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Is Nuclear Power Viable in Russia?

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Is Nuclear Power Viable in Russia?

A careful analysis casts doubt on the economic viability of expanded nuclear generation capacity in the Russian homeland. Given Russia's vast reserves of natural gas and modern turbine generation technology, it seems unlikely that nuclear power will emerge as the low-cost generation alternative.

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I. Introduction

Nuclear power is back in the spotlight both domestically and internationally. In the U.S. at the height of the natural gas price bubble, there were calls in the U.S. for reassessment of nuclear power as an alternative to fossil fuel generation. Currently, the Department of Energy is moving ahead on plans to convert weapons-grade plutonium into fuel to be burned in modified, existing reactors. This obviously represents a commitment to keep these reactors in operation into the foreseeable future.

Internationally, many countries are engaged in expansion of their nuclear generation capacities. India, China, Iran, and most importantly, Russia, are all engaged in construction projects.[1] Russia holds particular importance because it is a key player in the construction projects of these other countries.

As a consequence of this renewed interest in nuclear power it seems appropriate to reexamine the economics of nuclear power. This articles does so using data and cost estimates from various sources, including information from the Federal Energy Regulatory Commission

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Form 1 for U.S. utilities and a study by the Organization for Economic Cooperation and Development (OECD) of the cost of electricity across countries for all types of generation.[2]

Interest is focused especially on Russia because Russia is engaged in major restructuring efforts in both the electric and gas industries. Russian president Vladimir Putin has stated explicitly that the goal of the deregulators is to revamp the energy sector in order to attract direct foreign investment in electric generation capacity and in natural gas. The Ministry of Atomic Energy (Minatom) has proclaimed that it will be a major force in this process. Minatom has set the goal of expanding nuclear generation from around 15 to 20 percent of electricity production in Russia over the next 10 years. Moreover, it anticipates achieving this goal by also attracting direct foreign investment. In this article we will analyze the likelihood of Minatom's success.

II. Background

The analysis presented here projects the capital and operating expenditures of nuclear power plants as well as the capital and operating costs of natural gas, combined-cycle generators. The focus is placed on this comparison because these are likely to be the ultimate investment alternatives, especially for private foreign capital. Estimates both for Russia and the U.S. are presented for purposes of comparison. The estimates are given in 2001 U.S. dollars.[3]

The forecasts presented here for electric generation costs are an amalgamation of estimates, facts, and assumptions taken from several sources. The estimates start with an OECD study that projected the cost of electricity generation using various technologies and factoring differing international conditions.[4] The study is comprehensive and has been updated several times. Some of the assumptions used by the OECD are modified based on data obtained from U.S. sources, and the OECD assumptions are cross checked from other international sources.[5] Several of the estimates are corroborated by statements from Minatom officials.

Putin has stated explicitly that the goal of deregulators is to revamp the energy sector in order to attract direct foreign investment in electric generation and natural gas.

Estimates of the cost of electricity generation are broken into capital and operating costs. Operating costs are further broken into fuel and non-fuel components. The cost figures are expressed as cents per kilowatt-hour (¢/kWh). These costs can be thought of as the tariffs that the owner of a generator would need to receive over the life of the facility in order to make the project a break-even venture at the start of construction. In other words, this is the wholesale price of electricity necessary to cover the construction and operating costs of a generator based on the expected life and annual output of that unit. This is called "levelized cost" in the OECD study.

A. Generic assumptions

There are three assumptions that affect cost in a generic way. They are the discount rate used to assess the project, the expected life of the generation facility, and load factor under which the generator will operate. The OECD study used two different discount rates, 5 and 10 percent. The 10 percent discount rate is used here, for both the U.S. and Russian estimates. Even a rate of 10 percent for Russia is arguably too low in the context of attracting private investment. Real rates of return of 15 percent or more are likely required to attract private capital.[6] However, varying the discount rate between 10 and 15 percent does not dramatically affect the conclusions.

The operating life and load factor assumptions used here are somewhat different for the two different technologies.[7] Based on analysis of the U.S. data and

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discussion with U.S. electricity experts, the useful life of natural gas turbines is projected to be 25 years and the capacity utilization to be 75 percent. For nuclear units, based on the international experience, nuclear generators on average are being retired or substantially refitted after 30 years. Also, based on the U.S. operating data, the capacity utilization of nuclear units is estimated to be 79 percent.[8] While Russian nuclear units in the past have not been achieving this percentage, one of the goals of Minatom is to increase capacity utilization in this dimension.[9]

III. Nuclear Generation

A. Capital cost

The capital cost of electric generation units is comprised of land acquisition and site preparation, equipment and installation, interest cost during construction, and for nuclear plants decommissioning costs. The OECD study estimates nuclear power capital cost to be $2,448/kW in Russia and $2,064/kW in the U.S. These capital costs are the full cost of the plant at the time it is connected to the load plus discounted future cost of decommissioning, which generally amounts to around 2 percent of the total. The length of the construction period along with the assumed discount rate determines the construction interest cost. The typical construction time for a nuclear unit is five to nine years.[10] The OECD study assumes construction interest to be 15 percent of total cost in the U.S. and 25 percent in Russia. This is based on a shorter project construction schedule in the U.S. compared with Russia.

The forecasted nuclear capital cost for the U.S. can be compared to the actual experience of U.S. electric utilities.

One of the goals of Minatom is to increase capacity utilization of Russian nuclear units.

Capital cost expenditures are available for existing plants on FERC Form 1 distributed by the U.S. Department of Energy. Data were compiled on nuclear plants built in the U.S. between 1965 and 1972 that are in the lower 25 percentile of capital costs for all nuclear plants currently operating in the U.S. This gives a capital cost estimate based on the best-case experience in the U.S. The average capital cost of these plants stated in current dollars is $3,722/kW. This is substantially higher than the OECD estimate.[11]

For both Russia and the U.S. the OECD estimate is based on a 604 MW unit. This estimate is scaled up to 1,000 MW, which is the size of the standard unit being built by Russia today. Construction cost is related with the number and size of units to be built on a site. ''The cost reduction is calculated to be 10 percent for a site with two units and 20 percent for a site having four units provided that the construction interval is less than two years.''[12] A similar phenomenon exists for scale effects in the size of the unit. An average cost elasticity of −0.2 is used to project the OECD cost estimates to 1,000 MW units. That is, for each 10 percent increase in size, capital cost per MW goes down by 2 percent. This is roughly equal to the scale factors observed in U.S. construction costs across all types of generators. Using this scale elasticity gives a capital cost estimate that is 10 percent lower than the OECD estimate per kilowatt of capacity.

Thus, the full capital cost for a 1,000 MW Russian nuclear power plant is estimated to be $2.213 billion. Amortizing this cost over 30 years at 10 percent interest and dividing by the number of kilowatt-hours that the plant is expected to produce each year gives a unit cost attributable to capital of 3.76 ¢/kWh. This is shown in **Table 1**.

The nuclear power capital cost figure shown in Table 1 for the U.S. is based on the OECD estimate modified only for plant life, load factor, and price level. This estimate is presented in

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Table 1: Overview of Power Plant Construction & Operating Costs (¢/kWh)

	Gas	Nuclear	Russia	United States
Assumptions				
Life (years)	25	30		
Capacity utilization (percent)	75	79		
Interest rate (percent)	10	10		
Combined-cycle natural gas				
Capital cost			1.58	0.96
Operation & maintenance cost excluding fuel			0.49	0.37
Fuel cost			2.39	1.79
Total			4.46	3.12
Nuclear				
Capital cost			3.69	3.46
Operation & maintenance cost including fuel			1.02	1.68
Total			4.71	5.14

Notes: All costs are in ¢/kWh. Estimates are based on adjustments to the OECD study of the cost of electric generation internationally. Capital cost per unit are the discounted cash flow over expected life and capacity utilization necessary to pay back construction, interest, contingency, and decommissioning expenditures. Scaling Russian nuclear capital costs from 604 to 1,000 MW lowers the unit cost per kilowatt of capacity by 10 percent. Natural gas fuel costs for gas turbines are based on thermal efficiency of 0.55, and gas prices of $2.98/Mcf in the U.S. Gas price in baseline case in Russia is $3.96/Mcf.

spite of the fact that it is substantially below the best-case prior U.S. experience and is based on a very short construction schedule. The unit capital cost estimate is 3.46 ¢/kWh. Using the historical experience in the U.S. for the lowest-cost plants, the unit capital cost estimate is 6.24 ¢/kWh.

B. Operating cost

Table 1 reports the OECD estimates of fuel and non-fuel operation and maintenance (O&M) costs for nuclear power plants. These estimates are modified to account for assumptions made here concerning plant life and capacity utilization, and they are inflated to the 2001 price level. Based on the OECD numbers, forecast O&M costs for U.S. power plants is 1.6 ¢/kWh.

In order to corroborate these estimates, two different sources of U.S. data on nuclear power plant operating expenses were checked. From a sample drawn from FERC Form 1 data for 1996, total O&M costs including fuel cost were estimated as a function of capacity utilization. Operating costs per unit of output are a declining function of capacity utilization. The forecast value of O&M costs per kWh for 79 percent capacity utilization based on the 1996 experience of U.S. utilities is 2.08 ¢/kWh in 2001 prices. This is over 25 percent higher than the OECD estimate. Another cross check of these estimates comes from the Nuclear Energy Institute (NEI) for U.S. firms between 1998 and 2000.[13] NEI reports a cost range from 1.27 ¢/kWh for the first cost quartile to 2.46 ¢/kWh for the last quartile. Restating in 2001 price level, the median is 1.68 ¢/kWh and the average is 1.80 ¢/kWh.

From this wide range of estimates, the median estimate from NEI is used, which is 1.68 ¢/kWh. The NEI estimate was chosen because it represents the most recent actual experience in the U.S. The median estimate is used because it represents the operating experience that is closest to the assumed forecast load factor.

For Russia, the OECD estimate for nuclear O&M cost is used. It is 1.02 ¢/kWh. This estimate is supported by statements from Russian nuclear officials. In 2001, an EGK official stated that the average operating cost of Russian nuclear plants is around 1.18 ¢/kWh.[14] The difference in these two numbers can be attributed to a load factor effect. Load factors for nuclear plants in Russia today are around 65 percent and the baseline estimates assume a load factor of 79 percent. Thus, the OECD estimate for O&M cost is used in Table 1. However, the current Russian experience is reported as well

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in the cost scenarios shown in Table 3.

IV. Natural Gas

The capital cost of natural gas electric generators is estimated in the OECD study to be $847/kW in Russia and $510/kW in the U.S. The base cost of equipment and installation is $710/kW and $422/kW, respectively. These are in 1996 prices.

For combined-cycle natural gas units built in the U.S., the capital cost assumptions used in the OECD can be independently corroborated.[15] The OECD estimate of capital cost for gas units for Russia is higher than that for the U.S., but this can be reasonably explained based on the fact that the U.S. is the world leader in natural-gas turbine development and production. Nonetheless, it is also reasonable to expect that competition internationally is likely to push the capital cost of natural gas turbines in Russia down toward the cost in the U.S.

For gas turbines, fuel is the largest cost share. Hence, it is useful to separate fuel and non-fuel O&M for gas turbine generation. The OECD O&M estimates for gas turbines were cross checked against the FERC Form 1 data for combined-cycle turbines, regular turbines, and conventional boiler units. In 1996, there were not many combined-cycle units in operation by regulated utilities in the U.S., but the Form 1 cost data that is available is fairly close to the OECD estimates for the U.S.[16] The basis for OECD's higher non-fuel O&M costs in Russia compared to the U.S. is not obvious.

The OECD study makes various assumptions about fuel cost escalation over the life of the plant and discounts those changes back to the present. This approach is unsatisfying because there is no real evidence to suggest that natural gas prices will systematically increase in the future. Especially in Russia, the main uncertainty is how close the domestic price will come to the export price. The approach taken here is simply to make different assumptions about the price of natural gas at start-up and hold this constant over the life of the plant. Various scenarios about natural gas prices and costs calculations for the fuel cost of natural gas electric generation are given in **Table 2**.

The baseline case in Russia is built on the assumption that deregulation of the natural gas industry will drive up the domestic price of gas to equal the export price. The Energy Information Administration reports that the export price of natural gas from Russia is approximately $4/Mcf.[17] This compares to approximately $3/Mcf currently in the U.S. The domestic price in Russia is one-tenth of the export price and it is this domestic price that domestic electric generators are now paying. However, deregulation of the natural gas industry is

Table 2: Fuel Cost Component of Natural Gas Electric Generation

		Natural Gas Price	Thermal Efficiency (Percent)	Electricity Fuel Cost (¢/kWh)
Alternative assumptions about fuel prices and thermal efficiencies				
Russia	Export price (2001)	$3.96/Mcf	55	2.39
	Domestic price (2001)	$.42/Mcf	55	0.26
	Mid-range price	$2.19/Mcf	55	0.26
	Domestic price (2001)	$.42/Mcf	21	0.66
United States	Spot price in November 2001	$2.98/Mcf	55	1.80
	Spot price in November 2001	$2.98/Mcf	60	1.65
	High price in 2000	$10.00/Mcf	55	5.69

Notes: Mid-range price is the average of the export and domestic prices for 2001. Conversions: Btu/kWh = 3,412; there are 1,030 Btu's per cubic foot of natural gas. Thermal efficiency is rate at which an electric generator converts fuel energy into electric energy.

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unfolding and it will certainly drive up the price of gas, especially the gas prices paid by electric generators.

Table 2 shows the variation in the fuel cost component of gas turbine electricity generation. Clearly, there is substantial variation. This is strikingly evident by looking at the variation in fuel costs per kilowatt-hour derived from the natural gas price fluctuations experienced in the U.S. over the 2000–01 period. These natural gas price fluctuations translated directly into electricity prices and were the cause of great consternation throughout the U.S. Price differentials of similar percentage magnitude exist in Russia between the domestic and export prices and the implied effect on electricity prices is likewise dramatic.

Table 2 converts gas prices in dollars per thousand cubic feet into the implied cost per kilowatt-hour of electricity based on the thermal efficiency of the generator. Modern combined-cycle generators have thermal efficiencies of somewhere between 55 and 60 percent.[18] Older-generation units have much lower efficiency ratings. An efficiency rating of 21 percent is used in one scenario for Russia. This is the Low Price/Low Efficiency case. It is intended to reflect the likely fuel cost for the bulk of the gas units currently in operation. The assumed thermal efficiency of 21 percent comes from the lower quartile of conventional oil and gas units operating in the U.S. in 1996.

V. Comparison of Cost Estimates

A quick review of Table 1 shows that the lowest-cost electricity is generated by natural gas turbines in the U.S. These units

have a levelized cost of 3.12 ¢/kWh. This projected cost for the U.S. is roughly consistent with historical experience in wholesale electricity prices over the last several years.

The fuel cost for these plants accounts for approximately two-thirds of the unit cost of output. The U.S. fuel cost component is based on the November 2001 spot price for natural gas in the U.S. and the heat/energy conversion factor (0.55) for the turbine units currently being installed in the U.S.

In Russia, natural-gas electricity generation costs from units similar to the ones being employed in the U.S. is forecast to be 4.49 ¢/kWh. This estimate is constructed by assuming that gas will be priced at the current export price in Russia as shown in Table 2.

The full cost of electricity generation from natural gas units is estimated to be higher in Russia than it is in the U.S. Part of this difference is based on the cost of the turbines themselves. The OECD study assumes the cost of turbines to be 66 percent higher in Russia than the U.S. No doubt this difference existed in 1998 when the OECD study was last updated and may still exist. However, it will disappear over time. One can expect the price of turbines in Russia to fall toward the cost paid by electric generating companies in the U.S. This is especially true if Russia is able to attract foreign investment into the electricity generating industry.

Next, consider the costs for nuclear power. The most important point to note in Table 1 is that the full unit cost of electricity is higher for nuclear-powered generators than for gas turbines in both Russia and in the U.S. Estimates of the cost of nuclear power in the U.S. are shown for comparison purposes only because there are no nuclear power plants currently under construction or in the planning stage in the U.S. The cost disadvantage of nuclear power is greater in the U.S. than in Russia, but it is driven largely by the same consideration. That is, gas turbines are cheap and so is gas.

One other point to note in Table 1 is that the non-fuel O&M

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Table 3: Generation Cost Scenarios for Russia (¢/kWh)

Scenario	Cost
Nuclear	
Baseline	4.71
Poor load factor (65 percent)	4.87
Low capital cost	4.64
O&M only (including fuel; assuming 65 load factor)	1.18
Natural gas	
Baseline—high gas price	4.46
Mid-range gas price	3.40
Low capital cost	3.84
O&M only (including fuel; lowest gas price and lowest efficiency)	1.15

Notes: All costs are in ¢/kWh, 2001 price level. Baseline cases are full cost from Table 1. Low capital cost cases assume Russia can achieve the capital costs estimates applied to the U.S. in both nuclear and gas turbine generation. Mid-range gas price estimate uses the capital and non-fuel O&M for natural gas from Table 1 with the mid-range gas price scenario from Table 2. The O&M only estimate for natural gas uses the current domestic gas price and the estimate of the thermal efficiencies of the existing conventional generators. This fuel price scenario is also shown in Table 2.

costs in Russia are lower for nuclear plants and higher for natural gas turbines than in the U.S.

It is useful to summarize the comparisons most pertinent in anticipating the future of the Russian energy market. **Table 3** shows cost estimates under different assumptions about capital and operating costs.

The cost estimates shown in Table 3 paint an interesting picture. By almost every measure, natural gas turbines are a more economical technology for electricity generation in Russia than nuclear power. In the baseline comparison, nuclear generation is 9 percent higher than the projected cost of gas generation in Russia. If the low-capital-cost scenarios for both nuclear and gas are compared, the gap widens. The low-capital-cost scenarios are based on the assumption that Russia enjoys the same capital cost as the U.S.[19] In both of these scenarios, the assumption is that gas fuel for electric generation is priced at export levels. This assumes that deregulation of the gas market is complete. If deregulation does not fully equalize the domestic and export prices, nuclear generation is put at an even greater disadvantage. In the mid-range gas price scenario, nuclear generation is 43 percent more expensive than electricity from gas-fired turbines.

The operating cost comparison between nuclear power and gas-fired generation are also shown in Table 3. This scenario uses the current domestic gas price and an estimate of the thermal efficiencies of the existing gas-fired generators in Russia. The interesting thing about the O&M comparison is that it gives us a sense of the choice of generation from the current capital stock in Russia.

VI. Conclusions

The analysis presented in this article does not paint a very favorable picture for the economics of nuclear power either in the U.S. or in Russia. Construction of new nuclear power plants is not a serious consideration in the U.S. but it is in Russia. Moreover, Russia is promoting nuclear power initiatives in several other countries worldwide. The analysis presented here casts serious doubt on the economic viability of expanded nuclear generation capacity in the Russian homeland.

Russia's power choices are much like those in the U.S. Russia has vast reserves of natural gas. Given this available fuel supply and modern turbine generation technology, it seems very unlikely that nuclear power will emerge as the low-cost generation alternative. Certainly, nuclear power will be a hard-sell project to private investors even those interested in energy projects in Russia.■

Endnotes:

1. However, at the same time many countries are significantly backing away from nuclear generation. For instance, Germany has declared its intention to shut down all of its nuclear reactors.

2. See Organization for Economic Co-operation and Development (Paris), Nuclear Energy Agency, International Energy Agency, *Projected Costs of Generating Electricity*, 1998.

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3. The OECD study reports the costs in 1996 U.S. dollars. The implicit price deflator is calculated by the U.S. Bureau of Economic Analysis is used to inflate U.S. dollar estimates.

4. The OECD study focuses on ''technologies and plant types that could be commissioned in the respondent countries by 2005–10 and for which they have developed cost estimates'' (p. 15). As a consequence, one can expect their estimate to diverge in many cases from the cost of existing technologies and plant types.The data were obtained by circulating a questionnaire to OECD member countries and non-OECD participant countries through IAEA. ''In addition to numerical data, the questionnaire sought qualitative information such as lists of elements included in the cost estimates and country-specific accounting methodology that may impact cost and thereby explain significant differences among countries in the cost of generating electricity'' (p. 21).

5. Until recently, data on the operation of electric generators in the U.S. was reported to the Federal Energy Regulatory Commission on what was known as Form 1. These data are available for the year 1996 and we use them to estimate the operation and maintenance cost of nuclear and conventional power plants in the U.S. Also, data on the construction of new, non-regulated power plants in the U.S., called merchant plants, were obtained from the Center for Energy Studies at Louisiana State University. These data were used to corroborate the OECD estimates of the cost of new gas-fired combined-cycle turbine generators. Finally, the data on the start-up, production, and shut-down records of all nuclear power plants around the world were examined. These data come from the International Atomic Energy Agency.

6. Real rates of return mean returns on Russian investments designated in inflation-protected U.S. currency denominations. Even absent the currency risks, returns at least as large as 10 percent are necessary to offset both the business and political risks in Russia. Renaissance Capital analysts estimated that an appropriate rate for Russia would be 25 percent. See, *Mosenergo: Solid Prospects Even without Restructuring*, AlfaBank, May 26, 2000, at 8.

7. The OECD study assumed a 40-year plant life and 75 percent capacity utilization for all technologies.

8. In the U.S., the nuclear refuel cycle is longer than one year. Even so, using U.S. data for 1996 it is estimated that each unit is down about 10 percent of its fuel cycle for maintenance, repair, and refueling. When the unit is up and running, variation in consumption causes it to run at less than full capacity. As a result, capacity utilization when running is around 88 percent. Thus, overall capacity utilization is 79 percent.

9. In general, nuclear power, as expected, is more competitive at lower discount rates while low-capital options such as gas-fired plants increase the competitiveness at higher discount rates. Capital-intensive options are more sensitive to load factor variation than low-capital-intensive options.

10. Evelyne Bertel and Geoffrey H. Stevens, *Comparative Costs of Generating Electricity*, OECD Nuclear Energy Agency, France, at 11th Pacific Basin Nuclear Conference (PBNC), Banff, Canada, 1998.

11. It is not clear from where the OECD obtained its information on the cost of nuclear power plant construction for the U.S., since there has been no construction in the U.S. for many years.

12. Ferrucia Ferroni, Hans-Jiirgen Kirchhof, and Juan B. Heredia, *Review of Cost-Reduction Measures for Nuclear Electricity*, Electrowatt Engineering Ltd, Switzerland, PBNC, 1998.

13. See http://www.nei.org/documents/Production_Cost_Quartiles.pdf.

14. EGK Executive Director Yuriy Yakovlev quoted in Russian in Irina Rybalchenko, *EGK Gets Additional Powers*, Moscow Kommersant, Sept. 11, 2001, at 4, claimed that operating costs were 352 rubles/1,000 kWh. At an average exchange rate of 29.94 for 2001, this gives a cost of 1.18 ¢/kWh.

15. Based on data obtained from the Center for Energy Studies, Louisiana State University, for new U.S. merchant plants built in the last several years the capital cost is $500/kW.

16. Combined-cycle units to other units in the U.S. are compared based on capacity utilization and size. Turbines have relatively low O&M costs excluding fuel compared to conventional units. For the average-size combined-cycle unit and at 75 percent capacity utilization, non-fuel O&M cost was 0.39 ¢/kWh. This is about one-third the cost for a coal unit. Adjusting the OECD estimates for an assumed life time of 25 years gives 0.37 ¢/kWh for U.S. and 0.55 ¢/kWh for Russia, which are the values reported in Table 1.

17. *Russia, Restructuring the Gas Sector*, http://www.eia.doe.gov/emeu/cabs/russia.html. These estimates are supported by data reported by the Russian financial press.

18. Thermal efficiencies come from conversations with General Electric Co. engineers. GE is the manufacturer of most commercial turbine generators in the U.S. The thermal efficiency range of 55 to 60 percent is conservative as a forward-looking estimate because GE continues to advance the technology of these machines.

19. Recall that nuclear generation units are higher in Russia than the U.S. largely because of the assumed time of construction. Alternatively, the higher capital cost of gas turbines in Russia is due to the price of equipment. Arguably, it is equally likely that either of these could change favorably for Russia.

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