Nuclear Power
how competitive down the line?

by Fatih Birol

The world's latest energy outlook sees a mixed future.

The world is facing twin energy-related threats: that of not having adequate and secure supplies of energy at affordable prices and that of environmental harm caused by its use. Soaring energy prices and recent geopolitical events have reminded us of the essential role affordable energy plays in economic growth and human development, and of the vulnerability of the global energy system to supply disruptions.

Safeguarding energy supplies is once again at the top of the international policy agenda. Yet the current pattern of energy supply carries the threat of severe and irreversible environmental damage. Reconciling the goals of energy security and environmental protection requires strong and coordinated government action and public support.

These concerns have revived discussion about the role of nuclear power. Over the past two years, several governments have made statements favouring an increased role of nuclear power in the future energy mix and a few have taken concrete steps towards the construction of a new generation of safe and cost-effective reactors.

Over the next two and a half decades, nuclear power along with energy efficiency and renewables, could help address concerns about over-reliance on fossil-fuelled electricity generation, especially worries about climate change and increasing dependence on gas imports:

✔ Nuclear power is a low-carbon source of electricity. Operation of one gigawatt of nuclear power generating capacity, if replacing coal-fired generation, avoids the emission of 5.6 million tonnes of CO_2 per year. Nuclear power plants do not emit any airborne pollutants such as sulphur dioxide, nitrogen oxides or particulate matter.

✔ Nuclear power plants can help reduce dependence on imported gas; and unlike gas, uranium resources are widely distributed around the world. Under current policies, gas-import dependence will rise in all regions of the OECD (Organization for Economic Cooperation and Development) and in key developing countries by 2030, an increase driven mainly by the power sector.

✔ Nuclear plants produce electricity at relatively stable costs, because the cost of the fuel represents a small part of the total production cost; the raw uranium accounts for about 5% and uranium fuel after treatment for about 15%. In gas-fired power plants, fuel accounts for about 75% of the total production cost.

Outlook for Nuclear Power

The *World Energy Outlook 2006*, the flagship publication of the International Energy Agency, includes two policy scenarios:

- The **Reference Scenario** assumes that current government policies remain broadly unchanged and that they go on with their current programmes to expand or to phase out nuclear power. Targets for nuclear power generation, if judged unrealistic, are assumed not to be achieved. The macroeconomic, technical and financial assumptions underlying many countries' targets are often different from those used in the *Outlook*.

- The **Alternative Policy Scenario** assumes additional policies will be put in place to combat global warming and to address security of supply, including measures to boost the role of nuclear power. Governments in countries that already have nuclear power plants are assumed to support lifetime extensions of existing reactors or the construction of new reactors. In all countries that have phase-out policies in place, it is assumed that reactors are shut down later than planned to hold down CO_2 emissions, to deal with concerns about security of supply and to postpone the need for new investment. In the Reference Scenario set out in the *Outlook*, world nuclear power capacity is projected to rise from 368 GW now to 416 GW in 2030 and to 519 GW in the Alternative Policy Scenario.

Reference Scenario. In the Reference Scenario, world nuclear electricity generation is projected to increase from 2789 TWh in 2005 to 3304 TWh in 2030. This is an average annual growth rate of 0.7% per year, compared with 2.5% per year for total electricity generation. Installed capacity increases from 368 GW to 416 GW. Nuclear capacity factors are assumed to improve over time, mainly in those countries that are now below the world average. Overall, the average world capacity factor increases from 85% in 2005 to 91% in 2030.

The most significant increases in installed capacity are projected in China, Japan, India, the United States, Russia and the Republic of Korea. Nuclear capacity in OECD Europe decreases from 131 GW to 74 GW. Nuclear power phase-outs in Germany, Sweden and Belgium account for 35 GW. All nuclear power plants in these three countries are assumed to be closed before 2030.

The share of nuclear power in world electricity generation drops from 15% to 10%. The most dramatic decrease in the share of nuclear power occurs in OECD Europe, where it drops from 29% in 2005 to 12% in 2030.

Alternative Policy Scenario. In the Alternative Policy Scenario, world nuclear electricity generation reaches 4,106 TWh in 2030, growing at an average rate of 1.6% per year. The share of nuclear power in total world electricity generation decreases slightly from the current 15%, hovering around 14% throughout the projection period. Installed nuclear capacity reaches 519 GW in 2030. The biggest difference between the two scenarios arises after 2020, because of the long lead times of nuclear power plants.

Installed capacity increases in all major regions except OECD Europe, where new construction is not projected to be large enough to offset plant closures. Changing this picture in the competitive markets in Europe is likely to require strong market signals arising from long-term commitments to reduce CO_2 emissions. As of mid-2006, there were no clear targets about the size of CO_2 emissions cuts beyond 2012. Phase-out policies are assumed to remain in place, but they are delayed by about ten years. On this basis, Germany is left with one reactor by 2030 while Belgium's and Sweden's reactors are still operating in 2030. In the United Kingdom, all but one reactor are retired, without being replaced.

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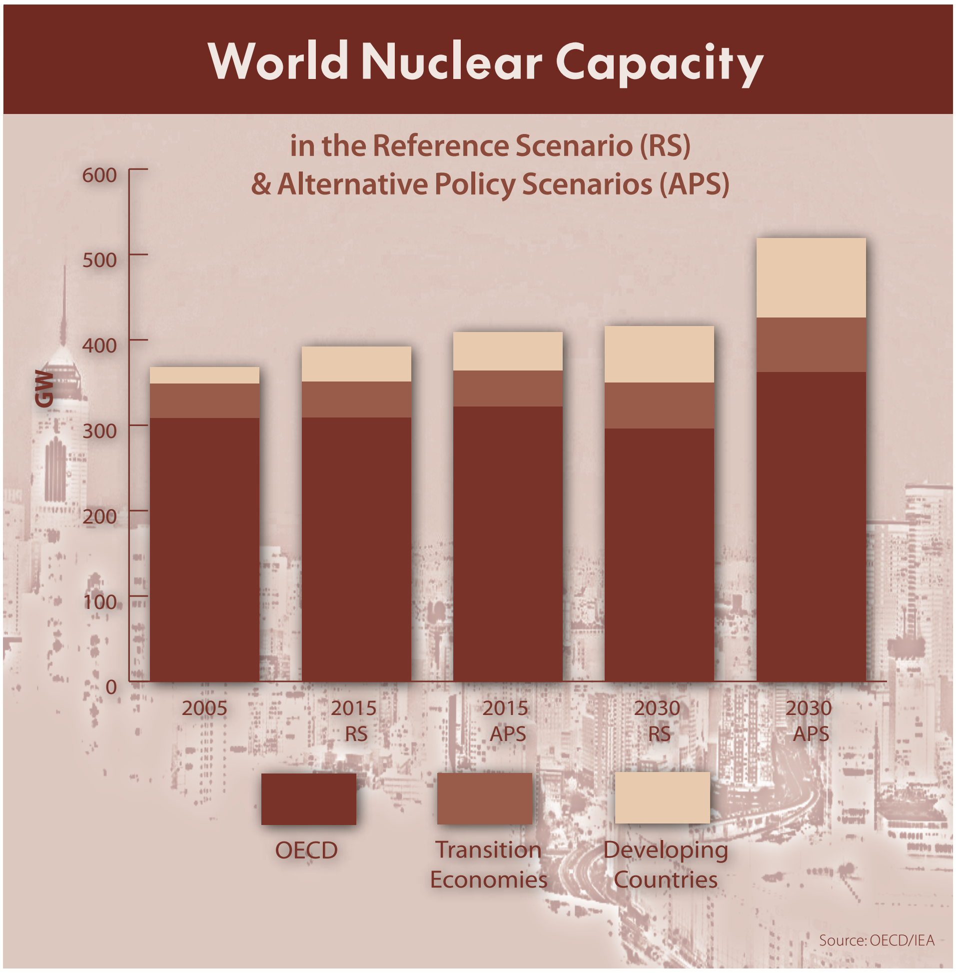
The largest increases in nuclear power generating capacity are expected in China, the United States, Japan, the Republic of Korea, India and Russia. These six countries are projected to hold two-thirds of the world's nuclear capacity in 2030, compared with just over half today. Nuclear capacity factors are the same as in the Reference Scenario.

The largest increase in the share of nuclear power in electricity generation is expected to be in OECD Pacific, where it reaches 41% in 2030, up from 25% now. In OECD North America, nuclear power maintains its current share. In OECD Europe, the share of nuclear power falls to 20% by 2030. This share is higher than in the Reference Scenario, but still lower than the current share of 29%. In the transition economies, the share of nuclear power rises from 17% to 23%. In China and India, these shares reach 6% and 9% in 2030, up from 2% and 3% now respectively.



Depending on the extent of the risks borne by investors in the power plant, whether they are the shareholders of the operating company or outside financiers, they will seek different returns on investment. The two cases analysed here are:

✔ A low discount rate case, corresponding to a moderate risk investment environment, where construction and operating risks are shared between the plant purchaser, the plant vendor, outside financiers and electricity users, through arrangements such as long-term power-purchase agreements.

✔ A high discount rate case, representing a more risky investment framework in which the plant purchaser and financial investors and lenders bear a higher proportion of the construction and operating risks.

The *Outlook* compares the generating costs of nuclear power with the main baseload alternatives in the low discount rate case. Under the high construction cost assumption ($2 500/kW) nuclear power is competitive with CCGT plants at gas prices around $6 per MBtu (which is close to the average OECD price in 2005 and within the assumed range of prices of around $6 to $7 per MBtu over the entire projection period), but more expensive than coal at $55 per tonne. Under the lower construction cost assumption ($2000/kW), nuclear is competitive with coal. (See graph, Electricity Generating Costs.)

The *Outlook* also looks at generating costs under the high discount rate assumption. The generating costs of nuclear power for the high and low construction costs estimates are 5.7 cents and 4.9 cents per kWh. In the high discount rate case, capital-intensive technologies, such as nuclear and wind power, are not competitive with CCGT or coal plants. Nuclear power generation costs are between 6.8 cents per kWh and 8.1 cents per kWh in this case. (See graph, Electricity Generating Costs.)

There are many uncertainties about the magnitude of the parameters used in the cost estimates presented above. The most important factors affecting the competitiveness of nuclear power are the investment cost, the discount rate and the plant's economic life. Increases in gas and coal prices or the introduction of a carbon value improve the competitive position of nuclear power against the alternatives. Location and size also affect costs.

Nuclear Power Economics in Competitive Markets

What are the economic underpinnings of new nuclear plants compared with competing mature technologies: gas-fired combined-cycle gas turbines (CCGT), steam coal, integrated gasification combined-cycle plants (IGCC) and onshore wind turbines?

The cost assumptions are based on expectations over the next ten to fifteen years. The construction cost of IGCC power plants and wind farms is lower than today by about 10% to 15%. Natural gas prices are assumed to be in the range of $6 to $7 per MBtu in the period to 2030. The coal price refers to the international market price for coal imported into the OECD ($55 per tonne in 2015 and $60 per tonne in 2030), but some countries, including the United States and Canada, have access to cheaper indigenous coal, making coal-fired generation more competitive. For nuclear plants, a range of construction costs has been used to reflect the uncertainty in the cost estimates for reactors that would enter commercial operation in 2015. These construction costs are for nuclear reactors built on existing sites. Greenfield projects are likely to be more costly. Most new reactors in OECD countries are likely to be built on existing sites, at least over the next ten to fifteen years.

Fuel costs are a small component of nuclear power generating costs. A 50% increase in uranium, gas and coal prices (compared with the base assumptions) would increase nuclear generating costs by about 3%, coal generating costs by 21% and CCGT generating costs by 38%, demonstrating the greater resilience of nuclear generation to fuel price risks.

What would the impact be of carbon prices on the costs of nuclear-, coal- and gas-fired generation in the low discount rate case? A price of about \$10 per tonne of CO_2 makes nuclear competitive with coal-fired power stations, even under the higher construction cost assumption. This low carbon price suggests that nuclear power is a cost-effective mitigation option. The average carbon price in the EU Emissions Trading Scheme has often been much higher. The average CO_2 price in 2005 was €18.3 per tonne (about \$23), and it rose to €22.9 (\$33) in 2006 until the end of April, when the price collapsed. From the price collapse in April 2006 to the end of August 2006, CO_2 prices have averaged €15.5 (\$19). In the high discount rate case, a carbon price of about \$10 to \$25 is required to make nuclear competitive with coal respectively in the lower and higher capital cost assumptions and \$15 to \$50 to make it competitive with gas-fired plants. (See graph, Impact of CO_2 Price on Generating Costs.)

Nuclear power is much more capital-intensive than alternative baseload fossil-fuel technologies such as gas-fired CCGT and coal-fired plants. Of the three major components of nuclear generation cost—capital, fuel and operation and maintenance—the capital cost component makes up approximately three-quarters of the total. It represents only about 20% of total costs for a CCGT. Nuclear power plants require initial investment between \$2 billion and \$3.5 billion per reactor. Large upfront capital investment can be more difficult to finance.

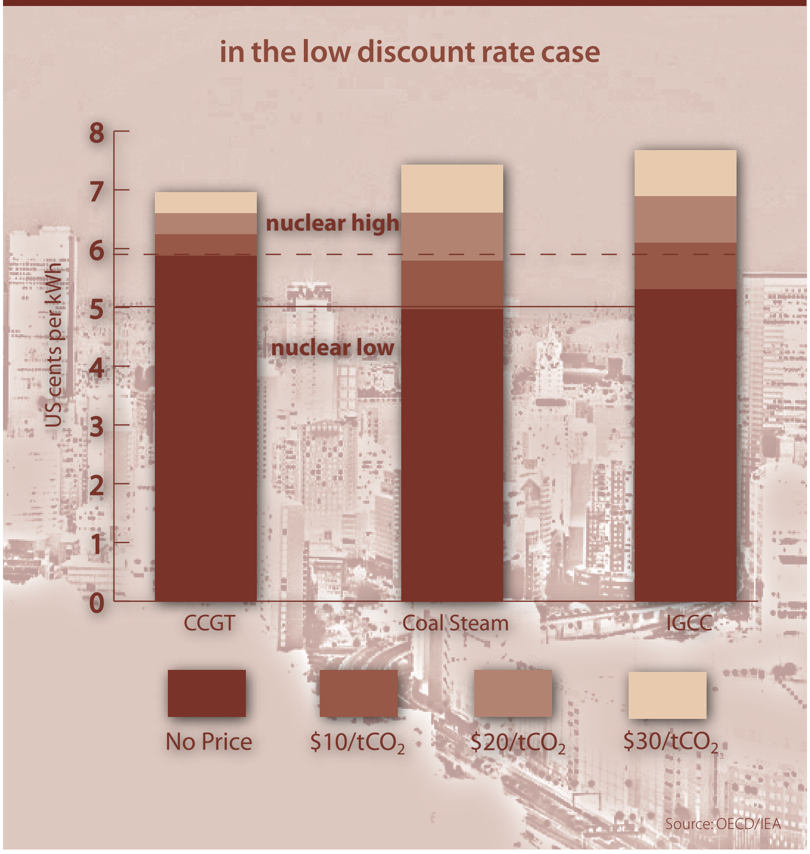
Nuclear power plants have long lead times, both in the planning and licensing phase and in the construction phase. Countries with the entire infrastructure in place can expect a total lead time, between the policy decision and commercial operation, of seven to 15 years. Nuclear power plant construction times are much longer than those for CCGT plants (typically two to three years), wind power plants (one to two years) and, to a lesser extent, coal-fired plants (four years).

Construction times of nuclear power plants have been long in a number of countries, notably in the United States and the United Kingdom. In Japan, nuclear power plants have been built in less than four years. In China and the Republic of Korea some nuclear power plants have been built ahead of schedule.

Nuclear-fuel costs consist of front-end and back-end costs. The front-end costs are the cost of uranium (about 25% of the total fuel cost), its conversion (5%), enrichment in light water reactors (30%) and fabrication into fuel assemblies (15%). The back-end costs (roughly 25% of the total fuel cost) include direct disposal or reprocessing followed by recycling of the fissile material for reuse. The costs of direct disposal, as currently borne by utilities, consist of the cost of on-site storage plus the provision for ultimate waste disposal levied in some countries. These costs are only a small percentage of the total generating cost.

Decommissioning costs reported for existing plants range from \$200-500/kW for western PWRs (in year-2001 dollars), \$330 for Russian VVERs, \$300-550 for BWRs, \$270-430 for Canadian CANDU, and as much as \$2 600 for some UK gas-cooled Magnox reactors. Decommissioning costs for plants built today are estimated at 9% to 15% of the initial capital cost, but when discounted, they amount to only a small percentage of the investment cost. Overall, decommissioning accounts for only a small fraction of total electricity generation costs. In the United States, power companies are collecting 0.1 cents to 0.2 cents per kWh to fund decommissioning.

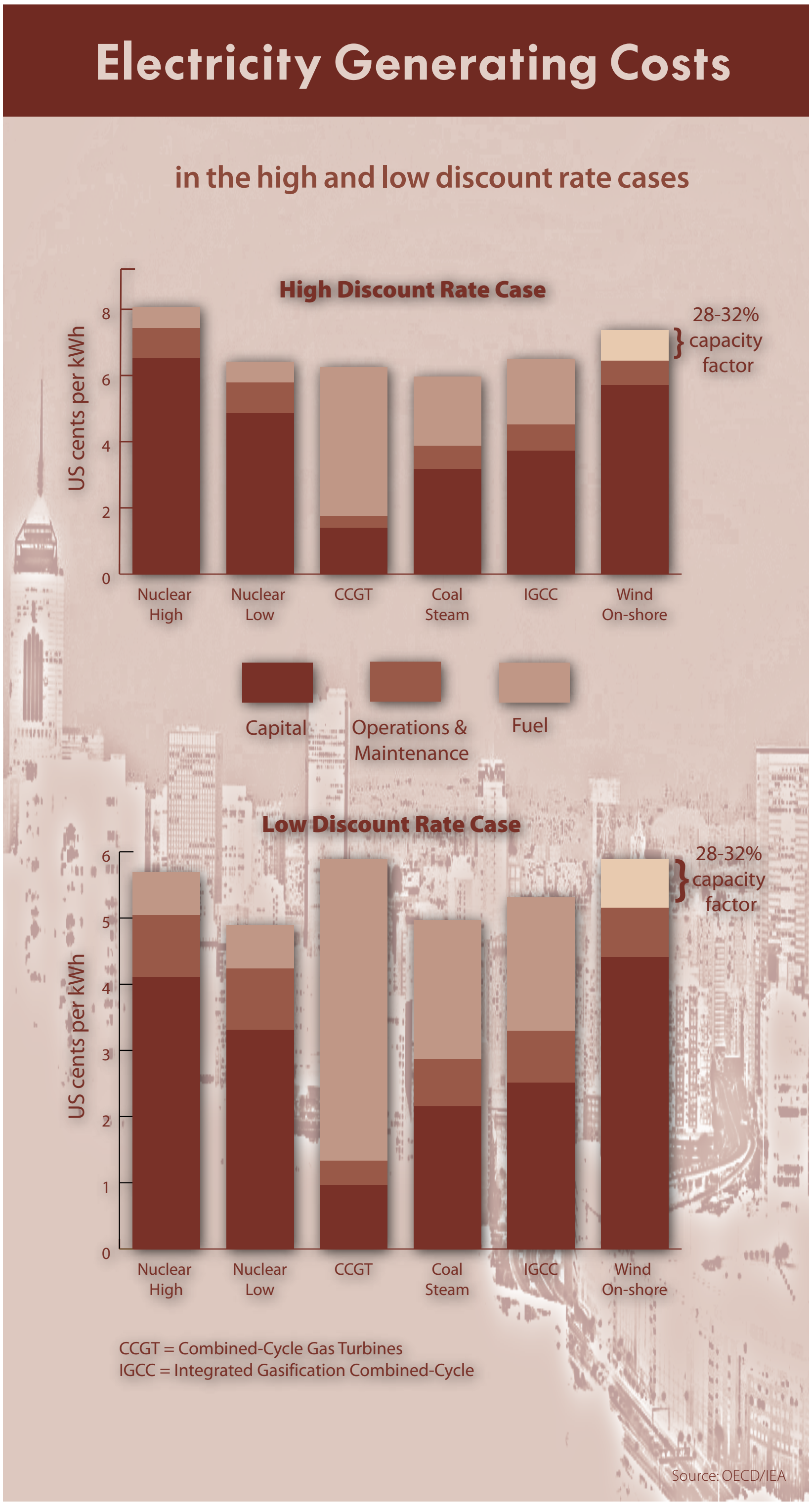
Impact of CO_2 Price on Generating Costs



Policy Implications

The analysis presented above shows that new nuclear power plants can produce electricity at competitive prices—if gas and coal prices are high enough and if nuclear construction and operating risks are appropriately handled by the plant vendor, the operating company and/or the regulatory authorities (where markets remain regulated), keeping the cost of capital or discount rate sufficiently low. Nuclear power generating costs are in the range of 4.9 cents to 5.7 cents per kWh in the lower discount rate estimate, making nuclear power a potentially cost-effective option for reducing CO_2 emissions, diversifying the energy mix and reducing dependence on imported gas.

Economics is only one factor. Many other issues must be addressed to facilitate nuclear investment. The nature of the regulatory process that leads to obtaining a licence to construct and operate a nuclear power plant is a key factor. The uncertainty and costs of the siting and licensing process need to be minimised. A number of countries now discussing the role of nuclear power have not built a nuclear power plant in a long time. The US government has taken steps to review and streamline the regulatory process. It also provides economic incentives for new power plants. In the UK Energy Review, the government has stated its intention of streamlining the regulatory and planning process.



Safety, nuclear waste disposal and the risk of proliferation are all issues which test public acceptability and which must be convincingly addressed. In liberalised markets, private investors will carry the cost of decommissioning and waste from new nuclear construction and will need to be able to evaluate the arrangements in place to manage these costs. International cooperation (for example, sharing waste disposal capacity and infrastructure) can help. Fear of proliferation arising from civil nuclear activities can be mitigated only by full participation in and demonstrated compliance with international conventions related to the use of nuclear power.

Where governments are determined to enhance energy security, cut carbon emissions and mitigate undue pressure on fossil fuel prices, they may choose to play a role in tackling the obstacles on the path of nuclear power, facilitating the large initial investment required for nuclear plants — between \$2 billion and \$3.5 billion per unit —and in paving the way for the development of a new generation of reactors. These objectives have become more explicit in recent years and the economics have moved in nuclear power's favour. However, concrete measures have so far been few.

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For information on the World Energy Outlook 2006, see www.worldenergyoutlook.org