Economic performance of nuclear plants: How competitive?

A review of IAEA and other studies indicates a strong position

by Leonard L. Bennett

In general, it can be stated that nuclear power plants of the sizes presently on the market are and will continue to be economically competitive with oil-fired plants. In fact, the economic advantage of nuclear power plants over oil-fired plants is overwhelming, given the present level of international oil prices.

In comparing electricity costs from nuclear and coal-fired power plants, the results depend on a number of factors, and there is no single global answer. However, in most situations large nuclear power plants becoming operational in the near future can produce electricity cheaper than coal-fired power plants. In some special situations, however, such as in areas of the United States and Canada with low-cost coal available to plants at nearby or mine-mouth locations, coal-fired power plants can deliver electricity at costs competitive with or lower than nuclear plants.

The key economic factor for coal-generated electricity is the cost of coal delivered to the power station. IAEA studies indicate that coal plants have an economic advantage when coal can be delivered to the power plant at costs below US $30 per ton. For nuclear power, the key factor is the total capital investment cost, which is significantly increased when interest rates are high and lead times long. For coal-fired plants, stringent environmental protection regulations are expected to be applied in the future. These will increase their capital and operational costs, placing nuclear power in a more competitive position.

National papers presented during the IAEA International Conference on Nuclear Power Experience held in September 1982 confirmed the generally positive experience from – at that time – some 2600 accumulated reactor-years of nuclear power plant operation up to mid-1982. Several countries, notably Belgium, stressed the importance of nuclear generation, when it has reached a significant level in a country, in keeping constant, or even decreasing, electric energy prices.

Mr Bennett is Head, Economic Studies Section, in the Agency's Division of Nuclear Power.

Although the load factors of base-loaded nuclear power plants are somewhat lower than the expected value used for planning purposes, experience has confirmed the expectation that nuclear plants would produce cost savings in comparison with coal- or oil-fired plants in most countries. In the reporting countries, it was clearly documented that nuclear plants are by a considerable margin the economic choice over oil-fired power plants and, except in certain regions where coal is abundant and cheap, also over coal-fired power plants.

This conclusion also is supported by IAEA studies of projected generation costs for nuclear power plants larger than 600 megawatt-electric (MWe) capacity. In this size range, nuclear plants are estimated to have generation costs substantially lower than oil-fired plants, and are economically competitive with coal-fired plants except in the case of low coal prices.

Economics of smaller reactors

There is no currently available information which would provide reliable cost data for new nuclear power reactor projects in the size range below about 600 MWe. However, the IAEA has some data from potential suppliers of small- and medium-power reactors (SMPRs), providing rather rough cost estimates in the size range between 200 and 400 MWe. These data lead to generation cost estimates indicating that nuclear power plants within this size range might be competitive with oil-fired plants, which will remain the most important source for electricity generation in the majority of developing countries.

In comparison with electricity generation costs of coal-fired power plants, nuclear plants appear only marginally competitive in sizes as small as about 300 to 400 MWe, and only when the coal price is high. It should, however, be noted that a large expansion of electricity generation with coal-fired plants in developing countries would also require large investments for the necessary infrastructure, especially transportation systems; these costs have not been included in this analysis. The environmental impact of a large coal programme also would have to be taken into consideration.

In light of these rather encouraging preliminary results with regard to SMPRs, the Agency is conducting a study to more precisely determine their probable costs and economic competitiveness and to identify the possible market for this type of nuclear power plant in the future.*

Components of nuclear power generation costs

The main components entering into the calculation of nuclear power generation costs, as shown in the accompanying box, are capital investment, nuclear fuel cycle, and operating and maintenance (O&M) costs. Also shown are some indicative values for the percentage contribution of each of these three elements to the total cost of electricity production.

Additional elements that should be factored in are infrastructure development costs, such as research and development (R&D), transfer of technology from developed countries, and domestic industrial and manpower development associated with a nuclear power programme. However, it should be considered that there are also national benefits in the development of such activities. Plant performance is reflected in its load factor, power rating, and economic life; the economy of the country is reflected through domestic and foreign interest, escalation, and discount rates used in the analysis.

* For further information, see "Assessing prospects for smaller reactors," in the *IAEA Bulletin,* Vol.26, No.4, December 1984.

Components of electricity costs

	Share of total generation costs		
Main cost components	Nuclear	Coal	Oil
Capital investment	55–80%	25–55%	10–25%
Fuel	15–30%	40–65%	70–85%
Operating & Maintenance	5–15%	5–10%	5%

Other influencing factors

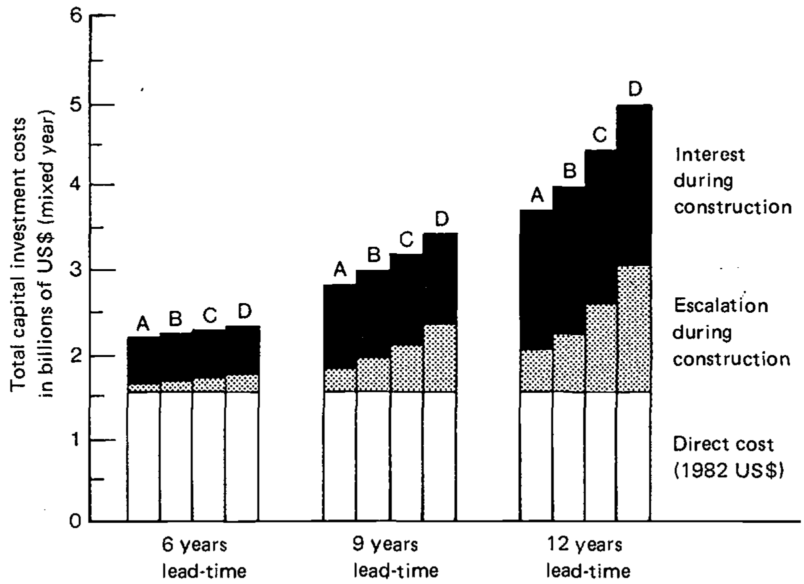
Infrastructure development	Interest rate (foreign and local)
Plant construction duration	Escalation rate (foreign and local)
Plant load factor	Discount rate (national economy)
Plant net electric power rating	
Plant economic life	

Nuclear plant capital costs

Due to its large contribution to total cost of nuclear power, the capital investment cost of nuclear plants deserves particular attention.

One of the most dominant factors in the changing costs of nuclear power during the last several years has been the sharp increase, in most countries, of plant investment costs.

Effects of lead-time and escalation during construction on total capital investment costs (1250 MWe LWR).



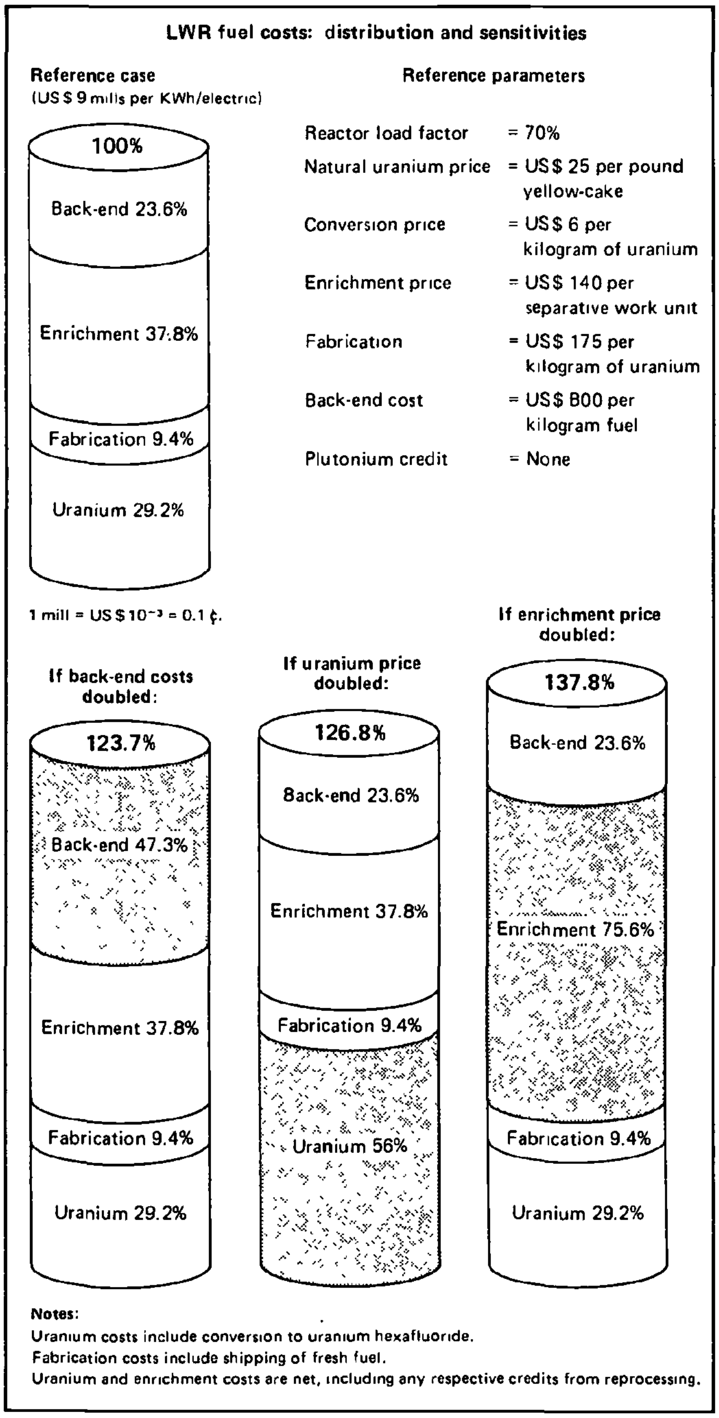
Assumptions:

Real escalation rates during construction: Bars A = 0%, Bars B = 2%, Bars C = 5%, Bars D = 8%

Before tax cost of money: 5.425% per year (real), 11.75% per year (deflated)

Inflation rate: 6% per year

Source: "Nuclear and Fossil Power Plant Economics", Chaim Braun (EPRI), paper presented at ANS Topical Meeting on Financial and Economic Bases for Nuclear Power, Washington D.C., 8–11 April 1984.



One major contribution to increases in capital costs (in constant money) has been attributed to the changes in regulatory requirements in some countries and the consequently required changes in designs, increases in scope of supply, and backfitting during execution of projects. In addition to their direct costs, all these factors will cause lengthened project times, resulting in very much higher charges for during construction, especially with high interest rates such as those that prevailed during the late 1970s and early 1980s.

The importance of project time and escalation rate, as driving factors in plant costs, are shown in the figure on page 41. The direct costs (sometimes referred to as "overnight" cost) of the plant is about US $1.5 billion. If we assume a modest 5% per year real rate of cost escalation and a six-year project time, the total investment cost, including interest and escalation during construction, is about US $2.2 billion. That is, interest and escalation costs add about 50% to the direct costs in the case of a six-year project time. However, at the same escalation rate, but with a 12-year project time, interest and escalation add over 200% to the direct costs!

Nuclear fuel costs

As previously noted, fuel costs contribute only 15 to 30% to the total cost of electricity from nuclear power plants. By comparison, in fossil-fuel-fired plants the cost of fuel accounts for 40 to 65% of the total generation cost for coal-fired plants and up to 85% for oil-fired plants.

The major components of the fuel cycle cost for a light-water reactor (LWR) using enriched uranium as fuel are shown in the chart. It is of interest to examine the sensitivity of the nuclear fuel cost, and the total nuclear generation cost, to possible future changes in these major components. Results from such a sensitivity analysis are shown.

Changes in uranium price

With a reference case value of US $25 per pound of yellow-cake (U_3O_8), it can be seen that if the uranium price were doubled (that is, a 100% increase), the total nuclear fuel cycle cost would increase by 27%. However, as the fuel cycle contributes only about 15 to 30% to the total generation cost, the assumed 100% increase in the uranium price would increase nuclear generation costs by only about 4 to 8%. By comparison, a 100% increase in fossil-fuel prices would increase generation costs by about 40 to 65% for coal-fired plants and about 70 to 85% for oil-fired plants.

Thus, it is clear to see that, once a nuclear power plant is built, the future generation costs are much less sensitive to changes in fuel prices than in the case of fossil-fuel-fired plants.

Effect of changes in enrichment prices

With a reference case value of US $140 per separative work unit (SWU), the results are similar to those already discussed for uranium prices. A 100% increase in enrichment prices would lead to about a 38% increase in fuel cycle costs, resulting in only about a 6 to 11% increase in total generation costs.

Changes in back-end costs

The third major component of the LWR nuclear fuel cycle is the cost of managing the spent fuel, which includes reprocessing and waste disposal – the so-called "back-end" of the fuel cycle. As shown in the chart, assuming a reference case value of US $800 per kilogram of fuel, a 100% increase in the back-end costs would lead to about a 24% increase in fuel cycle costs, resulting in only about a 4 to 7% increase in total generation costs.

Other cost considerations

Based on the studies reviewed here, the IAEA concludes that nuclear power is an economically competitive option for future energy and electricity supplies. However, the economic advantage of nuclear power depends greatly on the particular circumstances of each case; generalized figures have little applicability.

The high investment requirements and heavy front-end loading of the expenditure cycle on a nuclear power station may be a difficult burden in a developing country having to rely on relatively hard loans for a nuclear power programme.

Also, a pre-condition for the introduction of nuclear power is that the local infrastructure should be adequately developed. Creating an infrastructure into which nuclear power can be introduced may be a lengthy and costly process, but it is *essential.* The nuclear power option differs in this respect from other power plant alternatives where the infrastructure demands are far less stringent and also are more similar to those previously encountered.

On the other hand, the development of a coal industry, or its major expansion, is, as many countries have learned, a complicated exercise dependent on the careful planning of production and transport facilities to assure regular supplies to consuming industries. Where coal has not been previously used for power generation, a substantial front-end investment will be needed for coal transportation to the power plants, storage, handling, and ash disposal arrangements. There is little foreign investor interest in coal so the major investments required to open new mines and expand old ones must come from domestic sources, in practice largely governmental. Compared with oil, coal is expensive to transport and difficult and dirty to handle, thus seriously reducing its comparative price advantage.

The transport element is particularly important in imported coal. While ocean transport is not expensive on a tonne-kilometre basis, the costs of inland transport are very much higher, thus limiting coal use in practice to coastal regions or to inland situations which are particularly well served by rail links. None of these problems is in and of itself insuperable. But together they add up to a formidable list of constraints, the overcoming of which requires a firm commitment by producing, transporting, and consuming entities.

Limits of economic comparisons

There is no uniquely correct cost for nuclear or other modes of electricity production, and there is little to be gained by seeking complete standardization of reference values used in making cost comparisons, for example, between nuclear and fossil-fuelled power plants.

Even at the national level, such inter-fuel comparisons (nuclear versus fossil) have only limited "generic" value, due to the number of assumptions and operating conditions that are behind each example.

Nevertheless, results from such studies can contribute to an improved understanding of the worldwide economic viability of nuclear power.

Therefore, this article reviews some of the reported experience with nuclear power economic performance and estimates of future nuclear power costs, in comparison with fossil-fuel-fired plants.

It is reemphasized, however, that the cost data presented *should not be used* as reference data for planning purposes, but are valid only to give an overall indication of the general economic competitiveness of nuclear power.

A rigorous analysis of the economics of nuclear power should consider this energy source within the overall energy and economic development scenario of a country, including treatment of factors particular to the local conditions. Examples of relevant local conditions are the existence, volume, and cost of traditional indigenous energy reserves; the physical infrastructure (harbour, roads, industry); the institutional infrastructures; the manpower availability at all levels; and the financial resources available for a nuclear power programme.

In this way, the economic effects of the nuclear power programme on the energy supply market, as well as on the national industrial and manpower infrastructures, can be properly assessed.

Such a global assessment is very difficult to achieve, so normally a more modest approach is used, consisting of the economic analysis of the electric power generating system expansion.* This approach can provide a reasonably clear indication of the economics of nuclear power at the "pre-feasibility study" level, although many additional studies are required to reach a final decision on the economic merit of nuclear power in the country.

An even simpler approach, and the one used in this article, consists of a direct economic comparison between power plants and their competitors, mainly fossil-fuelled power plants for base-load power generation. This approach can provide rough indications regarding the economic competitiveness of nuclear power. But obviously such an analysis would disregard the fact that different power plants have different operational characteristics and also would not include economic effects due to the interactions between individual power plants and the rest of the generating system and associated transmission facilities. Such comparisons can, however, give a general indication about the competitive position of nuclear-generated electricity vis-à-vis its alternatives, although the result is not as conclusive as the other approaches mentioned above.

* The IAEA is carrying out a Co-ordinated Research Programme which gives emphasis to research that examines the broad economic implications of introducing nuclear power into national energy systems. Encouragement is being given to economic research that considers the effects of nuclear power programmes on the overall economic development of developing countries. Particularly the investment and financing requirements for energy programmes, overall industrial investment requirements, quality and quantity of manpower requirements, balance of payments, stimulation of other economic sectors, and the environmental impact, risks, and benefits of nuclear power, as compared with alternative energy supply options, will be assessed.

International cost experience

Many national and international studies of nuclear power costs have been made, in addition to those of the IAEA. Highlights from a few of these are reviewed here, together with some reported actual experience with nuclear power costs.

NEA and UNIPEDE

In December 1983 the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (NEA) published the study *Costs of Generating Electricity in Nuclear and Coal-Fired Power Stations,* which included a number of Western European countries, Canada, Japan, and the United States. This study expanded on an earlier one covering fewer countries, which was carried out by the International Union of Producers and Distributors of Electrical Energy (UNIPEDE).

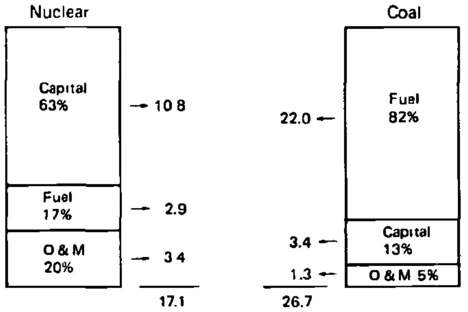
The NEA study comes to the conclusion that in Europe and Japan nuclear power will have a cost advantage over coal stations commissioned in 1990, ranging from 30% to 70%. On the other hand, in the United States and Canada the competitiveness depends very much on the region considered. Nuclear will have an economic advantage in Central and Atlantic Canada and may retain a small advantage in the northeastern and southeastern parts of the United States. On the reference assumptions, however, a new coal plant close to the major North American coal fields is likely to produce cheaper electricity even when the plant is equipped with flue gas desulphurization systems.

Among other factors, the cost comparisons are very sensitive to load factors, capital costs, site dependent factors, etc. However, the NEA study concluded that the economic advantage of nuclear could still hold in Western Europe, Japan, and Central Canada, even with a 50% increase in nuclear capital costs, or a two- to three-fold increase in nuclear fuel cycle costs, or for operation of nuclear stations at or below a 50% load factor.

Comparative costs in selected countries

Also summarized here are studies done in Canada, France, Japan, and the United States comparing the costs of nuclear power and alternatives.

In Canada, Ontario Hydro issued a report in March 1982 comparing two specific plants – the Bruce A nuclear station, with four 740 megawatt-electric units, which entered into full commercial operation in 1979, and the Nanticoke coal-fired station, with eight 490 megawatt-electric units, which started to be fully operational in 1978. Figures are quoted in Canadian mills per kilowatt-hour electric of 1981, for base-load operation.



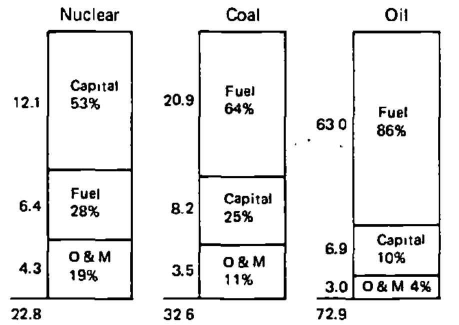
Costs in Canadian mills per KWh/electric

In Japan, some recently published data show nuclear generating costs to be far cheaper than any of the other alternatives considered. Capital costs are expressed in US dollars per kilowatt-hour electric; generating costs in US cents per kilowatt-hour.

	Capital*	Generating**	Fuel share***
Nuclear	1080	4.8	25%
Thermal			
Oil	520	8.0	80%
Liquid natural gas	680	7.6	70%
Coal	800	6.0	50%
Hydro	2400	8.0	0

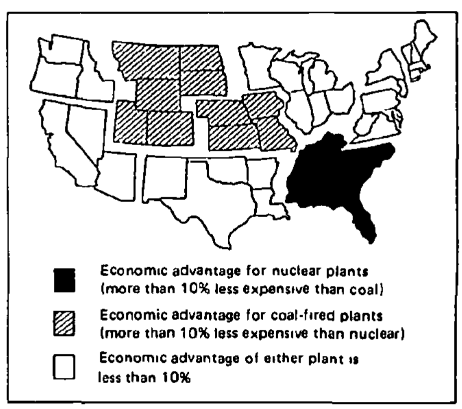
* US dollars per KWh/electric.
** US cents per KWh/electric.
*** Fuel as per cent of generating cost.
Source. *Nuclear Engineering International,* August 1984.

In France, nuclear power plants hold a significant edge over coal- or oil-fired plants, based on a comparative estimation of generation costs by the French Atomic Energy Commission (CEA) published in *Enerpresse* in December 1984. Data are related to average standard generating plants operating at full capacity. All values are expressed in French centimes per kilowatt-hour electric of 1984, but refer to a plant connected to the grid in 1992.



Costs in centimes per KWh/electric

In the United States, a study by the Oak Ridge National Laboratory (ORNL) concluded that nuclear and coal-fired generation costs, for plants starting up in 1995, are very close in most regions.* Nuclear power has a cost advantage in the South Atlantic region where coal must be transported from far away, while coal-fired generation has an advantage in the Central and North Central regions where large reserves of cheaply mineable coal exist. In several regions, small changes in the base economic parameters could cause either option to have an economic advantage.



* *Regional Projections of Nuclear and Fossil Electric Power Generation Costs,* ORNL/TM-8958 (December 1983).