Biennial Assessment of the Fifth Power Plan

Gas Turbine Power Plant Planning Assumptions

October 17, 2006

Simple- and combined-cycle gas turbine power plants fuelled by natural gas are among the bulk power generating technologies considered in the portfolio analysis of the Fifth Power Plan. The favored bulk power generating technology of the 1990s and early 2000s, natural gas combined-cycle power plants comprise about 11 percent (5914 megawatts) of Northwest generating capacity. Simple-cycle units, valued for provision of system reliability, regulation, load following and in the Northwest, hydro firming, comprise about 3 percent (1654 megawatts) of generating capacity. Most of the combined-cycle capacity was completed between 1995 and 2004 when the combination of low natural gas prices, and reliable, low-emission and efficient gas turbine technology made combined-cycle gas turbine power plants the "resource of choice". Higher natural gas prices since 2001 have reduced the attractiveness of bulk power generation using natural gas. Construction of only one large combined-cycle project has been initiated since 2001. That plant is the Port Westward project, a 399-megawatt project of Portland General Electric, located near Clatskanie, Oregon, scheduled for completion in 2007. That plant employs a higher-efficiency "G-class" gas turbine to help offset high natural gas costs.

The resource portfolio of the Fifth Power Plan includes additional gas-fired power plants following 2018. Up to 800 megawatts of additional simple-cycle capacity and 1220 megawatts of combined-cycle capacity may be needed by the end of the planning period. Because of established technology and the relatively short time required to site and permit these types of plants, no actions regarding these resources were called for in the 5-year action plan.

Technology and Applications

The two basic classes of gas turbines are aeroderivative machines and industrial machines (also called "frame" or "heavy duty" turbines). Aeroderivative turbines, as the name suggests, are derived from the gas turbine engines used for aircraft. They are characterized by light weight, relatively high efficiency, quick startup, rapid ramp rates and ease of maintenance. Aeroderivative turbines tend to be more costly than industrial machines because of more severe operating conditions and more expensive materials. Industrial gas turbines are designed for extended high output duty. They are characterized by heavier components, somewhat lower efficiency, slower startup time, slower ramp rates and more complex maintenance procedures.

Gas turbines for electricity generation applications are employed in two principal configurations. Simple-cycle units consist of a gas turbine generator and appurtenant equipment. The hot turbine exhaust is discharged to the atmosphere, limiting the efficiency of these units to about 36 percent. Combined-cycle units include a heat recovery steam generator on the exhaust to recover otherwise wasted energy. Steam from the heat recovery steam generator powers an additional steam turbine, providing extra electric power from the same amount of fuel as a comparable simple-cycle unit. Combined-cycle efficiencies range to about 50 percent. In addition, the steam generator of combined-cycle units can be fitted with fuel burners ("duct firing") to boost peak power output. Most combined-cycle plants employ industrial gas turbines.

Because of their higher efficiency, combined-cycle plants are used for base and intermediate load power generation. Simple-cycle units (and the duct firing section of combined-cycle units) are used to meet peak period loads and to provide ancillary services such as frequency regulation and load following where flexibility is more important than efficiency. Industrial simple-cycle machines are suited to longer duration peaks whereas aeroderivative simple-cycle machines are better suited to short duration peaks, short-term load following and frequency regulation.

A new gas turbine configuration has been introduced to production since development of the Fifth Power Plan. The General Electric 100 megawatt LMS100™ simple-cycle gas turbine incorporates an external intercooler between the low-pressure and high-pressure air compression stages. The intercooler cools and increases the density of air entering the high-pressure compressor, allowing a higher compression ratio to be achieved with less energy. This results in higher thermal efficiency over a wider load range and lower sensitivity to high ambient air temperatures. Basin Electric's Groton Generation Station, the first North American project using the LMS100, was commissioned in July 2006.

Fifth Power Plan planning assumptions for simple- and combined-cycle gas turbine power plants are shown in the following table. Also shown are published data for the intercooled LMS100. The cost of the LMS100 plant is based on the announced cost of the Basin Electric Groton plant. This is a first of a kind installation and may not be representative of future plant costs because of possible first-of-a-kind discounts and potential design and production economies.

	5th Plan Aeroderivative Simple-cycle	**5th Plan Industrial Simple-cycle**	**5th Plan Combined-cycle[1]**	**Intercooled Simple-cycle (LMS100™)**
Unit capacity (MW)[2]	2x47	2x80	540/70	96
Heat Rate[3] (Btu/kWh)	9650	10240	6710/9060	8430
Efficiency (%)	35	33	51/38	41
Cold Startup (min)	8	20	180	10
Capital cost ($/kW)[4]	$673	$420	$586/$250	$708[5]

Assessment of Cost and Performance Assumptions

[1] First value is combined-cycle increment; second value is duct firing increment.
[2] ISO, new and clean, derated for inlet and exhaust losses.
[3] ISO, higher heating value, new and clean.
[4] Overnight cost, 2006 dollars for 2006 order.
[5] Estimated overnight cost of Basin Electric Groton plant using Council financing assumptions.

The most significant factors affecting the cost-effectiveness of natural gas power plants are the cost of natural gas (assessed elsewhere), capital cost and thermal efficiency. Capital costs are important for all plants, efficiency is more important for combined-cycle plants.

Capital cost of aeroderivative simple-cycle gas turbine power plants

The Fifth Power Plan cost assumptions for aeroderivative simple-cycle gas turbines are compared in Figure 1 to announced project costs taken from a data base maintained by the Council, as well as budgetary planning estimates published in *Gas Turbine World*. The horizontal axis represents the year of equipment order. The vertical axis represents "overnight" capital cost (2006 dollars). "Overnight" cost is the total construction cost less costs of financing, escalation and interest during construction. The "Aero project" series (triangles) are the estimated overnight costs of projects constructed in the WECC region for which costs have been announced. Announced capital costs are assumed to be total project costs. Overnight costs were calculated from these using the Council's generic financing assumptions for the type of project developer. The single unit project costs were increased by 10 percent for consistency with Fifth Plan assumptions. The cyclical nature of the market is evident. Prices (and number of projects) increased through 2002 (2003 service), as a result of the energy crisis and peak load growth. The market subsequently collapsed and prices and number of projects declined. The higher cost ($737/kW) of the most recent plant suggests the possible effects of recent increases in materials cost.

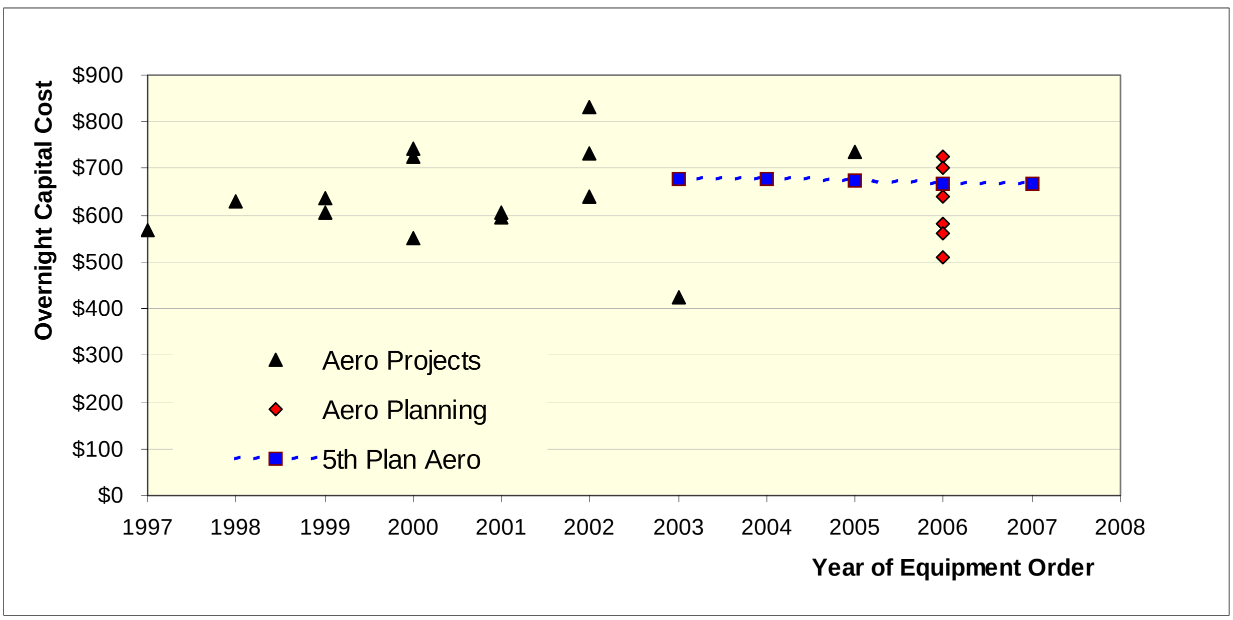

Figure 1: Simple-cycle aeroderivative gas turbine power plant capital cost estimates

The "Aero planning" series (diamonds) are based on equipment list prices reported in the *Gas Turbine World 2006 Handbook* and rule-of-thumb balance-of-plant costs. Costs range from $511 to $727/kW.

The Fifth Plan cost estimates are shown as box points along the dashed line. They slowly decline in real terms under the assumption that continuing technical development should result in declining capital cost. The Fifth Plan cost is well within the *Gas Turbine World* planning range though slightly lower than the cost of the most recent WECC project. The equipment prices upon which the *Gas Turbine World* series are based are characterized as representing a recovering market, and as such could be expected to be lower than the equilibrium market price estimates of the power plan. The Fifth Plan assumptions appear to remain reasonably representative.

Capital cost of industrial simple-cycle gas turbine power plants

The Fifth Power Plan cost estimates for representative industrial simple-cycle gas turbines are compared in Figure 2 to historical project costs and budgetary planning estimates derived from vendor list prices. As in Figure 1, the horizontal axis represents the year of equipment order and the vertical axis represents overnight capital cost. The "Frame project" series (triangles) are the estimated overnight costs of projects constructed in the WECC region for which costs have been announced. Overnight costs were estimated as described for aeroderivative units. A cyclical market is strongly evident. Unlike the aeroderivative market, the market for industrial turbines appears not to have recovered from the post-energy crisis collapse. Despite rising materials costs, the cost of industrial gas turbine equipment (representing half of the total plant cost, or more) has remained low because of the glut of surplus industrial turbines, many from cancelled combined-cycle projects.

The "Frame planning" series (diamonds) are based on current vendor list prices as reported in the *Gas Turbine World 2006 Handbook* and rule-of-thumb balance-of-plant costs. Estimated overnight project costs range from $360 to $620/kW.

The Fifth Plan assumptions (boxes along the dashed line) are within the *Gas Turbine World* planning range and appear to represent an equilibrium market, as intended. However, because most new capacity, by definition, is developed in a seller's market, consideration might be given in future power plants to correlating capital costs to need for new capacity.

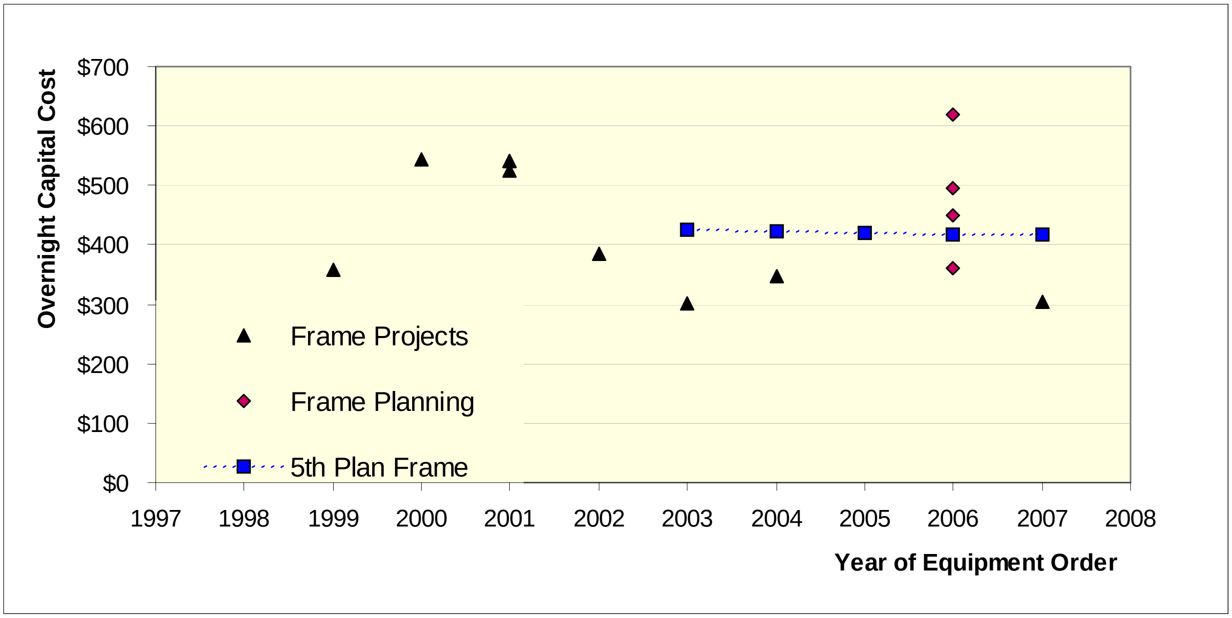

Figure 2: Simple-cycle industrial gas turbine power plant capital cost estimates

Capital cost of combined-cycle gas turbine power plants

The Fifth Power Plan cost estimates for representative combined-cycle gas turbine power plants are compared in Figure 3 to historical project costs. *Gas Turbine World* budgetary planning estimates do not appear in this comparison because of the larger sample of available actual project costs, and because of the greater diversity of combined-cycle plant configurations make simple rule-of-thumb estimates of balance-of-plant costs less feasible. As in Figures 1 and 2, the vertical axis represents overnight capital cost. Here, however, the horizontal axis represents the year of service. The "Combined-cycle project" series (triangles) are the estimated overnight costs of combined-cycle projects constructed in the WECC region for which costs have been announced. Overnight costs were estimated as described for simple-cycle units. Unlike simple-cycle power plants, there is no evidence of a post-energy crisis decline in the cost of combined-cycle plants. This may be because few, if any combined-cycle plants have used equipment acquired through the secondary market. Moreover, the increased balance of plant complexity results in greater sensitivity to recent escalation in the prices of steel, copper, concrete and other materials.

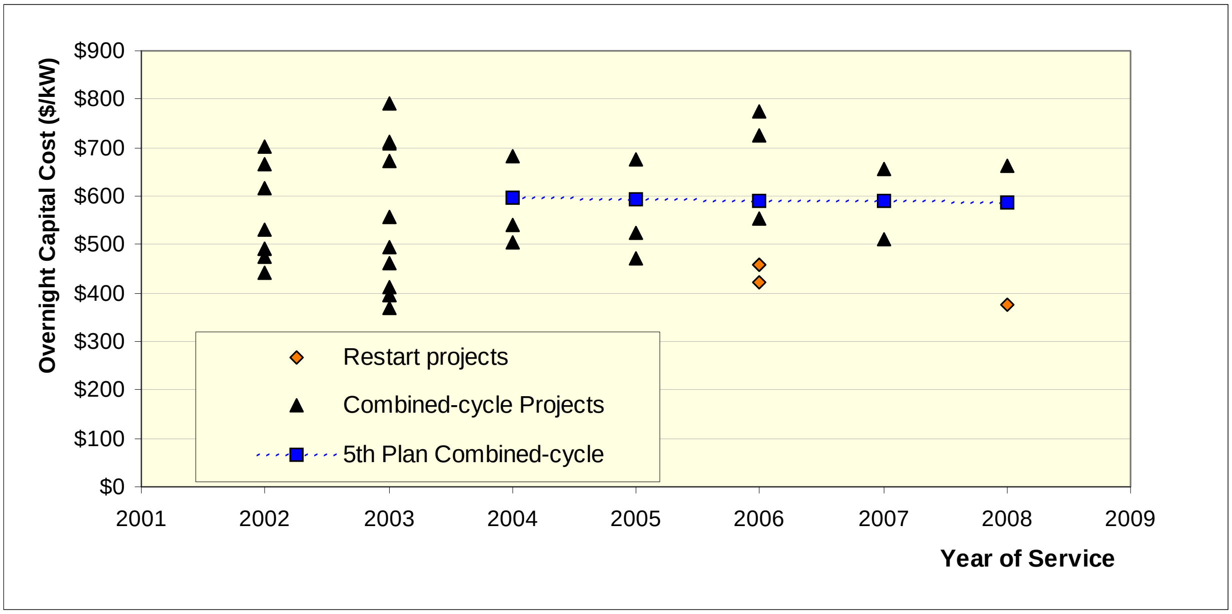

Figure 3: Combined-cycle gas turbine power plant capital cost estimates

The Fifth Plan assumptions (box points along the dashed line) slowly decline in real terms under the assumption that continuing technical development should result in declining capital cost. The Fifth Plan cost estimates continue to adequately represent the real-world cost of constructing new combined-cycle plants.

The "restart project" series (diamonds) in the lower right of Figure 3, ranging from $376 to $457/kW, represent three projects for which construction was restarted after a prolonged period of suspension. While the cost of completing suspended projects will vary depending upon the extent to which the project was completed prior to suspension and other factors, these values provide a sense of the likely cost of completing suspended projects in the Northwest.

Efficiency of combined-cycle gas turbine power plants

The Fifth Power Plan assumptions for the heat rate of combined-cycle gas turbine power plants are compared in Figure 4 to the estimated heat rates of recently constructed combined-cycle plants. The vertical axis represents heat rate (the engineering measure of plant efficiency) in Btu/kWh[6] and the horizontal axis represents the year of service. The "Combined-cycle project" series (triangles) are the estimated heat rates for recently constructed combined-cycle projects in the WECC region. Because the actual heat rates of power plants are rarely published because of proprietary concerns, the heat rates shown in the figure are equipment vendor's published heat rates for the type and configuration of plant equipment. Information regarding equipment is

[6] Heat rate values used here are based on higher fuel heating value consistent with the units used in the Fifth Power Plan.

often available and maintained in the Council's gas turbine power plant database. The heat rates are derated to represent lifecycle values for consistency with Fifth Plan assumptions. Because heat rates vary significantly with plant size, the sample is limited to plants of the same size class (Frame 7) as the plant on which the Fifth Plan assumptions are based The lower value appearing in 2008 is for the Inland Empire power plant in California, first North American application of advanced "H-Class" technology.

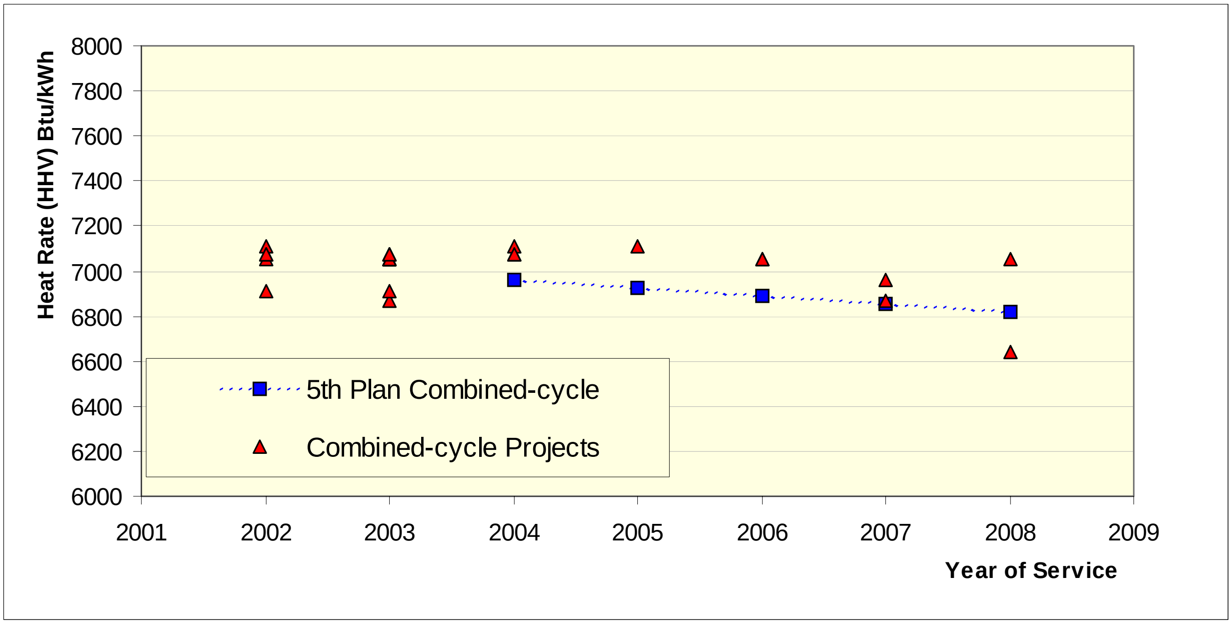

Figure 4: Combined-cycle gas turbine power plant efficiency estimates

The Fifth Plan heat rate estimates (boxes along the dashed line) slowly decline under the assumption that continuing technical development should result in improving efficiency (declining heat rate represents improving efficiency). The Fifth Plan estimates appear to adequately represent the efficiency of new combined-cycle plants.

Conclusions

This assessment of the key non-fuel planning assumptions of the Fifth Power Plan regarding new gas turbine power plants indicates these assumptions continue to be representative of real-world experience. This finding, together with the conclusion of the biennial assessment of the natural gas price forecast suggests that the role of natural gas fuelled simple and combined-cycle power plants for bulk power generation in the Fifth Power Plan is unlikely to significantly change.

Because the earliest need for gas turbine plants in the Fifth Power Plan portfolio lies well beyond the period of the action plan, no actions pertaining to the possible bulk power generation role of these resources were included in the action plan. Other factors, however, might result in a need for these resources in the nearer term. These include a possible need for capacity to maintain system reliability and possible need for additional system regulation and load following capability for the integration of wind power. The former will be better understood once system reliability criteria are established; the latter is being addressed in the regional wind integration project.

Another factor that might affect the real-world role of gas-fired gas turbine power plants in the Northwest is the presence of over 900 megawatts of combined-cycle plant on which construction was suspended following the collapse of power prices subsequent to the 2000-01 energy crisis. Recent experience in California indicates that these projects might be completed at two-thirds to three-quarters the cost of a greenfield plant. This would reduce the cost of energy from a new combined cycle by about 5%, possibly enough to make completion of one of these projects attractive in the face of the cost increases being experienced for other new generating resources.

A final conclusion results from cyclical market evident here for simple-cycle units and observed for windpower and other generating resources. The generating resource capital cost assumptions of the Fifth Power Plan and earlier plans are based on equilibrium market conditions - neither a buyer's nor a seller's market. Historically, however, most generating capacity is acquired during buyer's market conditions, resulting in higher costs than those forecast for equilibrium markets. The cost-effectiveness values of different resources are not equally sensitive to these fluctuations. Future portfolio analyses might consider possible correlations between electricity market activity and resource capital costs.

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