The Economics of Nuclear Power

(*July 2009*)

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- **Nuclear power is cost competitive with other forms of electricity generation, except where there is direct access to low-cost fossil fuels.**
- **Fuel costs for nuclear plants are a minor proportion of total generating costs, though capital costs are greater than those for coal-fired plants and much greater than those for gas-fired plants.**
- **In assessing the economics of nuclear power, decommissioning and waste disposal costs are taken into account.**

The relative costs of generating electricity from coal, gas and nuclear plants vary considerably depending on location. Coal is, and will probably remain, economically attractive in countries such as China, the USA and Australia with abundant and accessible domestic coal resources as long as carbon emissions are cost-free. Gas is also competitive for base-load power in many places, particularly using combined-cycle plants, though rising gas prices have removed much of the advantage.

Nuclear energy is, in many places, competitive with fossil fuel for electricity generation, despite relatively high capital costs and the need to internalise all waste disposal and decommissioning costs. If the social, health and environmental costs of fossil fuels are also taken into account, the economics of nuclear power are outstanding.

See also the December 2005 World Nuclear Association report (pdf 310 kB) The New Economics of Nuclear Power.

External costs

The report of a major European study of the external costs of various fuel cycles, focusing on coal and nuclear, was released in mid 2001 - ExternE. It shows that in clear cash terms nuclear energy incurs about one tenth of the costs of coal. The external costs are defined as those actually incurred in relation to health and the environment and quantifiable but not built into the cost of the electricity. If these costs were in fact included, the EU price of electricity from coal would double and that from gas would increase 30%. These are without attempting to include the external costs of global warming.

The European Commission launched the project in 1991 in collaboration with the US Department of Energy, and it was the first research project of its kind "to put plausible financial figures against damage resulting from different forms of electricity production for the entire EU". The methodology considers emissions, dispersion and ultimate impact. With nuclear energy the risk of accidents is factored in along with high estimates of radiological impacts from mine tailings (waste management and decommissioning being already within the cost to the consumer). Nuclear energy averages 0.4 euro cents/kWh, much the same as hydro, coal is over 4.0 cents (4.1-7.3), gas ranges 1.3-2.3 cents and only wind shows up better than nuclear, at 0.1-0.2 cents/kWh average. NB these are the external costs only.

The cost of fuel

From the outset the basic attraction of nuclear energy has been its low fuel costs compared with coal, oil and gas fired plants. Uranium, however, has to be processed, enriched and fabricated into fuel elements, and about half of the cost is due to enrichment and fabrication. In the

into fuel elements, and about half of the cost is due to enrichment and fabrication. In the assessment of the economics of nuclear power allowances must also be made for the management of radioactive spent fuel and the ultimate disposal of this spent fuel or the wastes separated from it.

Areva figures early in 2008 showed 17% of the total kWh generation cost for its EPR being fuel costs, and these broke down: 51% natural uranium, 3% conversion, 32% enrichment, and 14% fuel fabrication.

In January 2007, the approx. US $ cost to get 1 kg of uranium as UO_2 reactor fuel at likely contract prices (about one third of current spot price):

Uranium:	8.9 kg U_3O_8 x $53	US$ 472
Conversion:	7.5 kg U x $12	US$ 90
Enrichment:	7.3 SWU x $135	US$ 985
Fuel fabrication:	per kg	US$ 240
Total, approx:		US$ 1787

At 45,000 MWd/t burn-up this gives 360,000 kWh electrical per kg, hence fuel cost: 0.50 c/kWh.

If assuming a higher uranium price, say two thirds of current spot price: 8.9 kg x 108 = 961, giving a total of $2286, or 0.635 c/kWh.

But even with these included, the total fuel costs of a nuclear power plant in the OECD are typically about a third of those for a coal-fired plant and between a quarter and a fifth of those for a gas combined-cycle plant.

Fuel costs are one area of steadily increasing efficiency and cost reduction. For instance, in Spain nuclear electricity cost was reduced by 29% over 1995-2001. This involved boosting enrichment levels and burn-up to achieve 40% fuel cost reduction. Prospectively, a further 8% increase in burn-up will give another 5% reduction in fuel cost.

Comparing the economics of different forms of electricity generation

For nuclear power plants any cost figures normally include spent fuel management, plant decommissioning and final waste disposal. These costs, while usually external for other technologies, are internal for nuclear power (ie they have to be paid or set aside securely by the utility generating the power, and the cost passed on to the customer in the actual tariff).

Decommissioning costs are about 9-15% of the initial capital cost of a nuclear power plant. But when discounted, they contribute only a few percent to the investment cost and even less to the generation cost. In the USA they account for 0.1-0.2 cent/kWh, which is no more than 5% of the cost of the electricity produced.

The back-end of the fuel cycle, including used fuel storage or disposal in a waste repository, contributes up to another 10% to the overall costs per kWh, - less if there is direct disposal of used fuel rather than reprocessing. The $26 billion US used fuel program is funded by a 0.1 cent/kWh levy.

The cost of nuclear power generation declined over the 1990s and into the new decade. This was because declining fuel (including enrichment), operating and maintenance costs, while the plant concerned has been paid for, or at least is being paid off. In general the construction costs of nuclear power plants are significantly higher than for coal- or gas-fired plants because of the need to use special materials, and to incorporate sophisticated safety features and back-up control equipment. These contribute much of the nuclear generation cost, but once the plant is built the cost variables are minor.

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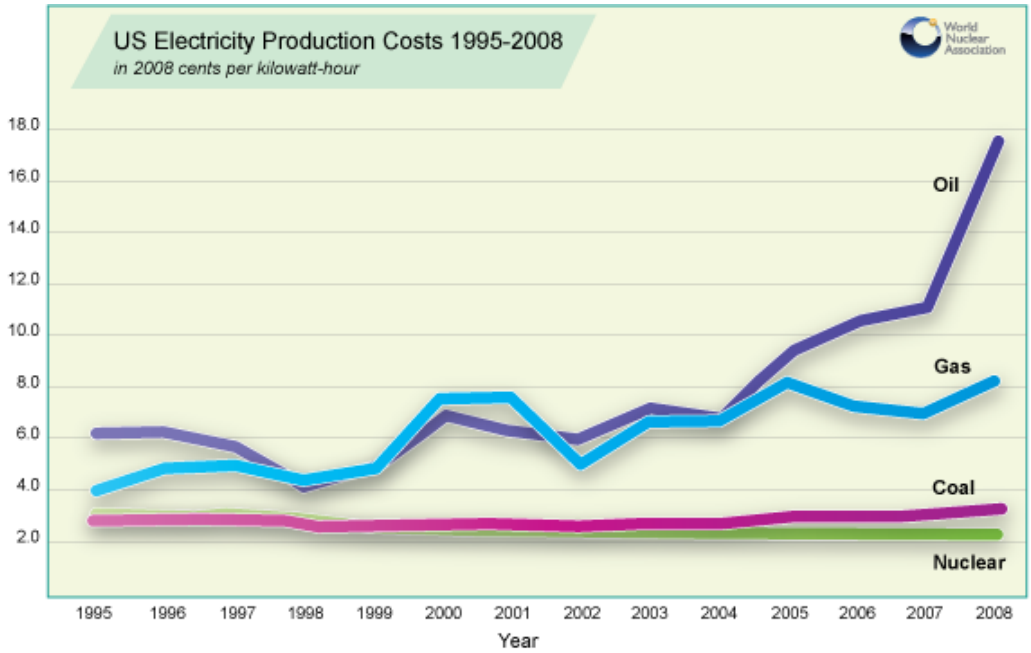
Long construction periods will push up financing costs, and in the past they have done so spectacularly. In Asia construction times have tended to be shorter, for instance the new-generation 1300 MWe Japanese reactors which began operating in 1996 and 1997 were built in a little over four years, and 48 to 54 months is typical projection for plants today.

US cost figures for 2007 published by the Energy Utility Cost Group showed nuclear utility generating costs averaging 2.866 c/kWh, comprising 1.832 c/kWh operation and maintenance, 0.449 c/kWh fuel and 0.585 c/kWh capital expenditure (NB apparently not amortisation of the plants). US figures from a different source for 2007 published by NEI gave 1.68 c/kWh for fuel plus O&M.



Production Costs = Operations & Maintenance + Fuel. Production costs do not include indirect costs or capital.

Source: *Ventyx Velocity Suite, via NEI*

Note: the above data refer to fuel plus operation and maintenance costs only, they exclude capital, since this varies greatly among utilities and states, as well as with the age of the plant.

Future cost competitiveness

The future competitiveness of nuclear power will depend substantially on the additional costs which may accrue to coal-fired generation, and the cost of gas for gas-fired plants. It is uncertain how the real costs of meeting targets for reducing sulphur dioxide and greenhouse gas emissions will be attributed to fossil fuel plants.

Understanding the cost of new generating capacity and its output requires careful analysis of what is in any set of figures. There are three broad components: capital, finance and operating costs. Capital and financing costs make up the project cost.

-- **Capital cost** may comprise several things: the bare plant cost (usually identified as engineering-procurement-construction - EPC - cost), the owner's costs (land, cooling infrastructure, administration and associated buildings, site works, switchyards, project management, licences, etc), cost escalation and inflation. (Owner's costs may include transmission infrastructure, though strictly this is extrinsic.) The term "overnight capital cost" is often used, meaning EPC plus owners costs and excluding financing, escalation due to

often used, meaning EPC plus owners costs and excluding financing, escalation due to increased material and labour costs, and inflation. Construction cost – sometimes called "all-in cost", adds to overnight cost any escalation and interest during construction and up to the start of construction. It is expressed in the same units as overnight cost and is useful for identifying the total cost of construction and for determining the effects of construction delays.
-- **Financing costs** will depend on the rate of interest on debt, the debt-equity ratio, and if it is regulated, how the capital costs are recovered.
-- **Operating costs** include operating and maintenance (O&M) plus fuel, and need to allow for a return on equity.

Any capital cost figures from a rector vendor, or which are general and not site-specific, will usually just be for EPC costs. This is because owner's costs will vary hugely, most of all according to whether a plant is Greenfield or at an established site, perhaps replacing an old plant.

A 2005 **OECD comparative study** showed that nuclear power had increased its competitiveness over the previous seven years. The principal changes since 1998 were increased nuclear plant capacity factors and rising gas prices. The study did not factor in any costs for carbon emissions from fossil fuel generators, and focused on over one hundred plants able to come on line 2010-15, including 13 nuclear plants. Nuclear overnight construction costs ranged from US$ 1000/kW in Czech Republic to $2500/kW in Japan, and averaged $1500/kW. Coal plants were costed at $1000-1500/kW, gas plants $500-1000/kW and wind capacity $1000-1500/kW.

OECD electricity generating cost projections for year 2010 on - 5% discount rate

	nuclear	coal	gas
Finland	2.76	3.64	-
France	2.54	3.33	3.92
Germany	2.86	3.52	4.90
Switzerland	2.88	-	4.36
Netherlands	3.58	-	6.04
Czech Rep	2.30	2.94	4.97
Slovakia	3.13	4.78	5.59
Romania	3.06	4.55	-
Japan	4.80	4.95	5.21
Korea	2.34	2.16	4.65
USA	3.01	2.71	4.67
Canada	2.60	3.11	4.00

US 2003 cents/kWh, Discount rate 5%, 40 year lifetime, 85% load factor.
Source: OECD/IEA NEA 2005.

At 5% discount rate nuclear, coal and gas costs are as shown above and wind is around 8 cents. Nuclear costs were highest by far in Japan. Nuclear is comfortably cheaper than coal in seven of ten countries, and cheaper than gas in all but one. At 10% discount rate nuclear ranged 3-5 cents/kWh (except Japan: near 7 cents, and Netherlands), and capital becomes 70% of power cost, instead of the 50% with 5% discount rate. Here, nuclear is again cheaper than coal in eight of twelve countries, and cheaper than gas in all but two. Among the technologies analysed for the report, the new EPR if built in Germany would deliver power at about 2.38 c/kWh - the lowest cost of any plant in the study.

OECD electricity generating cost projections for year 2010 on - 10% discount rate

	nuclear	coal	gas
Finland	4.22	4.45	-
France	3.93	4.42	4.30

Germany	4.21	4.09	5.00
Switzerland	4.38	-	4.65
Netherlands	5.32	-	6.26
Czech Rep	3.17	3.71	5.46
Slovakia	4.55	5.52	5.83
Romania	4.93	5.15	-
Japan	6.86	6.91	6.38
Korea	3.38	2.71	4.94
USA	4.65	3.65	4.90
Canada	3.71	4.12	4.36

US 2003 cents/kWh, Discount rate 10%, 40 year lifetime, 85% load factor.
Source: OECD/IEA NEA 2005.

Based partly on these figures the European Commission in January 2007 published comparative cost estimates for different fuels:

Comparative generating cost in EU - 10% discount rate (EUR)

	2005	Projected 2030 with EUR 20-30/t CO2 cost
Gas CCGT	3.4-4.5	4.0-5.5
Coal - pulverised	3.0-4.0	4.5-6.0
Coal - fluidised bed	3.5-4.5	5.0-6.5
Coal IGCC	4.0-5.0	5.5-7.0
Nuclear	4.0-5.5	4.0-5.5
Wind onshore	3.5-11.0	2.8-8.0
Wind offshore	6.0-15.0	4.0-12.0

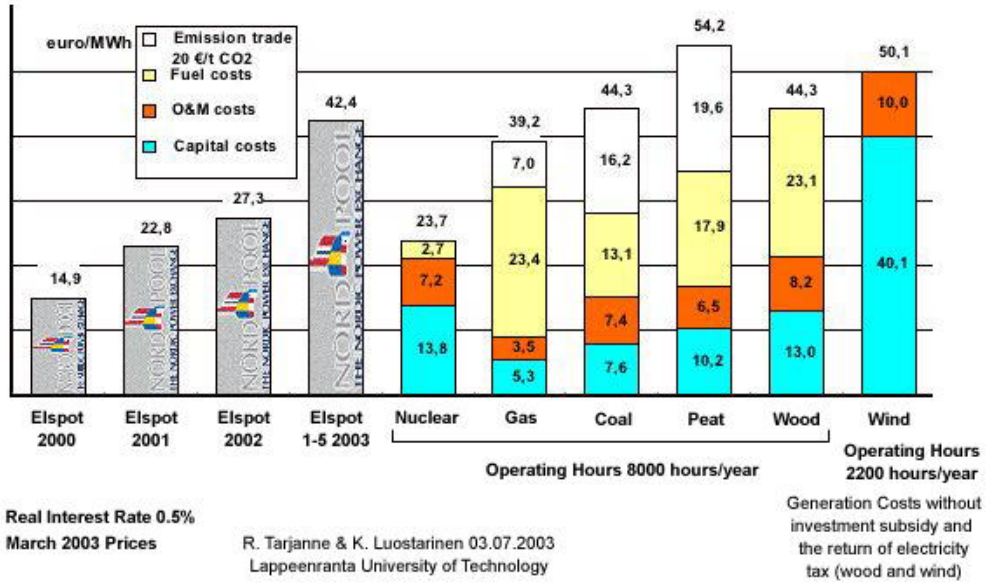
A **1997 European electricity industry study** compared electricity costs from nuclear, coal and gas for base-load plant commissioned in 2005. At a 5% discount rate nuclear (in France and Spain) at 3.46 cents/kWh (US), was cheaper than all but the lowest-priced gas scenario. However at a 10% discount rate nuclear, at 5.07 c/kWh, was more expensive than all but the high-priced gas scenario. (ECU to US$ @ June '97 rates)

In **1999 Siemens** (now Framatome ANP) published an economic analysis comparing combined-cycle gas plants with new designs, including the European Pressurised Water Reactor (EPR) and the SWR-1000 boiling water reactor. Both the 1550 MWe EPR if built as a series in France /Germany and the SWR-1000 (with an 8% discount rate) would be competitive with gas combined cycle, at EUR 2.6 cents/kWh. The current-generation Konvoi plants operating in Germany produce power at 3.0 cents/kWh including full capital costs, falling to 1.5 c/kWh after complete depreciation.

A detailed study of energy economics in **Finland** published in mid 2000 showed that nuclear energy would be the least-cost option for new generating capacity. The study compared nuclear, coal, gas turbine combined cycle and peat. Nuclear has very much higher capital costs than the others --EUR 1749/kW including initial fuel load, which is about three times the cost of the gas plant. But its fuel costs are much lower, and so at capacity factors above 64% it is the cheapest option.

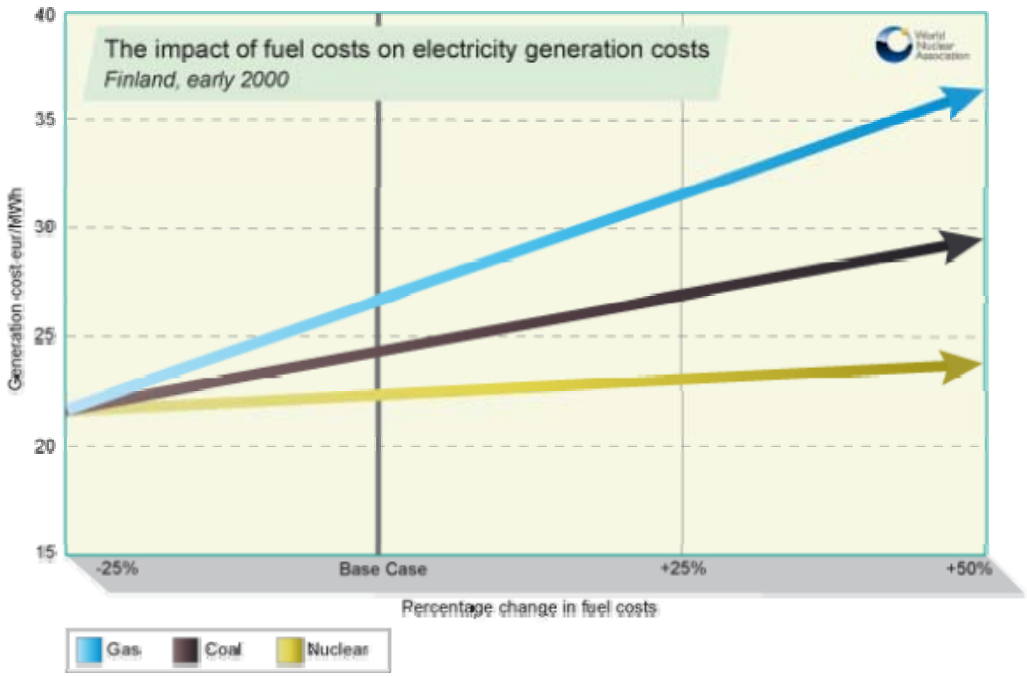
August 2003 figures put nuclear costs at EUR 2.37 c/kWh, coal 2.81 c/kWh and natural gas at 3.23 c/kWh (on the basis of 91% capacity factor, 5% interest rate, 40 year plant life). With emission trading @ EUR 20/t CO2, the electricity prices for coal and gas increase to 4.43 and

3.92 c/kWh respectively:



In the middle three bars of this graph the relative effects of capital and fuel costs can be clearly seen. The relatively high capital cost of nuclear power means that financing cost and time taken in construction are critical, relative to gas and even coal. But the fuel cost is very much lower, and so once a plant is built its cost of production is very much more predictable than for gas or even coal. The impact of adding a cost or carbon emissions can also be seen.

The Finnish study in 2000 also quantified fuel price sensitivity to electricity costs:



These show that a doubling of fuel prices would result in the electricity cost for nuclear rising about 9%, for coal rising 31% and for gas 66%. These are similar figures to those from the 1992 OECD report (bar chart below). Gas prices have already risen significantly since the study, partly reflected in the 2003 figures above.

In **2003 the MIT** published the outcome of a 2-year study of nuclear energy prospects in the USA. Adjusting its assumptions to those more in line with industry expectations ($1500/kW & 4

CCGT. Adjusting its assumptions to those more in line with industry expectations ($1500/kW & 4 year construction, 90% capacity factor, interest rate 12%, and adding fees & taxes) the generation cost came out at 4.2 c/kWh, the same as coal without any carbon cost. The study was updated in 2009 - see below.

The **French Energy Secretariat in 2003** published updated figures for new generating plant. The advanced European PWR (EPR) would cost EUR 1650-1700 per kilowatt to build, compared with EUR 500-550 for a gas combined cycle plant and 1200-1400 for a coal plant. The EPR would generate power at 2.74 cents/kWh, competitively with gas which would be very dependent on fuel price. Capital costs contributed 60% to nuclear's power price but only 20% to gas's. While the figures are based on 40-year plant life, the EPR is designed for 60 years. These figures were again updated in 2008 - see below.

A **UK Royal Academy of Engineering report in 2004** looked at electricity generation costs from new plant in the UK on a more credible basis than hitherto. In particular it aimed to develop "a robust approach to compare directly the costs of intermittent generation with more dependable sources of generation". This meant adding the cost of standby capacity for wind, as well as carbon values up to £30 per tonne CO_2 (£110/tC) for coal and gas. Wind power was shown to be more than twice as expensive as nuclear power.

Without the carbon increment, coal, nuclear and gas CCGT ranged 2.2-2.6 p/kWh and coal gasification IGCC was 3.2 p/kWh - all base-load plant. Adding the carbon value (up to 2.5 p) took coal close to onshore wind (with back-up) at 5.4 p/kWh - offshore wind is 7.2 p/kWh, while nuclear remained at 2.3 p/kWh. Nuclear figures were based on a conservative £1150/kW (US$ 2100/kW) plant cost (including decommissioning).

2004 cost of generating UK electricity (p/kWh) from new plant

	Basic cost	With back-up	With £30/t* CO_2
Nuclear	2.3	n/a	n/a
Gas-fired CCGT	2.2	n/a	3.4
Coal pulverised fuel	2.5	n/a	5.0
Coal fluidised bed	2.6	n/a	5.1
Onshore wind	3.7	5.4	n/a
Offshore wind	5.5	7.2	n/a

* £110/t C

A **2004 report from the Canadian Energy Research Institute** gives an updated comparison of generation costs for Ontario. As well as comparing different fuels and technologies for base-load power, it compares public and private investor funding in deriving the actual levelised power cost. Both the new ACR-700 and the well-proven Candu-6 units are examined for the nuclear case. (Levelised cost means average costs of producing electricity including capital/finance and operation over a plant's lifetime. It may take into account amortising development costs over several units.)

Ontario base-load costs from new plant

	$Can	coal	gas	ACR-700	Candu-6
Capital	$/kW	1600	711	2347	2972
Power - public finance	c/kWh	4.8, 6.1*	7.2, 7.8*	5.3	6.3
Power - merchant finance	c/kWh	5.9, 7.3*	7.5, 8.1*	7.3	8.9

* with C$ 15/y CO_2 cost.

On capital cost, figures include $300 million owner's cost added to the overnight capital cost for the nuclear plants - which are twin units. The ACR is on first-of-a-kind basis. The power

the nuclear plants - which are twin units. The ABWR is on first of a kind basis. The power production costs are based on 30-year operating life and 90% capacity factor. Merchant figures include higher financing plus tax costs. Gas figures are very sensitive to fuel prices.

A 2004 report from the **University of Chicago,** funded by the US Department of Energy, compared the levelised power costs of future nuclear, coal, and gas-fired power generation in the USA. Various nuclear options were covered, and for an initial ABWR or AP1000 they range from 4.3 to 5.0 c/kWh on the basis of overnight capital costs of $1200 to $1500/kW, 60 year plant life, 5 year construction and 90% capacity. Coal gives 3.5 - 4.1 c/kWh and gas (CCGT) 3.5 - 4.5 c/kWh, depending greatly on fuel price.

The levelised nuclear power cost figures include up to 29% of the overnight capital cost as interest, and the report notes that up to another 24% of the overnight capital cost needs to be added for the initial unit of a first-of-a-kind advanced design such as the AP1000, defining the high end of the range above. For more advanced plants such as the EPR or SWR1000, overnight capital cost of $1800/kW is assumed and power costs are projected beyond the range above. However, considering a series of eight units of the same kind and assuming increased efficiency due to experience which lowers overnight capital cost, the levelised power costs drop 20% from those quoted above and where first-of-a-kind engineering costs are amortised (eg the $1500/kW case above), they drop 32%, making them competitive at about 3.4 c/kWh.

Nuclear plant: projected electrcity costs (c/kWh)

Overnight capital cost $/kW		**1200**	**1500**	**1800**
First unit	7 yr build, 40 yr life	5.3	6.2	7.1
	5 yr build, 60 yr life	4.3	5.0	5.8
4th unit	7 yr build, 40 yr life	4.5	4.5	5.3
	5 yr build, 60 yr life *	3.7	3.7	4.3
8th unit	7 yr build, 40 yr life	4.2	4.2	4.9
	5 yr build, 60 yr life *	3.4	3.4	4.0

* calculated from above data

The study also shows that with a minimal carbon control cost impact of 1.5 c/kWh for coal and 1.0 c/kWh for gas superimposed on the above figures, nuclear is even more competitive. But more importantly it goes on to explore other policy options which would offset investment risks and compensate for first-of-a-kind engineering costs to encourage new nuclear investment, including investment tax breaks, and production tax credits phasing out after 8 years. (US wind energy gets a 1.8 c/kWh production tax credit.)

Under a DOE program for promoting building of new-generation nuclear plants, a $4 million feasibility study on building two ABWRs at Bellefonte in Alabama was undertaken in 2004 by the **Tennessee Valley Authority** (TVA) plus vendor GE as well as Bechtel and others. The study showed that twin 1371 MWe ABWRs would cost $1611 per kilowatt, or if they were uprated to 1465 MWe each, $1535 /kW, and be built in 40 months.

Based on this study, **Florida Power & Light** in February 2008 released projected figures for two new AP1000 reactors at its proposed Turkey Point site. These took into account increases of some 50% in material, equipment and labour since 2004. The new figures for overnight capital cost ranged from $2444 to $3582 /kW, or when grossed up to include cooling towers, site works, land costs, transmission costs and risk management, the total cost came to $3108 to $4540 per kilowatt. Adding in finance charges almost doubled the overall figures at $5780 to $8071 /kW. FPL said that alternatives to nuclear for the plant were not economically attractive.

In March 2008 **Progress Energy** announced that its two new Westinghouse AP1000 units on a greenfield site in Florida would cost it about $14 billion, including land, plant components, cooling towers, financing costs, licence application, regulatory fees, initial fuel for two units, owner's costs, insurance and taxes, escalation and contingencies. If built within 18 months of

owners costs, insurance and taxes, escalation and contingencies. If built within 18 months of each other, the cost for the first would be $5144 per kilowatt and the second $3376/kW (average $4260/kW) - total $9.4 billion. Interest adds about one third to the combined figure - $3.2 billion, and infrastructure - notably 320 km of transmission lines - about another $3 billion. The units are expected on line in 2016 and 2017 and are expected to save customers some $930 million per year relative to natural gas-fired generation. Progress emphasised that nuclear would be more cost-effective than alternatives. At the end of December 2008 the company signed an engineering, procurement and construction contract for $7.65 billion ($3462/kW), of an overall project cost of about $14 billion, including land, inflation, site preparation, licensing, financing costs and fuel.

In May 2008 **South Carolina Electric and Gas Co.** and Santee Cooper locked in the price and schedule of new reactors for their Summer plant in South Carolina at $9.8 billion. The EPC contract for completing two 1,117-MW AP1000s is with Westinghouse and the Shaw Group. Beyond the cost of the actual plants, the figure includes forecast inflation and owners' costs for site preparation, contingencies and project financing. The units are expected to be in commercial operation in 2016 and 2019.

In November 2008 **Duke Energy** Carolinas raised the cost estimate for its Lee plant (2 x 1117 MWe AP1000) to $11 billion, excluding finance and inflation, but apparently including other owners costs.

In November 2008 **TVA** updated its estimates for Bellefonte units 3 & 4 for which it had submitted a COL application for twin AP1000 reactors, total 2234 MWe. It said that overnight capital cost estimates ranged from $2516 to $4649/kW for a combined construction cost of $5.6 to 10.4 billion. Total cost to the owners would be $9.9 to $17.5 billion.

A comparative study published in January 2008 for a **Connecticut Integrated Resource Plan**, USA, assumed that nuclear at $4038/kW was most expensive in overnight capital cost but even so it produced the least expensive electricity:

	Overnight capital cost (2008 $/kW)	Electricity cost (c/kWh)
nuclear	4038	8.34
supercritical coal	2214	8.65
supercritical coal +CCS	4037	14.19
IGCC	2567	9.22
IGCC + CCS	3387	12.45
gas combined cycle	869	7.60
gas combined cycle + CCS	1558	10.31

CCS = carbon capture & storage

A **UK study** on the economics of new nuclear capacity published early in 2008 put the average cost of four new 1250 MWe units at £1200 ($2400) per kilowatt and electricity cost 3.0 to 3.4 p/kWh (6-7 cents/kWh) on the basis of 40-year lifetime and 70% debt, 30% equity.

The **US Congressional Budget Office** undertook a study over 2007-08 quantifying the effects of likely carbon emission costs and limited federal subsidies on the commercial viability of new advanced nuclear technology in the USA. With carbon emission costs of about $45 per tonne CO_2, nuclear would be competitive with coal and natural gas even without other incentives. Conversely, the subsidies offered for the first 6000 MWe of advanced nuclear capacity would make it an attractive investment even without carbon emission costs. However, uncertainties regarding nuclear plant construction costs and future gas prices could deter investment in nuclear projects.

The **French Energy & Climate Directorate** published in November 2008 an update of its 2003 study. This shied away from cash figures to a large extent due to rapid changes in both fuel and

study. This shied away from cash figures to a large extent due to rapid changes in both fuel and capital, but showed that at anything over 6000 hours production per year (68% capacity factor), nuclear was cheaper than coal or gas combined cycle (CCG). At 100% capacity CCG was 25% more expensive than nuclear. At less than 4700 hours per year CCG was cheapest, all without taking CO2 cost into account.
With the nuclear plant fixed costs were almost 75% of the total, with CCG they were less than 25% including allowance for CO2 at $20/t. Other assumptions were 8% discount rate, gas at 6.85 $/GJ, coal at EUR 60/t. The reference nuclear unit is the EPR of 1630 MWe net, sited on the coast, assuming all development costs being borne by Flamanville 3, coming on line in 2020 and operating only 40 of its planned 60 years. Capital cost apparently EUR 2000/kW. Capacity factor 91%, fuel enrichment is 5%, burnup 60 GWd/t and used fuel is reprocessed with MOX recycle. In looking at overall fuel cost, uranium at $52/lb made up about 45% of it, and even though 3% discount rate was used for back-end the study confirmed the very low cost of waste in the total - about 13% of fuel cost, mostly for reprocessing.

In **May 2009 an update of the 2003 MIT study** was published. This said that "since 2003 construction costs for all types of large-scale engineered projects have escalated dramatically. The estimated cost of constructing a nuclear power plant has increased at a rate of 15% per year heading into the current economic downturn. This is based both on the cost of actual builds in Japan and Korea and on the projected cost of new plants planned for in the United States. Capital costs for both coal and natural gas have increased as well, although not by as much. The cost of natural gas and coal that peaked sharply is now receding. Taken together, these escalating costs leave the situation [of relative costs] close to where it was in 2003." The overnight capital cost was given as $4000/kW, in 2007 dollars. Applying the same cost of capital to nuclear as to coal and gas, nuclear came out at 6.6 c/kWh, coal at 8.3 cents and gas at 7.4 cents, assuming a charge of $25/tonne CO2 on the latter.

Regarding bare **plant costs**, some recent figures apparently for overnight capital cost (or Engineering, Procurement and Construction - EPC - cost) quoted from reputable sources but not necessarily comparable are:

EdF Flamanville EPR: EUR 4 billion/$5.6 billion, so EUR 2434/kW or $3400/kW
Bruce Power Alberta 2x1100 MWe ACR, $6.2 billion, so $2800/kW
CGNPC Hongyanhe 4x1080 CPR-1000 $6.6 billion, so $1530/kW
AEO Novovronezh 6&7 2136 MWe net for $5 billion, so $2340/kW
KHNP Shin Kori 3&4 1350 MWe APR-1400 for $5 billion, so $1850/kW

FPL Turkey Point 2 x 1100 MWe AP1000 $2444 to $3582/kW

Progress Energy Levy county 2 x 1105 MWe AP1000 $3462/kW

NEK Belene 2x1000 MWe AES-92 EUR 3.9 billion (no first core), so EUR 1950 or $3050/kW
UK composite projection $2400/kW
NRG South Texas 2 x 1350 MWe ABWR $8 billion, so $2900/kW

CPI Haiyang 2 x 1100 MWe AP1000 $3.25 billion, so $1477/kW
CGNPC Ningde 4 x 1000 MWe CPR-1000 $7.145 billion, so $1786/kW
CNNC Fuqing 2 x 1000 MWe CPR-1000 (?) $2.8 billion, so $1400/kW
CGNPC Bailong/Fangchengang 2 x 1000 MWe CPR-1000 $3.1 bilion, so $1550/kW
CNNC Tianwan 3&4, 2 x 1060 MWe AES-91 $3.8 billion, so $1790/kW

AEP Volgodonsk 3 & 4, 2 x 1200 MWe VVER $4.8 billion, so $2000/kW

On the assumption that overall costs to the utility are twice the overnight capital cost of the actual plants, then the figures quoted above give:
SCEG Summer 2 x 1100 MWe AP1000 $2200/kW

Another indication of financing costs is given by Georgia Power, which said in mid 2008 that twin 1100 MWe AP1000 reactors would cost $9.6 billion if they could be financed progressively by ratepayers, or $14 billion if not. This gives $4363 or $6360 per kilowatt including all other owners costs.

Another estimate was reported in June 2009. Nuclear Innovation North America (NINA), comprising NRG Energy and Toshiba Corporation, said that the all up cost of its two 1350 MWe ABWR units at South Texas Project near Houston would be about $10 billion, including financing costs. This would be a merchant plant, not a regulated one operating on cost plus basis. The first unit is expected on line in 2016.

Mid 2008 vendor figures for overnight costs (excluding owner's costs) have been quoted as:
GE-Hitachi ESBWR just under $3000/kW
GE-Hitachi ABWR just over $3000/kW
Westinghouse AP1000 about $3000/kW

There are several possible sources of variation which preclude confident comparison of overnight or EPC capital costs - eg whether initial core load of fuel is included. Much more obvious is whether the price is for the nuclear island alone (Nuclear Steam Supply System) or the whole plant including turbines and generators - all the above figures include these. Further differences relate to site works such as cooling towers as well as land and permitting - usually they are all owner's costs as outlined earlier in this section. Financing costs are additional, adding typically around 30%, and finally there is the question of whether cost figures are in current (or specified year) dollar values or in those of the year in which spending occurs.

Finally, in the USA the question of whether a project is subject to regulated cost recovery or is a merchant plant is relevant, since it introduces political, financial and tactical factors. If the new build cost escalates (or is inflated), some cost recovery may be possible through higher rates can be charged by the utility if those costs are deemed prudent by the relevant regulator. By way of contrast, a merchant plant has to sell all its power competitively, so must convince its shareholders that it has a good economic case for moving forward with a new nuclear unit.

Comparison of cost projections

Bringing together the above studies to 2007 and attempting to present them on a comparable basis, the following figures emerge:

Electricity cost (US cent/kWh)

	MIT 2003	France 2003	UK 2004	Chicago 2004	Canada 2004	EU 2007
Nuclear	4.2	3.7	4.6	4.2 - 4.6	5.0	5.4 - 7.4
Coal	4.2		5.2	3.5 - 4.1	4.5	4.7 - 6.1
Gas	5.8	5.8, 10.1	5.9, 9.8	5.5 - 7.0	7.2	4.6 - 6.1
Wind onshore			7.4			4.7 - 14.8
Wind offshore			11.0			8.2 - 20.2

First 5 gas row figures corrected for Jan 2007 US gas prices of $6.5/GJ (second figure for France & UK columns is using EU price of $12.15/GJ).
Chicago nuclear figures corrected to $2000/kW capital cost. Canada nuclear shows figures for ACR, not Candu.
Currency conversion at June 2007.

In January 2009 CEZ published cost comparisons (EUR c/kWh) for new plant in the Czech Republic:

cost (€ cent/kWh)

	capital	fixed costs	fuel costs	CO2 emissions	TOTAL
Nuclear	3.8	1.0	1.2	0	6.0

Hard coal, supercritical	2.1	0.6	2.0	2.6	7.3
Hard coal + CCS	4.4	1.0	2.4	0	7.8
IGCC	2.5	0.6	2.0	2.6	7.2.
IGCC + CCS	3.7	0.9	2.3	0	6.9
CCGT	1.0	0.3	4.2	1.4	6.9

At the end of 2008 EdF updated the overnight cost estimate for Flamanville 3 EPR (the first French EPR, but with some supply contracts locked in before escalation) to EUR 4 billion in 2008 Euros (EUR 2434/kW), and electricity cost 5.4 cents/kWh (compared with 6.8 c/kWh for CCGT and 7.0 c/kWh for coal, "with lowest assumptions" for CO2 cost). These costs were confirmed in mid 2009, when EdF had spent nearly EUR 2 billion. A second unit would be more expensive, and would deliver power at 5.5 to 6.0 cents/kWh.

Generally, plant choice is likely to depend on a country's international economic situation. Nuclear power is very capital-intensive, while fuel costs are relatively much more significant for systems based on fossil fuels. Therefore if a country such as Japan or France has to choose between importing large quantities of fuel or spending a lot of capital at home, simple costs may be less important than wider economic considerations.

Development of nuclear power, for instance, could provide work for local industries which build the plant and also minimise long-term commitments to buying fuels abroad. Overseas purchases over the lifetime of a new coal-fired plant in Japan, for example, may be subject to price rises which could be a more serious drain on foreign currency reserves than less costly uranium.

Factors Favouring Uranium

Uranium has the advantage of being a highly concentrated source of energy which is easily and cheaply transportable. The quantities needed are very much less than for coal or oil. One kilogram of natural uranium will yield about 20,000 times as much energy as the same amount of coal. It is therefore intrinsically a very portable and tradeable commodity.

The fuel's contribution to the overall cost of the electricity produced is relatively small, so even a large fuel price escalation will have relatively little effect. For instance, typically a doubling of the uranium market price would increase the fuel cost for a light water reactor by 26% and the electricity cost about 7% (whereas doubling the gas price would typically add 70% to the price of electricity from that source).

Reprocessing & MOX

There are other possible savings. For example, if spent fuel is reprocessed and the recovered plutonium and uranium is used in mixed oxide (MOX) fuel, more energy can be extracted. The costs of achieving this are large, but are offset by MOX fuel not needing enrichment and particularly by the smaller amount of high-level wastes produced at the end. Seven UO_2 fuel assemblies give rise to one MOX assembly plus some vitrified high-level waste, resulting in only about 35% of the volume, mass and cost of disposal.

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