# Cost of nuclear and conventional baseload electricity generation

*Nuclear power remains economically competitive in many countries*

**by P.M.S. Jones and G. Woite**

The costs for nuclear and conventional power investment and electricity generation are important for decisions on fuel choices for future electricity supply, not least for baseload power projects.

A cursory review of available information indicates that the investment costs of recently completed nuclear power plants range from about US $1300 to over US $6000 per kilowatt-electric (kWe). Relevant reasons for this wide variation include differences in project management; regulatory approach; site-related factors (e.g. multi-unit siting, seismicity, infrastructure); plant design (including extent of standardization); unit prices (e.g. of locally available materials and labour); and accounting (e.g. inclusion or exclusion of interest during construction, inventories of fuel and heavy water; cost reference date; currency exchange rates).

Most prominent for projects with high costs were difficulties with construction management and regulatory procedures. These factors also led to extended construction schedules up to about 14 years; some as yet unfinished projects may even take longer.

On the other hand, important features of low-cost projects with construction periods of 5-6 years (one unit) include efficient project management; strong feedback of experience; the detailed design is largely completed and regulatory issues are resolved before start of construction.

Experience is fed back through the co-operation of utilities, manufacturers, and regulatory staff, and through standardization and replication. It appears that many lessons from construction and operation experience have been learned. New or modified designs have been submitted in good time for regulatory review in order to get them approved and completed before the start of construction.

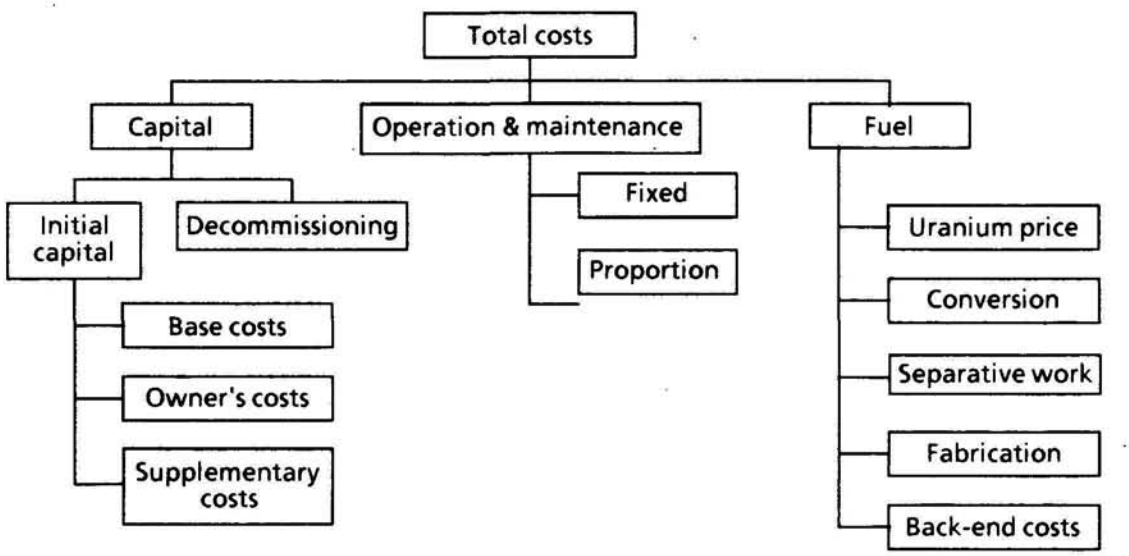
Efforts are also under way to establish internationally accepted safety and licensing criteria, and to make regulatory procedures more predictable. These should assist in bringing the benefits achieved in the most successful countries to others. *(See accompanying figure.)* They are, to some extent, taken into account in recent cost studies of the IAEA and the Organisation for Economic Co-operation and Development (OECD).

**Means to reduce the capital costs of nuclear power plants**

- Benefit from **feedback of experience**
  - — Replication, standardization, collocation
- Implement **technical progress**
  - — Design
  - — Construction techniques
- Extend **planning** quality and quantity
  - — Detailed design completed
  - — Political and regulatory issues resolved before construction start
- Improve **project management**
  - — Scheduling
  - — Cost control
- Achieve good operating performance

Prof. Jones is Chief Economic Adviser, AEA Technology, London, and Mr Woite is a staff member in the IAEA Division of Nuclear Power. The authors of the article were members of the OECD Working Group on Electricity Generating Costs which produced a report entitled *Prospected Costs of Generating Electricity from Power Stations for Commissioning in the Period 1995-2000.* Results and parts of this report were used in this article.

**Categories of electricity generation costs**




Notes: The initial capital costs include all direct and indirect expenditures for the construction and commissioning of the plant. The supplementary costs include transportation, insurance, spare parts, and contingencies. All cost items include real interest (and real escalation where applicable). Exclusions include cost elements due to general inflation; electric system costs (e.g. for transmission, power reserve); taxes on income and profits of the utility; impacts on the national economy, including costs and benefits of industrial and infrastructure development; external health and environmental impact; and provision for risks not covered by insurances.

## Summary of IAEA and OECD cost surveys

Expert groups from Member States of the OECD, IAEA, and International Union of Producers and Distributors of Electrical Energy (UNIPEDE) have recently reviewed the projected levelized electricity generation costs of the baseload power generation options expected to be available in the medium term, using an agreed common economic methodology.* Cost projections were obtained and evaluated for nuclear plants and fossil-fuel plants (mainly coal-fired) that could be commissioned in the mid- to late 1990s.

## Method and assumptions

The electricity production costs include all incremental charges to the utility, specific to the plants under consideration, in constant value money. These include all capital costs (including real interest charges during construction), fuel, operating and maintenance costs, waste management costs, decommissioning costs, and station-specific insurance costs. Taxes on income and profits, transmission costs, and other cost impacts common to the overall utility system, together with external costs such as those caused by environmental harm, are excluded. *(See accompanying figure.)* It should be noted, however, that all the generating plants and their fuel cycles are operated within the framework of current or planned national and international regulations and obligations concerning safety and environmental controls designed to ensure that potentially harmful effects are restricted to acceptable levels. Specific efforts were devoted to meaningful comparison of nuclear and coal-based electricity costs in each country.

The reader is advised against comparing absolute costs between countries because of their substantial variations of economic and social systems and different provisions for radioactive waste management, plant decommissioning, and environmental protection. For example, environmental protection laws in most of the OECD countries require flue gas desulphurization (FGD) and in some countries also abatement of nitrogen oxides at new coal-fired power plants. On the other hand, most of the non-OECD countries do not practice FGD so far. Nevertheless, six out of nine non-OECD countries included FGD in their cost estimates for future coal plants. The electricity generation costs on coal-fired plants with abatement for sulphur and nitrogen oxides

* See "Electricity Generation Costs Assessment Made in 1987 for Stations to be Commissioned in 1995", presented by UNIPEDE, Sorrento Congress (1988); *Projected Costs of Generating Electricity from Power Stations for Commissioning in the Period 1995-2000*, Working Group report, OECD/Nuclear Energy Agency/International Energy Agency (1989); and *Projected Costs of Nuclear and Conventional Baseload Electricity Generation in Some IAEA Member States*, IAEA-TECDOC-569 (1990).

are projected to be about 15% to 20% higher than those of plants without this anti-pollution measure.

The assumptions on decommissioning vary in a similar manner: all OECD countries included decommissioning provisions in their cost estimates, whereas four of the non-OECD countries did not. For the sake of comparability, a common assumption on decommissioning costs was chosen for the reference calculations for these four non-OECD countries.

## Investment costs

For some countries, various means of reducing the capital costs of nuclear power plants vis-a-vis previous experience were considered for the surveys. *Inter alia,* it generally is assumed that the project is reasonably well managed, the financing is secured, and the detailed design is completed and approved by the regulatory authority before start of construction so that costly design modifications and construction delays are avoided. The extent to which multi-unit siting; standardization; modularization; and advanced engineering and construction methods are already practiced or planned for future projects, varies among the countries.

Major differences in investment cost expectations remain between countries. They arise from differences in factor costs (e.g. costs of construction labour and materials), design, regulatory approach, siting, and exchange rates which often do not adequately reflect the differences in purchasing power between countries. There are also different levels of cost uncertainties stemming from different levels of relevant nuclear experience. *(See accompanying graphs.)*

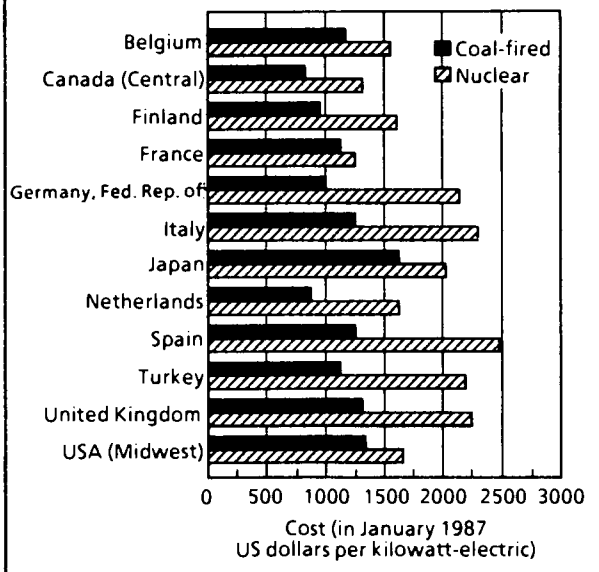
## Generation costs

Two sets of calculations of the levelized electricity costs were performed, one with country-specific assumptions on discount rate, plant life, operating regime, and decommissioning; and one with a common reference set of assumptions.

The reference calculations assume a real discount rate of 5% per annum, a 30-year life for both coal-fired and nuclear generating plants, a 72% lifetime levelized load factor, and a common assumption on decommissioning costs for those countries which did not provide their own estimates. These reference assumptions were based firmly on utility experience and expectations.

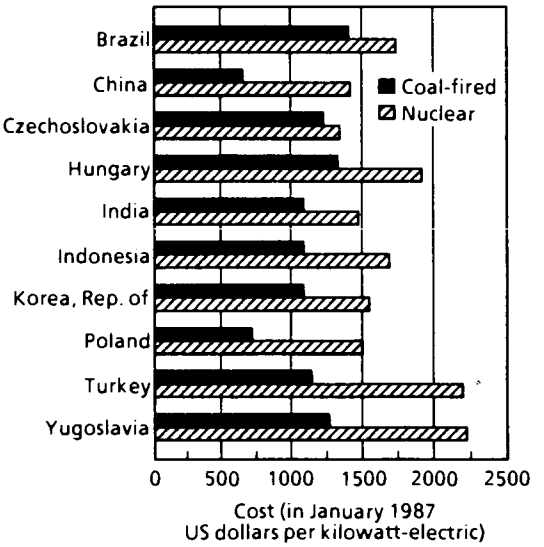
The reference discount rate corresponds closely to the costs most utilities expect to experience in obtaining external investment funds, expressed in real terms. The load factor and plant life are supported by baseload operational experience in industrialized countries and are considered appropriate in these countries for both types of plants being commissioned from the mid-1990s onwards. However, most of the developing countries, which have experienced lower average load factors, would have to take appropriate measures to raise the performance of their baseload plants; most of them

**Projected investment costs of coal-fired and nuclear power plants in OECD countries**




Note: Investment costs include real interest during construction (5% annually).

**Projected investment costs of coal-fired and nuclear power plants in some IAEA Member States**




Note: Investment costs include real interest during construction (5% annually).

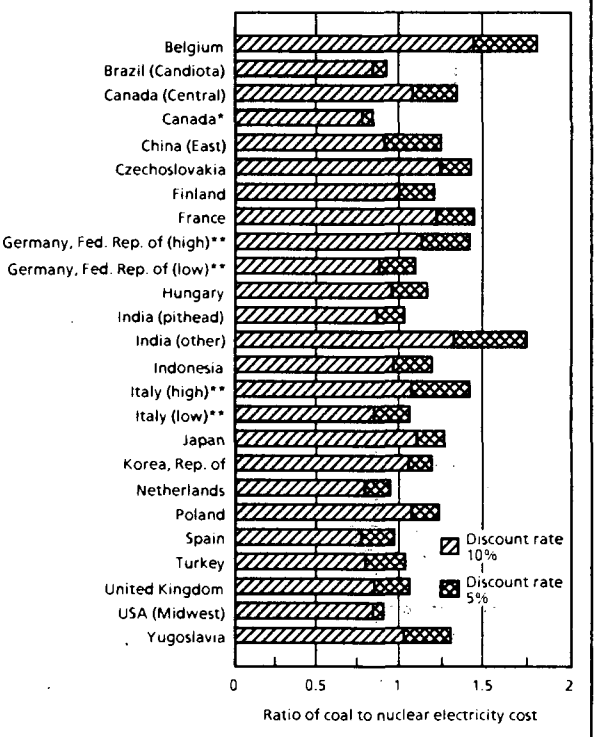
**The investment costs of nuclear and coal-fired power plants in OECD countries and nine other IAEA Member States are presented here. The projected overnight construction costs range from about US $1100 to US $2000 per kilowatt-electric (kWe) for nuclear power plants and from US $700 to US $1500 per kWe for coal-fired plants in January 1987 US dollar values.**

assume load factors of 70% or less for their national calculations.

Using the reference assumptions, nuclear plants are projected to have a significant economic advantage over coal-fired plants for lifetime baseload power production in most of the industrialized countries and some developing countries. *(See accompanying graph.)*

In particular, nuclear electricity is projected to be significantly cheaper than coal-based electricity in Japan, most European countries, in regions of North America, China, and India which are distant from coal fields, as well as in Indonesia and the Republic of Korea. On the other hand, coal-based electricity is projected to be cheaper in the coal regions of North America, Brazil, China, and India, and also in the Netherlands and Spain when electricity is produced from imported coal.

**Relative competitiveness of coal-based and nuclear electricity using 5% and 10% discount rate**




* Western coal compared to Eastern nuclear.
** Coal prices in high and low estimates.

## Sensitivities

The levelized generation costs and the relationship between them for nuclear and coal-fired plants depend greatly on the input parameters employed. They are most sensitive to the discount rate, future fossil-fuel prices, and plant capital costs.

Careful consideration was given to the more important parameters, in particular to the discount rate. Although the reference discount rate of 5% per annum corresponds closely to the costs of external financing expected for electricity utilities — which is close to the long-term government bond rate of interest — it is significantly lower than the average real rate of return on industrial investment in most OECD countries. The World Bank has often recommended a 10% real discount rate for project appraisals, particularly in countries with scarce investment resources. Calculations therefore were performed with an alternative discount rate of 10% per annum. Only Belgium, France, Japan, Czechoslavakia, and India (at sites distant from the pithead) show a clear cost advantage for nuclear power at this discount rate.

For the OECD study, alternative views on future coal prices were proposed by the Coal Industry Advisory Board (CIAB), an independent advisory board to the International Energy Agency of the OECD. Their average of best estimates, when adjusted for internal transport costs of consumers, was generally lower than the estimates of the majority of countries.

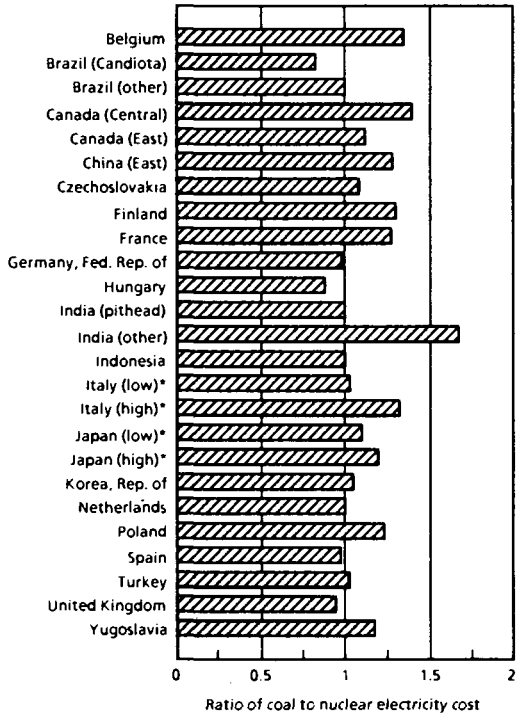
Using the alternative assumptions for higher discount rates and lower coal prices, the coal option becomes relatively more attractive. Using a 10% discount rate, coupled with utilities' assumptions for coal prices, three OECD countries show nuclear power having a significant cost advantage, two show approximate comparability, and four show coal having a significant advantage. The use of the coal price projections by the CIAB (which refer to coal imported into Western Europe and Japan only) would further lower the projected cost of coal-fired generation in most OECD countries. At a 5% discount rate, four OECD countries show a significant nuclear advantage, four show approximate equivalence, and one shows a significant advantage to coal. At a 10% discount rate and CIAB coal price projections, coal-fired generation would become the cheaper option in most countries.

Calculations were also performed with a levelized load factor of 63%, to approximately reflect the operating experience in some of the countries, and with a plant life of 25 years for both nuclear and coal-fired plants. These assumptions improve the competitiveness of coal, albeit to a lesser extent than the alternative discount rate.

## Study findings

Where participating countries use their own assumptions of discount rate, plant lifetime, and load factor, seven OECD countries, two Eastern European countries, plus Yugoslavia and India (in regions which are distant from the pithead) show nuclear electricity to have a significant cost advantage. *(See graph on page 22.)* The other countries project nuclear electricity to range from about break-even to about 10% more expensive than coal-based electricity; in their low-cost coal regions, coal-based electricity is the cheaper option.

**Relative competitiveness of coal-based and nuclear electricity using national assumptions on discount rate, load factor, and plant life**




* Coal prices in high and low estimates.

The use of the common reference assumptions of the international studies yields broadly similar results for the OECD countries, but would improve nuclear power's competitiveness in Eastern European and other non-OECD countries.

In short, most of the participating countries expect nuclear power to have a lower levelized generating cost than coal-fired generation or, at worst, to about break-even. However, for most countries, the projected comparisons between coal and nuclear generating costs are not clear cut when viewed across the full range of assumptions considered in the studies. Under some assumptions of parameter values, nuclear power has a sizeable cost advantage over coal; for other parameter values the reverse is the case.

Compared with previous studies, lowered perceptions of future coal prices have reduced the projected costs of coal-fired electricity generation in a number of countries relative to the costs of nuclear power. Projected nuclear generation costs themselves appear to have remained relatively stable or even decreased slighty on the basis of the same studies.*

* "International Comparison of Generation Costs", by P.M.S. Jones, G.H. Stevens, and K. Wigley, proceedings of *Good Performance in Nuclear Projects*, NEA/OECD (November 1989).

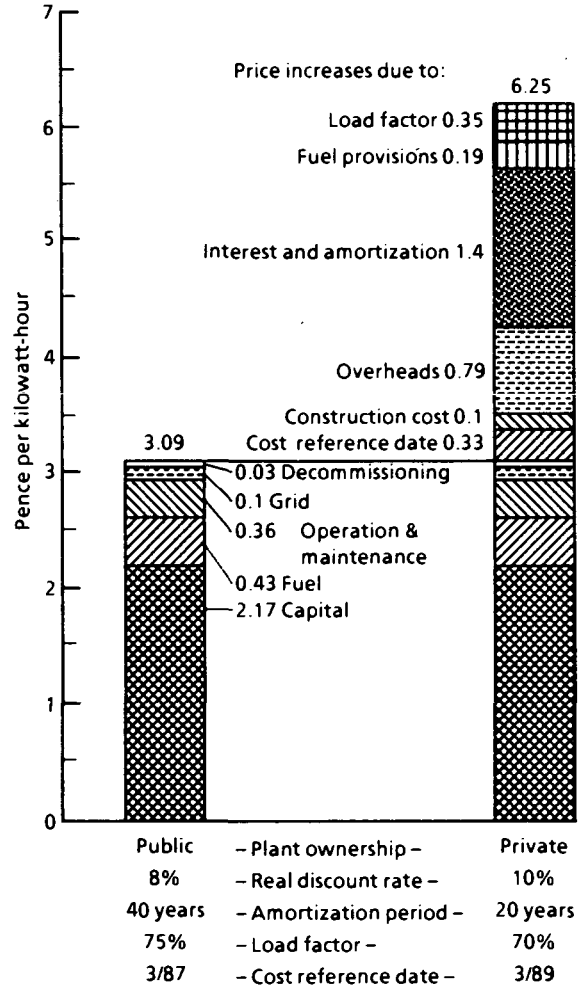
## The United Kingdom and its relevance

This general consensus, which suggests that (under the parameter values considered most appropriate for cost assessment) nuclear power will remain competitive or, at worst, about even with coal-fired generation, is in apparent conflict with claims that appeared in the United Kingdom press. These media reports claimed that nuclear generation costs in the UK were three times those for coal plants. It has been made clear, however, that the underlying costs for future electricity from pressurized-water reactors (PWRs) in the UK have only marginally changed.* They are largely consistent with those shown in the graphs on pages 21 and 22.

The indicative negotiating price a newly privatized generating utility might have sought for electricity from a new PWR included overhead costs, a different way of calculating profit, and a return on capital equivalent to a 14% per annum real internal rate of return over a

* "The Future for Nuclear Power", by W. Marshall, British Nuclear Energy Society Annual lecture (November 1989).

**Nuclear electricity**



20-year depreciation period; additionally, it introduced deliberately conservative performance and contingency assumptions. These were felt by the utility to be justified in a situation in which, unlike other countries, there was to be free competition in electricity supply with no long-term contractual assurance of sales to the separately privatized distribution companies and in the high interest rate environment currently prevailing in the UK.

The public sector incremental cost and private sector prices have been calculated with these different assumptions. *(See accompanying table and graph.)* It is striking that the private sector price is twice as high than the cost previously calculated for the public sector. One important reason for this is the switch from 8% real discount rate and 40 years annuitization to 10% real discount rate and 20 years linear depreciation, applied on an undepreciated capital basis. The public sector assumptions led to a capital charge rate of 8.4% whereas those of the private sector yielded on average 14% capital return. Thus, the major part of the increase is due to assumptions on relevant economic parameters (interest rate and money units) and to the accounting approach (amortization basis, overheads, and extra contingency allowances). Very little is due to any anticipated real increase in construction costs or in the provisions needed for spent-fuel and radioactive waste management. These private sector prices were wrongly compared in the media with electricity costs (excluding overheads, etc.) from new coal plants and with electricity prices considered suitable for existing, partly written-off coal plants in the private sector. Computed on the same risk-averse basis, electricity from new coal-fired plants might have been about 20% cheaper than nuclear electricity.

The extreme form of competitive environment that was envisaged in the UK does not exist in other countries (and the situation in the UK itself has changed with

**costs and prices in the United Kingdom** (pence per kilowatt-hour)

| Plant ownership | Public | Public | Private |
|---|---|---|---|
| Date of cost estimate | April 1987 | April 1989 | Mid-1990 |
| *Economic parameters* | | | |
| Real discount rate | 5% | 8% | 10%[a] |
| Depreciation period | 40 years | 40 years | 20 years |
| Levelized load factor | 75% | 75% | 70% |
| Cost reference date | March 1987 | March 1987 | March 1989 |
| *Incremental generation cost* | | | |
| Capital | 1.35 | 2.17 | |
| Grid connection | 0.07 | 0.10 | |
| Fuel | 0.45 | 0.43 | |
| Other operations | 0.34 | 0.36 | |
| Decommissioning | 0.03 | 0.03 | |
| Total | 2.24 | 3.09 | |
| *Price additions for private sector* | | | |
| Changed money base date | | | 0.33 |
| Additional building costs[b] | | | 0.10 |
| Overhead charges[c] | | | 0.79 |
| Changed interest and amortization basis[d] | | | 1.40 |
| Effect of reduced load factor[e] | | | 0.35 |
| Changed fuel provisions[e] | | | 0.19 |
| Sub-total for price additions | | | 3.16 |
| Total electricity generation price for private plant ownership | | | 6.25 |

[a] Applied on undepreciated capital basis.
[b] Share of extra "new design" costs from the Sizewell pressurized-water reactor.
[c] Central overheads, insurance, and local taxes normally common to generation options.
[d] Switch to shorter amortization and 10% return on initial capital (equivalent to 14% internal rate of return).
[e] Additional contingency built in, through pessimistic assumptions and provisions, to minimize financial risk to generating company.