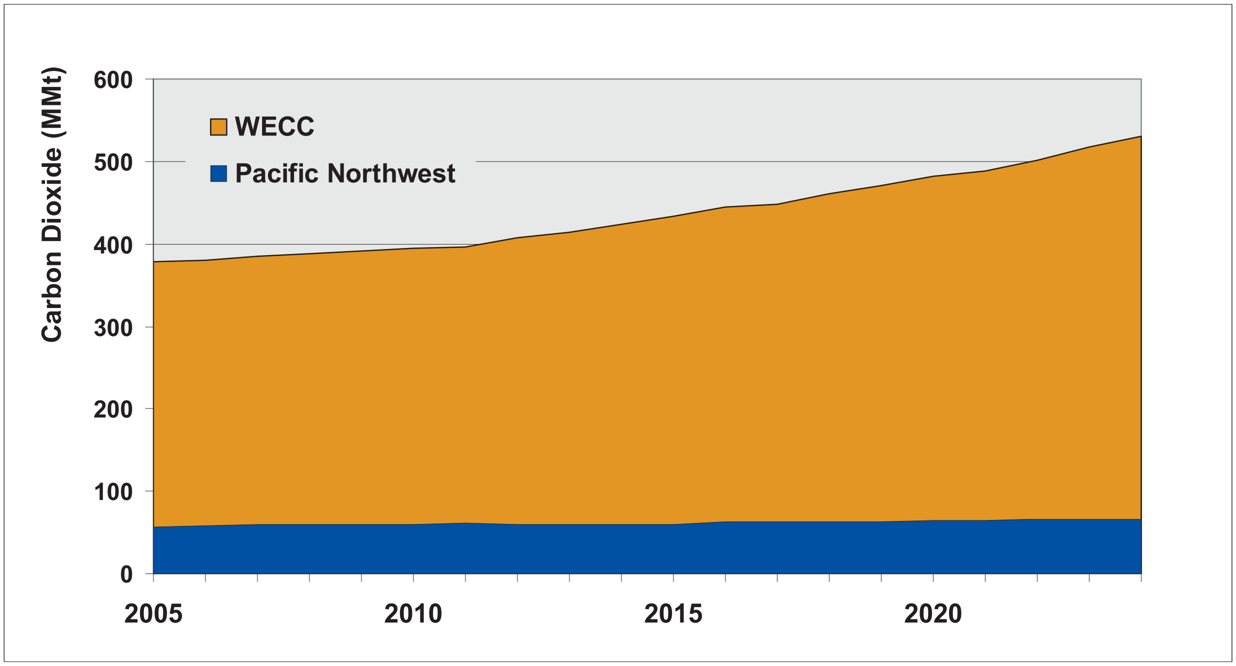

Figure 5: Forecast WECC and Northwest power system CO2 production

of 67 million tons in 2024 represents an increase of 51 percent over the historical annual rate of 44 million tons in 1990. The forecast average annual rate of increased CO2 production of 0.8 percent for the planning period of the Fifth Power Plan is half of the 2 percent average rate for 1990 - 2004 (2004 normalized).

Figure 5 compares forecast annual CO2 production for the Northwest and the WECC as a whole. In 2005, the normalized annual CO2 production by the Northwest power system represented 15 percent of the total WECC production. Because of its high proportion of hydropower, aggressive development of conservation, and recent additions of wind power and other non-hydro renewable resources, the Northwest enjoys a much lower per-kilowatt-hour CO2 production rate than WECC as a whole (0.52 lb/kWh vs. 0.90 lb/kWh in 2005). The forecast average annual growth rate for WECC as a whole is 1.7 percent, compared to 0.8 percent for the Northwest, so that by 2024, the production in the Northwest will have declined to 13 percent of the total WECC production. Because these estimates do not include the possible effects of the renewable portfolio standards in place in many Western states (including the Northwest states), the future growth of CO2 production for WECC may be less than forecast here.

Figure 6 illustrates the source of CO2 production in the Northwest in the base case forecast. By 2024, and assuming no retirements of existing thermal plants, 79 percent of Northwest power system CO2 production will be from existing coal-fired power plants, 4 percent from new coal-fired plants, 9 percent from existing gas-fired plants, and 7 percent from new gas-fired power plants. Though the aggressive acquisition of conservation and renewable resources called for in the Fifth Power Plan will hold the rate of growth in Northwest CO2 production to half the growth rate experienced from 1990 through 2004, serious efforts to reduce or even stabilize CO2 production beyond 2005 will likely require replacing existing coal-fired power plants with low CO2-emitting resources.

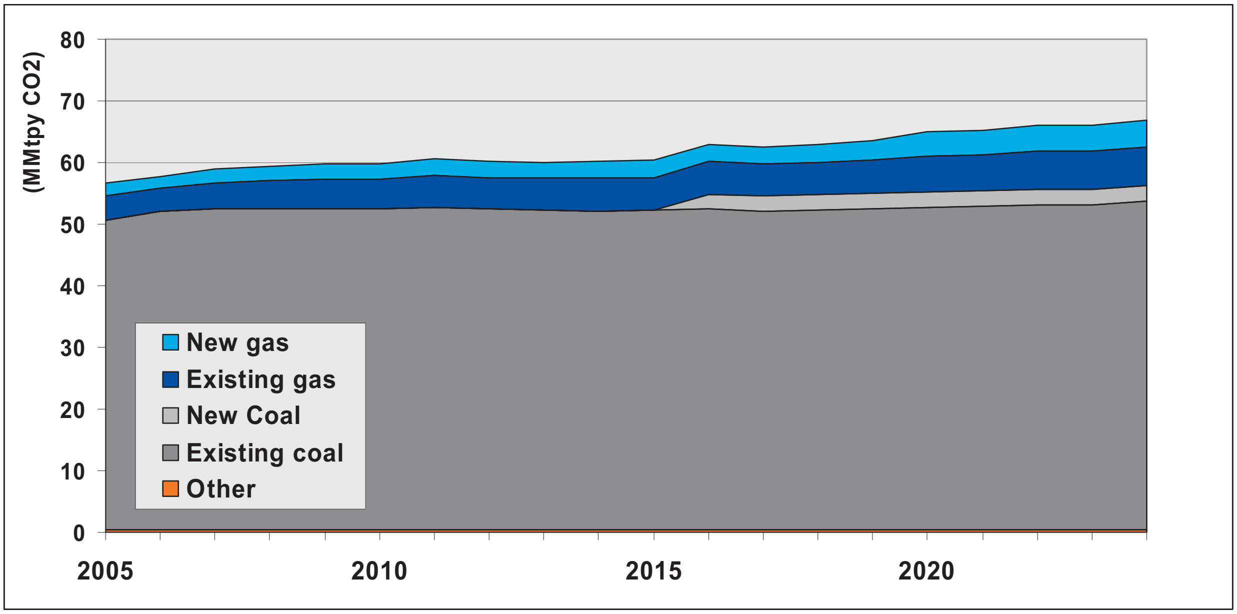

Figure 6: Sources of Northwest power system CO2 production

Alternative Resource Development

The CO2 production of two scenarios of alternative future resource development was forecast and compared to the base case forecast described earlier. The Northwest resource-development assumptions for each scenario are described below. Resource-development assumptions for WECC areas outside of the Northwest are the same as the base case. The impacts of all of the scenarios analyzed in this paper are assessed under average water conditions.

Alternative resource-development scenarios

A low-conservation scenario assumes that only 70 percent of the long-term conservation goals of the Fifth Power Plan are met by 2024. A resource portfolio (the "status quo" portfolio) representing this situation, developed during preparation of the Fifth Power Plan, was adopted for this scenario. As shown in Figure 7, this portfolio includes 800 fewer megawatts of conservation, 200 fewer megawatts of wind, and 275 fewer megawatts of simple-cycle capacity compared to the base case.[9] An additional 275 megawatts of coal and 610 megawatts of combined-cycle capacity make up for the energy and capacity of the unachieved conservation, wind, and gas turbine capacity.

A high-renewables scenario approximates full achievement of the Montana, Oregon, and Washington renewable portfolio standards (RPS). This scenario also includes a hypothetical RPS for Idaho, generally comparable to those adopted by the other states but with a lag of several years. Although these additional renewable resources were not found to be cost-effective in the Council's Fifth Power Plan, their acquisition has been mandated by many states, including Montana, Washington, and Oregon. Renewable-resource acquisitions to meet RPS goals are modeled as a combination of wind and biomass in the approximate proportions of wind currently being developed compared to other renewable energy resources. Though some geothermal, hydropower, solar, and marine energy resources are expected to be developed in response to renewable portfolio standards, the wind and biomass assumed for this scenario adequately represent the performance of the expected mix of intermittent and firm renewable energy resources for this purpose. The conservation-acquisition targets of the Fifth Power Plan were also assumed to be met. New coal-fired generation is excluded from this scenario. As shown in Figure 7, the high-renewables scenario includes an additional 500 megawatts of biomass, 1,600 megawatts of wind,

[9]In Figure 7 and following figures, column sections above the zero line represent resource capacity in excess of the amounts included in the base case, and column sections below the zero line represent resource capacity less than included in the base case. Conservation energy savings are shown as equivalent capacity.

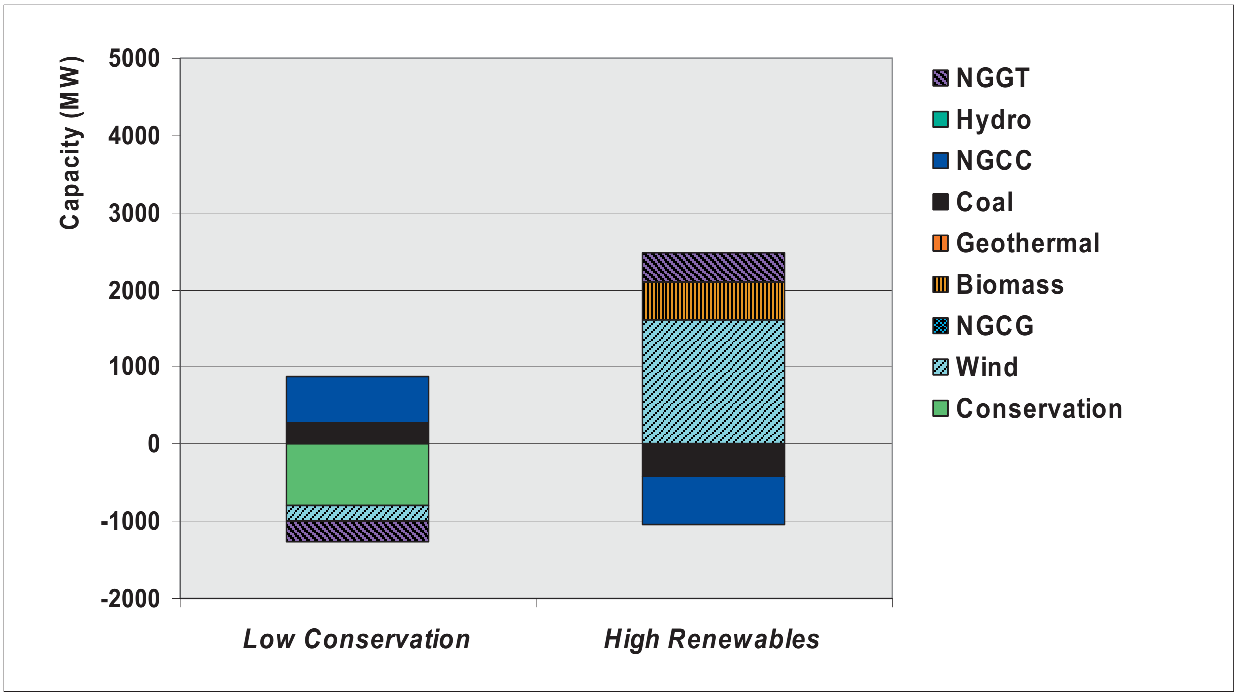

Figure 7: Incremental 2005-24 capacity compared to the base case

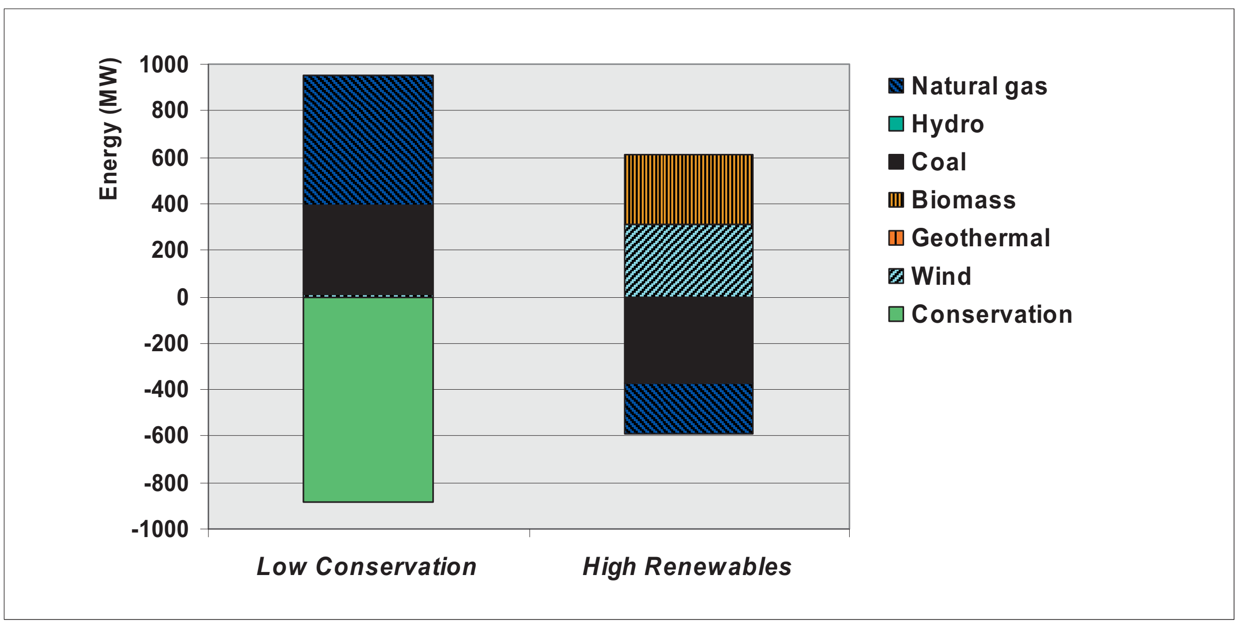

Figure 8: Average annual change in resource output vs. base case (WECC, 2015-24)

and 370 megawatts of gas turbines compared to the base case. The peaking capacity and energy balance of the base case was maintained by eliminating the 425 megawatts of new coal in the base case.

Effects of alternative resource-development scenarios

The production of CO2 is a function of the fuel and efficiency of resources dispatched to meet load. Alternative resource mixes will lead to changes in dispatch because of differing variable costs of operation and physical operating characteristics. Net changes for the entire WECC must be evaluated because of the effects of Northwest resources on resource dispatch in interconnected areas. A comparison of the average annual change in energy production by type of resource for 2015-24 for the two alternative resource-development scenarios compared to the base case is illustrated in Figure 8.

Low Conservation

Additional energy from coal (370 average megawatts) and natural gas (560 average megawatts) substitute for the reduced conservation of the low-conservation scenario. By 2024, annual CO_2 production from Northwest sources would be 71 million tons per year (MMtpy), 4.4 million tons greater than the base case and a 61 percent increase over the 1990 rate. Annual net CO_2 production for 2024 across the entire WECC system would increase 5.2 million tons compared to the base case, nearly the equivalent of two typical 400-megawatt coal-fired power plants. By 2024, this scenario includes about 770 fewer average megawatts of conservation than the base case. Each average megawatt of unachieved conservation would increase average net annual CO_2 production by about 6,700 tons per year.

Wholesale power prices are forecast to be higher on average in the low-conservation scenario compared to the base case. Higher prices result from the dispatch of higher variable-cost resources, such as gas turbines to serve the additional load resulting from lower conservation achievement.

High Renewables

Additional energy from wind (310 average megawatts) and biomass (300 average megawatts) in the high-renewables scenario would reduce energy production from coal by 370 average megawatts and natural gas by 220 average megawatts. By 2024, annual CO_2 production from Northwest sources would be 63 MMtpy, 4.2 million tons less than the base case. Although this would reduce the 2005-24 growth of CO_2 production rates by 44 percent, the resulting rate still represents a 41 percent increase over the 1990 rate. Annual net CO_2 production for 2024 across the entire WECC system would decline 5.1 million tons compared to the base case.

Wholesale power prices are forecast to be slightly lower on average in the high-renewables scenario compared to the base case. Lower prices result from the displacement of high variable-cost resources, such as gas turbines by the additional low variable-cost renewable resources of this scenario.

Removal of the Lower Snake River Hydroelectric Projects

Analysis of breaching the four federal hydroelectric projects on the lower Snake River[10] indicates the loss (on average under current river operations) of about 1,020 average megawatts of carbon-free energy and 2,650 megawatts of sustained peaking capacity. The impact of this loss on the production of CO_2 depends on the nature of the replacement resources. The resource replacement depends on the particular resource-development strategy, as illustrated in the resource-development scenarios described earlier.

Resource replacement

Three possible approaches to replacing the reduced hydroelectric output of the dams were considered. These were: replacement with market purchases, replacement with natural gas resources, and replacement with conservation and renewable energy resources and natural gas capacity. The results of the second approach are reported because they are considered the most consistent with the base case and the Fifth Power Plan. Replacement with market purchases would compromise system adequacy and reliability by reducing the amount of resource available to meet load. Replacement of the power lost by breaching the lower Snake River dams by increased acquisition of conservation and renewable energy could, at least in the near term, delay some of the CO_2 impacts of dam breaching. However, tying the increased development of conservation and renewables to dam breaching is misleading. If additional conservation and renewables are available and desirable, they should be pursued as part of a regional strategy to reduce CO_2 emissions. Thus, the effects of changes in renewable development and conservation achievements have been addressed in the resource-development scenarios discussed earlier. Removal of the lower Snake River dams will not make additional CO_2-free energy resources available to meet future load growth or retire any existing coal plants. More than 1,000 megawatts of emission-free generation eventually will have to be replaced unless the supplies of renewables and conservation are considered unlimited. Given the difficulty of reducing CO_2 emissions, discarding existing CO_2-free power sources has to be considered counterproductive

The lower Snake projects were assumed to ter-

[10]The projects are Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

minate production on December 31, 2014, and replacement resources were assumed to commence operation on January 1, 2015. This permitted the development of 10-year (2015-24) averages consistent with the other studies of this analysis. Resource-development assumptions for WECC areas outside of the Northwest were held constant.

The analysis assumes that the average energy output of the projects is replaced by natural gas-fired combined-cycle plants. The balance of the sustained peaking capacity of the projects is replaced by natural gas-fired simple-cycle gas turbines. The combined capacity of three combined-cycle units (1,830 megawatts) and 18 simple-cycle gas turbine units (846 megawatts) slightly exceeds the sustained peaking capacity of the four hydro projects. The analysis did not address replacement of ancillary services such as regulation, load following, and power factor control provided by the projects.

Effects of lower Snake dam replacement

When the operation of the changed power system is simulated, the lost hydro energy is replaced with the additional production of 170 average megawatts from existing coal-fired units and about 810 average megawatts from new and existing natural gas units. By 2024, annual CO2 production from Northwest sources would be 70 MMtpy, 3.6 million tons greater than the base case and a 59 percent increase over the 1990 rate. Annual CO2 production for 2024 across the entire WECC system would increase 4.4 million tons compared to the base case.

A modest increase in wholesale power prices is forecast, resulting from replacement of the hydro energy with higher variable-cost thermal energy. Significant capital expenditures would be incurred for replacement resources and costs associated with dam removal, which would increase cost-based utility electricity prices. System reliability should be relatively unaffected because of the capacity value and energy capability of the replacement resources. While the supply of ancillary services should be unaffected because of the replacement capacity, ancillary service prices may increase because of the higher operating costs of the replacement thermal resources.

Summer Spill Operations

The summer spill program at the lower Snake River and lower Columbia River hydroelectric projects is intended to facilitate the downstream migration of anadromous fish. The original summer spill requirements date to the 1990s and were incorporated in the 2000 Biological Opinion (BiOp). The 2004 BiOp incorporated the summer spill operation of the 2000 BiOp with minor changes. In 2005 and subsequent years, summer spill was increased further by court order (Preliminary Injunctive Relief Operation). The base case (the Fifth Power Plan portfolio) is based on 2004 BiOp operations, and thereby represents an intermediate level of summer spill.

This study estimates the CO2 production impacts of the two summer spill regimes by comparing the average Western system dispatch and net CO2 production for no summer spill operation and court-ordered summer spill operation to the average Western system dispatch and net CO2 production of the base case (2004 BiOp). The comparison in all scenarios is average dispatch and CO2 production for the period 2015-24.

The base case is as described earlier and includes summer spill operation as called for in the 2004 Biological Opinion.

The no summer spill scenario is based on the energy shape and output of the hydropower system without summer spill at the lower Snake River and Columbia River projects. In all other respects, the scenario is identical to the base case. About 550 average megawatts of hydropower energy would be gained under this operation compared to the base case.

The additional court-ordered spill scenario is based on the energy shape and output of the hydropower system under 2006 court-ordered spill operation. In all other respects, the scenario is identical to the base case. About 360 average megawatts of hydropower energy are lost under this operation compared to the base case.

No summer spill

In the no summer spill scenario, the additional hydro energy would displace about 190 average megawatts from coal-fired power plants and about 330 average megawatts from natural gas power plants (Figure 9). This would reduce average annual CO2 production for 2024 from Northwest sources by 1.1 million tons compared to the base case (2004 BiOp). By 2024, 66 MMtpy of CO2 would be produced directly from Northwest sources, a 48 percent increase over the 1990 rate. Annual CO_2 production for 2024 across the entire WECC system would decrease 2.4 million tons compared to the base case.

Sensitivity Cases

Comments on the draft of this analysis requested sensitivity cases on some of the basic assumptions used in all of the scenarios. These included the effects of higher CO_2 costs, higher fuel prices, and wind variability.

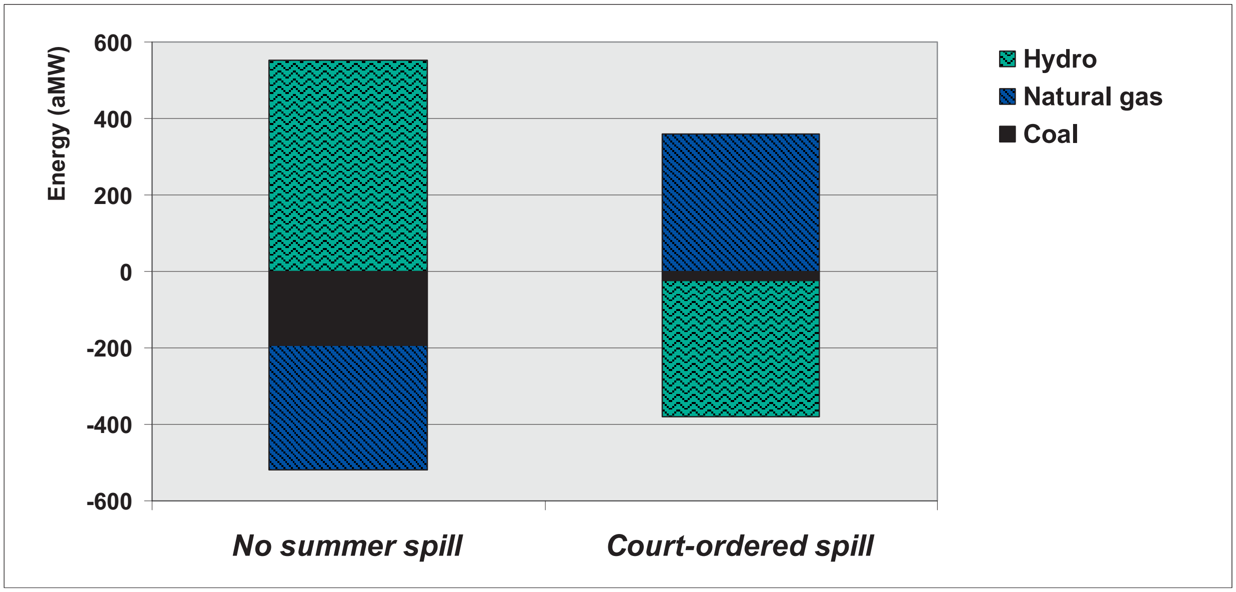

Figure 9: Average annual change in resource output vs. base scenario (WECC, 2015-24o

Court-ordered spill

About 20 average megawatts from coal-fired power plants and about 360 average megawatts from gas-fired power plants are needed to compensate for the lost hydro energy of the court-ordered spill scenario. This increases average annual CO_2 production for 2024 from Northwest sources by 0.5 million tons compared to the base case (2004 BiOp). By 2024, 67 MMtpy of CO_2 would be produced directly from Northwest sources, a 52 percent increase over the 1990 rate. Annual CO_2 production for 2024 across the entire WECC system increases 1.5 million tons compared to the base case.

The overall effect of court-ordered spill compared to no summer spill operation within the Northwest is to increase the average annual CO_2 production for 2015-24 by 2.1 million tons. For WECC as a whole, court-ordered spill increases average annual CO_2 production 5.2 million tons compared to no summer spill operation.

Higher CO2 costs

All scenarios investigated in this study included the mean value CO_2 prices from the portfolio risk assessment of the Fifth Power Plan. This price, representing a carbon tax or the cost of carbon allowances under a cap and trade system, appears in 2009 and gradually rises to about $9.00 per short ton of CO_2 by 2024 (2006 dollars). A sensitivity case with doubled CO_2 price was run to explore the possible effect of increased CO_2 price on resource dispatch and CO_2 production. The resource mix was held constant for this case, so the impacts of the higher CO_2 prices are generally limited to shifting from coal to natural gas fueled plants. Higher power prices might also induce demand response and load curtailment.

With doubled CO_2 prices, WECC-wide dispatch of coal declined 9 percent, with the difference largely met with increased dispatch of natural gas plants. A slight increase in demand response was also observed. Northwest CO_2 production in 2024 does not significantly change from the base case, but for WECC in its entirety, 2024 CO_2 production declined 9 million tons.

Higher fuel costs

All scenarios investigated in this study were based on the medium case fuel price forecast of the Fifth Power Plan. Current forecasts of fuel prices, including the recent revision of the Council's fuel price forecast, are generally higher than earlier forecasts, including that of the Fifth Plan. Though the Council's revised fuel price forecast had not been adopted when the base case analysis was under development, a sensitivity analysis was run using the medium-high fuel price forecast case of the Fifth Power Plan. North American wellhead gas prices in the Fifth Power Plan medium-high fuel price forecast are $5.20/MMBtu in 2024, compared to $4.60/MMBtu in the medium case (2006 dollars). The equivalent western mine mouth coal prices are $0.67 and $0.59 per MMBtu. The resource mix was held constant for this case, so the impacts of the higher fuel prices are generally limited to shifting between natural gas and coal. As in the higher CO2 price case, higher power prices might also induce demand response and load curtailment.

For WECC as a whole, the overall dispatch of coal and natural gas plants was essentially unchanged in the medium-high fuel price case. A slight increase in demand response was observed, as was increased dispatch of geothermal plants (geothermal plants are modeled as dispatchable with a variable fuel cost). Higher fuel prices did not significantly affect CO2 production in the Northwest or for WECC as a whole.

Windpower volatility and intermittency

Wind is currently modeled in AURORA with a flat energy output equivalent to annual capacity factor. A sensitivity case in which the hourly intermittency of wind was modeled using historic hourly output of several geographically diverse Northwest wind projects resulted in an insignificant change in CO2 production. Further testing of the impact of hourly intermittency may be desirable as more extensive actual and synthetic wind output data becomes available from the Northwest Wind Integration Action Plan.

Though hourly wind volatility did not significantly affect CO2 production in this sensitivity case, it is possible that sub-hourly wind volatility might impact CO2 production. In the later years of the study period, increasing loads and higher levels of wind penetration may increase the demand for regulation and load following services beyond the capability of the hydro system to provide these services. Fossil resources such as simple-cycle gas turbines may be called upon to provide regulation and load following, which would increase CO2 production.

Achieving Significant Reductions in CO2 Production

The findings described in this paper illustrate the difficulty of reducing CO2 production to rates considered necessary for climate stabilization. Current rates of conservation acquisition, and policies such as renewable portfolio standards mandating acquisition of low carbon resources, will help reduce growth of CO2 production. However, as discussed earlier, these activities are likely to be insufficient to maintain current levels of CO2 production, much less to reduce CO2 production to levels sought by greenhouse gas control policies. Achieving these goals will require deep cuts in the CO2 production from existing fossil plants or equivalent offsets from other sectors or geographic areas.

To give some perspective to the challenge of meeting proposed CO2 reduction targets, we have calculated the amount of CO2 emissions that would need to be reduced from the base case (Fifth Power Plan) forecast for 2020. Two cases are illustrated to give some perspective on the size of the challenge. One is the Western Climate Initiative (WCI) target of reducing CO2 emissions to 15 percent below 2005 levels by 2020. Another is to reach 1990 levels by 2020, which is both Washington's target and the target in the proposed Lieberman-Warner "America's Climate Security Act."

Assuming the Northwest power system met similar percentage reductions in its 2020 CO2 emissions, what is the magnitude of the reduction in terms of million tons per year and how can that be put into perspective?

Taking the WCI target first, the required reductions would depend on how the 2005 CO2 emissions were determined. As illustrated earlier, 2005 was a poor water year. Actual CO2 production from the power system was estimated to be 67 million tons per year. The WCI target, if based on actual emissions, would be 57 million tons per year. To reduce the base case forecast of CO2 production in 2020, which is 65 million tons, down to actual 2005 levels would require a reduction of 7 million tons of CO2. However, if based on normal hydro conditions, the WCI target would be 48 million tons per year. Achieving a WCI target based on normal hydro would require a reduction of 17 million tons.

One way to put this into perspective is to calculate how much coal capacity would have to be replaced with a carbon-free source or with conservation, as shown in Table 2. More existing capacity than indicated in the table would require replacement if a portion of the replacement resource were low-carbon, such as coal gasification plants with partial CO2 separation and sequestration. Further analysis would be needed to estimate the amount of replacement capacity needed, as this depends on the CO2 and economic characteristics of the replacement resources.

Policy	2020 Target (MMtCO2)	Reduction Needed (MMtCO2)[11]	Equivalent Coal Capacity (MW)
WCI - 15% below actual 2005 by 2020	57	7	910
WCI - 15% below normal 2005 by 2020	50	17	2330
WA - 1990 by 2020[12]	44	21	2780
OR - 10% below 1990 by 2020	40	25	3300

Table 2: CO2 reductions from base case (Fifth Power Plan) forecast to achieve various 2020 policy targets

A multipronged effort is required for the industry to cost-effectively achieve the goals of greenhouse gas control policies.[13] This effort must include the following elements:

- Reduction in demand through more aggressive improvements in end-use efficiency.
- Shifting new resource acquisitions to low-carbon resources.
- Reducing the CO2 production of existing fossil generation through efficiency improvements, carbon capture and sequestration, and substituting low-carbon baseload generating capacity.
- Marketing and credit transfer mechanisms to help secure CO2 reductions in other economic sectors and geographic areas where cost-effective.

In short, achieving greenhouse gas control targets economically requires broadening cost-effective resource planning and acquisition to consider a global scope of CO2-reduction options.

While developing mechanisms to facilitate cost-effective global CO2 reduction lies largely outside the control of the Northwest power industry, the following options can be cultivated within the industry:

Expand the supply of cost-effective energy-efficiency measures: An expanded inventory of end-use efficiency options will reduce the growth in demand for electricity, thereby reducing CO2 production from generating resources. Historically, conservation has been among the most cost-effective and abundant of new resource options. New conservation opportunities have continued to unfold even as older opportunities are developed. Production of CO2 from power generation can be reduced by aggressive implementation of existing conservation measures and development of new measures with a focus on those most effective during the hours that CO2 -intensive generating resources are on the margin.

Existing low-carbon generating resources: The efficiency, energy output, and operating life of existing low-carbon resources can be improved. For example, each percentage point increase in the capacity factor of Columbia Generating Station will offset approximately 0.05 million tons of CO2 per year.[14] Opportunities to improve the efficiency and capacity, and extend the life of the region's existing biomass, hydropower, and nuclear resources can be explored and pursued where cost-effective.

New renewable generation: Expanding the supply and improving the cost-effectiveness of new renewable resources involves concurrent efforts: First, the

[11] Reduction from base case (Fifth Power Plan) 2020 forecast.
[12] Also the target of the proposed Lieberman-Warner America's Climate Security Act.
[13] A recent study by the Electric Power Research Institute provides a very useful illustration of the challenge to significantly reduce power system CO2 emissions. See EPRI, "The Power To Reduce CO2 Emissions: The Full Portfolio," August 2007.
[14] Based on an average systemwide marginal CO2 production rate of 0.9 lb/kWh as estimated by the Council ("Power System Marginal CO2 Production Factors," Northwest Power and Conservation Council, April 2006).

supply of regulation, load following, shaping, and storage capability needed for integrating intermittent resources such as wind, tidal currents, wave, and solar need to be expanded through the development of improved methods of marketing and transferring these services within the existing system. Because the supply of these services will eventually need to be augmented, options for supplying these services, including generation, storage, and load-side proposals such as plug-in hybrid vehicles need to be better understood. Secondly, the capacity of the existing transmission system to serve new renewable resources needs to be expanded by developing products such as a conditional-firm service that more effectively utilizes the existing transmission capacity. New transmission will be needed to serve increasing amounts of remote renewable capacity and to improve the geographic diversity of wind and other intermittent renewable resources. Mechanisms are needed to facilitate planning, financing, and construction of new transmission, including "merchant" transmission primarily serving new resources. Finally, new renewable resources and technologies, including wave and tidal current power production, low temperature and engineered geothermal resources, dedicated energy crops, and more efficient biomass technologies need to be developed.

New fossil generation: Even with aggressive conservation measures and an expanded supply of renewable resources, new, lower-carbon fossil generation may be the most cost-effective source of baseload power. Moreover, gas turbines may be needed to augment the supply of integration services for intermittent renewable resources. Improving the efficiency of conventional gas turbine and pulverized-coal power plants, and commercializing coal gasification and other advanced coal technologies will extend fuel supplies and lower CO2 production at the source.

Carbon capture and sequestration: CO2 capture technology suitable for coal gasification plants is commercially available. However, while technically feasible, CO2 capture for conventional and advanced coal-steam plants and gas turbine plants is at the early demonstration stage. Development and commercialization of CO2 capture technology for all forms of fossil generation need to be accelerated to provide options for both new and retrofit applications.

Bulk CO2 transportation and sequestration has been demonstrated for depleted oil and gas reservoirs. While some oil and gas reservoirs are present in Montana, a greater potential in the Northwest are the basalt flows of the Columbia Basin and Snake River Plain. Additional Northwest potential may be available in deep coal seams, carbonate saline aquifers, oceanic storage, and soil carbon sequestration in croplands, grazing lands, and forests. Work needs to proceed on investigating and field-testing promising sequestration options for the Northwest.

New nuclear generation: A new generation of nuclear plants could provide bulk quantities of carbon-free baseload power. Approximately 30 new nuclear units are proposed for construction in the United States. The license application for the first two has recently been filed with the Nuclear Regulatory Commission and license applications for additional units are expected in 2008. While the first new units completed are likely to be located in the Southeast (a region with less favorable renewable resource potential than the Northwest) and not be completed until 2014-15, new nuclear plants may become attractive to the Northwest once new units are successfully operating and resolution of the spent fuel disposal issue is achieved.

Appendix A: Methodology and Analytical Issues

The CO2 production of each scenario was forecast using the AURORAxmp™ Electric Market Model. Though primarily used to forecast wholesale electricity prices, AURORA is also capable of forecasting pollutant emissions and CO2 production resulting from system operation. AURORA forecasts power prices by simulating the economic dispatch of individual generating units as needed to meet system load. Fuel consumption is tracked because fuel prices are a major component of the variable cost of electricity production with which plant dispatch is evaluated and power prices determined.

CO2 production was calculated using the following emission factors: natural gas 117 lb/MMBtu, fuel oil 166 lb/MMBtu, coal 212 lb/MMBtu, and petroleum coke 225 lb/MMBtu. Complete conversion of fuel carbon to CO2 was assumed. Biomass fuels, including municipal solid waste, are assumed to produce no net CO2. While some of the combustible content of municipal solid waste fuels is of petroleum or non-closed carbon cycle derivation, the small consumption of municipal solid waste for power production in the

Northwest has a negligible effect on net CO_2 production. The CO_2 output of fossil-fueled cogeneration units is based on "fuel charged to power" heat rates—the portion of fuel consumption attributable to electricity production.

With the exception of a sensitivity analysis on water conditions, described later, this work was based on 50-year average hydropower conditions, the medium-case fuel price forecasts, and the medium-case load growth forecasts of the Fifth Power Plan. As a result, the CO_2 production forecasts are representative of long-term averages (to the extent that forecast fuel prices and demand are realized). Actual CO_2 production will vary from the average depending on hydropower conditions, actual fuel prices, and actual loads. As illustrated earlier in Figure 2, CO_2 production is sensitive to hydropower conditions, including runoff patterns. In general, hydropower displaces more thermal energy in good water years than in poor. Heavy spring runoff may displace coal-fired power plants during light springtime load periods, whereas delayed runoff may displace natural gas combined-cycle plants during heavier early summer loads. While economically beneficial because of the higher cost of natural gas, the later runoff would have less impact on CO_2 production because of the lower carbon content of natural gas and the higher thermal efficiency of combined-cycle plants.

A question has been raised regarding the symmetry of the incremental effects on CO_2 production of good and poor hydropower years of equal probability. If incremental CO_2 production effects are not symmetrical, the estimates reported here may be biased, as they are based on average water conditions. A comparable effect has been observed, and is adjusted for, in the Council's electricity price forecasting. While time did not permit comprehensive testing, a limited comparison of forecast CO_2 production in a very good water year to that of a very poor water year indicated a slight increase in the incremental CO_2 production for the poor water year compared to the good water year. While further analysis would be required to confirm the consistency and magnitude of this effect, if true, the CO_2 production estimates reported in this paper would tend to be slightly low.

The geographic scope of the analysis is the WECC interconnected system. Northwest resource development and operational decisions result in operational effects outside the Northwest because of transmission interconnections and Westwide markets. For this reason, CO_2 production results are reported on a WECC basis. "Northwest" results, where reported, include the CO_2 production of units physically located within the four Northwest states, plus the production from large thermal units outside the region dedicated to serving Northwest loads. These include the Jim Bridger plant in Wyoming and the Idaho Power share of the North Valmy plant in Nevada.

The net changes in CO_2 production estimated in this study are the direct effects of power plant fuel consumption. Secondary impacts, not assessed here, may be present (e.g., CO_2 from diesel oil combustion for the rail transportation of additional coal).

Price elasticity may result in reduction of demand due to higher prices caused by carbon taxes, higher-cost low carbon resources, cost of CO_2 allocations, or other factors associated with climate change and policies addressing climate change. While the evaluation of this is beyond the scope of the current study, price elasticity will be considered in the Sixth Power Plan.

California, Oregon, and Washington have adopted policies prohibiting the long-term acquisition by utilities of resources or resource output where the associated CO_2 production exceeds certain defined levels (generally exceeding the CO_2 production of a natural gas-fired combined-cycle plant). Partial account of these carbon content policies is included in current analysis by permitting no new conventional coal plants to be located in California, Oregon or Washington when using the AURORAxmp capacity expansion feature. However, because AURORAxmp does not permit differentiation by resource type of economic inter-regional transfers, there appears to be no effective method of modeling carbon content policies.

Sufficient simple or combined-cycle gas turbine capacity was added in each scenario to maintain the pilot capacity reserve targets of the Resource Adequacy Forum. (The capacity value of wind power was set at 15 percent for these assessments.) This gas turbine capacity would also provide "system flexibility" suitable for integrating intermittent resources. However, it will not be possible to accurately estimate the amount of flexibility augmentation needed to accommodate the intermittent resources of these portfolios until the capability of the existing system to provide intermittent resource integration is better understood. Estimates of the intermittent resource integration capability of the existing system are being refined as part of the Northwest Wind Integration Action Plan. The needed capacity composition of future resource portfolios can be refined as better estimates of the capabilities of the existing system (and likely flexibility demands of future intermittent resources) become available. This information may also support estimates of the likely CO2 production resulting from possible operation of fossil capacity for intermittent resource integration purposes.

Appendix B

	Conservation (aMW)	Coal (MW)	Gas (MW)	Hydro	Wind (MW)	Other (MW)
2005	96		178 (SC)		300	(26) Oil
2006	136	109 (PC)	47 (SC)	14 Hyd (26) Hyd	487	10 Geo 12 Bio
2007	139		745 (CC)	2 Hyd (29) Hyd	440	20 Bio (32) Oil
2008	147		650 (CC)	(23) Hyd		
2009	150			(23) Hyd		
2010	159			(23) Hyd		
2011	161			(23) Hyd	100	
2012	169			(23) Hyd	900	
2013	172			(23) Hyd	400	
2014	176			(23) Hyd	600	
2015	378			(23) Hyd	300	
2016	185	425 (IGCC)		(23) Hyd	1200	
2017	105			(23) Hyd	600	
2018	93			(23) Hyd	400	
2019	89		184 (SC)	(23) Hyd	200	
2020	86		610 (CC)	(23) Hyd	100	
2021	85		644 (SC)	(23) Hyd	300	
2022	84			(23) Hyd	100	
2023	86		276 (SC)	(23) Hyd	100	
2024	85		276 (SC)	(23) Hyd	900	

Table B1: Pacific Northwest resource development schedule for the base case (MW)[15]

[15] Values in brackets are retirements.

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