CLIMATE CHANGE AND NUCLEAR POWER 2009

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MAIN MESSAGES

Main messages

Global greenhouse gas emissions will need to peak within the next decade or so and then fall substantially below the 2000 emission levels by the middle of the century in order to keep the increase in global mean temperature below 2°C relative to pre-industrial levels. Managing anthropogenic climate change is one of the foremost environmental challenges humanity is facing in the 21st century. There is increasing evidence put forward by climate modellers that the climate system of the Earth is warming due to increasing concentrations of greenhouse gases (GHGs), especially carbon dioxide (CO_2), resulting from human activities, mainly from the burning of fossil fuels. A rapid reversal of the increasing emissions trends and reductions by 50–80% is required by 2050 to avoid distressing climate change impacts in ecological and socioeconomic systems.

Energy is indispensable for development. Enormous increases in energy supply are required to lift 2.4 billion people out of energy poverty. Without a paradigm shift in the global approach to energy, however, GHG emissions will increase even further. Meeting the soaring energy demand would require primary energy of the order of 17 gigatonnes of oil equivalent (Gtoe) in 2030 and around 23 Gtoe in 2050. In the absence of sweeping policy interventions, this will lead to an increase in energy related CO_2 emissions by 55% in 2030 and by 130% in 2050 relative to 2005. The double challenge over the next 10–20 years will be to keep promoting economic development by providing reliable, safe and affordable energy while significantly reducing GHG emissions.

Nuclear power belongs to the range of energy sources and technologies available today that could help meet the climate–energy challenge. GHG emissions from nuclear power plants are negligible and, together with hydropower and wind generation, they belong to the lowest CO_2 emitters when emissions through the entire life cycle are considered. In the electricity sector, nuclear power has been assessed to have the largest potential (1.88 Gt CO_2-equivalent) to mitigate GHG emissions at the lowest cost: 50% of the potential at negative costs due to co-benefits from reduced air pollution, the other 50% at less than US $20/t CO_2-equivalent. Nuclear energy could account for about 15% of the total GHG reduction in power generation in 2050.

Nuclear energy can contribute to resolving other energy supply concerns and it has non-climatic environmental benefits. Significant increases in fossil fuel prices in recent years, fears of their sustained high levels in the future and concerns about the reliability of supply sources in politically unstable regions are fundamental items to consider in present-day energy strategies. Nuclear power can help alleviate these concerns because ample uranium resources are available from reliable sources spread all over the world and the cost of uranium is only a small fraction of the total cost of nuclear electricity. Nuclear power can also help reduce local and regional air pollution. Among the power generation technologies, it has one of the lowest external costs (i.e. costs in terms of damage to health and the environment, for example, which are not accounted for in the price of electricity). Such costs attributed to nuclear power are minuscule.

The economics of nuclear power is improving and will be further enhanced by the increasing CO_2 costs of fossil based electricity generation. Recent assessments indicate that the ranges of levelized costs of electricity from natural gas, coal and nuclear sources largely overlap between 2 to 9 US cents/kW•h, hence the choice among them depends on local circumstances, such as the lack or availability of cheap domestic fossil resources. The costs of CO_2 emission reduction by CO_2 capture and geological disposal and charges for the emitted CO_2 arising for fossil based electricity gives competitive advantage to nuclear power. Despite increasing construction costs, financing nuclear power investments will be feasible under stable government policies, proper regulatory regimes and adequate risk allocation schemes. Once the business case for increasing nuclear investments is established, manufacturing and construction capacities will expand as required.

Concerns about nuclear energy regarding radiation risks, operation safety, waste management and proliferation are easing, as reflected in improving public acceptance. Nevertheless, the nuclear sector needs to improve further and provide adequate responses to these concerns in order for it to realize its full potential. Radiation risks from normal plant operation remain low, that is, at a level that is virtually indistinguishable from natural and medical sources of public radiation exposure. Concerted efforts by international organizations, such as the IAEA, and by operators of nuclear facilities have made nuclear power plants one of the safest industrial branches for their workers and the public at large. Geological and other scientific foundations for the safe disposal of radioactive waste are well established. The first repositories will start operation in 10–15 years. Institutional arrangements are being improved and further technological solutions sought to prevent the diversion of nuclear material for non-peaceful purposes.

Climate change mitigation is one of the salient reasons for increasingly considering nuclear power in national energy portfolios. Other reasons include fears of sustained high fossil fuel prices, price volatility and supply security. Nuclear power is also considered in adaptation measures to climate change, such as sea water desalination or hedging against hydropower fluctuations. Where, when, by how much and under what arrangements nuclear power will contribute to solving these problems will depend on local conditions and national priorities, and on international arrangements, such as the flexibility mechanisms under the new protocol of the United Nations Framework Convention on Climate Change. Yet the decision about introducing or expanding nuclear energy in the national energy portfolio rests with sovereign States.

CONTENTS

Introduction

Climate change remains one of the principal problems the world is facing in the early 21st century. Together with the economic crisis and poverty, it is one of the three main global challenges highlighted in the declaration of the G8 Summit 2009 in L'Aquila, Italy. In their Declaration, leaders of the G8: "…recognise the broad scientific view that the increase in global average temperature above pre-industrial levels ought not to exceed 2°C…" (see Ref. [1]).

The possibility of global climate change resulting from increasing anthropogenic emissions of greenhouse gases (GHGs) has been a major concern in recent decades. A principal source of GHGs, particularly carbon dioxide (CO_2), is the fossil fuels burned by the energy sector. Energy demand is expected to increase dramatically in the 21st century, especially in developing countries, where population growth is fastest and, even today, some 1.6 billion people have no access to modern energy services. Without significant efforts to limit future GHG emissions, especially from the energy supply sector, the expected global increase in energy production and use could well trigger "dangerous anthropogenic interference with the climate system", to use the language of Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) [2].

To take the initial steps in reducing the risk of global climate change, industrialized countries (listed in Annex I of the Convention[1]) have made commitments to reduce their collective GHG emissions under the Kyoto Protocol to the UNFCCC during 2008–2012 by at least 5.2% below 1990 levels. Since the USA did not ratify the Kyoto Protocol, the actual reduction will be only about 3.8% of the 1990 Annex I emissions. This reduction is far outweighed by increases of emissions in non-Annex I countries in the same period. However, much deeper global emissions cuts will be necessary in the next few decades to achieve the 2°C goal declared by the G8 Summit. Intense negotiations under the UNFCCC and the Kyoto Protocol through 2009 aspire to reach a comprehensive global agreement for the post-2012 period in order to achieve those dramatic reductions over the long term.

Nuclear power plants produce virtually no GHG emissions during their operation and only very low amounts of emissions on a life cycle basis. Nuclear energy could, therefore, be an important part of future strategies to reduce GHG emissions. Nuclear power is already an important contributor to the world's electricity needs. It supplied 14% of global electricity and a significant 27% of electricity in western Europe in 2008. Despite this substantial contribution, the future of nuclear power remains uncertain. In liberalized electricity markets, there are several factors which may contribute to making nuclear power less attractive than fossil fuelled power plants, including the high upfront capital costs for building new nuclear power plants, their relatively long construction time and payback period, the lack of public and political support in several countries for new construction — as well as renewable portfolio requirements. These factors have, however, altered in recent years due to concerns about climate change, fossil fuel prices and energy security.

This report summarizes the potential role of nuclear power in mitigating global climate change and its contribution to other development and environment challenges, as well as its current status, including the issues of cost, safety, waste management and non-proliferation. The publication is a revised and updated version of the 2008 edition.

[1] Annex I includes the member States of the Organisation for Economic Co-operation and Development (drawing from the 1990 membership) as well as Belarus, Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, the Russian Federation, Slovakia, Slovenia and Ukraine.

The climate change challenge

There have been an increasing number of scientific assessments of the many impacts of climate change in recent years. These assessments indicate that anthropogenic GHG emissions will need to be reduced drastically over the next few decades in order to avoid severe climate change impacts that would be difficult or impossible to cope with, and to achieve what politicians aspire to as targets for tolerable levels of climate change. According to the findings of the Intergovernmental Panel on Climate Change (IPCC), the biophysical changes resulting from a global warming of more than 3°C trigger increasingly negative impacts in all climate sensitive sectors in all regions of the world [3]. In mid-latitudes and semi-arid low latitude regions, decreasing water availability and increasing drought will expose hundreds of millions of people to increased water stress. In agriculture, cereal productivity is expected to decrease in low latitudes (partly compensated by increased productivity at mid-latitudes and high latitudes). Natural ecosystems will also be affected negatively: up to 30% of species will be at a growing risk of extinction in terrestrial areas; in addition, increased coral bleaching is forecast in the oceans. In coastal areas, damage from floods and storms will increase. Human health will also be affected, especially in less developed countries, by the increasing burden from malnutrition, and from diarrhoeal, cardiorespiratory and infectious diseases. Increased morbidity and mortality are foreseen from heatwaves, floods and droughts.

Figure 1 presents the pathways towards stabilizing climate change in various ranges of global warming as established by the IPCC [4]. The underlying calculations imply that in order to prevent a global mean temperature increase by more than 2.0–2.4°C above the pre-industrial level, GHG concentrations should not exceed the range of 445–490 ppm CO_2-equivalent[2] (CO_2-eq.). This means that global CO_2 emissions would need to peak by 2015 and return to the 2000 level by 2030 at the latest, and should decline by 50–85% relative to 2000 by 2050. The Synthesis Report of the 2009 Copenhagen Conference on Climate Change [5] presents three emission pathways for energy related CO_2 emissions towards stabilizing GHG concentrations at three levels (400, 450 and 550 ppm CO_2-eq., shown as coloured lines in Fig. 1) that imply three confidence levels of keeping the global mean temperature increase below 2°C: at 15%, 50% and 75% probability, respectively. The lowest trajectory entails negative global emissions after 2070.

This illustrates the enormous mitigation challenge the world will face over the next decades. In the Fourth Assessment Report (AR4) of the IPCC, Chapters 4–10 of the Working Group III (WGIII) [6] review a large number of bottom-up studies that assessed mitigation potential in seven sectors (energy supply, transport, buildings, industry, agriculture, forestry and waste) by focusing on specific technologies and regulations in large world regions (Organisation for Economic Co-operation and Development (OECD) countries, economies in transition (EIT) and non-OECD/EIT countries) over two time horizons: medium term (up to 2030) and long term (through to 2100).

Both the IPCC WGIII and the Copenhagen Synthesis reports maintain that many mitigation technologies and practices that could reduce GHG emissions are already commercially available. According to the IPCC [6], technical solutions and processes could reduce the energy intensity in all economic

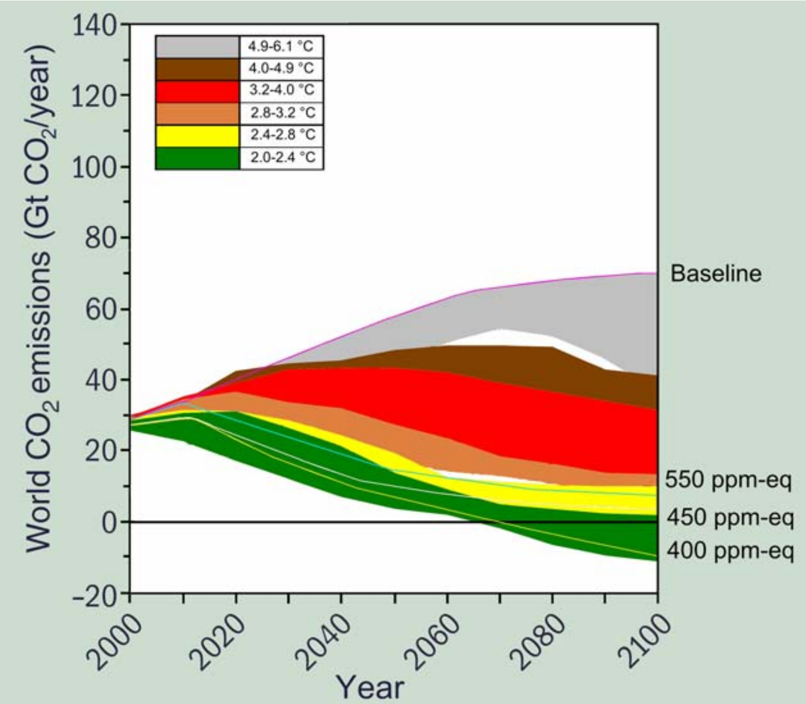
[2] The definition of carbon dioxide equivalent (CO_2-eq.) is the amount of CO_2 emissions that would cause the same radiative forcing as an emitted amount of a well mixed GHG (CO_2, methane (CH4), nitrous oxide (N2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF6)) and ozone depleting substances (ODSs: chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons) or a mixture of well mixed GHGs, all multiplied by their respective greenhouse warming potentials to take into account the differing times they remain in the atmosphere.

sectors and provide the same output or service with lower emissions. Fuel switching and modal shift (from road to rail, from private to public) in the transport sector, heat recovery, material recycling and substitution in industry, improved land management and agronomic techniques and energy crop cultivation in agriculture, and fuel switching, efficiency improvements, the increased use of renewables and nuclear power, as well as carbon capture and storage (CCS) in the energy sector, could result in significant GHG reductions. Aggregating the options in each sector, the economic mitigation potential is estimated to be between 0.7 (waste management) and 6 (buildings) Gt CO_2-eq. annually on the basis of carbon prices below \$100/t CO_2-eq. in 2030. The aggregated global economic mitigation potential in 2030 amounts to some 16–31 Gt CO_2-eq./year at this carbon price out of total baseline GHG emissions of about 56 Gt CO_2-eq. About 6 Gt CO_2-eq. of the total mitigation potential could be realized at negative cost, because the associated benefits (reduced energy costs and less damage due to lower local and regional air pollution) exceed their costs.

The IPCC AR4 confirmed that, compared with other anthropogenic sources, GHG emissions from the energy supply sector grew at the fastest rate between 1970 and 2004. Currently, energy related CO_2 emissions (including feedstocks) comprise by far the largest share (about 60%) of total global GHG emissions. In the absence of additional policy interventions (relative to those already in place), annual GHG emissions from energy production and use are projected to reach 34–52 Gt CO_2 by 2030. This implies, as Chapter 4 of the WGIII puts it, that:

> “[T]he world is not on course to achieve a sustainable energy future. The global energy supply will continue to be dominated by fossil fuels for several decades. To reduce the resultant GHG emissions will require a transition to zero- and low carbon technologies” (Ref. [6], p. 255).

FIG. 1. CO_2 emissions and equilibrium temperature increases for a range of stabilization levels (based on Refs [4, 5]).



The global energy challenge

Energy is generally recognized as a central issue in sustainable development. Several high level conferences and declarations have emphasized that the provision of adequate energy services at affordable costs, in a secure and environmentally benign manner, and in conformity with social and economic development needs, is an essential element of sustainable development. Reliable energy services are the preconditions for investments that bring about economic development. They facilitate the learning and study that are crucial for developing human capital. They also promote equity by giving a chance for the less well off to study and thus provide a possible escape from poverty. Therefore, energy is vital for alleviating poverty, improving human welfare and raising living standards. Yet, worldwide, 2.4 billion people rely on traditional biomass as their primary source of energy, and 1.6 billion people do not have access to electricity [7] — conditions which severely hamper socioeconomic development.

All recent socioeconomic development studies project major increases in energy demand, driven largely by demographic and economic growth in today's developing countries. Of the world's 6.8 billion people, about 82% live in non-OECD countries and consume only 53% of global primary energy. Alleviating this energy inequity will be a major challenge. A growing global population will compound the problem. The Medium Variant of the latest projections of the United Nations estimates an additional 1.5 billion people by 2030, and another 840 million by 2050, bringing the world's population to about 9.15 billion by the middle of this century [8].

The rising population will enjoy increasing economic welfare despite the current economic crisis. According to the World Bank [9], after the projected meagre 0.9% global GDP growth in 2009, it is expected to rebound to 2% in 2010 and 3.2% in 2011. Developing countries are projected to expand at 4.4% (2010) and 5.7% (2011), still below the robust performance before the crisis. Over the long term, the World Bank [10] projects a 3.1% average annual growth rate for the world economy up to 2015 and 2.5% between 2015 and 2030. Developing countries will grow fastest, while OECD countries will grow at the slowest rate. Per capita incomes in developing countries are projected to triple from $1550 in 2004 to $4650 in 2030.

The International Energy Agency (IEA) of the OECD makes similar assumptions about these two main drivers of global energy demand in its World Energy Outlook (WEO) 2008 [11]. World population is projected to increase to 8.2 billion by 2030, while the global economy is assumed to grow at an annual average rate of 4.2% up to 2015 and 2.8% between 2015 and 2030. Based on these two main drivers, and additional assumptions about technological development and resource availability for the energy sector, the IEA projects in its Reference Scenario that world total primary energy demand will grow to over 17 Gtoe by 2030 [11] and will exceed 23 Gtoe in 2050 according to the extended Reference Scenario presented in the Energy Technology Perspectives (ETP) 2008 [12]. The evolution of the resulting global primary energy mix and the corresponding global energy related CO_2 emissions are shown in Fig. 2.

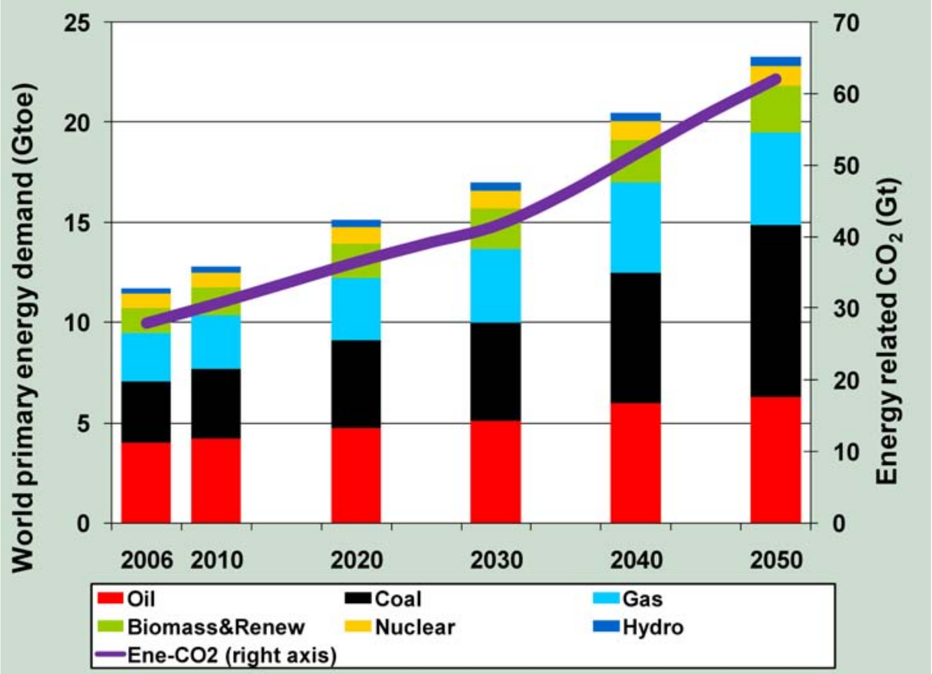
Reflecting upon the elevated oil prices in preceding years, the IEA drastically increased its assumptions about the future international oil prices in WEO 2008 relative to WEO 2007 [13]: from $60 to $100 on average between 2008 and 2015 and from $62 to $120 on average between 2015 and 2030. Yet these changes are projected to cause only minor shifts in the world primary energy demand up to 2030. Global energy demand and energy related CO_2 emissions are projected to be only about 4% lower in 2030 in the 2008 projection than was the case in the WEO a year earlier.

The ETP study [12] presents the global energy prospects up to the middle of the century. The most notable changes projected for the next half century in the IEA Reference Scenario include the following:

— Coal is expected to surpass oil as the largest primary energy source by 2040, due to the persistent high growth in demand for electricity in coal rich countries such as China and India.
— Gas is projected to level out at around 4.5 Gtoe by the middle of the century.
— Despite a 31% increase in volume between 2005 and 2050, the nuclear share in the global primary energy balance is projected to decline from 6.3% in 2005 to 4.8% by 2030 and to 4% by 2050.

The climate change implications of the Reference Scenario are severe. Energy related CO_2 emissions — the largest component of global GHG emissions — increase by 55% in 2030 and by 130% in 2050 relative to 2005 (see Fig. 2). Assuming that other GHGs increase at comparable rates, this would put the Earth on track towards atmospheric GHG concentrations of the order of 1000 ppm CO_2-eq. and an equilibrium warming of over 5°C in terms of global mean temperature increase above the pre-industrial level (see the grey corridor in Fig. 1). Consequently, these trends sharply contradict the G8 declaration of the need to keep global mean temperature increase below 2°C and point to the urgent requirement for deploying low carbon technologies.

FIG. 2. Global primary energy sources (left axis) and energy related CO_2 emissions (right axis) in the IEA's WEO 2008 (up to 2030) along with the ETP 2008 (2030–2050) Reference Scenarios [11, 12].



Nuclear power is a low carbon technology...

Dozens of studies in recent years have estimated the life cycle GHG emissions from a suite of power generation technologies. The results of serious technical studies tend to diverge somewhat due to varying assumptions about the different components of the technology, conversion efficiencies and GHG emissions factors of the energy sources involved, and other features of the fuel chain.

For nuclear power, the most important component in determining the life cycle emissions is the technology (and fuel mix) used to enrich uranium. Gaseous diffusion, the technology widely used in the past and still in use in several countries, requires a substantial amount of electricity: "roughly 3.4% of the electricity generated by a typical US reactor would be needed to enrich uranium in the reactor's fuel" [14]. However, the industry has been increasingly switching to gaseous centrifuge technology, which requires only about 2% of the energy input needed for gaseous diffusion (less than 50 kW•h/SWU[3] in contrast to the 2400 kW•h for gaseous diffusion), thereby drastically reducing the life cycle GHG emissions from nuclear power, even if the electricity is supplied from fossil sources. The share of centrifuge based enrichment is approaching 70% globally; hence, there is still room to improve the life cycle emission balance of the nuclear fuel cycle. All other GHG emissions from generating nuclear power, including cement, iron and steel production for constructing the power plants, are very low when spread over the lifetime electricity generation of the plant.

A recent paper by Weisser [15] reviews a set of life cycle GHG assessments published between 2000 and 2006. The studies reviewed represent the state of the art with respect to the details, methods and complexity of the assessments and the electricity generation technologies, including upstream (before generation) and downstream (post-generation) processes. The full technology chain for nuclear energy includes uranium mining (open pit or underground), milling, conversion, enrichment (diffusion or centrifuge), fuel fabrication, power plant construction and operation, reprocessing, conditioning of spent fuel, interim storage of radioactive waste, and the construction of the final repositories. Weisser finds that for the most widely used reactor technology (light water reactors), GHG emissions during the operational stage of the reactor, relative to cumulative life cycle emissions, are of secondary importance — ranging between 0.74 and 1.3 g CO_2-eq./kW•h. The bulk of the GHG emissions arise in the upstream stages of the fuel and technology cycle, with values between 1.5 and 20 g CO_2-eq./kW•h. As noted, this span is largely due to which enrichment process the various assessments considered and to what extent they accounted for nuclear fuel recycling. The GHG emissions associated with downstream activities, such as decommissioning and waste management, range between 0.46 and 1.4 g CO_2-eq./kW•h. Cumulative emissions for the studies reviewed by Weisser lie between 2.8 and 24 g CO_2-eq./kW•h. Figure 3 presents a summary of life cycle GHG emissions for a range of power generation technologies and fuels.

Figure 3 shows that nuclear power, together with hydropower and wind based electricity, is one of the lowest emitters of GHGs in terms of g CO_2-eq. per unit of electricity generated on a life cycle basis. Coal based generation, even if equipped with CCS, is estimated to emit about one order of magnitude more GHGs per unit of electricity than the three truly low carbon generating

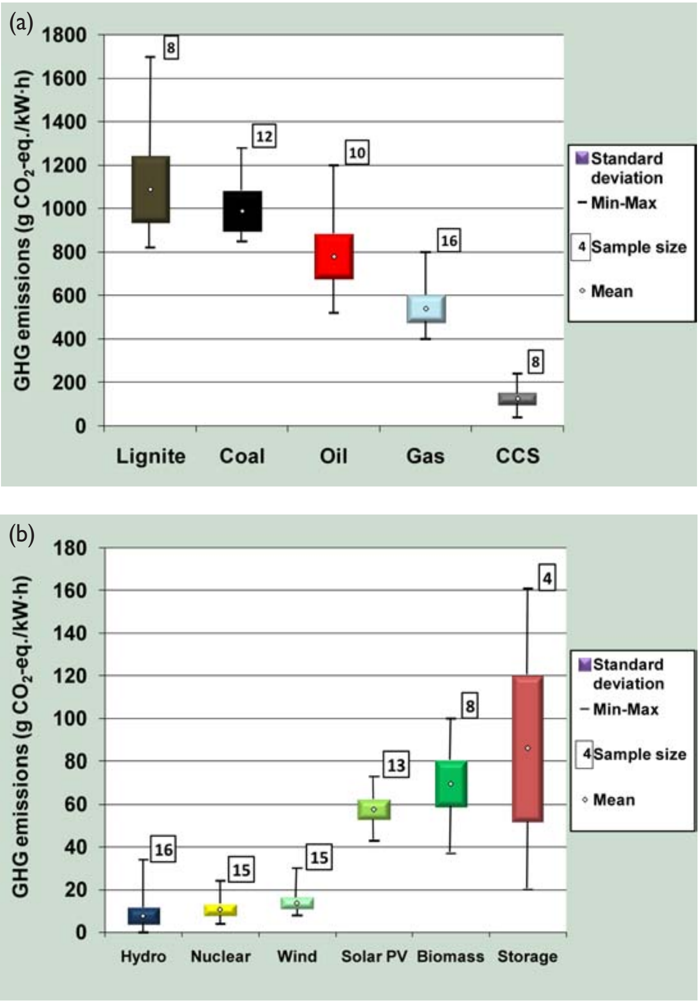
[3] The separative work unit (SWU) combines the amount of uranium processed, the composition of the starting material and the degree to which it is enriched into a single indicator. The SWU indicates the amount of energy used in enrichment, when feed, tails and product quantities are expressed in kilograms. For example, processing 100 kg of natural uranium takes about 61 SWU to produce 10 kg of low enriched uranium with 4.5% ^{235}U content, at a tails assay containing 0.3%.

technologies (note the different vertical scales in Figs 3(a) and (b)). These results are consistent with the conclusions of similar studies by extensively cited authors and organizations [16–18].

It is possible to reduce GHG emissions from nuclear energy technologies even further. Dones et al. [19] highlight three key areas of improvement: (1) reduce electricity input for the enrichment process (e.g. replacement of diffusion by centrifuges or laser technologies); (2) use electricity based on low or non-carbon fuels; (3) extend nuclear power plant lifetimes and increase burnup (the amount of electricity generated from 1 t of uranium).

While the technology based life cycle assessments provide useful information about the relative merits of power generation technologies in terms of GHG emissions, the real proof of the competitiveness of technologies in a carbon constrained world will be the introduction of a uniform price on all GHG emitting activities via a carbon tax or emission permit trading. This arrangement will also demonstrate the relative merits of the technologies in the broad context of market competition.

FIG. 3. Life cycle GHG emissions for selected power generation technologies [15]: (a) fossil technologies; (b) non-fossil technologies.



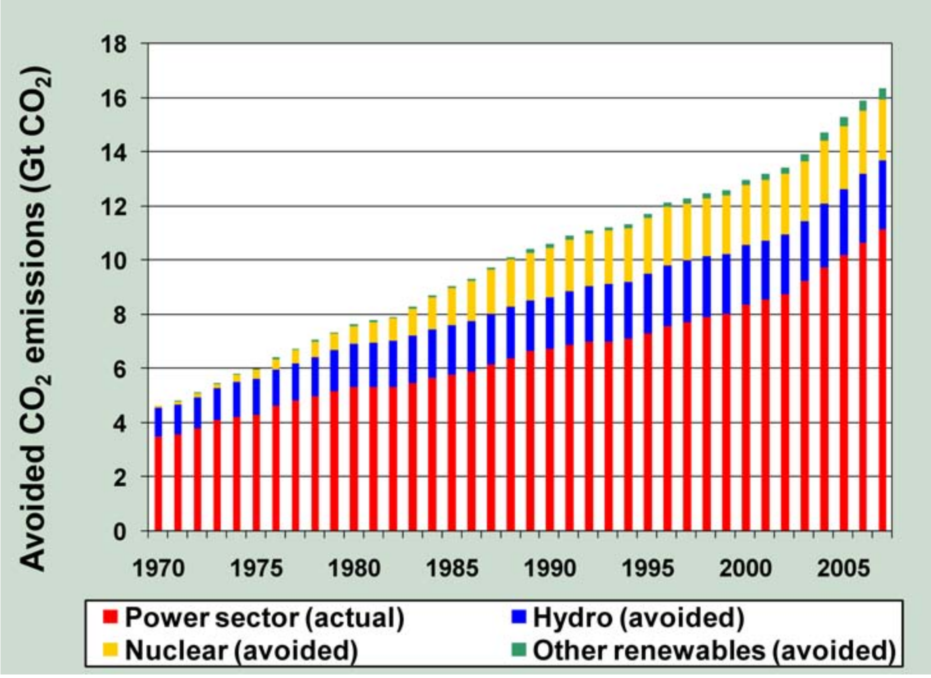
…and has been contributing to avoided GHG emissions for decades

Over the past 50 years, the use of nuclear power has resulted in the avoidance of significant amounts of GHG emissions in 30 countries around the world. Globally, the amount of prevented emissions is comparable with that of hydropower. This is demonstrated by calculating CO_2 emissions avoided by hydroelectricity, nuclear power and renewables in global electricity generation. Clearly, the calculated amounts of avoided emissions depend on the assumptions about which technology and fuels would have replaced the low carbon emitting technologies. For the purposes of this analysis, it was assumed that the electricity generated by hydropower, nuclear energy and renewables would have been produced by increasing the coal, oil and natural gas fired generation in proportion to their respective shares in the electricity mix in any particular year. This approach underestimates the emissions avoided, as most of the nuclear capacity expansion in the 1970s and early 1980s would have been substituted by coal rather than by oil and natural gas, since the rationale for investing in nuclear power was specifically a reduction in the oil and gas dependence of electricity generation (an effect of the oil crises of the 1970s).

During the 'dash for gas' period after the mid-1980s, only a few nuclear power plants were built and thus there is no overestimation, as the coal share would have been much higher (in the absence of nuclear power and other low carbon electricity sources) than it was in reality (even if only gas had substituted for nuclear power).

Figure 4 shows the historical trends of CO_2 emissions from the global power sector and the amounts of avoided emissions by using hydropower, nuclear energy and other renewable electricity generation technologies.

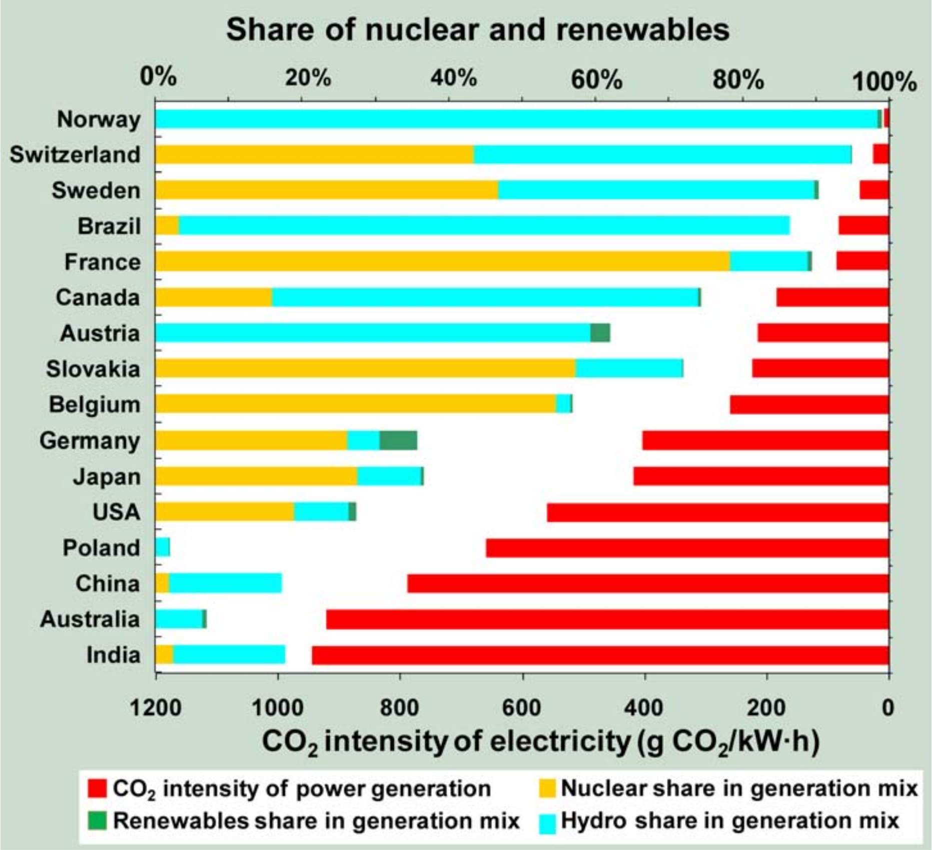
FIG. 4. Global CO_2 emissions from the electricity sector and emissions avoided by three low carbon generation technologies. (Source: IAEA calculations based on IEA data [20].)



The height of the red columns indicates the total CO_2 emissions in any given year. The applicable amounts of avoided emissions in a given year were added to the actual emissions to illustrate the relative contribution of the three low carbon electricity sources and to show the estimated global power sector CO_2 emissions in their absence. In 2007, for example, global CO_2 emissions from electricity generation exceeded 11.1 Gt CO_2, but they would have amounted to 11.6 Gt CO_2 in the absence of non-hydro renewable sources, 13.7 Gt CO_2 without hydropower, 13.4 Gt CO_2 in a world without nuclear power and almost 16.4 Gt CO_2 without all these three low carbon sources.

Figure 5 confirms these global trends by depicting the CO_2 intensity and the shares of non-fossil sources in power generation for selected countries. The top scale shows from left to right the relative contributions of nuclear, hydro and other renewable (wind, solar, geothermal, etc.) technologies to the total amount of electricity generated in 2006. The bottom scale measures from right to left the average amount of CO_2 emitted from generating 1 kW•h of electricity in the same year. The chart clearly demonstrates that countries with the lowest CO_2 intensity (less than 100 g CO_2/kW•h, below 20% of the world average) generate around 80% or more of their electricity from hydro (Norway and Brazil), nuclear (France) or the combination of these two (Switzerland and Sweden). At the other extreme, countries with high CO_2 intensity (800 g CO_2/kW•h and more) have none (Australia) or only limited (China and India) shares of these sources in the power generation mix.

FIG. 5. CO_2 intensity and the shares of non-fossil sources in the electricity sector of selected countries. (Source: IAEA calculations based on IEA data [21].)



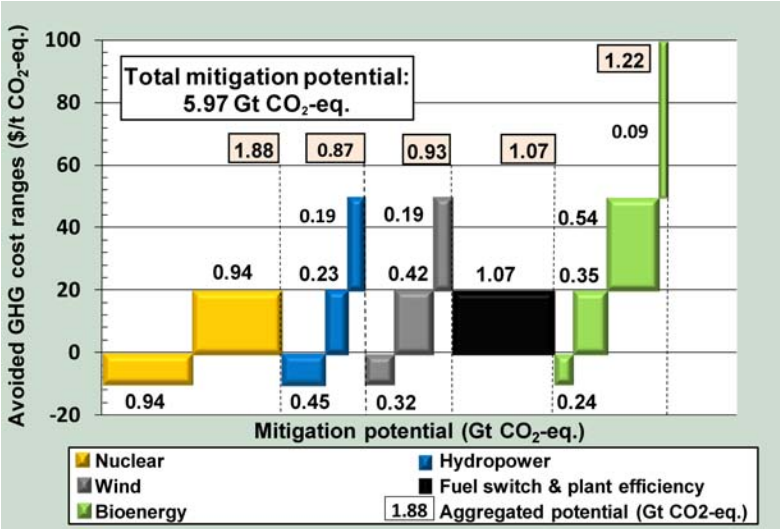
IPCC: Nuclear has the largest and lowest cost GHG reduction potential in power generation

The IPCC [6] presents GHG mitigation potentials for seven sectors (energy supply, transport, buildings, industry, agriculture, forestry and waste management). This section focuses on the power sector. The IPCC [6] estimates the mitigation potential in terms of GHG emissions that can be avoided by 2030 by adopting various electricity generating technologies in excess of their shares in the baseline scenario (the Reference Scenario in the IEA's World Energy Outlook 2004 [22]). The technologies include fuel switching within the fossil portfolio, nuclear, hydropower, wind, bio-energy, geothermal, solar photovoltaic (PV) and concentrating solar power (CSP), as well as coal and gas with CO_2 capture and storage (CCS).

The IPCC analysis assumes that each technology will be implemented as far as economically and technically possible, taking into account practical constraints (stock turnover, manufacturing capacity, human resource development, public acceptance, etc.). Each technology is assessed in isolation (i.e. possible interactions between deploying various technologies simultaneously are not accounted for). The estimates indicate how much more (relative to the baseline) of each technology could be deployed in major world regions at costs falling in ranges between less than 0 (possible for nuclear, hydropower, wind, bio-energy and geothermal sources), 0–20, 20–50, 50–100 and more than \$100/t CO_2-eq. Mitigation costs reflect differences between the cost of the low carbon technology and that of what it replaces. Negative costs indicate reduced energy costs and ancillary benefits arising from reduced local and regional air pollution.

Given the overwhelming share of fossil fuels in electricity generation, the first option is to replace existing fuels and technologies by less carbon intensive fossil fuels and more efficient technologies, respectively. Another possibility to reduce CO_2 emissions from fossil fuel combustion is CCS. However, as the IPCC notes about CCS: "[P]enetration by 2030 is uncertain as it depends both on the carbon price and the rate of technological advances in cost and performance" (Ref. [6], p. 298). For 2030, the potential global emissions reductions from CCS used with

FIG. 6. Mitigation potential in 2030 of selected electricity generation technologies in different cost ranges. (Source: Based on data in Table 4.19 of Ref. [6], p. 300.)



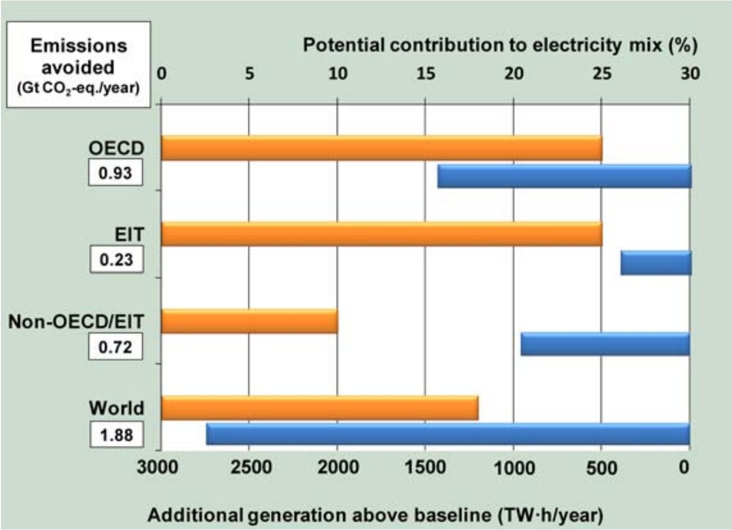
coal and gas fired power plants are estimated at 0.49 Gt CO_2-eq. and 0.22 Gt CO_2-eq., respectively.

Of the low carbon power generation technologies assessed in the IPCC report [6], those with a mitigation potential of more than 0.5 Gt CO_2-eq. are considered more closely. Figure 6 shows the potential GHG emissions that can be avoided by 2030 by adopting the selected generation technologies. The figure indicates that nuclear power represents the largest mitigation potential at the lowest average cost in electricity generation: 50% at negative costs, the other 50% at less than \$25/t CO_2-eq. Hydropower has the second cheapest mitigation potential, but its volume is the smallest among the five options included in Fig. 6. The mitigation potential of wind energy is also significant, but it is spread across three cost ranges, albeit more than one third of it can be utilized at negative cost. Bio-energy, too, has a significant total mitigation potential, but only less than half of it could be harvested at costs below \$20/t CO_2-eq. by 2030.

The mitigation potential of nuclear power is based on the assumption that it displaces fossil based electricity generation. The mitigation volume estimated by the IPCC for nuclear power reflects the contribution it could make to global climate protection by increasing its share of 16% in the global electricity mix in 2005 to 18% by 2030. This is a small increase in share, yet a major increase in volume if we consider the fast growth of power generation projected for the given time horizon. The potential nuclear share in the electricity mix and the resulting additional (above baseline) power generation are presented in Fig. 7 for the three large global regions and the world.

Nuclear power clearly belongs to the set of options available to reduce GHG emissions in the electricity sector. A significant part (about 2 Gt CO_2-eq.) of the GHG reduction potential offered by nuclear, hydropower, wind and bio-energy can be realized at negative cost if they displace fossil fuel power plants. Nonetheless, fossil fuels are likely to remain important players even in a carbon constrained world, especially if they can realize the mitigation potentials arising from fuel switch and plant efficiency improvements, and from adding CCS to coal and gas fired power plants. The relative costs of these technologies vary widely according to national and regional conditions that will determine which energy sources and mitigation options will be used in different parts of the world.

FIG. 7. Nuclear power shares, generation volumes and avoided GHG emissions. (Source: Based on data in Table 4.11 of Ref. [6], p. 296.)



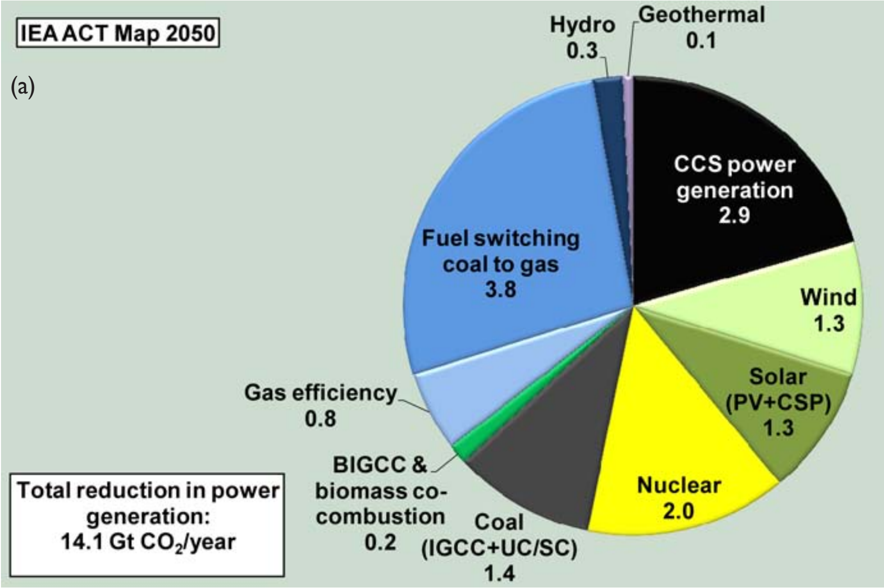
IEA: Nuclear contribution to GHG mitigation can be significant

The International Energy Agency (IEA) publishes biannually an in-depth energy technology assessment for the world. The 2008 report on Energy Technology Perspectives [12] presents an in-depth survey of energy technologies and prospects for their evolution up to 2050. The study extends the IEA Reference Scenario projection [13] of global energy supply and GHG emissions to 2050. The report's mitigation scenarios involve two targets for reducing energy related CO_2 emissions relative to the Reference Scenario (62 Gt CO_2) by 2050. The so-called ACT scenarios stipulate that CO_2 emissions peak around 2030 at 34 Gt CO_2 and decrease to 2005 levels (27 Gt CO_2) by 2050. In the much more ambitious BLUE scenarios, global emissions peak before 2020 and decline to 50% of the 2005 level, to around 14 Gt CO_2 by 2050.

According to the IEA scenarios sorted by *technology areas*, end use efficiency improvements and changes in the power sector represent the bulk of the low cost mitigation opportunities. End use fuel efficiency and electricity end use efficiency account for 44% and 36% of the CO_2 emissions reduction under the ACT Map and the BLUE Map scenarios, respectively. End use fuel switching and higher levels of electrification contribute an additional 3% and 7%. Fuel switching, CCS and nuclear energy comprise 31% and 23% of the reductions in the ACT Map and BLUE Map scenarios, respectively.

Sorting the two mitigation scenarios according to *sectors and technology options*, the projected CO_2 reductions are: in buildings, 7 Gt CO_2/year and 8.2 Gt CO_2/year; in the transport sector, 8.2 Gt CO_2/year and 12.5 Gt CO_2/year; whereas in industry, 5.7 Gt CO_2/year and 9.2 Gt CO_2/year in the ACT Map and BLUE Map scenarios, respectively. Nevertheless, power generation is projected to

FIG. 8. Nuclear contribution to the mitigation of energy related CO_2 emissions by 2050 in two IEA scenarios [12]: (a) 2050 CO_2 emissions at 2005 level (27 Gt CO_2); (b) 2050 CO_2 emissions at 50% below 2005 level (14 Gt CO_2). (Symbols used in the figure are explained as follows: PV: photovoltaic; CSP: concentrating solar power; IGCC: integrated gasifier combined cycle; UC/SC: ultra/supercritical coal; BIGCC: biomass integrated gasifier combined cycle.)



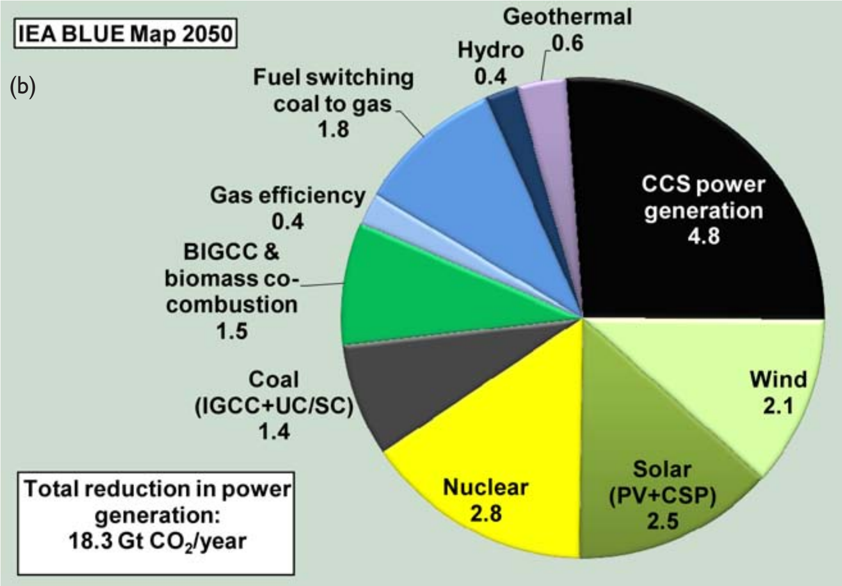
contribute most to CO_2 mitigation: about 35 Gt CO_2/year (40%) in the ACT Map and 48 Gt CO_2/year (38%) in the BLUE Map scenario. Nuclear energy is a significant component of the emission reductions in the power sector, by accounting for about 15% of the CO_2 savings in both mitigation scenarios (see Fig. 8).

The projected amount of CO_2 avoided by nuclear power is estimated at 2 Gt CO_2/year in the main ACT scenario and 2.8 Gt CO_2/year in the main BLUE scenario in 2050. This would require expanding the world nuclear fleet by 24 (ACT) and 32 (BLUE) additional 1000 MW units annually above the nuclear investments in the Baseline Scenario without GHG constraints. These rates are 18% (ACT) and 60% (BLUE) above the highest historical expansion rates of the global nuclear energy capacities, but are considered to be feasible according to the IEA scenarios.

Among the variants of the ACT and BLUE scenarios, the IEA report [12] also presents a high nuclear variant, in which the nuclear generation capacity is allowed to grow to 2000 GW in 2050, compared with the constraints in the ACT and BLUE Map scenarios limiting nuclear capacity to a maximum of 1250 GW in the same year. The underlying IEA model calculates that almost all of this huge nuclear capacity potential will be used. Total global emissions in this variant are 0.5 Gt CO_2 lower in 2050 than in the BLUE Map scenario (Ref. [12], pp. 88–89). Nevertheless, this variant requires stretching nuclear construction capacities even further, to an average of 50 GW each year between now and 2050. This is 20 GW/year more than the highest recorded construction rate in the past. It is important to recall, however, that the historical high rates of the 1970s and 1980s reflect nuclear expansions in relatively small regions in terms of global energy demand growth (North America, Japan and Europe), whereas the future nuclear expansion will also involve additional regions with already fast growing nuclear manufacturing and construction capacities (east and south Asia).

The special early excerpt of the World Energy Outlook 2009 (released in October 2009) confirms the importance of nuclear power in achieving the emission trajectory towards a GHG concentration limit of 450 ppm CO_2-eq: world nuclear generation capacity is projected to grow to 500 GW by 2020 and exceed 700 GW by 2030. This entails a doubling of global nuclear energy capacities between 2008 and 2030.

FIG. 8. (cont.)



Contribution to resolving other energy supply concerns

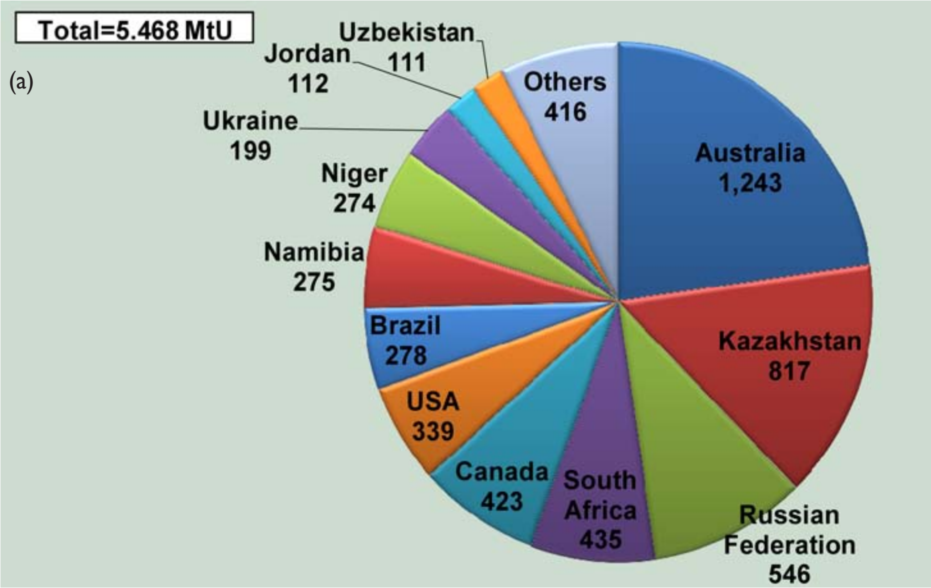
In addition to staggering increases in demand for all forms of energy, particularly electricity, and the need to reduce GHG emissions, there are several other issues on the current energy policy agendas of many countries that nuclear energy might contribute to resolving.

The first factor is the price of fossil energy sources. The rate of infrastructure development in fossil resource extraction and delivery in key supply regions is lagging behind the fast growing energy needs, and this exerts a sustained upward pressure on international oil and gas prices, even if one takes into account the speculative bubble that affected commodity prices and culminated in mid-2008. This in itself is a strong motivation for countries with high shares of imported fuels for their electricity generation to look for substitutes. Political conflicts in key supply regions exacerbate the price pressure and raise severe concerns over the security of supply per se, even at high prices. This is yet another reason for considering alternative electricity sources.

Energy importing developing countries tend to be more worried about the sustained high price level because it would severely increase their energy import bills, affect their current account balances and undermine the competitiveness of their export industries. In developed countries, energy is a relatively smaller fraction of their total import bills and the energy content of their exports is lower. Developed countries are more worried about direct losses due to supply disruptions, especially if they might render expensive capital and labour capacities idle for some time.

Another, but closely related, factor is price volatility. All elements of the energy supply infrastructure are long lived. Energy intensive industries base their investment decisions on cautious expectations about future energy and electricity prices. A reasonable degree of stability and predictability of resource prices is crucial for such decisions because hedging against large price fluctuations might be vastly expensive.

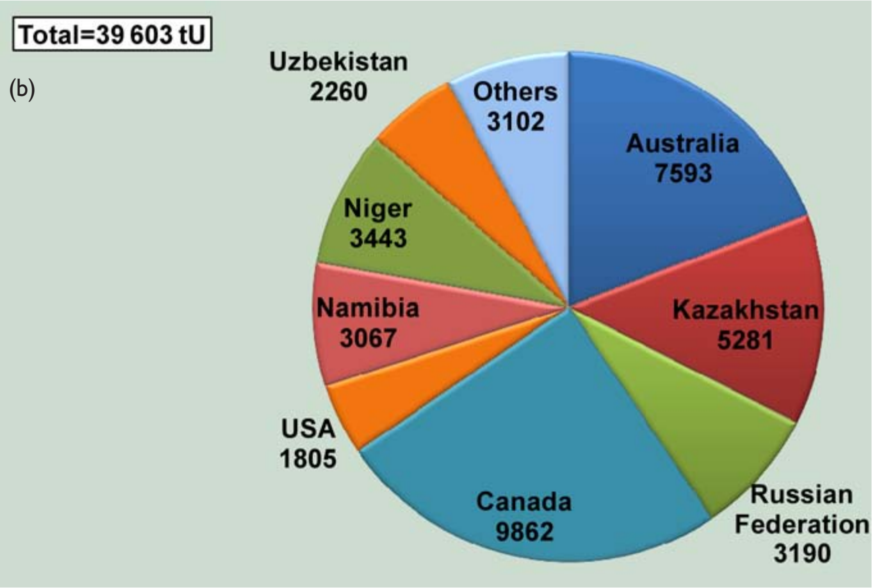
FIG. 9. The distribution of reported uranium resources and production in 2006: (a) uranium resources; (b) uranium production. (Sources: Refs [23, 24].)



Nuclear power can help mitigate these concerns. The price of uranium is a small fraction of nuclear based electricity, as opposed to power costs from coal and especially gas based generation. Doubling the price of uranium would increase the nuclear electricity price by about 4%, whereas doubling the price of coal would lead to an increase of about 40% and a doubled gas price to an increase of almost 70% in the corresponding electricity prices.

The best way to strengthen a country's energy supply security is diversification: increasing the number and resilience of energy supply options. For many countries, introducing or expanding nuclear power would increase the diversity of energy and electricity supplies. Nuclear power has one additional feature that generally further increases resilience. Figure 9(a) shows that currently known and reported resources and reserves of the basic fuel, uranium, are spread in politically stable regions over five continents. Figure 9(b) reveals a similar diversity of uranium production and supply in 2006. Moreover, the small volume of nuclear fuel required for one load to run a reactor for one year or so, makes it easier to establish strategic inventories on or close to the reactor site. In practice, the trend over the years has been away from strategic stocks towards supply security based on diverse and well functioning markets for uranium and fuel supply services. However, the option of relatively low cost strategic inventories remains available for countries that find it important.

FIG. 9. (cont.)



Nuclear energy applications beyond the power sector

In recent years, utilization of nuclear energy beyond the power sector has been increasingly considered. The emerging potential of its use in several non-electric applications is due to two special characteristics: the extremely high energy content of nuclear fuel and the wide temperature range in which different reactor designs can operate (200–1000°C). These two features offer various options for humanity to resolve resource constraints, ranging from freshwater supply to liquid and solid fossil fuel extraction, and to provide a new fuel for the transport sector. Among these non-power applications, water desalination, extraction of non-conventional oil sources, cogeneration with coal and hydrogen production for transport are discussed here. The required temperature ranges and the corresponding reactor types are presented in Fig. 10.

Freshwater availability is a severe problem in many countries, as 2.3 billion people live in water stressed regions and among them 1.7 billion live in water scarce areas [26]. Adding to other impacts of climate change, more frequent or longer lasting droughts will require alternative ways to provide potable water in many semi-arid and drought-prone areas. Currently, around 40 million m^3/day of water are distilled in some 15 000 plants, most of which are located in the Middle East and North Africa. Desalination is very energy intensive, and most desalination plants today use fossil fuels as their primary energy source, thus contributing to GHG emissions.

Nuclear desalination is already a method used by some countries in order to meet freshwater requirements. In Kazakhstan, the BN-350 fast reactor at Aktau produced up to 135 MW of electricity and 80 000 m^3/day of potable water for over 27 years until it was retired in 1999. In Japan, several desalination facilities are linked to power reactors and each provides 1000–3000 m^3/day of potable water for the reactor's own cooling system. India also has been operating a Nuclear Desalination Demonstration Project at the Madras power station since 2002 [27]. According to the IAEA [28], using 20% of the electrical capacity of a 600 MW nuclear reactor operating in cogeneration mode can purify 500 000 m^3/day of water. Another option for nuclear desalination is using deep pool reactors that provide heat as a source for sea water desalination and cogeneration of heat for district heating if needed. An economic analysis of this desalination system shows that it will decrease the total specific capital investment and levelized water cost [29].

As the availability of sweet crude is declining, the remaining hard crude has to be extracted in order to meet oil demand. Refining hard crude needs more energy and hydrogen, in which nuclear energy can play a significant role. Donnelly and Pendergast [30] propose a process in which hydrogen produced by nuclear power might have high importance, especially in the extraction of oil from the tar sands of the Athabaska region in Canada, and hard crude in other regions of the world. Currently, a lot of CO_2 is released due to energy use and hydrogen production for oil extraction and refining from the tar sands of Alberta, since the present major source of energy is gas. Using nuclear reactors for supplying energy and producing hydrogen will significantly reduce the carbon emissions from recovering oil from the tar sands.

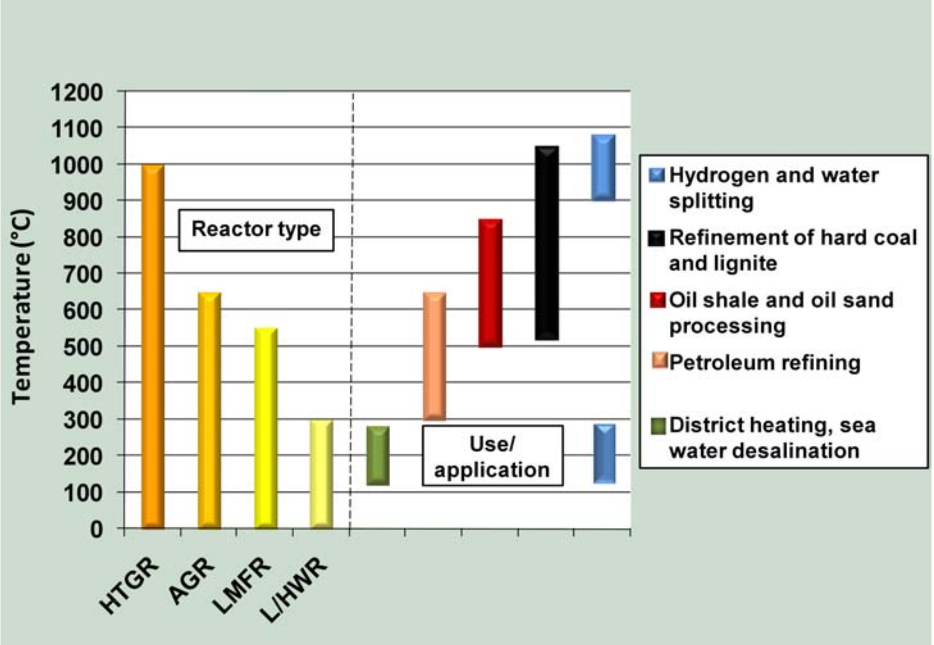
Rather than as a rival energy source for coal, nuclear energy can help to reduce the carbon emissions from coal burning. Given the huge coal deposits in several countries and regions (China, India, Australia, South Africa, North America), the gasification of coal for integrated gasification combined cycle (IGCC) combustion might be a feasible GHG emission mitigation technology. Nuclear heat from high temperature gas cooled reactors (HTGR) can be used for the gasification of coal along with the generation of electricity, which would reduce carbon emissions significantly [31].

GHG emissions from transport have been growing at a fast rate globally. As a result, there has been increasing attention to the options to reduce emissions from the transport sector without constraining the mobility of people and goods. Increasing the fuel efficiency of internal combustion engines still holds considerable reduction potential. Another option is to look for alternative fuels and engine technologies. Using hydrogen as a fuel has been on the research and development agenda for some time, but progress in terms of its potential commercial utilization was stalled owing to the ample availability of cheap fossil fuels.

There are different processes to produce hydrogen. Among them, thermochemical water splitting (heat plus water yields hydrogen and oxygen) is considered as highly efficient and more economical than electrolysis of water with electricity [32]. This process needs a high temperature (750–1000°C). Nuclear reactors can provide the heat required to split water to produce hydrogen. This offers many possibilities, because reactors could be installed with peak load capacities, and the excess power during the baseload operation could be used for producing hydrogen that can be stored and used for transport and other applications.

It is not possible to predict which of these non-electric options will be used in the energy hungry 21st century, or to what extent, but evidence has been accumulating in recent years that promising opportunities might emerge for using nuclear energy beyond baseload electricity generation.

FIG. 10. Possible uses of nuclear energy beyond power generation [25]. (Symbols used in the figure are explained as follows: HTGR: high temperature gas cooled reactor; AGR: advanced gas cooled reactor; LMFR: liquid metal cooled reactor; L/HWR: light/heavy water reactor.)



Nuclear power has non-climatic environmental benefits

In addition to helping to mitigate climate change, the displacement of fossil based power plants by nuclear power can also reduce the emissions of other air pollutants that lead to negative human health and environmental impacts at local and regional scales.

Nuclear power plants emit virtually no air pollutants during their operation. In contrast, fossil based power plants are major contributors to air pollution. The World Health Organization (WHO) has estimated that air pollution causes approximately two million premature deaths worldwide per year [33]. Air pollution also contributes to health disorders from respiratory infections, heart disease and lung cancer. In many cities in developing countries, the level of particulate matter in the air exceeds 70 micrograms per cubic metre (μg/m^3), and by reducing it to 20 μg/m^3 (which is the air pollution concentration level recommended by WHO), air quality related deaths could be cut by around 15%. Currently, the energy supply sector accounts for one quarter of the total particulate matter (PM10) emissions in the European Union [34]. Although the air quality in Europe has improved significantly in recent years, particulate matter in the air decreases life expectancy of every European by, on average, almost one year.

A recent study [35] analyses the consequences (including the implications for local air pollution) of lifting the restrictions on a potential expansion of the nuclear capacity in Europe (projecting a 45% nuclear expansion by 2030). According to the analysis, the resulting reduction of particulate matter concentration in Europe would lead to significantly lower chronic diseases (–3% in the number of people with bronchitis and –2.5% in restricted activity days), as well as premature deaths (–1.9%) by 2030, amounting to a welfare gain of €32–559 billion (a median estimate of €165 billion).

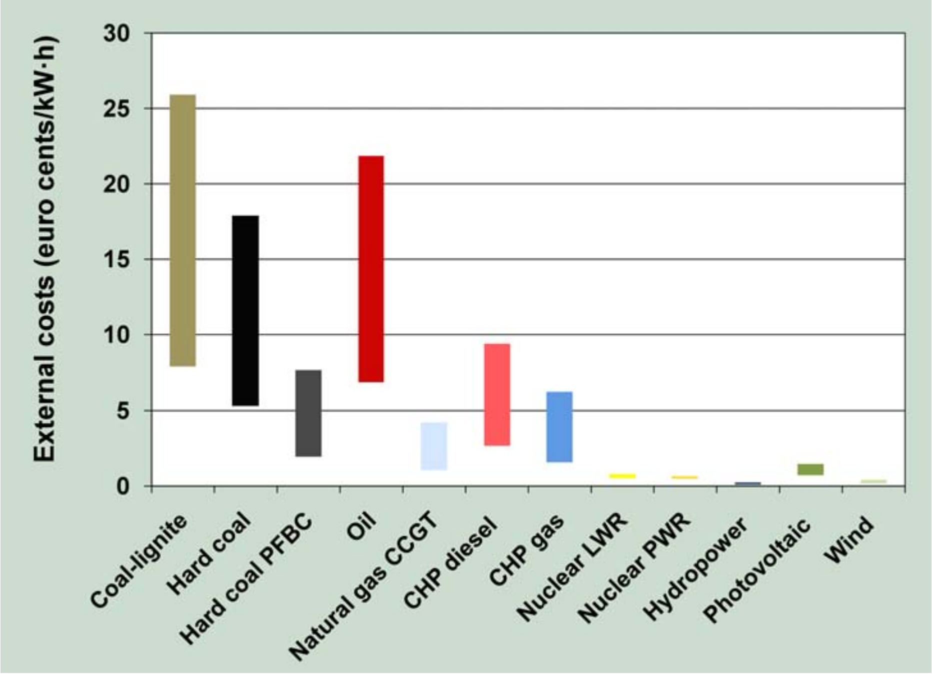
At the regional scale, air pollutants travelling long distances cause acid rain, harming nature at large. Acid rain disturbs ecosystems, leading to adverse impacts on freshwater fisheries and on natural vegetation and crops. In particular, acidification of the forest ecosystems could lead to forest degradation and dieback. Furthermore, it causes damage to certain building materials, including historic and cultural monuments. Acid rain is caused by sulphur and nitrogen compounds, and fossil fuel based power plants, particularly coal power plants, are the major source of the emission of the precursors of those compounds. Sulphate and nitrate, transported across national borders, also contribute to the occurrence of haze, strongly limiting visibility and reducing sunlight, and possibly changing the atmospheric and surface temperature as well as the hydrological cycle [36]. Technology solutions exist to reduce these emissions but the cost of installation might make nuclear power more attractive.

An extended assessment was coordinated by the European Commission within the framework of the ExternE project that compared the externalities (positive and negative side effects not reflected in the price of electricity) of different power supply options in monetary terms [37]. The European Environmental Agency used the ExternE results and other information sources for quantifying one of its energy related indicators referred to as 'external costs of electricity production' [38]. The estimated average European Union external costs for electricity generation technologies in 2005 are presented in Fig. 11. They are calculated by assessing and aggregating three components: climate change damage costs from CO_2 emissions, damage costs (health, crops, etc.) caused by the emissions of other air pollutants (NOx, SO_2, PM10, etc.), and other non-environmental social costs for non-fossil power generation technologies. In the numerous methodological challenges, and the attribution and quantification of uncertainties (see Ref. [39]), two stand out as particularly contentious. The first is the external costs of CO_2

emissions that range from 19 €/t CO_2 in the low estimates to 80 €/t CO_2 in the high estimates adopted for the fossil fuel technologies included in Fig. 11. The second issue is the external cost arising from a nuclear power accident. The ExternE-Pol study [37] excluded this cost item due to the methodological difficulties of estimating it. Therefore, the EEA used the corresponding estimate from a study prepared for the IEA's Implementing Agreement on Renewable Energy Technology Deployment [40] that estimates the accident related externality of nuclear power at 0.25 eurocents/kW•h.

These results demonstrate that, due to strict technology and safety regulations, meticulous environmental impact assessments, rigorous design, site and operation licensing procedures, the nuclear industry has already internalized the bulk of the potential external environmental, health and social effects. This was achieved by adopting technological solutions that prevent harm rather than by payments to compensate for harm. This characteristic of nuclear power is the source of significant ancillary (non-climate) benefits when it is implemented for climate change mitigation.

FIG. 11. Estimated average European Union external costs for electricity generation technologies in 2005. Based on data from Ref. [38]. (Symbols used in the figure are explained as follows: PFBC: pressurized fluidized bed combustion; CHP: combined heat and power; CCGT: combined cycle gas turbine; LWR: light water reactor; PWR: pressurized water reactor.)



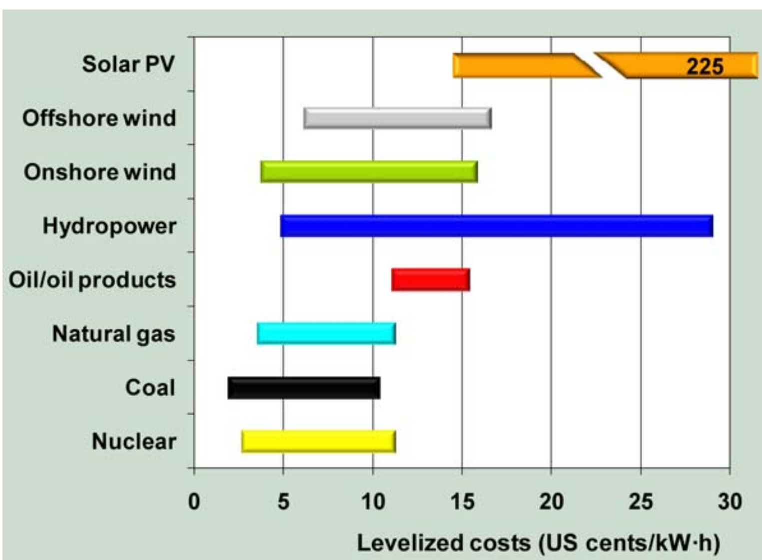
Nuclear power economics is becoming favourable

The economics of nuclear power needs to be addressed at two levels: firstly, the direct explicit costs of generating 1 kW•h of electricity levelized across the lifetime of the power plant; and, secondly, the social costs, including all externalities that happen to be predominantly positive in the case of nuclear power. The costs of decommissioning and waste disposal are collected and accumulated through the operating lifetime of the power plant, whereas the social benefits of avoided CO_2 emissions or increased supply security remain unaccounted for in the absence of comprehensive GHG taxes or emissions permit markets. In addition to regulatory uncertainties, both in the nuclear sector and in the electricity market in general, the unrewarded social benefits (equivalent to the gap between private and social costs of fossil competitors) represent another factor that discourages potential investors.

Nuclear power plants have a 'front loaded' cost structure (a feature shared with most renewables); that is, they are relatively expensive to build but relatively inexpensive to operate (compared with fossil based generating capacities). The low share of uranium costs in total generating costs protects plant operators and their clients against resource price volatility. Thus, existing well run operating nuclear power plants continue to be a generally competitive and profitable source of electricity. For new construction, however, the economic competitiveness of nuclear power depends on several factors. Firstly, it depends on the alternatives available. Some countries are rich in alternative energy resources, others less so. Secondly, it depends on the overall electricity demand in a country and how fast it is growing. Thirdly, it depends on the market structure and investment environment.

Other things being equal, nuclear power's front loaded cost structure is less attractive to a private investor in a liberalized market that values rapid returns than to a government that can consider the longer term, particularly in a regulated market that assures attractive returns. Private investments in

FIG. 12. Ranges of levelized electricity costs associated with new construction as estimated in recent studies for electricity generating technologies in different countries [41].



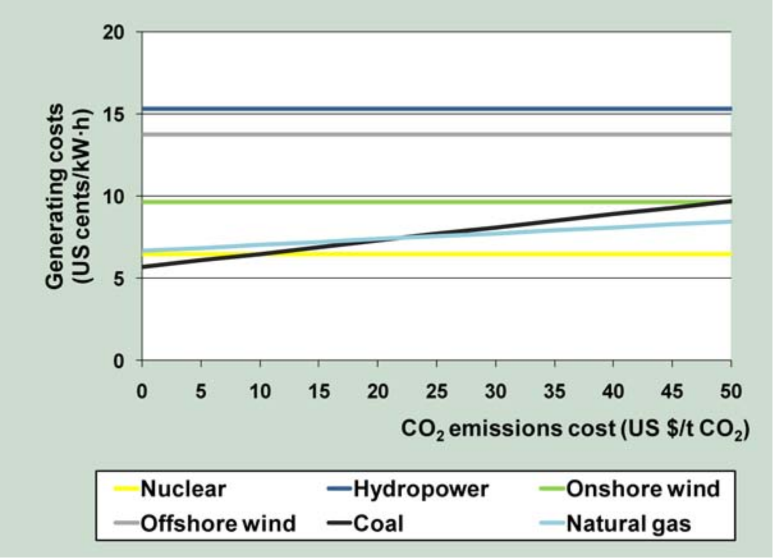
liberalized markets will also depend on the extent to which energy related external costs and benefits (e.g. pollution, GHG emissions, waste and energy supply security) have been internalized. In contrast, government investors can incorporate such externalities directly into their decisions. Also important are regulatory risks and political support for nuclear power. All these factors vary across countries.

In Japan and the Republic of Korea, the relatively high cost of alternative electricity sources benefits nuclear power's competitiveness. In India and China, rapidly growing energy needs encourage the development of all energy options. In Europe, high electricity prices, high natural gas prices and GHG emission limits under the European Union Emission Trading Scheme (EU ETS) have improved the business case for new nuclear power plants. In the USA, the 2005 US Energy Act significantly strengthened the incentives for new construction. Its provisions, including government coverage of costs associated with certain potential licensing delays, loan guarantees and a production tax credit for up to 6000 MW of advanced nuclear power capacity, have improved the business case enough for nuclear firms and consortia to file 17 applications for combined construction permit–operating licences.

Figure 12 summarizes estimates from recent studies of electricity costs for new power plants with different fuels. The wide ranges are due partly to different techno-economic assumptions across the studies, but also to the factors listed previously. Moreover, the ranges incorporate internalized costs only.

The impacts of CO_2 costs (carbon tax or emission permits) on electricity prices have already been shown in the European Union in recent years. High electricity prices through mid-2006 were partly due to the high allowance price in the EU ETS. Wholesale electricity prices fell after the permit price under the first phase of ETS collapsed but rebounded in 2007 and 2008, with higher prices under the second phase of the scheme. Figure 13 illustrates the changes in median levelized electricity costs of different power sources (depicted in Fig. 12) as a function of increasing CO_2 costs. The graphs show that at a CO_2 price of about \$10/t, the median cost of nuclear electricity becomes lower than that of coal based power and the gap between median costs of nuclear and gas based electricity reaches 20% at the CO_2 cost of \$30/t.

FIG. 13. The impact of CO_2 costs on levelized electricity costs of different power sources.



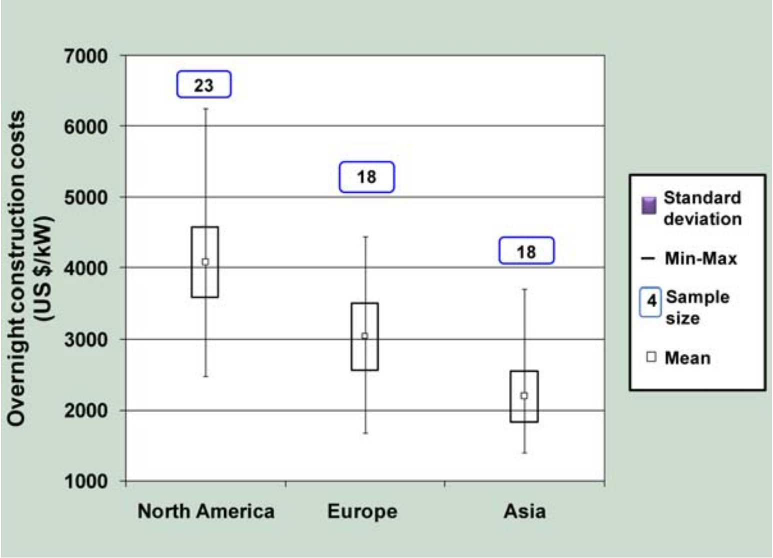
Nuclear investment costs are increasing, but …

Nuclear electricity is more capital intensive than fossil power generation. High upfront investment costs and long construction time, as well as political, regulatory and public perception risks make nuclear financing more challenging. However, once the plant is in operation, the low operating costs offset the high investment costs and result in the low levelized cost of electricity (the previous section on nuclear power economics addresses this issue).

The total investment costs of a nuclear power plant include overnight costs (OC), interest during construction (IDC) and escalation costs during construction. The OC shows how much the plant would cost if no interest were incurred during construction, and it includes engineering–procurement–construction costs (equipment, materials and labour are known as direct costs; plant design, engineering and support services, as indirect costs), owner's costs (site evaluation, site preparation and additional transmission infrastructure), and contingency costs (or unforeseen costs). IDC includes the costs of financing plant construction until it is connected to the grid and generates revenues. Since construction takes years, IDC alone can tilt the balance between an economically viable or unviable project. Assuming an OC of $3350/kW with a typical distribution over the construction period, a 10% real interest rate and a construction period of five years carries $1128/kW of IDC (or 37% of OC). An increase in the construction period from five years to six or ten years would increase IDC to 41% or 75% of OC, respectively.

The investment costs presented in cost studies and industry quotations between 2002 and 2005 range from $1000 to $2500/kW and show no obvious cost escalation. However, in estimates reported from 2007 to 2009, the OC range from $1400/kW to $6000/kW and the total investment costs range from $2250/kW to $8000/kW. Figure 14 groups the OC estimates by region. The data are taken from publicly available sources, which generally lack details about what is included in the indicated costs. This leads to large variations

FIG. 14. Ranges of nuclear power overnight costs by region 2007–2009. (All costs are in 2008 dollars.) (Source: Ref. [42].)

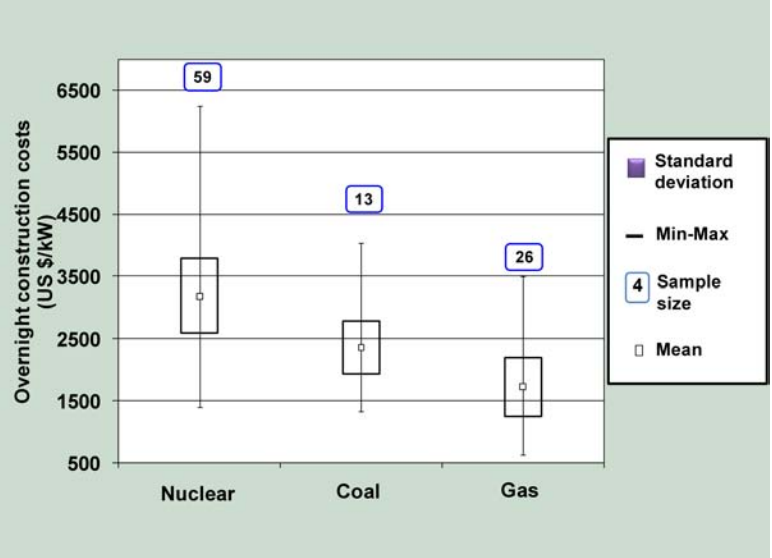


depending on differences in sites, local inputs, labour and material costs, accounting practices, connection cost, government and regulatory processes, electricity markets, exchange rate or currency fluctuations, financial markets, etc., as well as changes in these factors over time. Tight commodity markets and steeply rising international prices for iron ore, copper, steel, cement, energy, etc. up to 2008 have undoubtedly contributed to the escalating OC estimates. Commodity prices have eased somewhat in 2009 but they are not yet reflected in the nuclear cost estimates.

A possible explanation of the wide range of cost estimates can be the difference in perspectives: vendors have an incentive to be optimistic about costs, while utilities tend to be more conservative. Another factor contributing to regional differences is recent experience: the region with the most recent experience in building new reactors, Asia, has the lowest cost estimates and smallest variation. The region with the least recent experience, North America, has the highest estimates and greatest variation. Positive investment experience lowers perceived and real risks for investors. Lack of construction experience might entail higher contingency rates and may be seen as a risk that affects the credit rating of a utility and leads to higher interest rates. Moreover, in countries with ongoing nuclear power investments, the transition from second to third generation technology is likely to be smoother. The cost barriers associated with first of a kind plants are correspondingly lower than in countries without such recent experience and in countries investigating the nuclear power option for the first time. It is perceived that as successful experience accumulates, construction costs for the nth copy of any design is likely to decline. For example, the total cost of the fifth and sixth units of the Korean Standard Nuclear Power Plant was 15% below that for the first and second units [43]. A lengthening successful track record should also reduce risks perceived by lenders and shareholders, and thus lower the cost of capital.

As a complement to Fig. 12 (ranges of levelized costs of electricity), Fig. 15 presents ranges of the overnight construction costs for the three main power technologies. It is interesting to see that significant shares of the reported projects (mean ± one standard deviation) are in a relatively narrow range for nuclear, coal and gas.

FIG. 15. Ranges of OC estimates for the main electricity generation technologies 2007–2009. (Source: Ref. [42].)



… financing nuclear power investments is feasible

In the past, governments generally used public funds — either tax revenues or electricity tariff charges — to finance investments in nuclear power. Currently, however, governments are looking towards the private sector to a greater extent to finance new infrastructure investments. Cognizant of this fact, the utility industry and the financial sector have devised some incentives to invest in nuclear projects. The utilities would use their balance sheet to invest in joint ventures such as 'build–own–operate' schemes. The financial sector is also catering to the investor's need and interest in nuclear — evidence that the financial markets recognize an interest for investment in the nuclear industry, by venturing funds such as Van Eck's Market Vectors Nuclear Energy Exchange-Traded Fund (ETF) and the Nuclear Indices (such as Global Nuclear Energy Index and Standard and Poor Global Nuclear Energy Index).

Over the last decade, governments are relying more on industry and private sector participation to initiate new innovative financial structures for the nuclear industry. Figure 16 displays the ownership and risk transferability from public to private, with a move from the more traditional low risk government financing, where a new built project is financed on a state budget, to industry participation. These include financing models already employed in the nuclear industry where project sponsors have some options for generating equity among themselves. One source of equity could be balance sheet financing or corporate finance, where a new built project is financed on a corporate basis. The Flamanville 3 project in France is an example in which the French utility, Électricité de France (EDF), is financing most of the project on its robust balance sheet and future revenues (with some investment from ENEL of Italy [44]).

Other new models include equity partners who can provide equity in kind or principal customers (worried about security of supply and risk diversification) as major shareholders. An example is the Finnish model adopted for the Olkiluoto 3 power plant. This is a cooperative model in which a consortium formed by large industrial consumers and municipal utility companies contribute to the project investment, share the risks and rewards once the project completes and generates revenues. This can also be considered a type of hybrid financing (corporate/project finance), where the equity investment is financed by the shareholders, a long term purchasing power agreement (PPA) with large customers ensuring future stable revenue stream from the project, and leverage characteristics similar to project finance. The project also benefits from low financing costs, partly due to the long term PPA, the support from the French Government Export Credit Agency, and the turnkey contractual arrangement with the French firm, Areva.

More recently, some trends towards project finance have begun to emerge. Large utilities are forming companies to venture into the nuclear market, while others have clearly stated that if new nuclear power plants are feasible, separate project companies will be established to build the new plants on a 'build–own–operate' basis [45].

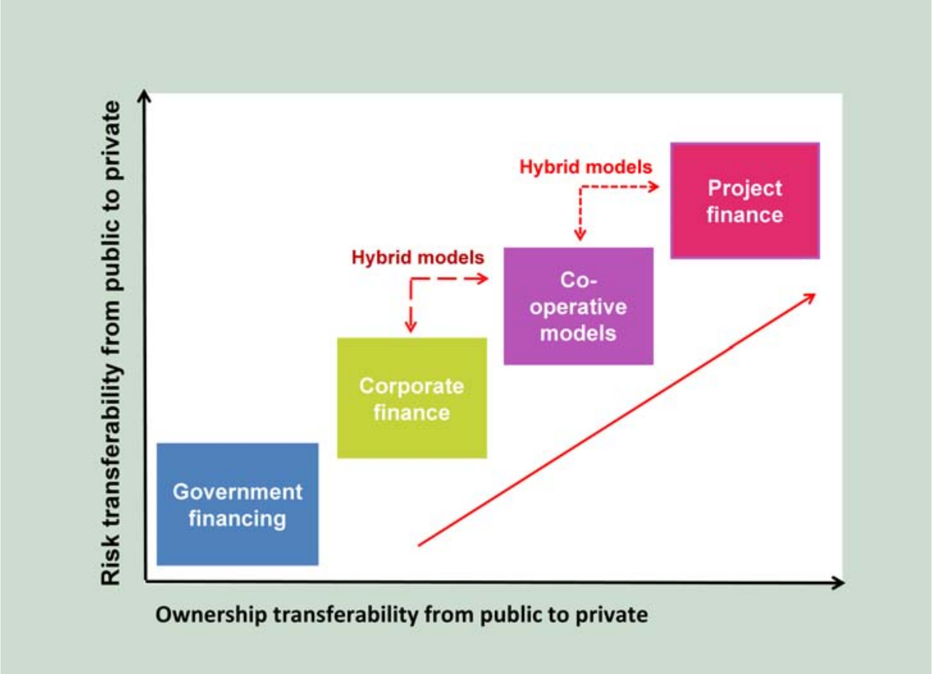
It is envisaged that, over time, as new plants are built, the hybrid style financing models might become more apparent in the nuclear industry, where multiple equity partners share the risk. Another risk mitigation option can be corporate bond issuance by the company owning the nuclear plant, with a higher stable credit rating. This might reduce financing costs by repaying the loans used to finance the new plant. Other options can be offering ownership to strategic and industrial partners [46] or through Initial Public Stock Offering (IPO).

Well structured nuclear projects, where risks are identified upfront, pose less uncertainty to financiers and are easier to finance. Risks arising from regulatory uncertainty can be mitigated by an efficient regulatory body.

Other risks, such as unknown costs, first of a kind, licensing, delayed construction, public acceptance and legal risks, can also be contained with a well planned project schedule and an appropriate risk allocation. Options such as phased financing can contain the risk of construction cost overruns. This involves financing a project in tranches, starting with construction. The cost of capital for each phase will reflect only the risks of that phase rather than a high risk premium for the whole construction. This model is already implemented in China and proposed for new plants in the USA. Well reputed vendors, operators and project managers along with some form of government guarantee can also give assurance to the finance industry to venture into new financing schemes for nuclear power plants. In developing countries, initial financing arrangements for a new nuclear plant that includes some government funding or support, along with assistance from multilateral financial institutions and export credit agencies might be attractive for private investors to join in.

In the short term, the financial crisis of 2008 will have an impact on the financing facilities available for investors regarding large scale infrastructure (such as nuclear), as the financial institutions restructure and rebuild their balance sheets. Tighter regulation of the financial industry might also affect commercial lending in the future. However, the historic low interest rates might be supportive of new investments, along with the decline in the commodity prices, which might reduce the construction costs for new plants. So far, nuclear power plants under construction have not been affected by the crisis. Some countries postpone or stretch out their construction schedules, while others consider it a favourable time and revise their nuclear planning programmes upward.

FIG. 16. Financing models.



Construction capacity will expand as needed

Assuming that nuclear power is competitive and financing new construction will be feasible, the next question is whether there will be sufficient specialized manufacturing capacity to build new reactors at the required rate. Moreover, a considerable amount of specialized knowledge is required to control the entire construction process and, later, to operate the plants. Therefore, a major challenge for the nuclear industry over the next decade will be to satisfy the increasing demand as well as to transfer nuclear knowledge to the next generation.

Growth in energy demand and the need to reduce GHG emissions in order to tackle climate change has created new prospects for the nuclear industry. China, India and the Russian Federation have all recently made the political decision to launch large scale nuclear programmes to add significant amounts of new generating capacity to their national grids. Several OECD countries (e.g. France and the United Kingdom) that have not built nuclear plants for years are now considering replacing their ageing reactors with new ones, and expanding their nuclear reactor fleet. By September 2009, applications for a combined construction permit–operating licence in the USA involved 17 sites and 26 possible new reactors [47].

Reactor pressure vessels, vessel heads, steam generators, steam turbines, reactor coolant pumps and other components must be manufactured to the highest standards to ensure safety. The most demanding items are the pressure vessels, which require high capacity presses for producing heavy forgings. Japan Steel Works (JSW) has been considered by many in the industry as the leader in ultraheavy forgings (see Fig. 17(a, b)). JSW has a series of hydraulic forging presses ranging from 3000 to 14 000 t, the latter able to take 600 t steel ingots, as well as a 12 000 t pipe-forming press. Currently, JSW can only produce four reactor pressure vessels and associated components per year, but capacity expansions are under way to triple this output to twelve by mid-2012. This involves an investment of ¥80 billion ($837 million) in two phases [49].

In recent years, many other companies established such capacities in preparation for meeting the rising expectations for nuclear power. The Japanese company Mitsubishi Heavy Industries (MHI) has the capacity to produce vessels for two-, three- and four-loop pressurized water reactors (PWRs), including the 1538 MW APWR at its Futami plant in Kobe. Recent plant upgrading is expected to enable the handling of even larger components. In total, MHI is to invest ¥40–50 billion ($380–470 million) in its facilities at Kobe and Takasago, and to hire 1000 more employees for its nuclear division by 2013 [50]. More recently, MHI announced a JPY 15 billion ($138 million) investment to double its capacity to make nuclear reactor pressure vessels and other large nuclear components by 2011 [51].

The Russian company, OMZ Izhora, also announced the doubling of its capacity, providing large forgings for Russian reactors to be built domestically and internationally [52]. Another Russian company in the heavy equipment manufacturing branch, ZiO-Podolsk, is increasing its capacity to the level sufficient for producing four nuclear equipment sets per year. This company will complete the reactor pressure vessel for the BN-800 fast reactor at Beloyarsk by early 2010 and will also produce steam generators for several new nuclear power plants in the Russian Federation [53].

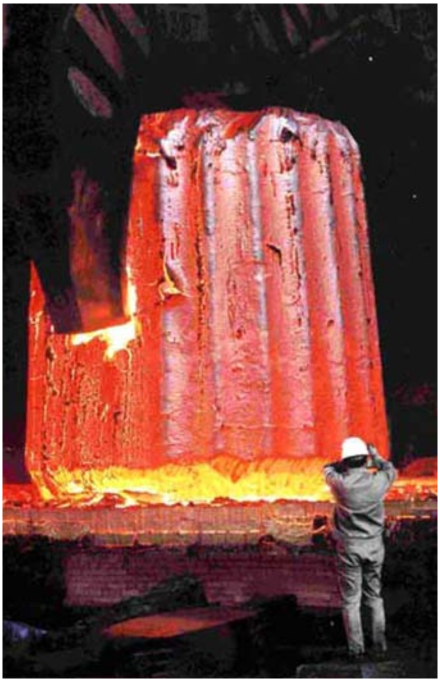
Doosan Heavy Industries in the Republic of Korea has established itself as an important actor in this market. The company plans to increase casting and forging capacities, including a 17 000 t forging press, by investing 405 billion won ($395 million) by 2011. Castings production will increase by almost 50% to 300 000 t, while forging capacity will be almost doubled to 190 000 t/year [54]. Still in eastern Asia, companies in emerging countries, such as the Dongfang Boiler Group, Shanghai Electric Group and Harbin Boiler Works (in China), are getting ready to enter the very large forgings market. In southern Asia, India's Larsen and Toubro are increasing their scope in this area to satisfy both domestic and international demand.

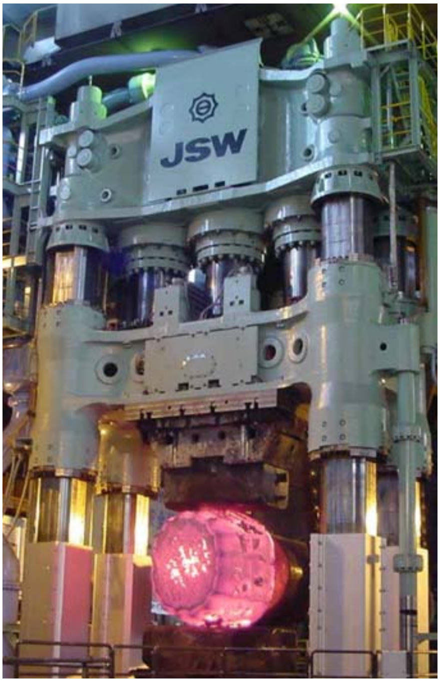
In western Europe, the nuclear industry is already enlarging its production capacity to match the upcoming market. To take part in the United Kingdom's new nuclear programme, Sheffield Forgemasters is considering expanding its heavy forging capacity with a 15 000 t press that would allow the production of large reactor pressure vessels, including Areva's 1650 MW European Pressurized Reactor, currently the largest on the market [55]. Meanwhile, Areva is also increasing its large forging capacity at Le Creusot in Burgundy, France.

Regarding nuclear staffing, the fast pace of the nuclear power industry will generate higher demand for skilled workers, energy experts, nuclear engineers and technicians. University programmes and industrial training capacities are expanding to meet the increasing demand. For example, in the United Kingdom, British Energy's flagship training facility will provide courses in nuclear technology and excellence in technical leadership to both new and experienced nuclear professionals [56]. Other nuclear expansion countries have already begun revitalizing their nuclear education or plan to do so in the near future.

It is obvious that the global nuclear supply chain will be able to satisfy even the most ambitious nuclear programmes, but this will certainly require further investments. Once the signals of reliable and persistent demand are sufficiently strong, companies will undoubtedly invest in new production capacities, since this is how the market responds and works. There may be some bottlenecks at the early stages, but the market will react and adjust itself to bring forward the required material, staff, components and services. Since the process of planning, licensing and preparing a new construction takes years, this will give sufficient time for manufacturers to establish the required capacities.

FIG. 17. Japan Steel Works [48]: (a) reheated 600 t ingot; (b) 14 000 t hydraulic press.





Sufficient uranium is available to fuel increasing nuclear power generation

An often heard concern is 'peak uranium' — the popular fallacy that the world is running out of uranium some time soon. The 2004–2006 price surges on the uranium spot market, as well as an interpretation of reserve to production ratios at face value, prompted proponents of 'peak uranium' to claim that uranium resources will run out within two to three decades, making any nuclear energy expansion a chimera.

Uranium is a metal approximately as common as tin or zinc, and it is a constituent of most rocks and even of the sea. The economically producible occurrences of any mineral (the reserves) are a function of demand, ore concentration, exploration and production technology, and market price. Hence, reserve estimates change dynamically with improved geological knowledge, advances in production technology, demand and price expectations. At higher prices, lower concentration occurrences may become economically attractive, while new innovative production methods may enable production from deposits previously beyond reach. Low prices may limit reserves to low cost, easy to produce high concentration occurrences. This does not mean that physical occurrence of the mineral no longer exists — it just delineates the economically recoverable portion of that resource at a given point in time [57]. Thus, assessments of the future availability of uranium tend to err on the conservative side.[4]

Uranium resources are plentiful and per se do not limit future nuclear power development. As is often the case, the limiting factor is the timely investment in new mining capacities. The past two decades have seen a wide gap between actual reactor requirements and fresh uranium production — only 40–60% of global demand was met by freshly mined uranium. The remainder was made up from so-called secondary sources: strategic cold war stocks, down blending of highly enriched weapons grade uranium (megatons to megawatts), reprocessed uranium and plutonium from spent fuel, etc. Uranium prices were depressed and many mines closed as prices of $20/kg U no longer covered variable operating costs. Consequently, global production capacity is well below reactor requirements. In the absence of upstream investments, therefore, the industry will continue to depend on secondary sources for another decade or so.

Uranium spot prices have been fluctuating along a declining path from a peak of almost $300/kg U in 2006 to about $115/kg U in June 2009. This price level has stimulated exploration and new mine capacity development around the world. There are even plans to reopen previously closed mines. Uranium producers, however, are wary of the secondary supplies. Their future will depend on economics and policy, especially with regard to spent fuel reprocessing and high level waste disposal.

According to the latest report published jointly by the Nuclear Energy Agency of the OECD (OECD/NEA) and the IAEA [24], approximately 5.5 million t of global uranium resources had been identified by 2007 (considerably higher than the 4.74 million t uranium reported three years earlier). This amount is equivalent to 130 times the global production of uranium estimated for 2008 (or more than 80 times the reactor requirements). Even without considering unidentified and speculative uranium resources, which amount to some 10.5 million t uranium [58], unconventional uranium occurrences or reprocessing of spent nuclear fuel, the resource abundance of uranium is one of the advantages of nuclear energy over fossil fuels. In addition, uranium resources are geographically more evenly distributed so that supply is not concentrated in geopolitically unstable regions.

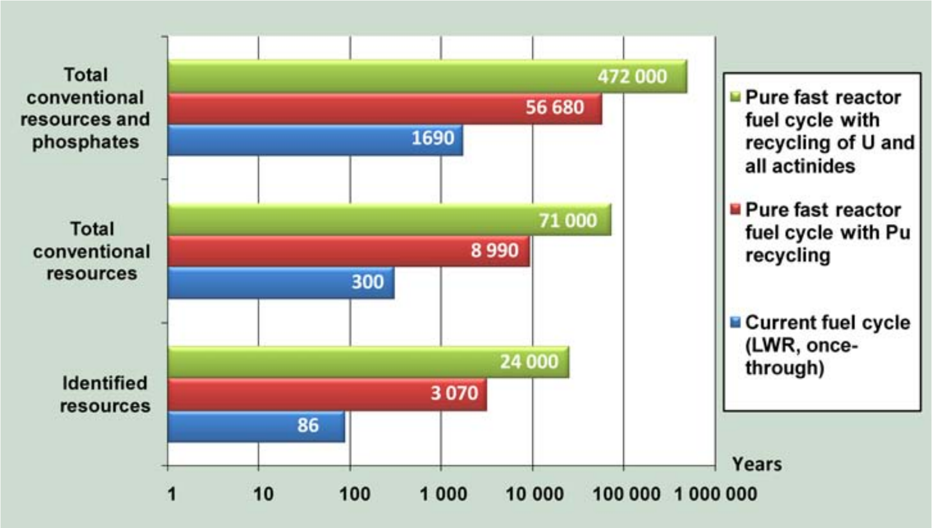
[4] Uranium reserves and resource assessments are capped at production costs of $130/kg U and higher production cost occurrences are ignored in uranium resource statistics [24].

Reprocessing of spent nuclear fuel (still containing some 95% of its original energy) can contribute to a much lower uranium demand and supply balance. Annual discharges of spent fuel from the world's reactors total about 10 500 t of heavy metal (t HM) per year, approximately one third of which is reprocessed to extract usable material (uranium and plutonium) for new mixed oxide (MOX) fuel consisting of fresh uranium as well as recycled uranium and plutonium. The remaining spent fuel is considered waste and is stored pending disposal.

Advanced reactor designs (such as fast breeder reactors) and associated fuel cycles utilize uranium more efficiently than current reactors and fuel cycles [59]. The advanced technologies, however, will require reprocessing. There are presently no fast breeder reactors using reprocessed plutonium operated commercially anywhere in the world (reprocessing is more expensive than fresh uranium fuel), but more than 200 reactor-years of experience has been accumulated in industry scale breeder reactors (in France and the Russian Federation), which provides a good basis for designing and building commercial fast breeder reactors when they become economically competitive. Figure 18 shows the lifetime of various types of uranium resources under different fuel cycle and reactor technology scenarios.

In summary, the lifetime of uranium resources will be determined by demand, technological change and economics rather than by geology. As and when cheap uranium sources become scarce, uranium prices will increase, which in turn will make reprocessing spent fuel or the extraction of low concentration sources profitable for traditional as well as breeder reactors.

FIG. 18. Estimated years of uranium resource availability for various reactor and fuel cycle scenarios at 2007 nuclear power utilization levels. (It is important to note that the reported uranium resource figures are only a part of the already known resources and are not an inventory of the total amount of recoverable uranium.



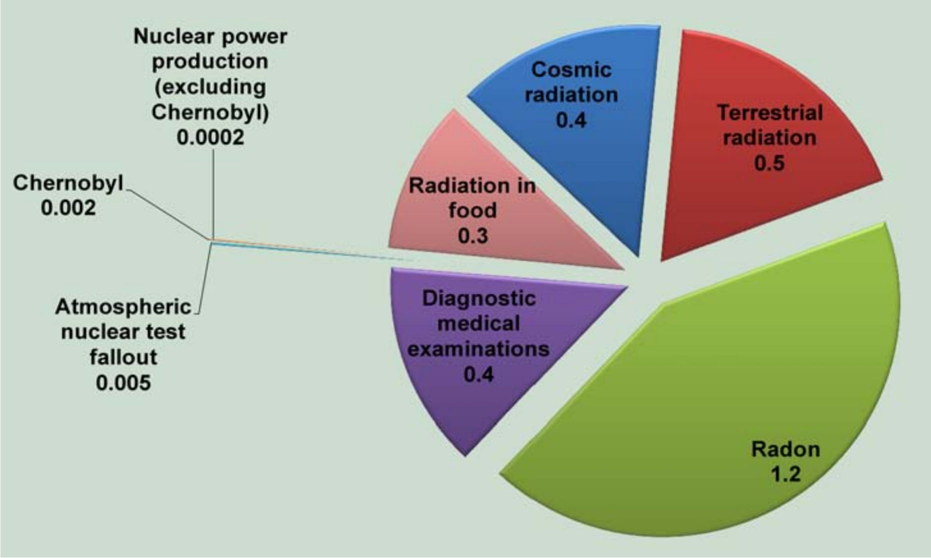
Radiation risks are low

The benefits of the lack of emissions of GHGs and air pollutants from nuclear power generation must be assessed in comparison with the higher levels of radiation associated with nuclear power plants and their entire fuel cycle, from mining and milling, uranium enrichment and fuel fabrication, nuclear reactor operation and fuel reprocessing, to solid waste disposal and transport. A report by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [60] presents a full account of radiation emitted by each and every nuclear power plant in the world as well as that emitted during fuel cycle operations. Although even a small amount of radiation is believed to increase the risk of cancer, it has been shown that the health risks due to radiation related to nuclear power generation are at a level that is statistically indistinguishable from those due to radiation exposure from radiation sources existing in nature. Average worldwide exposure to natural radiation sources for an average individual is 2.4 millisievert (mSv) per year, with a typical range of between 1 and 10 mSv. As shown in Fig. 19, radon accounts for half of the public radiation exposure from natural radiation sources, followed by terrestrial radiation, cosmic radiation and radiation in food. In comparison, radiation exposure due to nuclear power production including the full nuclear fuel cycle is 0.0002 mSv/year for an average individual.

The reported annual effective dose of individuals from a number of reactor sites (within 50 km from the sites) is in the range of 1 to 500 μSv (1 μSv = 0.001 mSv), with the average estimated as 5 μSv for pressurized water reactors (PWRs) and 10 μSv for boiling water reactors (BWRs). For mining and milling operations, the annual effective dose of an individual living within 1000 km from these sites is estimated to be about 40 μSv, whereas for fuel reprocessing it is estimated as 10 μSv (within 50 km from the sites).

According to an International Commission on Radiological Protection (ICRP) report [61], the cancer risk expressed in terms of cancer cases per 10 000 persons per Sv is 1715. Converting this risk into a health indicator, the exposure of 1 μSv increases the cancer risk to one in 5.8 million persons.

FIG. 19. Typical sources of public radiation exposure in 2000 (in mSv/year) [60].

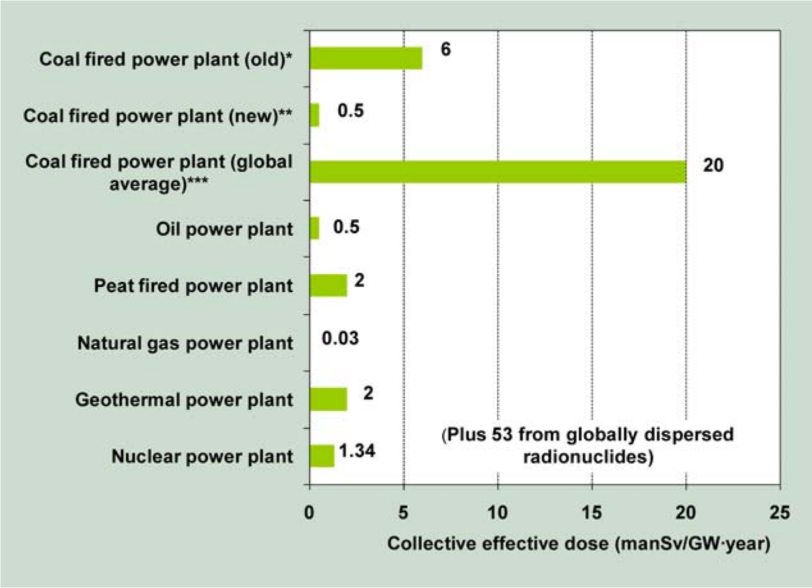


Public exposure to radiation is expected from other industrial activities as well, including power plants fuelled by energy sources other than nuclear. Typically, radiation from industrial activities is not systematically monitored, and the assessment of such exposure is based on sketchy information derived from isolated surveys [62]. Nevertheless, the UNSCEAR attempted comparisons of exposures from different energy production to the general population (in 1993 [62]) and to critical groups (in 2000 [60]). Thorough updates of these comparisons are in preparation.

Figure 20 shows the collective effective dose (i.e. effective dose aggregated over affected population, thus expressed in man-sievert) received by the public per unit electrical energy generated (GW•year), based on technologies evaluated in 1993. Due to improved emission control practices, these estimates are expected to be significantly lower when the updates become available. Only the number for nuclear power is updated and it is revised to 0.43 man-Sv/GW•year from 1.34 man-Sv/GW•year [60]. Nuclear fuel cycle adds 0.48 man-Sv/GW•year to this. Public radiation exposure from coal mining is considered insignificant, in the range of 0.1% to 0.006% of total contribution from coal fired power plants.

There are a number of occupations in which workers are exposed to human-made sources of radiation, including those at nuclear installations and at other fuel cycles. UNSCEAR [60] estimates that the average annual effective dose for workers at nuclear fuel cycle installations (including uranium mining) is 1.8 mSv, with 4.5 mSv for mining, 3.3 mSv for milling, 0.1 mSv for enrichment and conversion, 1.0 mSv for fuel fabrication, 1.4 mSv for reactor operation, 1.5 mSv for fuel reprocessing and 0.8 mSv for research in the nuclear fuel cycle. In comparison, the average annual effective doses for mine workers (excluding coal mining) and the crew in air travel are 2.7 mSv and 3 mSv, respectively. The average annual effective dose for coal miners is 0.7 mSv.

FIG. 20. Collective effective dose received by the public per unit electricity generated, based on technologies evaluated in 1993 [62].



* 90% of fly ash captured

** 99.5% of fly ash captured

*** assuming that one third uses 'old' plants, another one third uses 'new' power plants, and the rest emits 50 man Sv per GW•year

Nuclear plant safety keeps improving

The Chernobyl accident in 1986 was a major setback to nuclear power. Many lives were lost, thousands suffered major health impacts and there were significant environmental and social impacts. The accident was the result of an old reactor design, compounded by gross safety mismanagement. However, this event also prompted major improvements in the approach to nuclear safety [63].

A key change was the development of a so-called international nuclear safety regime. International conventions were put in place, creating legally binding norms to enhance the safety of nuclear activities. The IAEA updated its body of safety standards to reflect best industry practices. And, importantly, both the IAEA and the World Association of Nuclear Operators (WANO) created international networks to conduct peer reviews and exchange operating information to improve safety performance [63]. The outcome is shown in Fig. 21. The industrial safety accident rate shows the number of accidents among employees that result in lost work time, restricted work or fatalities. With less than one accident per one million person-hours worked, the nuclear industry belongs to the safest industrial work environments.

> "The international nuclear safety regime over the years has produced many insights on how to minimize safety risks. But we should not rest on our laurels. It is essential that existing safety standards, operational practices and regulatory oversight be adapted — and in some cases strengthened — to ensure enhanced levels of safety in the future" [63].

In a recent report, it was added:

> "[T]he risk of nuclear accidents or malicious acts can never be eliminated and there can be no room for complacency. Vigilance and continuous improvement are key, both at existing nuclear facilities and at new facilities being planned in a growing number of countries. The drive to introduce, or expand the use of, nuclear power always needs to be matched by a strong commitment to safety and security as indispensable enablers of nuclear technology" [65].

Since the Chernobyl accident, many improvements have been made, and one can point to a substantially improved nuclear safety situation throughout the world, even under extreme conditions.

> "Recent major natural events affected nuclear installations in a number of countries, particularly in Asia, beyond the original design levels. The devastating December 2004 Indian Ocean tsunami and earthquakes in Japan in 2003, 2005 and 2007 and in China in 2008 all resulted in flood, geological and/or vibratory ground hazards of intensities higher than expected by even the most stringently established design basis" [66].

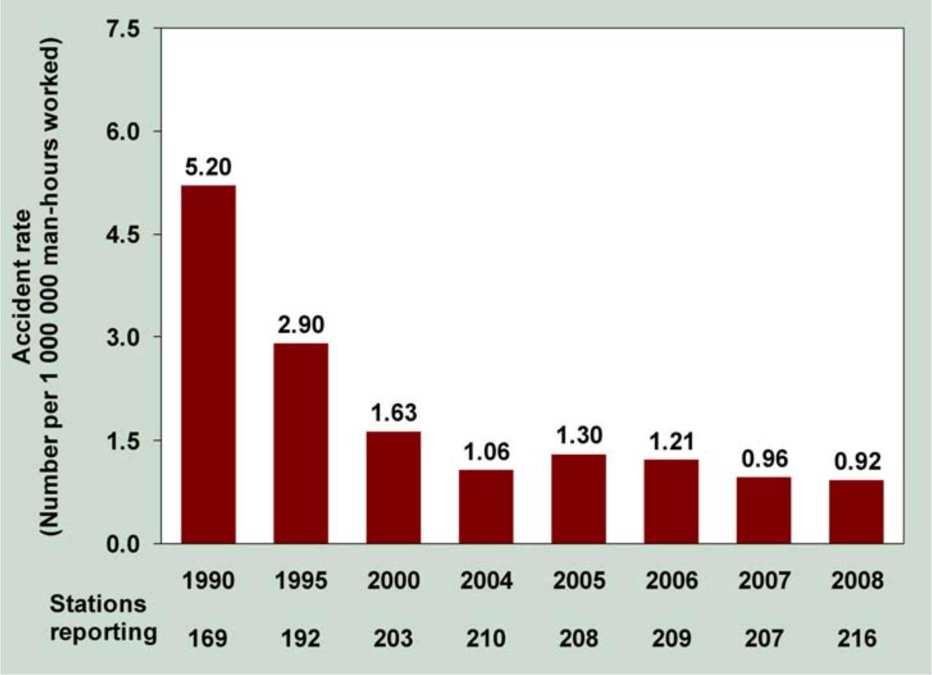
Safety systems at nuclear installations affected by these severe events responded as necessary to protect workers, the public and the environment from undue effects. However, in a few cases, the magnitude of the event was much more severe than previously thought possible or anticipated during the design and construction of affected installations. The re-evaluation of the integrity of existing nuclear installations, taking into account the increased magnitude observed during these events, has begun [67].

Nevertheless, there is a very real possibility that one will become complacent with the high level of performance. Operational safety is one of the most challenging areas that the IAEA deals with [68]. In addition to having to consider sound engineering and technology principles, one must take into account the human and organizational factors that can either contribute to, or detract from, safety. There are also economic, political and social pressures that must be taken into account. The margin for further safety improvement is smaller than in the past, and it is more of a challenge to find and implement continuous improvement. Without sustained safety improvement effort, a decline will occur. Therefore, one needs strong safety leadership, effective safety management and sustained safety culture, especially for those nuclear plants facing extended operations [68].

The third review meeting of the Contracting Parties to the Convention on Nuclear Safety [69] identified the fundamental need for openness and transparency in the nuclear industry. There was also special emphasis put on the need for leadership in nuclear safety from both regulators and operators, and about the need to continue and improve communication between them. For operational safety, probabilistic safety assessment is now a mainstream tool in most countries, although every Contracting Party stressed that it is not used in isolation. More and more countries are now requiring periodic safety reviews as part of their regulatory regimes. Knowledge management continues to be important as experienced staff retire and as facilities move into extended operation. It was also noted that peer reviews, such as those offered by the IAEA and WANO, play an important role in maintaining and improving operational safety. Finally, it was reinforced that the IAEA safety standards have matured and now offer a comprehensive suite of nuclear safety standards that embodies good practices and is a reference point to the high level of safety required for all nuclear activities [68].

The reduction of safety risks and the improvement of safety performance are conditions which begin with strong safety leadership, effective safety management and sustained safety culture [70]. When there is a strong safety culture, maintenance staff excel in the preparation and execution of the tasks in compliance with the safety, quality and technical specifications. The personnel element is crucial for the continuous improvement of safety culture, and this in turn enables each individual to contribute towards achieving the overall goals. Therefore, solid emphasis has been put on the proper education of employees in the past years to reinforce this notion.

FIG. 21. Industrial safety accident rate in the nuclear industry. (Source: Ref. [64].)



Waste management and disposal solutions are progressing

Another persistent concern surrounding nuclear energy is radioactive waste, which can create hazards for humans and the environment for centuries — or millennia. Over the past two decades, major advances have been made towards the safe temporary storage and final disposal of radioactive waste in terms of scientific understanding and technological development.

During the nuclear fission process in the reactor, the fuel becomes intensely radioactive (due to the formation of new radionuclides, known as fission products), which reduces the efficiency of the reactor and must be removed. Spent fuel requires a period of surface storage to reduce its heat output. The temporary storage phase is an important step in the safe management of radioactive waste, since it helps to reduce both radiation and heat generation prior to waste handling and transfer to the final disposal site. In fact, as long as active surveillance and maintenance are ensured, it has been demonstrated over the past decades that interim storage of radioactive waste can be relied upon. Moreover, storage is technically feasible and harmless over a long period of time if monitoring, control and care are properly implemented [71].

The disposal of radioactive waste in geological media is considered to be a safe method for isolating these substances from the hydrosphere, the atmosphere and the biosphere. A crucial but yet unresolved issue is retrievability, that is, whether the option to retrieve wastes from repositories is required and, if so, for how long. On the positive side, it is possible that future generations consider the buried waste to be a valuable resource. On the negative side, permanent closure might increase long term security of the repository. Relevant policies in France, Switzerland, Canada, Japan, the USA and most other countries require retrievability for at least 100 years.

The fundamental principles involved in geological disposal are well understood [72, 73]. Geological repositories are designed to be passively safe. This is ensured by the multibarrier principle, in which long term safety is ensured by the synergy of several engineered and natural barriers. These barriers prevent or reduce the transport of radionuclides in groundwater, which is generally the most important transport mechanism. They also influence the migration of gas, which will arise in radioactive waste repositories from chemical and biochemical reactions and radioactive decay.

In the multibarrier principle, the engineered barrier system (EBS) comprises the solid waste matrix and the various containers and backfills used to immobilize the waste inside the repository. The natural barrier (the geosphere) is principally the rock and groundwater system that isolates the repository and the EBS from the biosphere. The host rock is the part of the natural barrier in which the repository is located. Emplacement of the waste in carefully engineered structures placed at depth in suitable rock is chosen principally for the long term stability that the geological environment provides. At depths of several hundred metres in a tectonically stable environment, processes that could disrupt the repository are so slow that the rock and groundwater systems will remain almost unchanged for hundreds of thousands of years, and possibly longer [74].

Programmes to dispose of spent fuel are well advanced in several countries, aided by political support [75]. Site characterization and selection for deep geological repositories have been underway since the 1970s. The two countries closest to licensing and operation are Finland and Sweden. The general principles and designs of the disposal facilities are similar (see Fig. 22). In Finland, originally six sites were considered between 1987 and 1999. A government decision in 2000 selected the Olkiluoto bedrock where construction of the underground rock characterization facility began in 2004 and will be extended to the final disposal depth of about

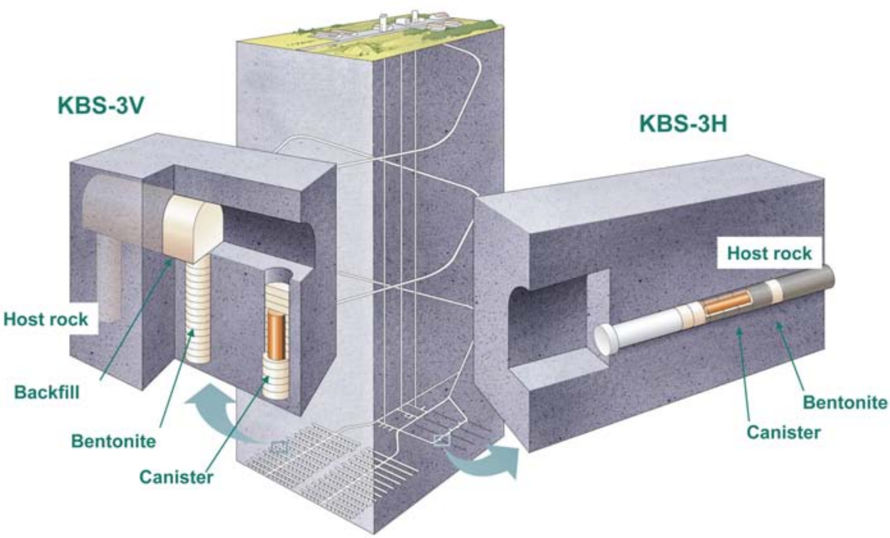
400 metres. Preparing applications for the construction licence in 2012 and the operating licence in 2018 is the next step. Emplacement of waste for final disposal is scheduled to start in 2020 [78].

In Sweden, owners of the nuclear power plants established the Swedish Nuclear Fuel and Waste Management Company (SKB), to jointly manage and dispose of radioactive waste. Feasibility studies of eight potential sites were completed in 2001, followed by site investigations in two municipalities (Östhammar and Oskarshamn) until 2007. In 2009, SKB decided to locate the repository at Östhammar (near Forsmark), due to favourable geological properties. An investment agreement was signed with both volunteer municipalities. Licence application to construct the repository are to be submitted in 2010, site works are scheduled to start in 2013, and disposal operations are to commence in 2023 [78].

Similar site characterization, selection and licensing processes are under way in France and Japan. In the USA, Yucca Mountain in Nevada was selected for a final repository, but this is now put on hold and awaiting a political decision [79]. All these cases demonstrate the long processes (e.g. scientific, political and public participation) of characterizing, analysing and selecting sites. In each case, deep geological disposal of high level waste and used fuel emerges as the best solution.

Storage and disposal are complementary rather than competing activities, and both are needed to ensure safe and reliable nuclear waste management. The timing and duration of these options depend on many factors. Although perpetual interim storage is not feasible because active controls cannot be guaranteed forever, there is no urgency for abandoning it on technological or economic grounds. However, ethical and particularly political reasons require the establishment of final disposal facilities. Such facilities are expected to start operation in 15–20 years and substantially reduce one of the current concerns about nuclear power.

FIG. 22. The KBS-3 disposal concept. (Source: Refs [76, 77].) (Symbols used in the figure are explained as follows: KBS: nuclear fuel safety; H: horizontal; V: vertical.)



Putting proliferation concerns at the forefront

There is still substantial concern that nuclear energy could pave the way for the proliferation of nuclear weapons. The source of such concerns is the possible dual-use of nuclear material, and fears that the establishment of a nuclear energy programme may lead to nuclear weapon building. Apart from this, there are non-State actors that also pose proliferation risks. An IAEA report, The International Status and Prospects of Nuclear Power [80], states that:

> "Though civil nuclear power plants in themselves do not pose an increased proliferation risk, increased nuclear material in use may increase the risk of diversion to non-peaceful uses or terrorism."

Such concerns are justified and considerable efforts are devoted to tackle them.

The non-proliferation regime backed by the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and IAEA safeguards proved successful in limiting the spread of nuclear weapons. The safeguards regime of the IAEA is especially efficient and effective in monitoring and safeguarding nuclear materials and technology from diversion to non-peaceful purposes (Fig. 23):

> "Effective IAEA safeguards remain the cornerstone of the world's nuclear non-proliferation regime aimed at stemming the spread of nuclear weapons and moving towards nuclear disarmament." [81]

As of mid-2009, 167 States have safeguards agreements with the IAEA in force, of which 159 are comprehensive safeguards agreements pursuant to the NPT. The States submit nuclear materials, facilities and activities to the scrutiny of the IAEA's safeguards inspectors.

Every country has the right to utilize nuclear power, as well as the responsibility to do it right. In the past four years, some 60 Member States without nuclear energy programmes have expressed interest in considering the possible introduction of nuclear power and have asked for IAEA support. Twelve

FIG. 23. IAEA monitoring and safeguard facilities: (a) video cameras used for remote monitoring of nuclear sites; and (b) the IAEA Safeguards Analytical Laboratory.

countries are actively preparing to introduce nuclear power. Increased demand for assistance has been particularly strong from developing countries, which seek expert and impartial advice in analysing their energy strategy options and which request help in choosing the best energy mix [82].

Apprehension over the proliferation of nuclear weapons is likely to persist. The wider use of nuclear energy and the spread of nuclear know-how, technology and material may intensify these concerns. There is a worry about the state of health of the nuclear non-proliferation regime, which the IAEA supports through verifying compliance with relevant legal agreements. Fears are intensifying that the regime is seriously threatened and needs to be bolstered in many ways [83].

Spent fuel reprocessing (for extracting plutonium and unspent uranium) and uranium enrichment are the two important stages in the nuclear fuel cycle that can contribute to a weapon building programme. These two key stages in the fuel cycle come under the safeguards regime of the IAEA, which has proven monitoring and accounting standards; this means that there is already an established regime of checks and balances that is capable of detecting the diversion of materials from a power programme [84, 85].

Strengthening further the non-proliferation regime has been proposed by bringing all reprocessing and enrichment under multinational control, avoiding the use of materials in nuclear energy systems that may be applied directly to making nuclear weapons, and considering multinational approaches to the management and disposal of spent fuel and radioactive waste [86].

In the medium term, projects such as the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) and the Generation IV International Forum (GIF) aim to develop more efficient nuclear power systems with proliferation resistance among the development criteria. INPRO intends to develop innovative nuclear power systems by bringing together technology holders and users under the auspices of the IAEA [87]. GIF is pursuing the development of advanced nuclear energy systems with increased safety, improved economics for electricity production and new products, such as hydrogen for transport applications, reduced nuclear waste for disposal and increased proliferation resistance [88].

FIG. 23. (cont.)

Increasingly favourable public acceptance

Factors affecting the public acceptance of any technology, including energy technologies, are classified into two categories: (a) technology specific (technical features, benefits, costs, human health risks, environmental impacts and other characteristics of the given technology); and (b) the socioeconomic context in which the given technology is considered or used. Shifts in both types of factors have affected the evolution of public acceptance of nuclear power in recent years.

Among the technology specific factors, historical and accumulated experience (safe operation of power plants and other nuclear installations) has led to improving public acceptance in most countries. In the broader socioeconomic context, three factors have contributed to a reviving interest in nuclear energy: reducing GHG emissions; enhancing energy supply security; and improving price stability. These factors have contributed to an improved social acceptance of nuclear power.

An assessment of public acceptance of nuclear energy is usually based on public opinion surveys. Results of such surveys should be handled with care, particularly when trying to compare them over time and across countries. The reason is that surveys often differ in scope, coverage, methods and other important aspects. The key determinant of the outcome of such surveys is how the questions are framed and phrased.

Figure 24 presents recent trends or snapshots of public acceptance of nuclear energy in countries already using nuclear power and those without it — of which, some are seriously considering (re-)introducing it. Since the number and content of response options vary across surveys, a simple normalization procedure was developed to portray all survey results by a Public Acceptance Index (PAI) on a scale from 0 (complete rejection) to 100 (complete approval).

Among the nine countries depicted in Fig. 24(a), public acceptance of nuclear power has been improving in most countries. The two exceptions are Spain and Germany (both phase-out countries) with sharp downturns in 2008. In contrast, the steady 60+ PAI in Sweden in recent years may have contributed to a reversal in the phase out. In Fig. 24(b), in the three countries that seriously consider adopting nuclear energy (Egypt, Indonesia and Thailand), public acceptance appears to be positive with PAIs slightly or significantly above the 50% mark.

An increasing number of surveys explore how the potential contribution to mitigating climate change affects the public acceptance of nuclear energy. Results from a few recent surveys are presented in Fig. 25. Formulations of both the initial question (i.e. 'Do you accept/agree with using nuclear energy?') and the climate change question (i.e. about the perceived benefits of nuclear power to combat global warming) differ across countries and surveys. Yet the climate change benefit of nuclear power seems to be known and appreciated by much larger shares of respondents in each country than the acceptance rates of nuclear power in general. The difference is around 25 percentage points in 'EU-15' (the 15 EU Member States as of 1993), 'EU-27' (the 27 EU Member States as of 2009) and Germany, and reaches 30 percentage points in Poland.

Nevertheless, the most useful information provided by such in-depth surveys is for designing public information campaigns that respond to the concerns and ignorance of people so that they can make an informed judgment in the subsequent and unavoidable social debates about nuclear energy. Informing the public is the first crucial step in the decision making process that needs to involve all stakeholder groups.

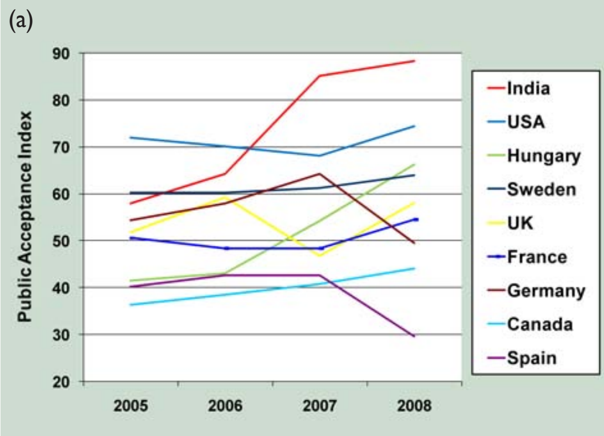


FIG. 24. Public acceptance of nuclear power: (a) countries with operating power plants.

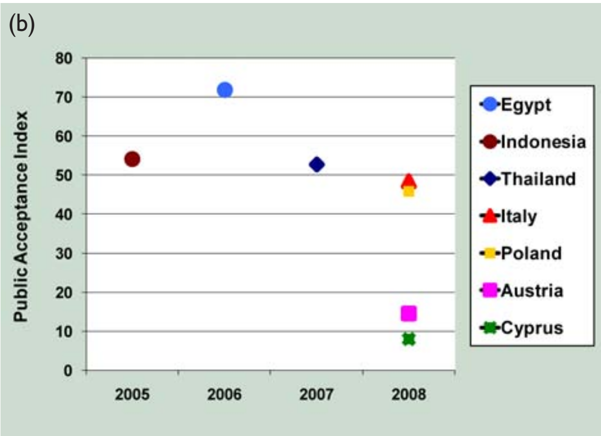


FIG. 24. Public acceptance of nuclear power: (b) countries without operating power plants. (Source: Ref. [89].)

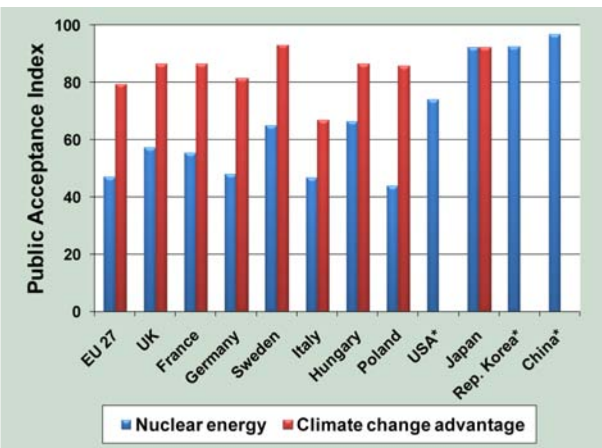


FIG. 25. Public acceptance of nuclear power in relation to climate change. (Source: Ref. [90].)

Note: The asterisk denotes surveys without comparable questions on climate change advantages. USA: in the same survey, 37% of the respondents associated nuclear energy with climate change 'a lot', 37% 'a little' and 24% 'not at all'. In the Republic of Korea (ROK) survey, for the question about why nuclear energy is needed, respondents ranked climate change fourth place after increasing electricity demand, replacing liquefied natural gas and economic efficiency. The Chinese study did not include the climate change question.

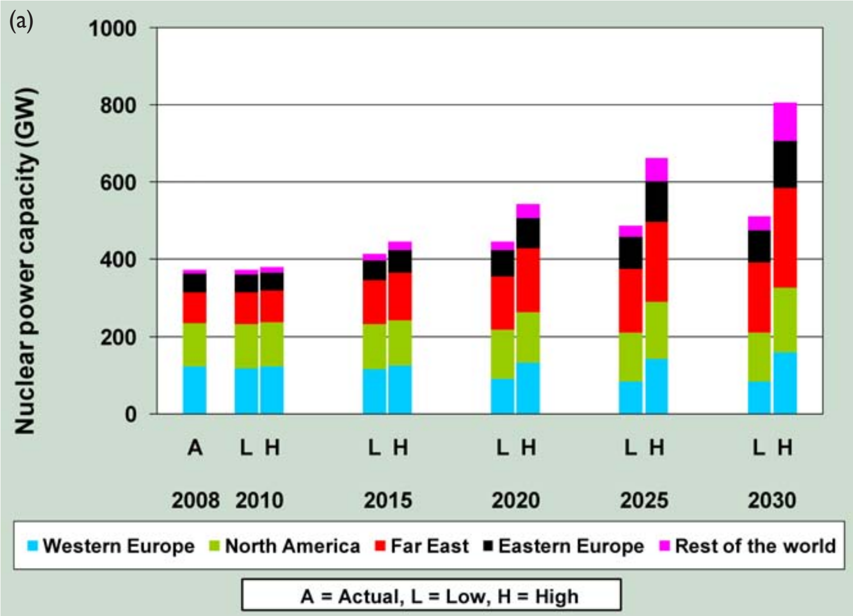
Projections reflect rising expectations worldwide

The IAEA has published the annual Energy, Electricity and Nuclear Power Estimates since 1981. This report focuses on the actual status and future estimates of energy use, electricity production and nuclear power generation in all regions of the world for the near to medium term. The underlying overall energy projections reconcile recent global and regional projections made by national and international energy organizations, development indicators published by the World Bank and national projections for many countries. Nuclear energy projections also draw on data in the IAEA's Power Reactor Information System (PRIS) [91]. The estimates are prepared in close collaboration and consultation with several international, regional and national organizations, as well as with international experts dealing with energy related statistics and projections.

The 2009 projections are based on the following: (1) national projections supplied by each country for a recent OECD/NEA study; (2) indicators of development published by the World Bank in its World Development Indicators; (3) estimates of energy, electricity and nuclear power growth continuously carried out by the IAEA in the wake of recent global and regional projections made by other international organizations.

The nuclear generating capacity estimates are derived from a country by country bottom-up approach. They are established by a group of experts and based upon a review of nuclear power projects and programmes in Member States. The low and high estimates reflect contrasting but not extreme assumptions on the different driving factors of nuclear power deployment. These factors, and the ways they might evolve, vary from country to country. The estimates provide a plausible range of nuclear capacity growth by region and worldwide. They are not intended to be predictive nor to reflect the whole range of possible futures from the lowest to the highest feasible.

FIG. 26. Prospects for nuclear power in major world regions: (a) estimates of installed nuclear capacities; (b) estimates of nuclear electricity generation. (Source: Ref. [92].)



The low case represents expectations about the future if current trends were to continue and there were few changes in policies affecting nuclear power other than those already in the pipeline. This case was explicitly designed to produce a 'conservative but plausible' set of projections. Additionally, the low case did not automatically assume that targets for nuclear power growth in a particular country would necessarily be achieved. These assumptions are relaxed in the high case.

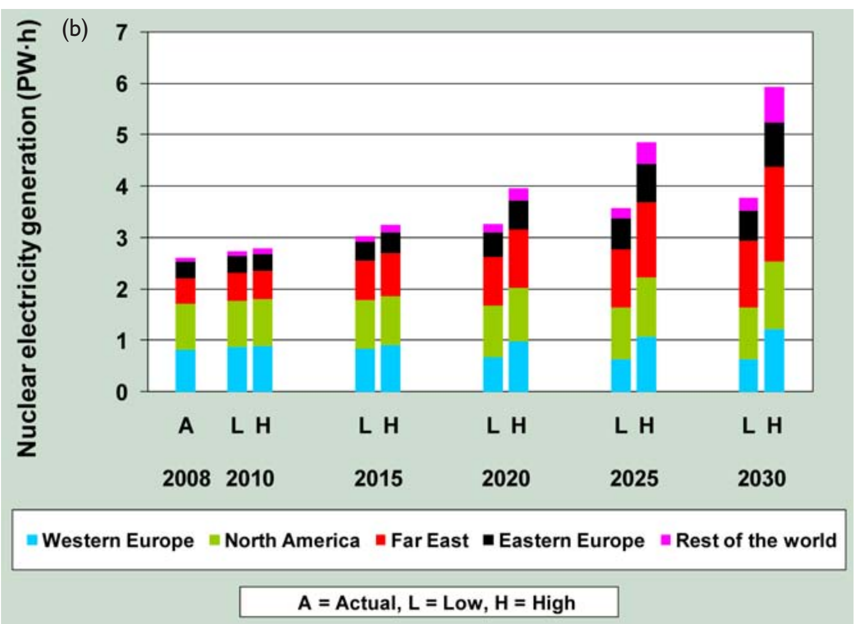
The high case projections are much more optimistic, but still plausible and technically feasible. The high case assumes that the current financial and economic crises will be overcome in the not so distant future and past rates of economic growth and electricity demand, especially in the Far East (including China, Japan and the Republic of Korea), would essentially resume. In addition, the high case assumes the implementation of policies targeted at mitigating climate change.

Figure 26 presents the most recent IAEA estimates [92] of the global nuclear generation capacities (Fig. 26(a)) and the electricity output (Fig. 26(b)) from the corresponding reactor fleet up to 2030. The projections show that the fastest growth rate of nuclear capacities will be in Asia and are a major factor in shaping global nuclear energy prospects.

There are, however, some open questions concerning the estimates, including whether the high economic growth rates in large developing countries will continue; how long the high fossil fuel prices will persist; what the architecture and flexibility mechanisms of the post-Kyoto regime will be; whether the industry will be able to deliver new reactors on time and on budget; whether public acceptance will continue to improve.

Balancing the general and region specific issues, and the high/low projections, nuclear power capacities in the future could exceed the high estimates if positive factors strengthen each other. Alternatively, they could stay below the low projection if some negative factors coalesce (e.g. collapse of fossil prices, as in the 1980s, poor construction performance or an accident).

FIG. 26. (cont.)



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National perspectives on climate change and nuclear power

This Annex[1] provides short summaries of how the relationship between climate change and nuclear power are perceived by various stakeholder groups in different countries.[2] The emerging picture concerning the contexts and perspectives in which these countries look at the climate–nuclear nexus is diverse.

Brazil is a non-Annex I party to the United Nations Framework Convention on Climate Change (UFCCC) and has no legal obligations to reduce its GHG emissions. Its electricity sector emits a very small amount of CO_2 per kW•h generated. Yet climate change is emerging as an important issue because the changing hydrological regime makes hydropower a less dependable source of electricity and a higher share of nuclear power in the generation mix might be required in a few decades to guarantee the security of electricity supply.

China still has very fast growth rates in demand, for energy in general, and for electricity in particular. Climate change considerations are emerging, especially with a view to the UNFCCC negotiations in Copenhagen, but the recent rounds of upward revisions of nuclear energy expansion are also prompted by the limits of further fast expansion of coal based generation due to constraints in mining and transport infrastructure.

Italy shut down its nuclear generation abruptly after the Chernobyl accident but was contemplating a fresh start for years until legislation opening the possibility for building new nuclear plants was passed in 2009.

In *Japan*, nuclear power has been and will remain a solid constant in the power sector, helping the country move towards a low carbon society.

Fears of depleting cheap domestic fossil sources and high global energy prices and considerations to reduce CO_2 emissions in the power sector lead to deliberations about introducing nuclear power in *Malaysia*.

Electricity demand is growing fast in *Thailand* as well, and it is mostly generated from fossil fuels, hence the intense political and public discussions about adopting nuclear energy in a decade or so.

In the *United Kingdom* and the *USA*, climate change mitigation is coupled with supply security concerns in recent government policies to boost the contribution of nuclear power to the national electricity generation mix.

Interestingly, the importance of permitting the use of nuclear energy projects and the recognition of the ensuing Certified Emission Reductions (CERs) in international mitigation activities under the new UNFCCC post-2012 Protocol (unlike in the Clean Development Mechanism and Joint Implementation in the current Kyoto regime) is raised and discussed in both potential host and investor countries, according to this small sample of eight countries.

[1] The views expressed in this annex do not represent those of the authors' organizations, the IAEA or its Member States.

[2] The contributions in this Annex are abridged and slightly edited versions of short essays prepared by R. Schaeffer and A.S. Szklo (Brazil), D. Liu and S. Zhang (China), M. Tavoni (Italy), K. Nagano (Japan), Sabar Md Hashim (Malaysia), N. Damrongchai (Thailand), M. Grimston (United Kingdom) and C.D. Ferguson (USA).

Climate change and nuclear power in Brazil: An unexpected link

A possible link between climate change and nuclear power in Brazil seems to arise from a rather unexpected direction: adaptation rather than climate change mitigation. Recent studies assessed the vulnerability of the energy system to climate change in Brazil (Lucena et al. [A–1, A–2, A–3]). They show that, because the availability and reliability of renewable sources very much depend on climatic conditions — which can vary due to global climate change (GCC) — and because of the country's heavy reliance on renewable sources, particularly hydropower, Brazil seems to be highly vulnerable to climate change. This vulnerability mainly results from reduced hydroelectricity production, but also from increased electricity demand due to an adaptation to higher temperatures.

These studies have focused on the impacts of GCC on the Brazilian energy sector, including hydropower production, natural gas fired thermoelectric production, wind power potential and electricity demand. The operation of the Brazilian hydropower system was simulated for the 2025–2100 time series of water flow at each plant, derived from the climatic simulations for temperature and precipitation. Results of the aggregate projected impacts show that the firm power of the country's hydroelectric generation system would fall by about 30% by 2035 [A–3]. Increasing temperatures may also affect the demand for electricity because of higher use and lower efficiency of air conditioning. Due solely to the higher temperatures projected for 2035, electricity demand of the residential and service sector is estimated to increase by 6% and 5%, respectively, in the worst case scenario compared to a scenario without GCC [A–1].

The most relevant impact is the decline in hydroelectric reliability. In planning the expansion of the electric system, the reliability of a source is of extreme importance. A hydroelectric based system must be dimensioned (or complemented by other sources) to guarantee supply in the worst hydrological condition. Therefore, firm power is a very relevant variable in Brazil.

The studies mentioned also estimate the extra capacity that would have to be installed by 2035 to prevent system failure due to the projected lack of reliability of hydroelectricity and other considered impacts. The Brazilian power system would have to be dimensioned to generate additional 150–160 TW•h/year by 2035, just to cover the 30% loss in firm power from hydroelectricity due to GCC [A–3]. The additional sources include natural gas fired power plants, higher efficiency sugarcane bagasse burning technologies, wind power, nuclear (some 6.1 GW of extra capacity by 2035 in the worst GCC scenario) and coal. The required capital investments amount to about $50 billion by 2035, representing almost the equivalent of 10 years of capital expenditures in expanding the country's power generation system, according to Brazil's long term energy plan [A–4], while the variable operational and fuel costs would depend on the extent to which the hydrological scenario approaches the worst case scenario.

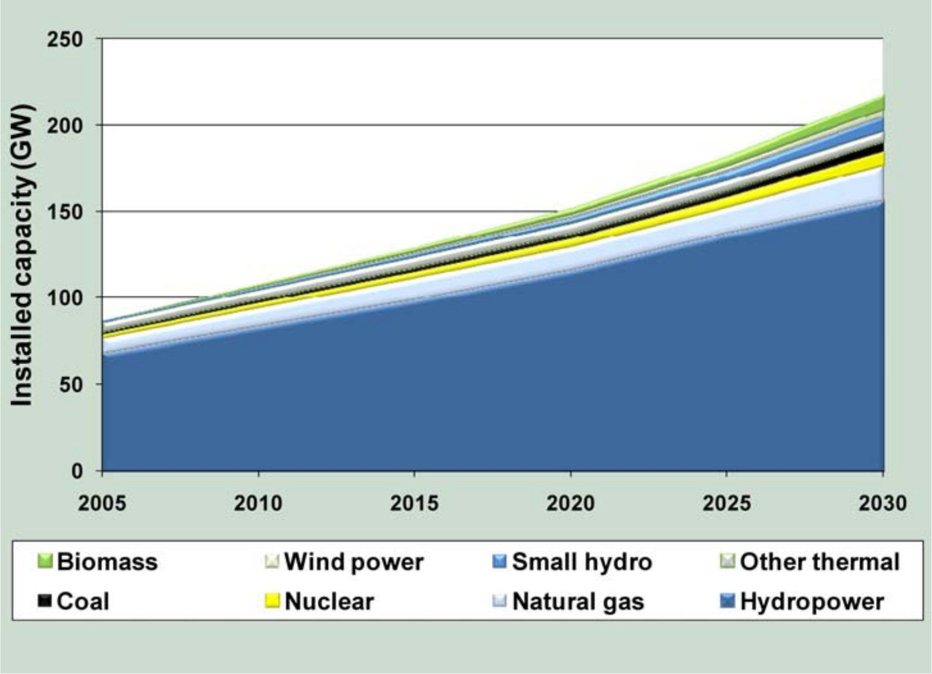
The Brazilian energy sector relies heavily on renewable energy sources with a 45% share in the total primary energy supply. In the power sector, hydroelectricity accounted for 80%, with natural gas (7%), biomass (5%), oil (3%), nuclear (3%) and coal (2%) power plants providing the rest in 2008 [A–5]. Bioenergy is becoming increasingly important, and wind power potential is also significant.

Nuclear energy is of relatively low importance in Brazil, with an installed capacity of 2000 MW compared to the country's total installed capacity of 104 000 MW as of July 2009. The deployment of this technology started in 1971 (commercial operation commenced in 1985) and its role is likely to increase in the future. A second unit was connected to the grid in 2000. The construction of a third plant was suspended for more than two decades but after a long debate, a decision was finally taken by the Government in 2009 in favour of its completion. The reference scenario in the most recent official long term energy plan includes 5345 MW additional nuclear capacity by 2030 [A–4], still a small fraction of the forecast total generation capacity, as shown in Fig. A–1. A related goal is to produce domestically 100% of the fuel needed for the country's nuclear reactors by 2014.

In October 2008, the Brazilian Government announced plans to invest $212 billion to increase the total nuclear power capacity to 60 000 MW over the next 50 years. This fact indicates the will of the current Government to promote the wider use of nuclear and to give priority to the resumption of the country's nuclear programme. However, most Brazilian experts doubt that this target is achievable or even represents a real official plan [A–6]. Nevertheless, none of these new plans have ever been related to domestic efforts to mitigate carbon emissions (which have been mostly concentrated on curbing deforestation in the Amazon region), but with strategic and technological aspects related to the full domain of the nuclear technology, plus environmental problems related to licensing new hydroelectric plants, that also leads to a higher reliance on fossil fuels (natural gas, oil and coal).

In sum, although nuclear energy may be in a process of revival in Brazil, the reasons for that revival have not, so far, been directly linked to climate change mitigation concerns. Indirectly, however, because of the likely vulnerability of the country's power sector to climate change itself, nuclear energy may be seen by some, in the future, as a technological path to be further pursued in Brazil not for mitigating the relatively low carbon emissions from energy use in the country, but as part of a broader adaptation strategy to climate change.

FIG. A–1. Forecast installed electricity generation capacity in Brazil's official long term energy plan (in GW) [A–4].



Nuclear power development and its nexus with climate change in China

China and other developing countries agreed to take appropriate mitigation actions along with the Bali roadmap. This shows that no matter what climate regime the international community achieves, China's domestic mitigation actions will be put on the agenda [A–7]. Developing nuclear power will be one of the most important actions to combat climate change, as expressed in the National Climate Change Programme [A–8] and other official documents. It is emphasized that all measures and actions in response to climate change (mitigation and adaptation) are integrated in the national sustainable development strategies.

In 2009, the National Development and Reform Commission (NDRC) of China issued the official file, China's Position on the Copenhagen Climate Change Conference [A–9]. It states that economic growth, poverty eradication and climate protection should be considered in a holistic and integrated manner so as to reach a win-win solution and to assist developing countries to secure their right to development. In this context, decisions about nuclear power will be made by considering many other factors, such as the current domestic situation concerning energy security, energy mix diversification, energy related heavy transport and environmental pollution. The development of nuclear power in China will accelerate continuously, which will certainly contribute to the mitigation of climate change.

Nuclear power plants are technology intensive and characterized by large upfront capital costs, and a long construction time and payback period, which means huge investment risk and need for capacity building and technology collaboration and transfer. Technology development and transfer from developed to developing countries is always a hot topic in climate negotiations. If institutional arrangements, financial and technology transfer mechanisms, and assessment and monitoring can be established for the post-2012 regime, it will be good news for nuclear power development in China, because nuclear energy could be incorporated into the global efforts to combat climate change in the form of an innovative Clean Development Mechanism (CDM) as described in the following discussion.

Despite the global economic recession, nuclear power development in China does not seem to slow down relative to the acceleration in the 11th Five-year Plan. The actual scale of nuclear power planning in China is expected to exceed the original plan set in 2007, i.e. 40 GW in operation and 18 GW under construction in 2020. The targets for 2020 might be revised to 60, 70 or even 84 GW, according to various sources. The latest news from the National Energy Administration of China [A–10] is that the plan for 2020 will be adjusted to make nuclear power about 5% of the generation mix, but the new capacity objective is not determined yet by the State Council. The total capacity of the nuclear power projects, including those under construction and approved by the NDRC, is already more than 47 GW, all of which is expected to generate electricity by 2015. In 2008, pre-project works in three inland provinces (Hunan, Hubei and Jiangxi) were approved by NDRC, which means that the nuclear power distribution in China has expanded from coastal to inland regions. The provinces, including Sichuan, Henan and Gansu have proposals to develop nuclear power, and the number of proposed nuclear power plant units is over 100 beyond those mentioned.

Nuclear power can realize its potential for reducing CO_2 emissions only if it is safe and economically acceptable. With the increasing number of nuclear power units, risk management will be a key factor for shaping the nuclear future, including safe operation, spent fuel and nuclear proliferation. The efforts to internalize the environmental costs of fossil fuel use (via energy or emission tax) also will improve the economics and stimulate the expansion of nuclear in the long term in China. The possible binding agreements for CO_2 mitigation will improve the competitiveness of nuclear power plants compared to other generation sources.

Currently Annex-I Parties refrain from using nuclear facilities in the CDM. However, nuclear power is a vital technology to achieve the long term global GHGs reduction target of at least 50% by 2050, especially by using proven new generation technology with inherent safety. Therefore, diffusion of these technologies should be promoted by making them eligible under flexibility mechanisms, such as the CDM. Meanwhile, it is necessary to ensure the safety, reliability and environmental integrity of these projects.

Innovative nuclear CDMs might involve some of the following elements:

(1) A nuclear specific institutional arrangement, methodological approach, project approval and monitoring, as well as Certified Emission Reductions (CERs) issuance procedures shall be established and adopted under the UNFCCC for nuclear CDM projects.
(2) Project participation requirements: Party of Kyoto Protocol and Member Party of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT).
(3) Given the large scale and nuclear nature of the project category, the baseline methodology and additionality, project leakage emissions, on-site monitoring and CER calculation should be defined appropriately:

    (i) Baseline may not be project based, but could be technology based instead.
    (ii) Existing nuclear power in developing countries does not mean that it is financially competitive and common practice in the electricity market, but shows that it is really restricted by technology and financing availability, even with governmental and social support. In this sense, nuclear power as a whole is really additional under CDM. Additionality for nuclear power projects should not be demonstrated on a project by project basis.
    (iii) The contribution of nuclear power to climate change mitigation may be attributed mainly to its future development under the nuclear CDM regime, if applicable, regardless of how it would have been planned by the host countries (additionality).
    (iv) Considering energy consumed in the nuclear fuel treatment process, the upstream and downstream leakage emissions might be taken into account fairly by using default values, if applicable.
    (v) On-site validation and verification should be implemented under the bilateral agreement signed between the Designated Operational Entity and the host project owner, in line with the rules and guidelines set out by the CDM Executive Board.
    (vi) An alternative and conservative approach may be applied to determine the CERs from nuclear CDM project activity, by which the monitored CO_2 emission reductions would be discounted by multiplying a percentage factor which reflects the historical baseline share of nuclear electricity in the whole electricity generation mix of the host country.

(4) Politically, the extent to which nuclear power is involved in the future CDM regime will be a critical issue closely linked with the outcome of the UNFCCC negotiations about the post-2012 regime.

Will climate policies foster a revival of nuclear power generation in Italy?

In a recent survey of European attitudes towards climate change, 40% of Italians put it on the top of the list of problems facing the world [A–11]. This value is below the European average (50%) but demonstrates how important the global warming challenge is perceived to be. Indeed, in the same report, 68% of Italians say they feel this is a very serious problem. The position of the Government has been rather ambiguous: threatening to veto the adoption of the European Union climate targets in 2008, but in 2009 hosting the G8 Summit where developed countries agreed to keep the global temperature increase below 2°C.

The Italian electricity sector is characterized by rather strong imbalances (see Fig. A–2). Natural gas and oil make up for about 60% of total power generation, well above the European average of 25%, to compensate for the low contribution of coal and the absence of nuclear. Hydroelectric and geothermal sources play an important role as well [A–12]. Due to the low diversification and heavy reliance on imported fuels, Italy has among the highest prices of electricity in the world, with an average residential price 40% higher than in the European Union. In addition, Italy relies heavily on fossil imports for non-electric energy consumption.

These structural weaknesses in the energy supply are somewhat compensated by the low national energy intensity of the economy, characterized by a relatively high efficiency and a small share of energy intensive industries. Energy and electricity demand has been increasing at 1.3% and 2.1% per year, respectively, in the period 2000–2005. GHG emissions have also been growing and are now roughly 11% higher than in 1990, although the Kyoto Protocol requires Italy to reduce its GHG emissions by 6.5% compared to 1990 levels by 2012, and further emission cuts are envisaged under the European Union climate objectives for 2020.

In the context of volatile energy prices, concerns over energy security and impending climate change mitigation policies, Italy faces a challenge and an opportunity to restructure its energy sector to make it more efficient, less dependent on imports and less carbon intensive. Various demand and supply side options might help meeting such criteria, and nuclear power generation is certainly among the possible candidates.

Italy banned nuclear power as a result of a referendum in 1987, shortly after the Chernobyl accident, incurring a severe economic penalty. However, the high fossil fuel prices of recent years and the new concerns over the adverse consequences of global warming have somewhat modified the public perception about nuclear electricity. In recent polls, Italians seem to be more favourable to its reintroduction, although preferences hardly score above 50% and are lower for hosting a plant in one's own region [A–13].

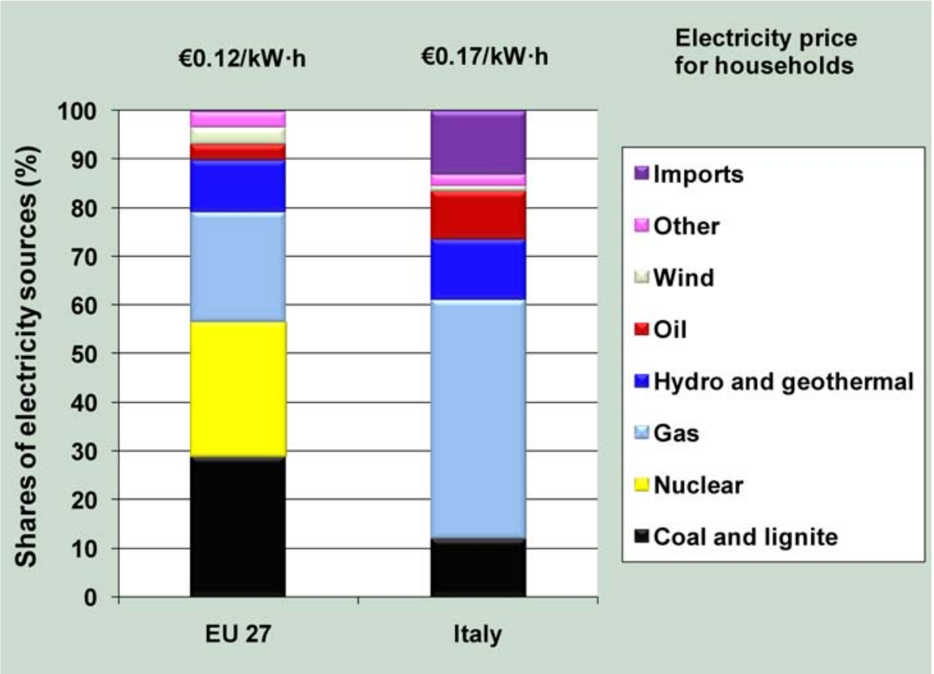
The incumbent Government has prioritized nuclear in its energy plans, with a stated long term goal of 25% in the electricity generation mix. This would require the deployment of up to 10 reactors over the next 20 years. Legislation was time consuming due to concerns over the budget coverage and the proposed government control over the to-be-created safety and regulatory agency. The bill approved in July 2009 is meant to ensure the simplification of the licensing process, the definition of local economic compensation, site characteristics, etc. Within six months, the Government is required to define the rules for site selection and waste management.

Such a provision is expected to facilitate the investments in the sector, but the final word is obviously left to the manufacturers and investors. The national industrial capacity, though weakened by the ban, can still count on a series of actors, such as Ansaldo Nucleare for engineering, Mangiarotti Nuclear for the manufacturing, SOGIN for decommissioning, Nucleco for waste management and ENEL for power generation. ENEL, through acquisitions in Spain and Eastern Europe, now generates 10% of its electricity from nuclear plants and participates in the construction of the Flamanville 3 reactor to acquire skills in the European Pressurized Reactor technology. However, ENEL's top executive recently stated that its company's commitment to build four reactors in Italy is conditional on having a guaranteed minimum sale price of electricity [A–14].

Concerning the role of climate change policies, several considerations emerge. The nuclear revival cannot help meeting the 2012 reduction targets of 100 Mt CO_2-eq. and chances of a significant deployment by 2020 are slim. The carbon intensity of the electricity sector is already quite low, thus the replacement of existing plants with nuclear ones would require a significant carbon price to be viable. Nuclear would also need to compete with renewables and natural gas. Without public support, investors might not embark upon the sizeable investments needed for a sufficiently large nuclear programme.

Looking beyond 2020 provides a rosier picture for nuclear energy. The European Union has committed itself to the long term objective of climate stabilization, so more stringent climate policies will probably follow. Italy's extremely high dependency on energy imports will be exacerbated in the likely case that fossil fuel prices rise. In addition, the possibility to electrify the transport sector and a greater role in the residential final use could lead electricity to grow significantly more rapidly than anticipated. Against this background, the nuclear option might eventually become a decisively attractive option. The next few years will be crucial in preparing a nuclear revival, but might disappoint those who expect a rapid turnaround in the way electricity is generated in Italy.

FIG. A–2. Net electricity generation mix and imports in 2007. The figures on top of the bars show the electricity prices charged to medium size households for the same year. (Source of data: Eurostat.)



ITALY

Climate change and nuclear energy in Japan

Climate change is recognized as an important policy issue in Japan with some notably distinctive psychological motives shared by the public. Extraordinary weather phenomena observed all over the country in recent years, such as sporadic heavy rainfalls causing unexpected, and occasionally fatal, flooding or later and lesser drift ice from the Sea of Okhotsk, have steadily raised fears about global climatic change as their cause. Moreover, the Japanese public has been proud of being the leading country in the field of environment friendly technology development as well as preservation of natural beauties, which naturally leads to the wish that Japan should maintain the leading position in international climate policy negotiation, symbolized by the Kyoto Protocol to the UNFCCC with the name of its ancient capital city, the venue of COP-3 in 1997.

The former Japanese Prime Minister, Taro Aso, declared in a press conference on 10 June 2009, that Japan's medium term target of carbon emission is "a 15% reduction from the 2005 level" by 2020 [A–15]. The target is an outcome of a nationwide discussion in which an advisory committee appointed directly by former Prime Minister Aso presented six GHG emissions pathways ranging from 4% to 30% reduction relative to the 2005 level, as shown in Fig. A–3. Public comments on the six options were polarized: the majority, including the industrial sectors, argued for the least stringent reduction (4% from 2005 level); while environmental NGOs argued for the most aggressive emission cut (30% from 2005 level). The Prime Minister's Office also conducted a special public opinion poll, in which about half of the responses supported the middle course (14% from 2005 level). The final decision is close to this poll result (15% from 2005 level). Its main drivers include a vigorous introduction of renewable energy sources, drastic measures in transport (including hybrid cars) and buildings (energy efficiency standards). The long term indicative target is 60–80% reduction by 2050 as a pursuit for a 'low carbon society'.

Contrary to these ambitious target settings, actual GHG emissions in Japan in Fiscal Year (FY) 2007 reached 1.374 Gt CO_2-eq., a 2.4% increase from the previous year. This increase was largely due to the temporary shutdown of all seven units of the Kashiwazaki-Kariwa Nuclear Power Station (8.212 GW, 17% of the total Japanese nuclear reactor fleet of 49.47 GW) for inspection after a major earthquake in July 2007. This resulted in an average availability factor of 60.7%. If the factor had been as high as 84.2% recorded in FY1998, the emission level of FY2007 would have been only 0.6% above FY2006 [A–16]. This clearly illustrates the importance of nuclear power in significantly reducing national GHG emissions. After thorough and extensive efforts, Unit 7 was officially admitted for restart in July 2009, followed by Unit 6 in August 2009.

As for the medium and long term energy supply and demand profile for Japan, the Steering Committee for Energy Policy published an outlook up to the year 2030 [A–17]. In the three cases analysed, nuclear power contribution was assumed uniformly to expand by nine reactor units to reach a total capacity of 61.5 GW, generating some 440 TW•h in 2030. This study implies that Japan should first ensure the stable operation of existing nuclear capacities, including the restart of all seven units of Kashiwazaki, smooth retirement and replacement of aged units, and further additions to reach the capacity targets in the outlook. Only after accomplishing all of these can any larger contribution of nuclear power be considered.

The Ministry of Economy, Trade and Industry (METI), the competent authority to promote energy policy, published the results of an Advisory Committee's discussion in Policy Enhancement Measures for Nuclear Power Promotion, in June 2009. The basic philosophy is clearly stated in the preamble:

> "Nuclear power is a quasi-domestic energy source superior in supply stability and economics. … Without promoting

nuclear power, it will be virtually impossible to ensure stable energy supply or to address global environmental issues." [A–18]

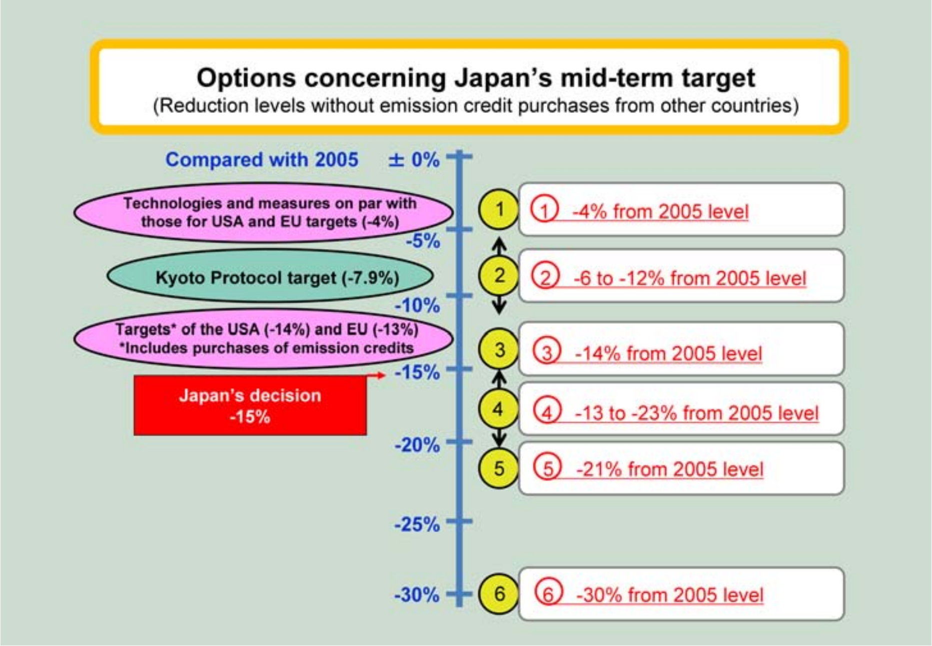
The Advisory Committee also produced a separate report focusing on the importance of international cooperation, which maintains:

"[I]ntroduction and expansion of nuclear power generation, which does not emit CO_2 during its generation process, lead to abatement and reduction of global GHG, including CO_2, emissions due to growing energy consumption. Thus, contribution to introducing and expanding nuclear power means a contribution to the global environment." [A–19]

Experts and leaders have been arguing about the eligibility of nuclear energy related projects in the Kyoto flexibility mechanisms, namely, the Clean Development Mechanism (CDM). Responding to the call from the Japanese Atomic Energy Commission, the Forum for Nuclear Cooperation in Asia (FNCA) decided at its 10th Coordinator Meeting in March 2009 that its member States interested in introducing nuclear power generation would conduct quantitative case studies to assess the economic merits, certified emission reductions of greenhouse gases, etc. of nuclear power projects, in order to support the inclusion of nuclear energy as CDM in the agenda of COP15 [A–20]. Seven countries agreed to carry out case studies.

In summary, it appears from these policy debates and documents that nuclear power does and will serve as the pillar of low carbon energy supply in Japan. While such political will is firm, there still remain issues and problems ahead, to maintain existing generating stocks, smooth retirement and replacement, and new installation. By solving these one by one, Japan intends to ensure its medium and long term emission reduction targets, and further the global society through active international cooperation in the area of nuclear power development.

FIG. A–3. The six options and the decision for Japan's mid-term (2020) GHG emission reduction targets [A–15].



JAPAN

Mitigating climate change: Malaysia's national perspective amid growing nuclear energy appeal

Malaysia has become increasingly concerned about the possible impacts of climate change. It experienced an unusually large flood in Johore in 2006, and other weather anomalies over the past few years. Hence, there are concerns about its possibly increasing vulnerability to extreme climate events, such as typhoons, droughts and floods. Mean annual temperature in Southeast Asia has increased by 0.1–0.3°C per decade over the last 50 years. Malaysia's national projections show that by 2050, the country is going to be hotter with a mean annual temperature rise of up to 1.5°C. More extreme precipitation patterns are also expected: intense rainfall in the wet period and a lack of rainfall in the dry period, leading to higher high flows with more severe floods, and lower low flows causing longer droughts. The expected sea level rise of 15–95 cm over a 100 year period is a concern in coastal areas [A–21].

As a non-Annex-I State Party to the UNFCCC, Malaysia is not bound by specific targets for GHG emissions. Yet the country is committed under the UNFCCC to shape national strategies which mitigate climate change. (Negotiations about crediting mechanisms for Nationally Appropriate Mitigation Actions by Non-Annex-I countries are under way.) Climate change mitigation and management is addressed by the Prime Minister's Cabinet Committee on Climate Change to encourage action on climate change across ministries. Sustainable utilization of energy is being given increasing attention and policies also aim to ensure affordability and energy security. The country plans to depart completely from subsidies, as they have hampered efficiency improvements throughout the energy system.

Malaysia's total CO_2 emission was 177.5 Mt in 2004 (which more than triples the 1990 total of 55.3 Mt). In the electricity sector, coal takes up approximately 29% of the generation mix with natural gas and hydro accounting for 64% and 7%, respectively (overall CO_2 intensity is about 500 g CO_2/kW•h).

Looking at the horizon of 2030, final energy demand from 2005 to 2030 is projected to grow at an average rate of 3.1%/year. Historically, 1% increase in gross domestic product (GDP) has been accompanied by 1.2–1.5% growth in energy demand (and associated GHG emission). Based on energy forecasts, the national electricity generation is expected to grow to around 158 TW•h by 2020 and 184 TW•h by 2025, compared to only 104 TW•h in 2006. In terms of emissions, the power sector shall account for almost 50% of it, while the transport and industry sectors contribute 28% and 20%, respectively (see Fig. A–4) [A–22].

Malaysia aspires to become a developed country by 2020. Energy is part of wealth creation as it creates jobs, allows cross-industry development and yields multiskilled workers with a rich knowledge base. Malaysia has been identifying options to diversify its energy sources so that it would not be too dependent on the depleting gas resources and imports of coal in its energy mix. In this respect, prudent use of domestic natural gas, LNG, nuclear and renewable energy sources look likely to remain the focal points of 21st century energy strategies. Large scale renewable energy is not yet commercially viable and practically feasible, because such energy sources have not yet reached technological maturity. Nuclear energy, therefore, presents itself as an attractive option, as shown by the excellent economic and energy results of countries including France and the Republic of Korea.

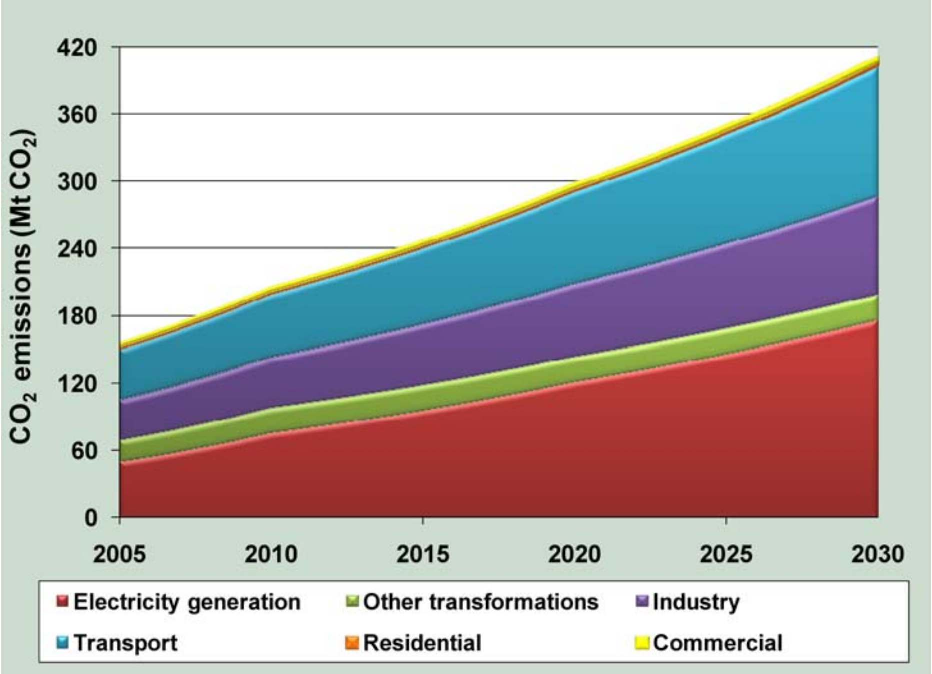
In September 2008, the Minister of Energy, Water and Communications announced that the Government would pursue domestic nuclear energy generation as a response to high global energy prices [A–23]. The Minister indicated that the Government was left with no choice but to use nuclear energy, since it was the better alternative to generate electricity by 2023 as supplies of fossil fuel would eventually run out. In June 2009, the Government agreed to allow nuclear energy to become an option to power its energy needs for the decades after 2020. The Government has considered the supply side constraints of other options based on resource endowment, technology maturity and economics. Subsequently, the Cabinet approved the setting up of a Steering Committee on Nuclear Power Development [A–24].

Nuclear seems to be a viable long term option, as it is very much green technology, clean, environmental and climate friendly, and features cutting edge technology — and, thus, wealth creation. The Government's advocacy is also because of total agreement with the utilization of nuclear energy for peace and non-proliferation activities.

A few studies have assessed nuclear energy in Malaysia. A 2008 study on the evaluation of sustainable energy strategies for addressing climate change issues has shown that Malaysia could reduce CO_2 emissions in the power sector by 22%, by adopting nuclear power by 2020 as compared to a baseline case of non-nuclear scenario [A–25]. Another study has revealed that Malaysia could avoid about 4.9 Mt CO_2 emissions per year per 1000 MW nuclear reactor commissioned — which would qualify Malaysia for carbon emission reduction (CER) certificates [A–26]. However, nuclear is yet to be included in the CDM instrument. The MNA, other ministries (notably NRE), agencies and energy policy makers must reconcile with each other in order to include nuclear as part of CDM instruments.

Notwithstanding some of these technicalities, nuclear energy remains an attractive focal point for energy planners and economists in Malaysia. The challenge, therefore, is to build the consensus on the necessity of making nuclear energy as part of — and a permanent feature of — the national energy supply mix in years to come.

FIG. A–4. Projected CO_2 emissions by sector in Malaysia (up to 2030) [A–23].



NATIONAL PERSPECTIVES

Climate change and nuclear power in Thailand: Balancing the driving forces

The National Economic and Social Advisory Council of Thailand, an impartial organization set up under the Thai Constitution to reflect on economic and social problems and provide advice to the cabinet, completed a study in 2008 about five 'emerging challenges' for the country [A–27]. The five topics that need urgent attention and preparedness include nuclear power and global warming. According to the report, climate change might trigger large scale migration of the population to safer areas and cause negative impacts for agriculture (increasing costs), occupation and lifestyle, as well as conflicts over limited and restricted resources. The study strongly urges the promotion of new non-fossil fuel sources and technologies for power generation as one measure to mitigate GHG emissions.

The report also revisited the issue of nuclear power after several aborted projects during the past 30 years. The key issues are safety from accident, management of radioactive waste (including spent fuel), the distrust in Thai operational capability and work culture to ensure the safe construction and operation of such plants, the lack of regulatory structure and competent human resources, budget and political will. Recommendations from the Council to the cabinet reflect the state of the debate but do not include a concrete suggestion for building nuclear power plants.

The National Strategic Plan on Climate Change Preparedness (2008–2012) [A–28], laid out six strategies to combat climate change through concerted efforts among different ministries. The first measure under the mitigation strategy is to decrease emissions from the energy sector. According to the plan, nuclear power is one of the alternative energies that "does not release greenhouse gas" and should be supported among other forms of alternative energy, including hydropower, wind and solar. The Ministry of Energy is designated to implement this measure, with the Ministry of Science and Technology (MOST) given the regulatory and supporting role.

Later in 2008, MOST hosted a four-month public congress on global warming. Many public forums were held in different regions of the country to discuss the impact of global warming and the role of science and technology in mitigating and adapting to the impacts. The proceedings addresses the urgency of the problem and presents a realistic analysis of the country's GHG emissions and viable alternative energy sources [A–29].

According to the proceedings, roughly 90% of current electricity is generated from fossil fuels such as lignite, imported coal and natural gas. Electricity demand is increasing by 5% annually, and without a major shift in fuel sources, GHG emissions will increase. All alternative fuels have their limitations: biofuels consume large arable land areas, solar energy is clean but still costly and has limited production capacity, and clean coal technology with carbon capture and storage (CCS) is expensive, not yet ready and carries an efficiency penalty. Nuclear power is shown to be the most environmental friendly. The MOST proceedings [A–29] states that nuclear energy could help mitigate global warming and enhance energy security even though it will not become the major source of fuel for electricity generation by the planned operation year of 2020. The proceedings concludes by recommending that the Government initiate megaprojects in large scale alternative energy technology development, including the strengthening of nuclear power capacity.

The Thailand Power Development Plan (PDP) 2007 [A–30] originally proposed 4000 MW nuclear power for consideration among other (smaller scale) coal fired, gas fired combined cycle and gas turbine power plants. The original plan was approved by the Cabinet in 2007, depicting a scenario in which natural gas remains the major fuel source for power generation, but by 2020, nuclear power will start to contribute. The

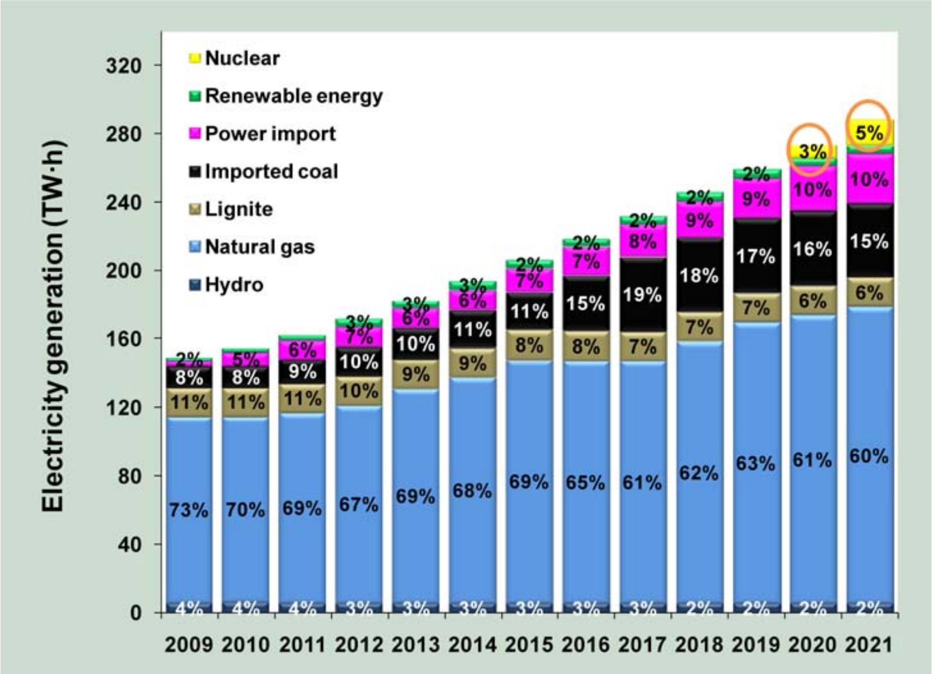
Plan was later revised giving nuclear power's contribution 2000 MW or 5% of total power generation by 2021 (Fig. A–5).

A formal policy decision is yet to be made on actual nuclear construction, nevertheless, the Government's keen interest in nuclear power can be attributed largely to concerns in energy supply security. An alternative scenario shows that imported power could expand to as much as 28% of the country's electricity generation by 2021. Since the announcement of the PDP 2007, nuclear power was put on the spot after many quiet years and has become a target of public attention and debate. At the same time, climate change has increasingly become another public concern — however, the connection between the two remains dubious in the eye of the public.

The public view of nuclear power in Thailand is mixed, and the view on nuclear–climate linkage is unclear due to opposing arguments and conflicting information. The debate is largely about safety issues, where discussions tend to become emotional, particularly when environmental NGOs are involved. The opposition usually claims that nuclear power is not carbon free considering the energy expended (and, therefore, GHG emitted) during plant construction and the fuel cycle. Many groups point to the availability of non-nuclear alternative energy sources and the increase of energy efficiency as the ultimate solution to global warming.

In summary, Thailand remains delicately balanced between the pros and cons of nuclear power, and the current Government has not come out firmly embracing the idea of Thailand's first nuclear power plant. Without strong implications of the UNFCCC negotiations for the post-2012 agreement, the prospects for nuclear power in climate change mitigation is not completely clear. In a wider context, any further domestic movement towards the adoption of nuclear power in Thailand will come down to balancing three key driving forces: energy security, international competitiveness (due to energy prices) and climate change mitigation.

FIG. A–5. Recommended plan for energy generation by different fuel types in the PDP 2007 [A–30].



THAILAND

Climate change and nuclear power in the United Kingdom: Clearing the path

By mid-2008, the antinuclear tone of government and opposition statements on nuclear energy which had characterized the British scene for two decades had been replaced by a recognition that nuclear new build was an increasingly attractive option for addressing problems of high energy prices, growing dependence on imports and growing GHG emissions. The UK's indigenous reserves of gas were running short, global energy prices were high and the UK's record on carbon dioxide emissions, impressive during the 1990s, had stalled as the use of coal for electricity production had grown. The 2008 Nuclear Power White Paper [A–31] stated that the Government had concluded that nuclear should have a role to play in the generation of electricity and the Conservative opposition had confirmed that it would not undermine any investment in new nuclear build should it come into power in 2010.

However, a number of obstacles stood in the way: the capacity of the licensing authority (the Nuclear Installations Inspectorate), questions over the planning and regulatory regime, siting issues and raising the finance for the programme. 2008 and 2009 have seen progress in these areas as the UK moves towards the first planning applications for new nuclear stations, which are expected in 2012.

Within Government, the main development was the creation of the Department of Energy and Climate Change (DECC) in October 2008, bringing together energy policy and climate change mitigation policy. Its creation:

> "reflects the fact that climate change and energy policies are inextricably linked — two thirds of our emissions come from the energy we use. Decisions in one field cannot be made without considering the impacts in the other" [A-32].

The three overall objectives for the new Department are: (1) ensuring Britain's energy is secure, affordable and efficient;(2) bringing about the transition to a low-carbon Britain; (3) achieving an international agreement on climate change at Copenhagen in December 2009.

One of the new Department's major initiatives was the announcement in April 2009 of the UK's first set of carbon budgets, claimed to be the first country in the world to do so. These budgets seek to set the limits on UK emissions for each of three five-year periods (until 2022), in order to remain on course for the Government's long term target of an 80% reduction by 2050. The proposed levels represent a 22% reduction in GHG emissions below 1990 levels for the first budget (2008–2012), over 28% for the second period (2013–2017), and over 34% for the third period (2018–2022). The Government announced its intention to achieve these targets through domestic effort aside from the EU ETS.

The new Secretary of State, E. Miliband, set out the Department's approach in the following newspaper article in April 2009:

> "As well as improving energy efficiency, we need to pursue the trinity of low-carbon technologies: renewables, nuclear and clean fossil fuels. On renewables, we are already the country with the largest offshore wind generation in the world. More capacity is being built. On nuclear, energy companies, not taxpayers, should pay the costs of clean-up — and that's now in legislation. But with safeguards on cost and safety in place, I believe, like many others seeing the threat of climate change and the need for a solid base of low-carbon power, that we should support new nuclear energy. And the low-carbon power that I believe to be the most important still to be developed is clean coal." [A–33]

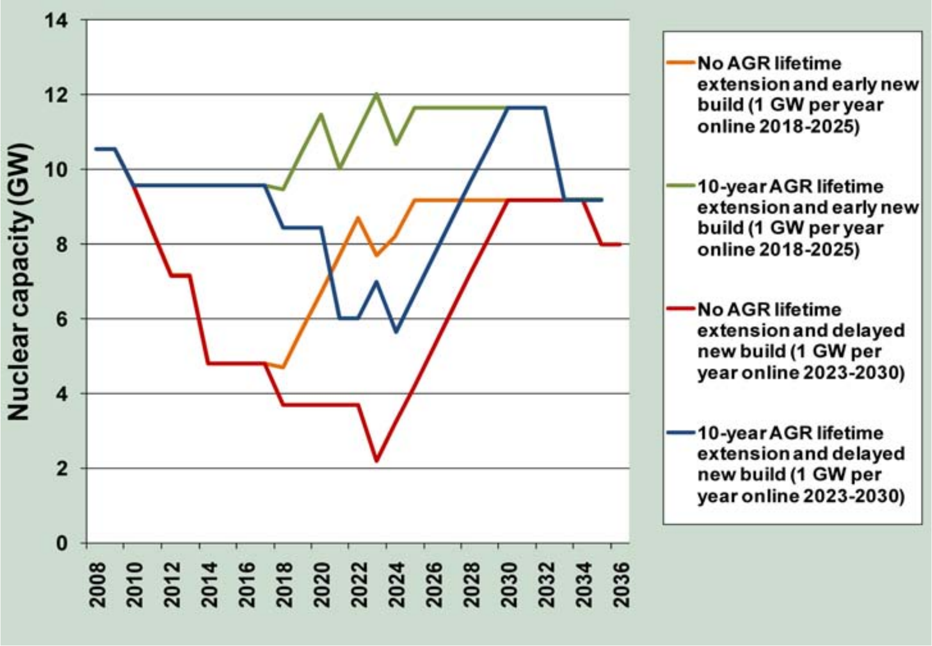
Some 40 consultations were carried out during the year on a range of aspects of new build and waste management policy, including Justification and Strategic Site Assessment to determine where new stations should be built. Eleven sites were announced as suitable for the first wave of new build, nine of which currently host nuclear stations (operating or decommissioned). A number of bidders for the sites came forward.

On the industrial side, the major development was the purchase by Électricité de France (EdF) of British Energy, the UK's main nuclear generating company, with a minority stake being taken by Centrica (which trades as British Gas). EdF stated its intention of investing some £22 billion in four new nuclear reactors, assuming a business case can be made. Other consortia are coming forward with similar plans. However, EdF has stated that new build may not be economically viable without government underpinning of carbon prices.

The stance of the environmental movement remains broadly antinuclear, with Greenpeace, for example, saying "a new generation of nuclear reactors simply won't deliver the urgent emissions cuts needed to tackle climate change" [A–34]. However, a number of high profile environmentalists, including S. Tindale (former Executive Director of Greenpeace) and C. Goodall, a Green Party parliamentary candidate, argued that a new nuclear programme was essential to address climate change [A–35]. Public support for nuclear energy also continues to grow.

One key issue remains the timing of a new build programme (see Fig. A–6). Even if the existing AGR stations receive lifetime extension, it would take a new build programme delivering some 1 GW of new capacity per year for eight years, starting in 2018 to maintain nuclear capacity at present levels, themselves quite a way below the peak achieved in the late 1990s. Any significant delay would open up a gap in nuclear output which would inevitably be filled by other sources, altering the commercial climate in which new build would operate. Furthermore, 1 GW of nuclear capacity generates some 8 TW•h/year, assuming a load factor of some 90%. Were 8 GW nuclear new build to be forgone, replaced by a mixture of coal and gas, carbon dioxide emissions would be some 45 Mt (about 8%) higher. This would severely undermine the UK's GHG mitigation strategy.

FIG. A–6. United Kingdom nuclear generating capacity under four scenarios.



US action on climate change and nuclear power

In early 2009, the US Global Change Research Program finished an updated assessment of the impacts of climate change on the USA [A–36]. The report concludes that impacts of climate change can already be observed, including:

> "… increases in heavy downpours, rising temperature and sea level, rapidly retreating glaciers, thawing permafrost, lengthening growing seasons, lengthening ice-free seasons in the ocean and on lakes and rivers, earlier snowmelt, and alterations in river flows." ([A–36] p. 27).

Climate change is forecast to increasingly affect the water, energy, transportation, agriculture, ecosystems, health sectors, coastal areas and the survival of species, with implications for society. J.P. Holdren, Assistant to the President for Science and Technology and Director of the White House Office of Science and Technology Policy said:

> "It tells us why remedial action is needed sooner rather than later, as well as showing why that action must include both global emissions reductions to reduce the extent of climate change and local adaptation measures to reduce the damage from the changes that are no longer avoidable." [A–37]

Americans are showing stronger support for US action on countering climate change and using nuclear power. A June 2009 Washington Post–ABC News poll found that 62% of Americans polled favour more government regulation in controlling GHG emissions, but indicated that support for a cap-and-trade system falls to only 44% when those polled believed that their monthly electricity bills could rise by $25 or more. Nonetheless, a majority supports having the USA take more action, even if other countries do less. A March 2009 Gallup Poll found that 59% of Americans favour using nuclear power to generate electricity in the USA and 27% strongly favour this energy source. This latter result shows a significant surge upward from 22% strong support in Gallup's previous 2007 poll.

This convergence of scientific findings and public opinion has occurred in a political environment that has become much more conducive to US action on climate change. The 2008 elections brought about a change in the administration's position regarding climate change in the context of campaign promises to pass legislation to reduce US GHG emissions. However, there are no clear signals about the role of nuclear power in this regard. Three recent policy issues will influence the future trajectory of nuclear power in the USA: (1) legislation on controlling GHG emissions; (2) federal loan guarantees for nuclear power plants; and (3) nuclear waste management.

On 26 June 2009, the US House of Representatives narrowly passed the first ever bill to regulate GHG emissions. This bill seeks to reduce GHG emissions to 17% below 2005 levels by 2020 and 83% below by 2050. The bill, if passed by the Senate and signed into law by President Obama, would enact a cap-and-trade system that would begin in 2012. The House version would initially give away most of the emission allowances and then, over time, increase the price tag on emission purchases. The projected initial price will be about \$13/t CO_2). This price may not be enough to level the economic playing field between nuclear and coal fired power plants. According to the May 2009 updated report of the MIT nuclear power study group, a minimum price of \$25/t CO_2 may be needed [A–38].

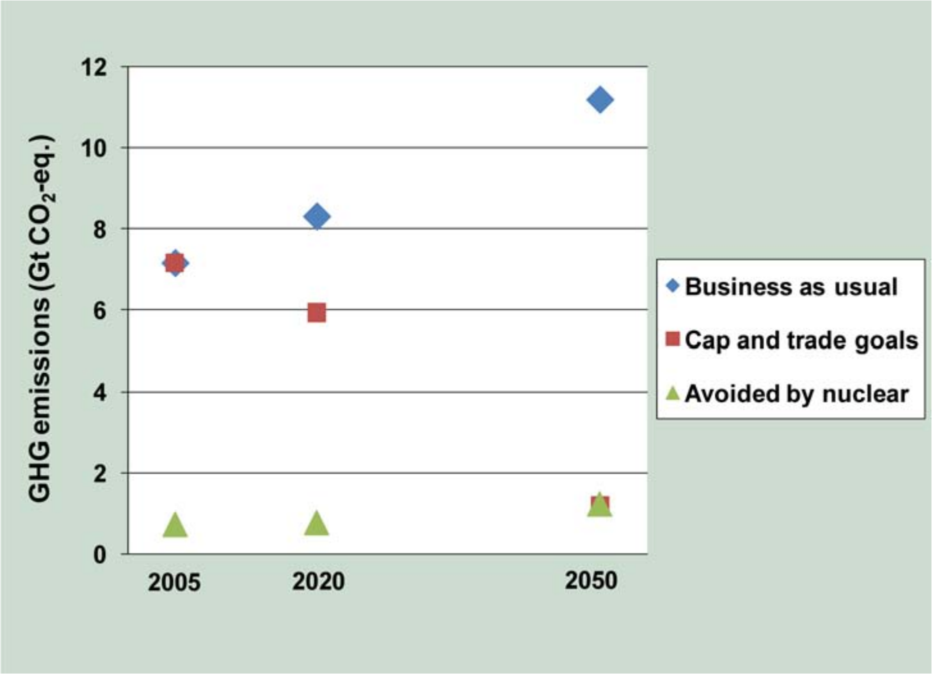
It is likely that the proposed emissions trading scheme would have little or no effect on the nuclear power plants that could begin construction next decade because of the long lead time for licensing, assessing the environmental impact, securing financial support and ordering of reactor components. However, this scheme could stimulate the second and following waves of nuclear power plant construction that may take place ten or more years from now.

In the climate change legislation, both the House Bill and the Senate proposal include the possible formation of the Clean Energy Development Agency, but they differ in that the House Bill excludes new nuclear generation from the power sales baseline for the proposed renewable energy standard. In addition to including nuclear energy in this standard, many Republican senators are pushing for a section of the Senate Bill that would provide federal loan guarantees for 100 new reactors by 2030. According to a US Environmental Protection Agency (EPA) analysis of the House cap-and-trade scheme, the market signal may stimulate financing for up to 260 new 1000 MW reactors by 2050 [A–39]. Based on these EPA results, Fig. A–7 shows the avoided emissions resulting from nuclear power, displacing coal under the proposed cap-and-trade system. As part of the 2005 Energy Policy Act, the US Government already has $18.5 billion of loan guarantees that it can offer for the first round of 6000 MW of new nuclear power plants.

Meanwhile, the future of Yucca Mountain as the ultimate disposal site for spent fuel is uncertain but this is not expected to delay the next round of nuclear plant construction. Experts agree that spent fuel can be safely stored in dry storage casks for many decades.

Although the ultimate outcome of congressional deliberations on climate change legislation and additional federal support for nuclear power remains uncertain, optimism is increasing that the USA will in the coming months commit to curbs on GHG emissions, most likely through a cap-and-trade scheme. Such a scheme could eventually provide the market signal necessary for the construction of up to 260 large reactors by mid-century.

FIG. A–7. Avoided GHG emissions due to nuclear power under the proposed cap-and-trade system.



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