COMPETITIVENESS OF NUCLEAR ENERGY – AN INTERNATIONAL VIEWPOINT

Nuclear Power Plants for Poland, Warsaw 1-2 June 2006

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Introduction

Economic competitiveness, which always has been a cornerstone in decision making for electricity generation options, has become even more important for investors in liberalised electricity markets. Assessing the relative competitiveness of different options for electricity generation is an essential element of policy making at the governmental level as well as at the level of economic actors from the private sector.

The OECD activities focus on economic and policy analyses in support to policy making in its member country governments. In the electricity sector, OECD studies cover all economic aspects including direct costs of generation, externalities and impact of market mechanisms and policy measures on the relative competitiveness of alternative options.

In this connection, an OECD study [1] published early in 2005 noted some evolution in the ranking of different electricity generation options as compared with results published seven years ago [2]. The main findings from the new study are the enhanced competitiveness of nuclear electricity in countries which rely on this option, the significant increase in the cost of gas-fired electricity owing to gas price rise, and the improved economic performance of wind power in some countries, under favourable conditions.

The study explored the factors responsible for this evolution and identified its key drivers. In particular, it was found that the price volatility of fossil fuels, notably natural gas, along with technical progress enhancing the reliability and availability factor of nuclear power plants have had a significant influence on comparative economic performance of base-load options.

Furthermore, it is expected that, as governments implement progressively policies to address global climate change threat and ensure security of supply, the competitiveness of domestic and low-carbon emission options, such as nuclear power and renewable energy sources, versus fossil fuels – producing carbon dioxide and often imported in OECD countries – will be reinforced.

Framework and scope of the OECD study

The two OECD agencies dealing with energy – the International Energy Agency and the Nuclear Energy Agency – have published a series of studies on the economics of generating electricity. The latest version of the publication – *Projected Costs of Generating Electricity: 2005 Update* – released in early 2005 illustrates the economics of different state-of-art technologies for electricity generation.

Cost data and technical characteristics of the power plants included in the study were provided by 21 countries for more than 130 units, including 27 coal-fired plants, 23 gas-fired plants, 13 nuclear plants, 35 power plants using intermittent renewable energy sources, 24 combined heat and power (CHP) plants using various fuels, and 10 plants based on other fuels or technologies. The technologies and plant types considered were either units under construction or planned that could be commissioned in the respondent countries between 2010 and 2015, or for which they have developed cost estimates,

generally through paper studies or bids. A few countries provided data for units built recently that are representative of state-of-the-art technology.

Costs of generating electricity were calculated using the same methodology for all units in order to provide a fair and transparent basis for comparison of alternative options. The levelised lifetime cost methodology which was adopted is a commonly used approach to estimate costs in the international framework. The main technical and economic assumptions needed to carry out the calculations were chosen in a consensual manner by the group of experts in charge of the study.

A key feature of the levelised cost methodology is to integrate the time value of money through a discount rate. Two discount rates – 5 and 10% real per year – were adopted by the experts as representative of a reasonable range of macroeconomic contexts worldwide. Indeed, except Japan which uses discount rates between 1% and 4% in its national estimates, all participating countries carry out national estimates with discount rates ranging between 5 and 10%.

The costs taken into account in the study include all the elements borne by the electricity generator except taxes and levies on electricity that affect alternative options equally and will, therefore, not discriminate options. Impacts on society of building and operating a power plant are included in the costs to the extent that they are internalised through policy measures. For example, costs of complying with health and environmental protection norms and standards prevailing in each country are reflected in the costs. On the other hand, the costs associated with residual emissions – including greenhouse gases – are not included in the costs calculated in the study because they are not supported directly by electricity producers and consumers but rather by society at large.

Regarding greenhouse gases, the implementation of the Kyoto Protocol, leading to the establishment of policy measures to reduce CO_2 emissions, will internalise progressively the cost of climate change threat. However, at the time of the study, there was no data, or even common expert view, on the likely cost of carbon emissions. Therefore, the issue was addressed in an appendix of the report through a qualitative and parametric approach, as illustrated below in the section on externalities.

The calculated electricity generation costs are bus-bar costs, at the station, and do not include transmission and distribution costs which may in some cases represent a significant part of the total costs of delivered electricity. Those costs could change the economic ranking of alternatives, in particular when comparing distributed generation with grid-connected centralised generation sources and technologies. Therefore, the results from the study do not replace detailed economic analyses to be carried out by investors taking into account specific characteristics of each project and the surrounding economic and technical conditions.

In order to facilitate the presentation and understanding of levelised costs calculated within the study, a series of generic assumptions were agreed upon and applied to all the power plants considered. The generic assumptions – summarised in Table 1 – were selected as representative of average conditions in the participating countries.

The data and cost estimates presented below focus on base-load options, i.e., coal, gas and nuclear power plants which are competing directly in electricity markets. Cost estimates for some intermittent renewable sources and for cogeneration are presented briefly for illustrative purpose but not analysed in detail because they can be compared to base-load option costs only in the context of electricity system analysis.

Table 1. Main generic assumptions adopted in the study

Economic lifetime	40 years (or technical lifetime if <40 years)
Availability factor	85% for coal, gas and nuclear plants
Date of commissioning	1st January 2010
Monetary unit used for cost calculation	National currency unit of 1st July 2003
Monetary unit used for cost presentation*	USD of 1st July 2003
Discount rate (real)	5 and 10% per annum

** Conversion made using the official exchange rate at the reference date*

Cost estimates for coal, gas and nuclear power plants

Coal-fired plants

Twenty seven state-of-the-art coal units with sizes varying from 100 to 1 000 MWe are considered in the study. All plants are equipped with emission control devices for nitrous and sulphur oxides, dust and particulate matters; only one of the plants considered is equipped with a carbon dioxide capture device. The plants use different fuel types, including lignite and brown coal, and different technologies, including fluidised-bed combustion and integrated gasification combined cycle (IGCC).

Most coal-fired power plants considered in the study have specific overnight construction costs ranging between 1 000 and 1 500 USD/kWe but the IGCC plants including the one with CO_2 capture have higher specific overnight construction costs. The construction time of coal-fired plants is around 4 years.

The expected coal prices at the time of commissioning of the plant, *i.e.* generally 2010, vary widely from country to country. Expressed in the same currency unit using official exchange rates, the coal prices vary between 0.15 USD/GJ in South Africa and more than 2 USD/GJ in many European countries and in Japan. Roughly half of the responses indicate coal price escalation during the economic lifetime of the plant while the others indicate price stability. When prices are assumed to increase, escalation rates lead to an average increase of some 50% between 2010 and the end of the plant economic lifetime, *i.e.* 2050.

At 5% discount rate, levelised generation costs range between 25 and 50 USD/MWh for most coal-fired power plants. Generally, investment costs represent slightly more than a third of the total, while O&M costs account for some 20% and fuel for some 45%. It should be stressed, however, that those shares may vary widely from country to country depending on local conditions and assumed coal prices.

At 10% discount rate, the levelised generation costs of nearly all coal-fired power plants range between 35 and 60 USD/MWh. Investment costs represent around 50% in most cases. O&M costs account for some 15% of the total and fuel costs for some 35%. Like at 5% discount rate, the variability of cost elements lead to significant differences in their respective shares of the total in different countries and sometimes for different plants in the same country.

Gas-fired plants

All but one of the twenty-three gas-fired plants considered are combined cycle gas turbine (CCGT) plants with unit capacities varying between 100 and 1 600 MWe. Three of the plants included in the study use liquefied natural gas (LNG) as fuel. The specific overnight construction costs of the gas-fired plants range between 400 and

800 USD/kWe. In all countries, the construction costs of the gas-fired plants are lower than those of coal-fired or nuclear power plants. Gas-fired power plants are built rapidly, generally in less than three years.

Gas prices assumed in 2010 vary significantly from country to country but variations are less dramatic than for coal. In this regard, it should be noted that for Japan and the Republic of Korea gas prices refer to liquefied natural gas (LNG) delivered at the plant. Most gas prices assumed in 2010 range between 3.5 and 4.5 USD/GJ but some are higher than 5.5 USD/GJ[1]. Nearly half of the participating countries assumed stable gas prices over the lifetime of the plants, i.e., generally 30 years, while the others assumed escalation rates leading in some cases to significant price increase.

At 5% discount rate, the levelised costs of generating electricity from gas-fired power plants vary between 37 USD/MWh and 60 USD/MWh. Fuel costs represent in average nearly 80% of the total levelised costs and up to nearly 90% in some cases. Consequently, the assumptions made on gas prices at the date of commissioning and their escalation rates are driving factors in the estimated levelised costs of gas-generated electricity. The investment costs represent a share lower than 15% and O&M costs which account for less than 10% in most cases are nearly negligible for some plants.

At 10% discount rate levelised costs of electricity generated by gas-fired plants range between 40 and 63 USD/MWh. They are barely higher than at 5% discount rate owing to the low overnight investment costs and very short construction periods of gas-fired plants. Fuel costs remain the major contributor to total generation costs but with a slightly lower share than at 5% discount rate, some 73%, while investment and O&M shares are around 20% and 7%, respectively.

Nuclear power plants

The nuclear power plants considered in the study are all water reactors (PWR, BWR or PHWR) with unit capacities ranging from 450 to 1 600 MWe. Those state-of-the-art nuclear power plants are advanced evolutionary reactors incorporating in their design feedback from some 10 000 reactor-years of industrial experience. Fuel cycle costs provided correspond in most cases to once-through operation but France, Japan and the Netherlands provided data for the closed cycle option.

The nuclear power plants considered in the study have specific overnight construction costs varying between 1 000 and 2 000 USD/kWe in most cases. Their construction times, which determine the added investment costs needed to finance interest during construction, range from 5 to 10 years but in nearly all countries 90% or more of the upfront capital expenses are incurred within 5 years or less. The cost of decommissioning is accounted for in most cases within the operating and maintenance costs because the fund to cover decommissioning expenses after the plant closure is accumulated annually. Some countries, however, include decommissioning costs in capital investment expenditures.

Nuclear fuel cycle costs calculated at 5 and 10% discount rates were provided by respondents. The impact of discount rate on levelised fuel cycle cost is negligible according to the values reported by most countries. The fuel cycle costs reported include all the costs associated with radioactive waste management and disposal. Although past and current trends indicate that fuel cycle costs have decreased significantly over time, all responding countries assume that those costs will remain stable during the economic lifetime of the nuclear power plants.

[1] At present, mid-2006, the average international market price of natural gas is around 8 USD/GJ.

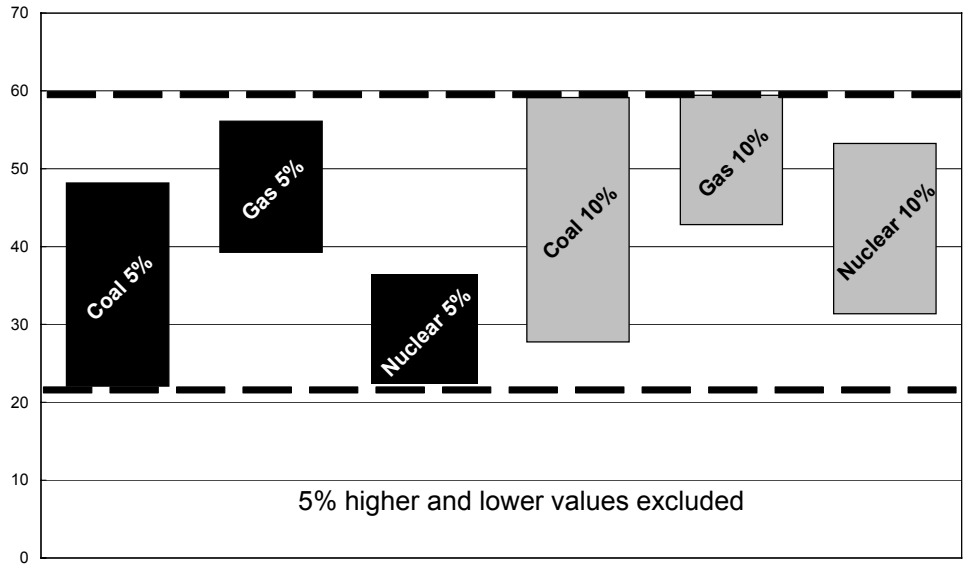
With a 5% discount rate, the levelised costs of nuclear electricity generation generally range between 21 and 31 USD/MWh. Investment costs represent the largest share of total levelised costs, around 52% on average, while O&M costs represent around 31% and fuel cycle costs around 17%.

With a 10% discount rate, the levelised costs of nuclear electricity generation generally range between 30 and 50 USD/MWh. The share of investment in total levelised generation cost is around 67% while the other cost elements, O&M and fuel cycle, represent in average 21% and 12%, respectively.

Comparative costs of base-load options

In most countries which provided data on two or more of the three alternatives (coal, gas and nuclear) for the study, the least expensive alternatives have levelised generation costs ranging between 25 and 35 USD/MWh at 5% discount rate and between 35 and 45 USD/MWh at 10% discount rate. Figure 1 shows the cost ranges for the three options at 5 and 10% discount rates (extreme values – 5% higher and 5% lower – are excluded).

Figure 1. Levelised cost ranges at 5 and 10% discount rate (USD/MWh)



The relative competitiveness of the three main options for base-load electricity generation may be summarised as follows:

At 5% discount rate:

- Coal is cheaper than gas by a margin of 10% or more[2] in eight countries;
- Coal is cheaper than nuclear in one country;
- Nuclear is cheaper than coal in seven countries;
- Nuclear is cheaper than gas in nine countries;
- Gas is never cheaper than coal[3] or nuclear.

[2] In the light of the uncertainties in cost elements, in particular projected fuel prices but also projected O&M costs and even investments and expense schedules, differences of less than 10% in levelised generation costs of alternatives cannot be considered significant.

[3] Except for one plant in Turkey.

At 10%discount rate:

- Coal is cheaper than gas by a margin of 10% or more in eight[4] countries;
- Coal is cheaper than nuclear in one country;
- Nuclear is cheaper than coal in seven countries;
- Nuclear is cheaper than gas in eight countries;
- Gas is cheaper than coal in one country.

The results are based upon the cost elements provided by participating countries but the levelised costs were calculated using the generic assumptions described above. Therefore, national estimations carried out with different assumptions may lead to different rankings.

Coal, gas and nuclear levelised generation costs result from three main components: investment, O&M and fuel. The shares of each cost component in the total vary from country to country and from plant to plant. However, some generic driving factors may be identified for each option.

Coal-fired power plants are more capital intensive than gas-fired power plants but less than nuclear power plants. The relative importance of investment and fuel in total levelised generation costs vary depending on the discount rate. Investment costs represent only around a third of the total at 5% discount rate while they account for 50% at 10% discount rate. On the other hand, fuel costs represent the major component with 45% at 5% discount rate but only one third at 10% discount rate. Operation and maintenance costs are not a driver for electricity generation cost from coal-fired plants.

For gas-fired plants, in average, investment costs represent some 15% of total levelised generation costs at 5% discount rate and some 20% at 10% discount rate while fuel costs account for some 75% of the total. Therefore, average lifetime levelised costs of electricity generated by gas-fired plants are not very sensitive to uncertainties in future demand which may lead to load factors lower than expected, based on technical capability. On the other hand, generation costs of gas-fired plants are very sensitive to future gas prices. Operation and maintenance costs are a marginal contributor to total generation costs.

For nuclear power plants, investment costs are driving the total cost with an average share in total levelised generation costs of more than 50% at 5% discount rate and more than 65% at 10% discount rate, while nuclear fuel cycle costs account for less than 20%. Therefore, average lifetime levelised costs of nuclear power plants are very sensitive to discount rate but not very sensitive to uranium or fuel cycle service price increase. The study does not include any detailed analysis of nuclear fuel cycle cost components. Operation and maintenance costs are a significant but not major component of total generation costs for nuclear power plants.

Externalities

External costs are costs associated with an economic activity which are not borne by the producer and passed on to the consumer but rather supported by society as a whole. According to this definition, only the effects of residual pollution are leading to external costs. For example, in most OECD countries, coal-fired power plants are equipped with abatement devices reducing their atmospheric emissions below levels judged harmful for health and the environment and, therefore, authorised by standards and regulation. It was the case for all coal-fired plants considered in the study and their external costs resulting from atmospheric pollution, besides greenhouse gases, are likely to be very low. In countries where SOx, NOx and particulate matter emissions are not strictly controlled, the situation may be different.

[4] Except for one plant in Germany.

Although external costs of generating electricity cannot be estimated as precisely as direct costs, authoritative studies carried out so far, e.g., the ExternE project of the European Commission, provide insights on their values for some illustrative electricity generation chains. Nevertheless, experts recognise that external cost estimates remain uncertain and depend largely on specific characteristics of the technology used as well as local conditions [3].

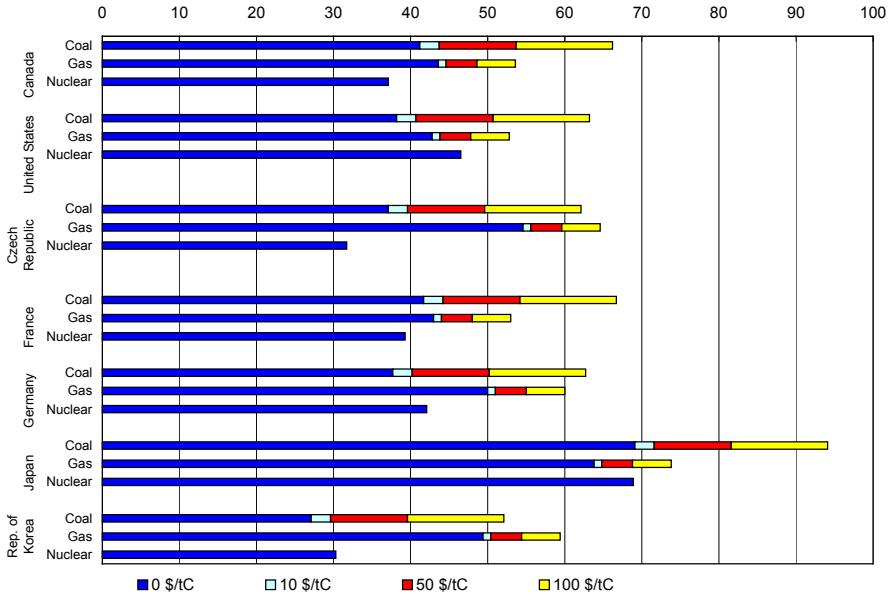
In the context of most OECD countries, for current technologies, the major external costs which could modify the ranking of alternative options, if they were internalised, are those associated with security of energy supply and global climate change. Key issues in this regard are: accuracy and reliability of cost assessments; and effectiveness of policy measures that may be implemented for their internalisation.

The estimation of the external costs resulting from the absence of security of supply is not an easy task because the analytical tools available today are not capable to address adequately the political and social dimensions of the issue. Therefore, decision makers tend to adopt a qualitative approach and generally do not base measures to ensure national security of energy supply on cost/benefit analyses.

For example, the choice to rely on nuclear energy, and to a lesser extent on renewable sources, has been motivated in several OECD countries by security of energy supply concerns but none has introduced a "value of security" that could be credited to producers using nuclear or renewable energies. Eventually, however, the contribution of domestic sources to diversity and security of supply might be valued in economic terms and internalised.

Regarding greenhouse gas emissions and climate change, although the economic value of avoiding global warming is unknown, internalisation of costs is progressing in some countries. The establishment of a carbon emission trading scheme in the European Union, aiming at meeting the Kyoto targets of the region, will provide a value of carbon and internalise it, in particular in electricity generation costs.

Figure 2. Levelised generation costs at 10% discount rate (USD/MWh)
Impact of a carbon value varying form 0 to 100 USD/tC



It is difficult, at this very early stage in the implementation of various policy measures for carbon-emission reduction, to predict what will be the future market value of carbon.

In particular, the evolution of carbon value in the post-Kyoto period, i.e., beyond 2012, will depend on decisions to be taken by Parties to the United Nations Framework Convention on Climate Change. The parametric approach illustrated in Figure 2 provides a means to assess the impact of a carbon value on generation costs. The relative competitiveness of nuclear versus gas- and coal-fired power plants at 10% discount rate is shown for carbon values varying from 0 to 100 USD/tC (the costs for a value of carbon equal to zero are those of the 2005 OECD study).

Combined heat and power (CHP), wind and other technologies

CHP plants

The study showed the interest of many responding countries for combined heat and power (CHP) plants fuelled with gas, coal or biomass. For the first time in the series of OECD studies on projected costs of generating electricity, the levelised costs of the electricity generated by CHP plants were estimated. The calculations relied on a simplified methodology based upon total levelised costs incurred for operating the plant, fuel cost distribution according to the production of heat and electricity, and an assumed heat value which was deducted from total costs. The value of heat was provided by participating countries according to expected heat prices in each specific case.

At 5% discount rate, the levelised electricity generation costs of CHP plants range between 25 and 65 USD/MWh. At 10% discount rate, the costs range between 30 and 70 USD/MWh for most plants. The impact of discount rate is small for most CHP plants with costs at 10% discount rate being 10 to 20% higher than at 5% discount rate. In countries which provided cost data for CHP and plants generating only electricity using the same fuel, CHP generated electricity is cheaper in nearly all cases.

Wind and other power plants

Ten countries provided data on wind power plants, demonstrating an increasing interest for this renewable energy source. Both on-shore and off-shore plants are included in the study. The overnight construction costs of the wind power plants considered in the study range between 1 000 and 2 000 USD/MWe.

The levelised lifetime costs of generating electricity from wind power plants estimated in the study are based on the methodology used for all energy sources and plants, for the sake of consistency. This approach does not reflect specific costs associated with intermittent electricity generation sources such as wind power. In particular, it ignores the need for backup power to compensate for the low average availability factor of wind power plants as compared to fossil-fuelled or nuclear power plants.

At 5% discount rate, the levelised costs of wind generated electricity range between 35 and 55 USD/MWh for most plants but exceed 80 USD/MWh in several cases. At 10% discount rate, those costs range between 50 and 95 USD/MWh for most plants but exceed 100 USD/MWh in several cases. In countries which provided data for wind and traditional base load options (coal, gas or nuclear), the levelised costs of wind generated electricity generally are not very far from competitiveness.

The main cost drivers for wind generated electricity, like for nuclear electricity, are discount rate and capacity factor. The data provided for the study indicate rather high capacity factors, ranging from 20 to nearly 40%. In this connection, it should be noted that off-shore wind farms which offer the highest capacity factors also have the highest investment and O&M costs.

Other sources and technologies covered in the study – including solar photovoltaic for which 20 data sets were provided – are rather far from competitiveness.

Concluding remarks

The OECD study provides insights on the relative ranking of alternative options for generating electricity in the participating countries. The results are based on projected generation costs estimated with a uniform methodology and generic assumptions. The limitations inherent to a generic approach are stressed in the report. In particular, the cost estimates presented are not meant to represent the precise costs that would be calculated by potential investors for a specific project.

Within this framework and limitations, the study suggests that none of the base-load technologies – coal, gas or nuclear – can be expected to be the cheapest in all situations. The most economically attractive base-load technology will depend on the specific circumstances of each project. The study indeed indicates that on a global scale there is room and need for all base-load technologies. Also, the data provided for the study highlight the increasing interest of participating countries in renewable energy sources for electricity generation, in particular wind power, and in combined heat and power plants.

Regarding nuclear power, the results from the study show that it is in most cases the least cost option for base-load electricity supply in countries which consider its use. At 5% discount rate, nuclear power is economically attractive in nearly all countries where it is considered. At 10% discount rate the picture is less clear; the most economically attractive option depending on local and national context, but nuclear electricity remains the cheapest in many cases.

The increasing competitiveness of nuclear energy is due to two main factors: enhanced performance of nuclear energy systems, in particular higher availability factors; and fossil fuel price escalation which affects dramatically the economic performance of gas-fired plants, the major competitor of nuclear energy in most countries. In countries having access to cheap domestic coal, coal-fired plants remain economically attractive as long as the value of carbon emissions is not accounted for.

Furthermore, nuclear electricity provides a guarantee of generation cost stability in the medium and long terms that cannot be provided by fossil fuels. A doubling of uranium price has an insignificant impact on the total cost of nuclear electricity generation while a doubling in the price of natural gas – that might occur anytime in the light of recent hydrocarbon price volatility – would add 70 to 90% to the cost of electricity generated by gas-fired plants.

The internalisation of external costs associated with carbon emissions, which will occur progressively at least in Annex I countries of the Kyoto Protocol, will enhance the competitive margin of nuclear energy. Similarly, the contribution of nuclear energy to diversity and security of supply is an external benefit that would decrease the cost of nuclear electricity generation if it would be internalised.

References

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