



## **Competitiveness of Nuclear Energy: IAEA's Perspective and Study Results for Europe**

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Energy is essential for human development. This fact is widely accepted and it is one of the reasons for the organization of this forum and the many discussions taking place here.

Facing any of the development challenges, such as poverty, hunger, health care and environment, requires energy. The global energy imbalance means that roughly 1.6 billion people live without access to electricity; and 2.4 billion rely on traditional biomass. Coupled with concerns about the risks associated to climate change and the security of energy supply, this anticipated growth in energy demand is leading to predictions of a greater role for nuclear power.

Nuclear energy has the potential to be a reliable, sustainable and environmentally friendly energy source. To fulfill this potential, any use of nuclear energy should be designed to be *beneficial, responsible and sustainable*. Here I will address only one of the beneficial aspects of nuclear power, meaning that its benefits outweigh associated costs and risks.

Each energy systems has its own set of benefits, costs and risks (e.g. economic, environmental, and proliferation related). It is this set of attributes that will make a particular system competitive in relation to others producing comparable energy products.

Can a case be made for nuclear being competitive? Existing well operated nuclear power plants have proven to be a competitive and profitable source of electricity, in large part due to significant improvements in nuclear plant reliability and an improved safety record. Nuclear can provide the reliable, large-scale electricity necessary for industry and large urban areas. Evidence of this can be found in the usual practice of extending a nuclear plant's life.

In the United States of America, the Nuclear Regulatory Commission (NRC) has approved 49 license renewals of 20 years (for a total licensed life of 60 years). Owners of approximately three-quarters of the USA's 104 reactors have applied for or intend to apply for such renewals. The situation is similar in other countries.

So the first factor is a proven competitiveness for existing reactors.

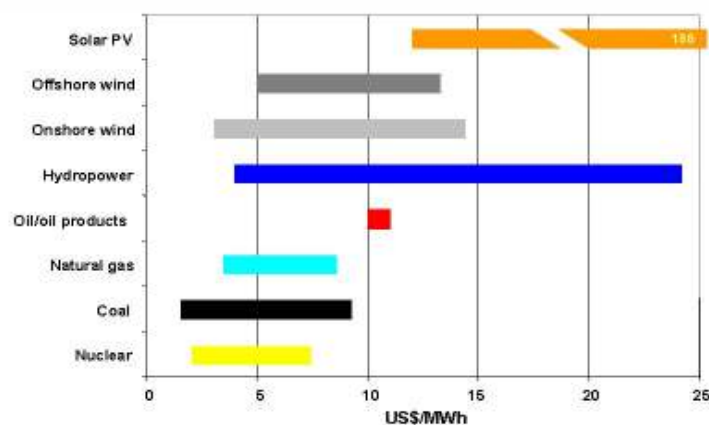
There are other factors. Growing concerns about CO<sub>2</sub> emissions and climate change could be addressed by nuclear power which emits only 1–6 grams of carbon equivalent per kilowatt-hour, many times less than coal, oil and natural gas. Also, nuclear power increases energy security of a country thanks to an existing large number of uranium producers that ensure the reliable supply of nuclear fuel and the small contribution of uranium costs to the cost of

produced electricity. In fact, uranium costs are only about 5–15% of the costs of nuclear generated electricity.

But when considering new construction, the economic competitiveness of nuclear power is not so obvious for investors and will depend on market structure and available alternatives, overall electricity demand and its rate of growth, the regulatory environment and the investment climate.

It is well known that nuclear power plants have a ‘front-loaded’ cost structure, i.e. they are relatively expensive to build but relatively inexpensive to operate.

The following figure summarizes electricity cost estimates from studies completed in 2003-2005 for new power plants with different fuels. The wide cost range reflects different techno-economic assumptions across the studies, different local conditions but also the uncertainty of many factors [1].



The Ranges of Levelized Generating Costs Associated with New Construction

What factors affect nuclear cost estimates? There are several:

- The definition of costs may vary widely depending on whether we include or exclude financing costs, first-of-a-kind costs or ‘nth’ of a kind; infrastructure expenditures; allowances for contingencies; etc.
- Assumptions made on discount/interest rates and finance arrangement
- The design and unit size, engineering work on site
- Vendors’ interest in presenting costs in a way that maximizes their chances of commercial success
- The local labour costs and the cost of raw materials, localization of the technology
- The exchange rate and inflationary aspects
- Recent material price hikes in the global market and long waiting periods for heavy reactor components.

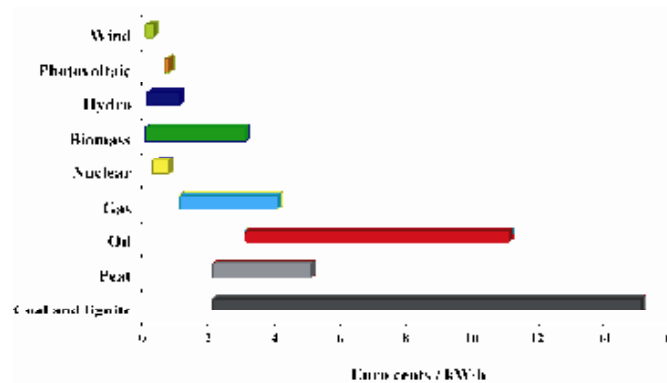
Capital costs determine 60-70% of nuclear generating costs and thus are sensitive to interest rates. A variation in interest rates translates directly into nuclear generating cost, which may affect nuclear competitiveness in the market place and thus is a cause of uncertainty.

Nuclear power’s front loaded cost structure is less attractive to a private investor - who values rapid returns - than to a government that is more likely to look at the long-term perspective

and may take other factors into consideration such as using nuclear power as a vehicle to increase a country's national technological development or increasing export revenues by substituting domestic demand, e.g. for natural gas, with nuclear power.

Private investments in liberalized markets will also depend on the extent to which energy-related external costs and benefits (e.g. pollution, greenhouse gas (GHG) emissions, and waste and energy supply security) have been internalized.

External costs are the impacts or damages caused by the energy producing activities on the health and environment and which are not included in the market price of electricity. Matters are complicated because the use of electricity provides also benefits to society which must be balanced against the losses incurred by its production and use. Several studies have attempted to quantify the external costs associated with electricity generation [2].



External costs associated with electricity generation (European Commission, 2003).

Another influencing factor is climate change. The Kyoto Protocol requires industrialized countries to limit GHG emissions in 2008–2012. Different countries have adopted different policies to meet Kyoto Protocol limits. In 2008, CO<sub>2</sub> traded in Europe between €19 and €24 per tCO<sub>2</sub>. A charge on carbon dioxide emissions improves a nuclear plant's generating costs relative to a modern coal-fired plant by 10–20 percent. In addition most nuclear externalities (waste disposal, decommissioning) are already internalized, and therefore included in the cost of the produced electricity, which is usually not the case with other technologies.

Furthermore, regulatory risks are also important. Political support for nuclear power varies across countries, and within a given country it can change over time. An investor must weigh the risk of political shifts that might require cancellation of the project midstream or introduce delays and costs that would change an originally attractive investment. Different countries also have different approval processes. Some are less predictable than others and create greater risks, from the investor's perspective, of expensive interventions or delays. In Japan and the Republic of Korea, the relatively high cost of alternatives benefits nuclear power's competitiveness. In India and China, rapidly growing energy needs encourage the development of all energy options. In Europe, high electricity and natural gas prices but also the GHG emission limits under the European Union Emission Trading Scheme (EU ETS) have improved the business case for new nuclear power plants. In the United States the 2005 US Energy Act significantly strengthened the business case for new construction. Previously new nuclear power plants had not been an attractive investment given plentiful low-cost coal and natural gas, the absence of GHG emission limits, and investment risks associated with the lack of recent experience in licensing new nuclear power construction. The provisions of the Energy Act, including loan guarantees, government coverage of costs associated with certain

potential licensing delays and a production tax credit for up to 6,000 MW(e) of advanced nuclear power capacity, have improved the business case enough to prompt announcements by nuclear firms and consortia of possible Combined License (COL) applications covering approximately 32 possible new reactors in the United States.

So in all that has been said, much is about uncertainty.

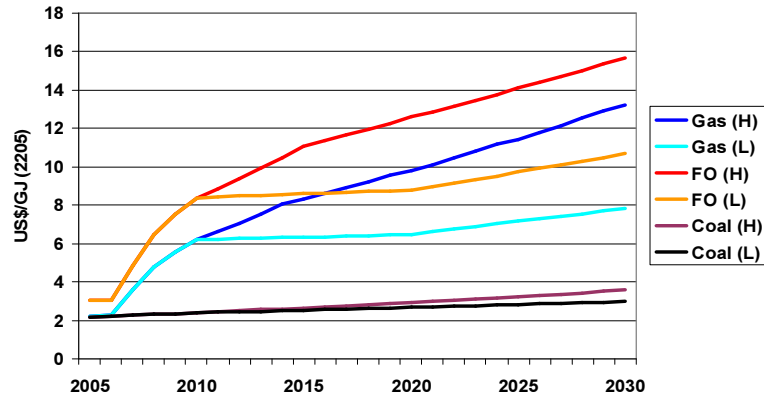
To decrease the uncertainty in the assessment of the competitiveness of nuclear power a country's detailed considerations have to be included in the assessment. The use of sensitivity tests on all critical variables – from fossil fuel prices, discount rates, capital costs, demand developments, etc helps to identify boundary conditions in which nuclear power is competitive. Such approach was used, for example, in the Agency's work with Bulgaria, Belarus and the Baltic countries. The advantages of different systems of electricity generation can be expressed either in the final price of electricity or in the cost of the electricity generation system producing the same amount of electricity at the same level of reliability.

In energy assessments that include nuclear power, a number of parameters are critical to the overall economics of a nuclear power plant. These have different local values and are selected in consultation with local experts.

- Demand – growing demand creates a more favorable environment for new investment than stagnation or retraction,
- Fossil fuel prices, especially gas and coal (whether they are domestic or imported can make a huge difference, as well as whether domestic gas can be exported)
- Investment costs for nuclear power
- Discount rates
- Climate change / carbon costs
- Policies favoring renewables

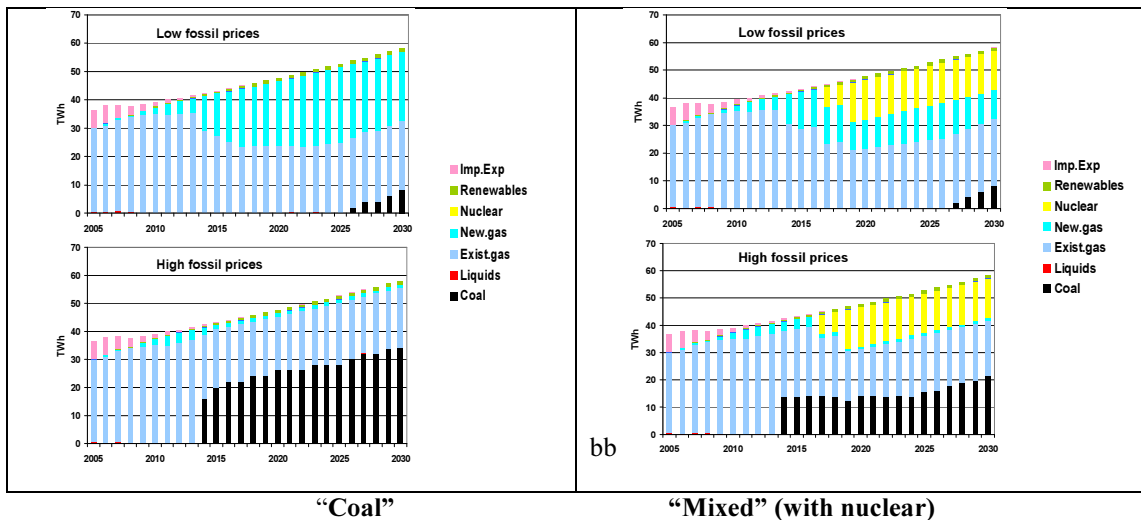
In our assessments sensitivity ranges are used for all critical variables: fossil fuel prices, discount rates, capital costs, demand developments, etc. The goal is to identify boundary conditions in which nuclear power is competitive versus alternative in electricity generation. Obviously, resource constraints do not permit to test all combinations of uncertain parameters, and we therefore concentrate on a subset of plausible parameter ranges (e.g. gas prices between 8 € and 14 € per GJ are used).

Let us first consider the case of Belarus. There are some specifics in this case that were taken into account. Energy demand is a boundary condition which has to be met subject to assumptions about the future prices of the imported fossil fuels, the need to maintain a significant level of cogeneration capacity operational supplying centralized heat for which the use of NP is not foreseen. These factors were taken into consideration by the Belarusian Government and guided their decision to limit nuclear power to a maximum of 2 GW(e). The study also explored the sensitivity of the competitiveness of nuclear power to the capital cost of the installed nuclear capacity.



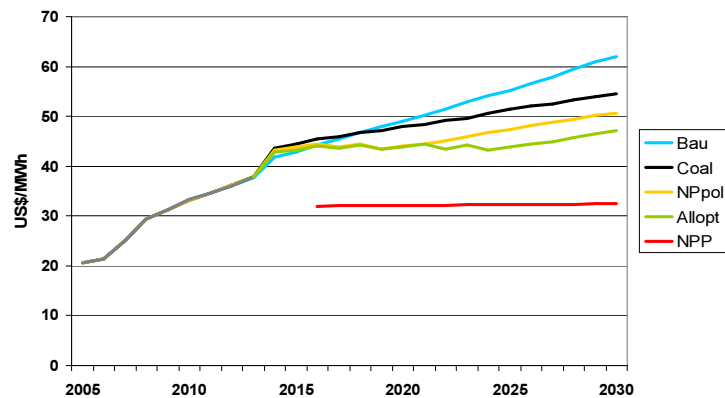
Fuel import price assumption, Belarus

Fuel price assumption took into account recent developments on international energy markets and the adjustments that the Russian Federation progressively introduced charging international market prices for energy exports to Belarus. Using all these assumptions, a minimal cost for an energy system with a mix of energy sources can be defined. The next figure shows shares of different energy sources within the structure of the energy system for two options: without and with nuclear power.



Electricity generation in “Coal” and “Mixed” scenarios (with nuclear)

And finally here (next figure) are the average weighted generating costs and the levelized cost of nuclear generation that conclude that the use of nuclear power will bring a reduction of the price of electricity even in the case of its restricted use. Levelized cost is the cost of nuclear electricity on the bars of NPP that indicate a competitiveness of nuclear power under specific conditions in Belarus.



Average weighted generating costs and the levelized costs of nuclear generation.

Sensitivity analysis indicated the range in which nuclear power is still attractive if capital costs increase from \$2500/kW up to \$4000/kW in the low and high price scenarios for fossil fuel and within a discount rate range of 4 -10%.

A second example is the case of regional integration in the Baltic electricity market. Lithuania has one operating NPP Ignalina which is scheduled for closure at the end of 2009. A study investigating replacement options indicated that a replacement NPP lacks economic rationale, if the electricity market served is limited to Lithuania as it can meet its energy needs by the refurbishment of existing capacity plus some new gas-fueled CHPs and discontinuing exports of electricity to its Baltic neighbours. However, stopping electricity exports would cause a supply shortage and a price increase in the Baltic region. When the three national systems are optimized as an integrated regional system, a new nuclear power plant is economically viable and the economic benefits include lower total system costs of 2.7 billion €. Furthermore, the new NPP would help meet the regional electricity demand. It is important to note that the fuel import price assumptions used in the study reflect the market outlook of 2004. At today's prices, the nuclear option would look even more attractive.

The third example is Bulgaria. A study assessed the economic consequences of the closure of Kozloduy NPP Units 3-4 at the end of 2006, i.e., well before their valid operating licenses expire in 2011 and 2013. Future electricity supply options for Bulgaria include new fossil fired power plants, renewable energy sources and the completion of the Belene NPP. The study considered several scenarios, all of which had Kozloduy Units 5&6 continue to operate well beyond the study horizon of 2025. Clearly the most economical scenario includes the operation of Unit 3&4 until the end of their licenses and the completion of Belene as soon as possible. The analysis tested different projections of natural gas, oil and coal import prices but the completion of Belene appeared to be a robust solution under – from today's perspective – relatively low price trajectory. The least cost scenario includes the completion of Belene NPP with two units (2 GW(e)) around 2015 plus an additional nuclear plant with a capacity of 1.65GW(e) in 2022.

The total system costs at an eight percent discount rate is almost 7 billion € lower for the scenario with nuclear power than without. This relatively large difference is in part the result of export revenues from electricity exports to Bulgaria's neighboring countries.

Concluding this part of the presentation, I would like to stress again that detailed studies are needed for assessing the competitiveness of nuclear power in the specific conditions of each country.

Now, here are some practical observations about methods used to increase competitiveness of nuclear power.

As previously discussed, capital costs for nuclear plants account for up to 70% of the total nuclear electricity generation costs. Decreasing capital costs presents a significant challenge, which design organizations are addressing by incorporating both proven means and new approaches for reducing costs into their advanced designs [3-6].

Experience has provided proven means for reducing costs of nuclear projects, such as:

- *Economies of scale* in large evolutionary water-cooled reactors, for example, in Western Europe(EPR), the Republic of Korea (APR-1400), India (HWR-700), Russia(AES-2006), Japan(ABWR-II) and the USA(ESBWR).
- *Shortening the construction schedule* by manufacturing modular systems and reducing on-site construction; by the licensing and completion of the detailed design before start of construction; by the use of integrated design tools such as Computer Aided Design and Engineering; and by the coordination of procurement with construction activities, etc
- *Standardization and construction in series* offer savings by spreading fixed costs over several units, in equipment manufacturing, field engineering, and construction. Standardization led to cost reductions in France, Japan (with the ABWRs), the Republic of Korea (with the KSNPs) and in India with the heavy water reactors (HWRs).
- *Multiple unit construction* at a single site can decrease the average cost by about 15% in comparison with the cost of a single unit, thanks to siting and licensing costs, site labour and common facilities. The 58 PWRs built in France as multiple units at 19 sites are good examples. This method is widely used in ROK.
- *Self-reliance and local participation* can also result in cost savings in materials and construction, training and labor result. For example, in China the construction cost (per kWe) of the Qinshan-II plant (2 x 600 MWe units) is less than for imported large-size plants because of the localization of design and the procurement of a large part of the equipment by domestic organizations.

In addition there are some new approaches that can be used for reducing plant costs:

For small and medium sized reactors, there is potential for economies of series in *in-plant manufacturing and on site delivery in assembled condition*

*Eliminating over-design* (i.e. more accurate data base, better code validation), removing excessively large margins built into the design improves calculation methodology and decreases uncertain data

Developing highly reliable “*smart*” *components and systems* which are instrumented and monitored for detecting incipient failures to improve system reliability

Incorporating *passive safety systems* for cases in which the safety function can be met more cheaply than with active systems

Further developing *Probabilistic Safety Analysis (PSA)* methods and data bases to develop *risk-informed regulations* and approaches for *maintenance*

*Reducing* a number of *nuclear grade* components and materials

Developing *systems with higher thermal efficiency and expanded applications* (e.g. co-generation of electricity and heat; sea-water desalination)

*Reaching an International* consensus regarding *standardized designs* which can be built in many countries without requiring significant re-design efforts.

**In Conclusion:**

1. Nuclear power has a strong potential as a chosen energy source but it is not a magic solution for all cases. Specific conditions in the country have to be taken into account.
2. Existing well functioning NPPs have proven their competitiveness.
3. Current assessments indicate the potential competitiveness of the nuclear option which, however, depends on many variable factors: energy demand and structure of the energy consumption, country specific risks and favorable conditions, internationalization of external costs, etc.
4. Country specific energy studies are needed as a prerequisite to the decision of following the nuclear route.
5. Nuclear industry and research organizations are continuously optimizing the design, construction and operation practices to increase the competitiveness of nuclear power.

## REFERENCES

1. International Atomic Energy Agency, Nuclear power and sustainable development, Vienna (2006)
2. EC (European Commission), 2003: External Costs — Research Results on Socio-Environmental Damages due to Electricity and Transport, EC Study EUR 20198, Brussels.
3. OECD/NEA, Reduction of Capital Costs of Nuclear Power Plants, OECD (2000).
4. INTERNATIONAL ATOMIC ENERGY AGENCY, Improving Economics and Safety of Water-Cooled Reactors: Proven Means and New Approaches, TECDOC-1290, IAEA, Vienna (2002).
5. INTERNATIONAL ATOMIC ENERGY AGENCY, Construction and commissioning experience of evolutionary water cooled nuclear power plants, IAEA-TECDOC-1390, IAEA, Vienna (2004).
6. Application of Advanced Construction Technologies to New Nuclear Power Plant, MPR-2610 (2004), prepared for the USDOE.