NUCLEAR POWER AND CLIMATE CHANGE

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Introduction

The World Climate Change Conference is a scientific conference in a politically important setting. Moscow is politically important right now for climate change policy because Russian ratification would trigger entry into force of the Kyoto Protocol. And, absent a highly unlikely policy shift in the United States, *only* Russian ratification will trigger entry into force. In addition to advancing the science of climate change, the WCCC therefore has the parallel task of laying out the science clearly and completely for Russian officials deliberating ratification. The WCCC is an initiative of President Putin, and it is important that the conference address the critical climate change decision now in front of his country's leadership – not by recommending a specific choice, but by objectively clarifying the options.

The issue on which I wish to add clarity is the potential of nuclear energy for reducing the world's future energy-related greenhouse gas emissions. This is immediately relevant for those weighing the benefits and costs of adopting the Kyoto Protocol's limits. It also addresses nuclear energy's special constraint under current Kyoto Protocol rules – specifically that Annex I Parties "are to refrain from using emission reduction units… [and] certified emission reductions generated from nuclear facilities to meet their commitments under Article 3, paragraph 1".[1] That is, nuclear power is currently excluded from joint implementation projects under the protocol and from the clean development mechanism (CDM). It is not excluded from the third Kyoto flexibility mechanism, emissions trading – a matter of potentially substantial importance to Russia's ratification decision.

Carbon Emissions from Electricity Generation

Figure 1 shows the IAEA's estimates of total greenhouse gas (GHG) emissions from the complete electricity generation chains for lignite, coal, oil, natural gas, solar photovoltaics, hydroelectricity, biomass, wind and nuclear power.[2] The results include all six Kyoto GHG's and are converted to "grams carbon equivalent per kilowatt-hour" (gC_{eq}/kWh) using the global warming potentials of the Intergovernmental Panel on Climate Change (IPCC). For nuclear power, it is important that we look at complete electricity chains and all GHGs. Some anti-nuclear lobbyists, while agreeing that nuclear electricity generation produces virtually no GHG emissions at the point of generation, have contended that the balance of the nuclear electricity chain produces emissions comparable to those from fossil fuels. Figure 1 refutes that claim. GHG emissions at the point of electricity generation are

[1] Report of the Conference of the Parties on Its Seventh Session, held at Marrakesh from 29 October to 10 November 2001, Addendum Part Two: Action taken by the Conference of the Parties, Vol. II (FCCC/CP/2001/13/Add.2), 21 January 2002.

[2] Joseph V. Spadaro, Lucille Langlois and Bruce Hamilton, "Greenhouse Gas Emissions of Electricity Generation Chains: Assessing the Difference," IAEA Bulletin, Vol. 42, No. 2, Vienna, 2000.

shown in the dark bar segments. Shown in the light bar segments are emissions from all other stages of the electricity chain, i.e., fuel mining, preparation, and transport; plant construction and decommissioning; the manufacture of equipment; and (in the case of some renewables like hydroelectricity) the decay of organic matter. Nuclear power, wind, biomass, and hydroelectricity have the lowest full-chain emissions.

Figure 1's estimates were developed in a series of IAEA advisory group meetings over several years. The process produced a range of emissions for each electricity generating option, reflecting differences in assessment methods, conversion efficiencies, practices in fuel preparation and subsequent transport to the location of the power plant, and local issues, such as the fuel mix assumed for electricity requirements related to plant construction and the manufacture of equipment. The several bars for each option in the figure show the range of estimates, including future projections incorporating improvements in the fuel-to-energy service conversion process, reductions during fuel extraction and transport, and lower emissions during plant and equipment construction.

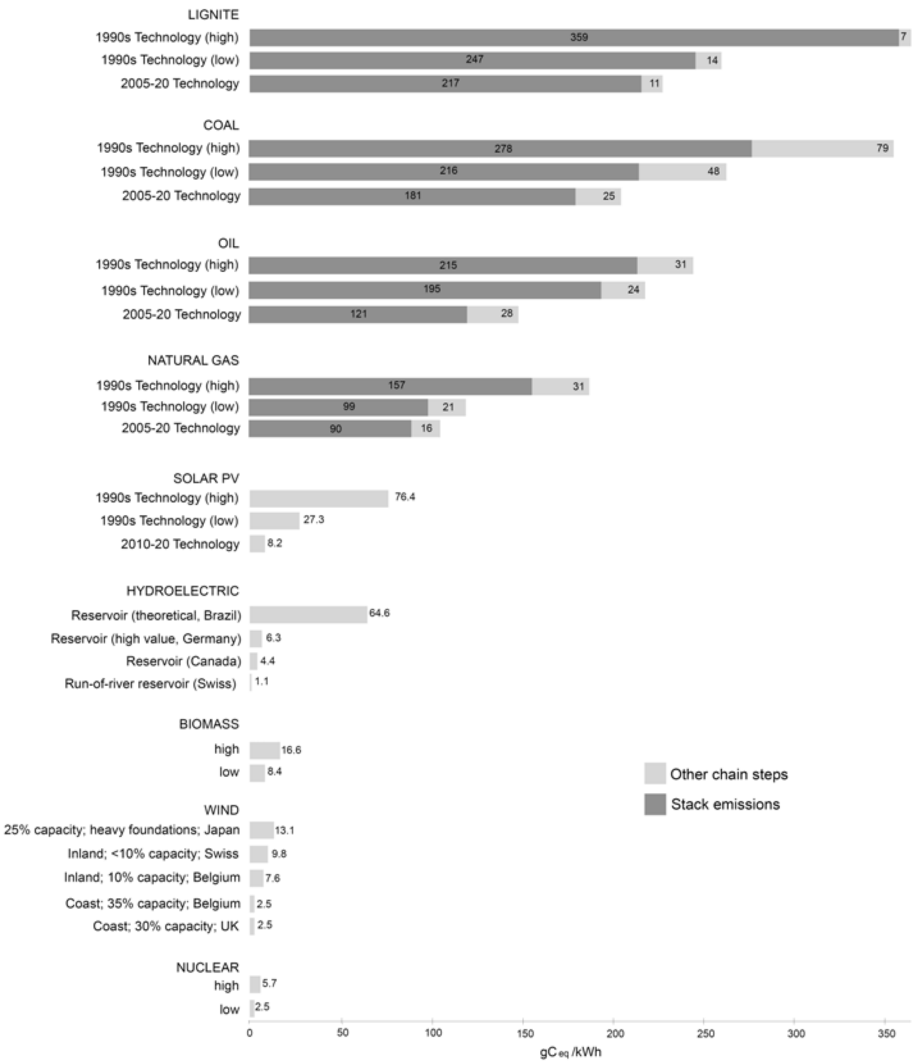

Figure 1. Full energy chain GHG emissions (in grams of carbon equivalent per kWh) for different electricity generating options. Ranges are from 1990s technology to advanced technology (2005-2020) (Source: Spadaro et al., IAEA Bulletin, Vol. 42, No. 2, Vienna, Austria.)

The IAEA results in Figure 1 are reinforced by the research of the European Commission on external costs of electricity generation, reported most recently in a new report entitled "External Costs: Research results on socio-environmental damages due to electricity and transport".[3] Figure 2, taken from that report, shows nuclear power, wind, and biomass as having comparably low GHG impacts.

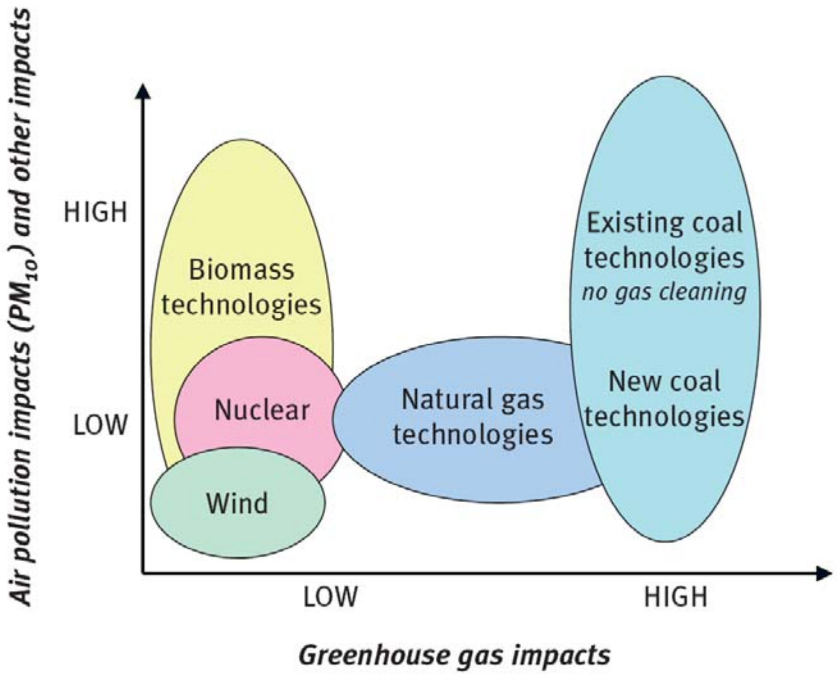

Figure 2. Comparison of GHG impacts and air pollution impacts for electricity generation from coal, natural gas, biomass, nuclear, and wind (EC, 2003).

Carbon Avoidance by Nuclear Power

Worldwide there are 437 nuclear power plants operating in 30 countries, and 33 new reactors under construction. For the last several years nuclear generation has grown at about the same pace as total global electricity consumption, an average of 2.8% per year over the last four years, and its share of global electricity has thus held steady around 16%. In 2002, in Russia, nuclear power was 16% of total electricity use. In the United States it was 20%, 30% in Germany, 34% in Japan, 36% in Hungary, 46% in Sweden, and 78% in France. Total experience operating nuclear power plants is now over 10,000 reactor-years.

How much are the world's GHG emissions currently reduced by those 437 reactors? It's a hypothetical question since we can never have an experimental "control" – i.e., an otherwise identical world except for the absence of nuclear power. The answer depends on what you think that experimental control would look like. What would replace nuclear power

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[3] European Commission "External Costs: Research results on socio-environmental damages due to electricity and transport," European Commission Directorate-General for Research, EUR 20198, Brussels, 2003 (http://europa.eu.int/comm/research/energy/pdf/externe_en.pdf).

in today's energy mix, if nuclear power were not available? A few countries with nuclear bans or phase-outs contend that today's nuclear reactors reduce GHG emissions not at all. They argue that its absence would be fully replaced by emission-free renewables, so there is no difference in GHG emissions between the real world and their hypothetical non-nuclear world, and nuclear power avoids no GHG emissions. A more objective answer assumes that the mix of energy sources in the 84% of global electricity supplied today from non-nuclear sources is the best indicator of what might replace nuclear power in a hypothetical non-nuclear 2003. The calculations in Table 1 therefore assume that non-nuclear electricity sources would expand their contributions proportionately, with the one exception of hydropower. It is more constrained than other sources of electricity, especially in the developed countries that are major users of nuclear power, so Table 1's calculations postulate that hydropower would be largely unable to expand. The table is based on data for 2000 from the *World Energy Outlook 2002* published by the OECD International Energy Agency (IEA).[4]

The first row in the table (not counting the header row) shows the global electricity generation mix in 2000. The second row shows carbon emissions from electricity generation, also from the *World Energy Outlook 2002*. The third row calculates the carbon intensity of electricity production by dividing the second row by the first. The fourth row shows the hypothetical energy mix when nuclear power is eliminated and its electricity generation is spread proportionately over the other electricity sources except hydropower. The fifth row calculates the resulting carbon emissions using the carbon intensities in the third row. The sixth row shows the differences in emissions between the hypothetical mix without nuclear and the actual 2000 energy mix, i.e. the carbon emissions avoided by nuclear power in 2000. The total in the bottom right corner is 622 MtC avoided due to nuclear power. Since some hydropower expansion is possible in developing countries with small nuclear shares, such as Brazil or China, the IAEA rounds this number down to "approximately 600 MtC" in its publications.

Table 1. Carbon emissions from electricity generation in 2000 from the IEA's "World Energy Outlook 2002" and from a hypothetical alternative mix with nuclear power's share distributed proportionately among coal, oil, gas, and other renewables, except hydro.

	Coal	**Oil**	**Gas**	**Nuclear**	**Hydro**	**Other renewables**	**Total**
Electricity generation, IEA (TWh)	5,989	1,241	2,676	2,586	2,650	249	15,391
Carbon emissions from electricity generation, IEA (MtC)	1,712	271	461	0	0	0	2,444
Carbon intensity (MtC/TWh)	0.286	0.218	0.172	0	0	0	0.159
Postulated electricity mix without nuclear (TWh)	7,514	1,557	3,357	0	2,650	312	15,391
Carbon emissions from postulated mix (MtC)	2,148	339	578	0	0	0	3,065
Carbon emissions avoided by nuclear (MtC)	436	69	117		0	0	622

[4] IEA (International Energy Agency), *World Energy Outlook 2002*, IEA, Paris, 2002.

Estimating Future Carbon Emissions Avoided by Nuclear Power

To estimate how much carbon avoidance nuclear power will or might provide in the future, scenarios are needed for the future evolution of the electricity generating mix and for improvements (reductions) in the carbon intensity of different generation options. The "reference scenario" of the IEA's *World Energy Outlook 2002* provides one such scenario. It assumes no new nuclear plants beyond what is already being built or seriously planned today, plus the retirement of older reactors as originally scheduled. The result is a small rise in nuclear electricity generation to 2010, but then a gradual decline through the end of the scenario in 2030, as retirements in Europe and North America start to outpace new nuclear additions in Asia.

Repeating the calculations in Table 1 for this scenario yields the projections in Figure 3 for avoided carbon emissions that could be attributed to nuclear power if the world develops along the path of the IEA's reference scenario. Annually avoided emissions attributable to nuclear power (the left panel in Figure 3) follow the same trajectory that the IEA scenario projects for nuclear generation, a slight increase to 2010 and then a gradual decline through 2030. The right panel shows cumulative avoided emissions from 2000 onwards – a steep and steady increase.

To estimate nuclear power's full *potential* for reducing future carbon emissions, however, the calculations have to be done for scenarios in which nuclear power truly expands its contribution to world energy supplies, rather than contracts as in the IEA scenario. Our starting point is the long-term scenarios of the IPCC's Special Report on Emission Scenarios (SRES).[5] Although these were not designed to explore specifically nuclear power or any other particular energy option, their objective of minimizing total long-term system costs leads to future expansions of nuclear energy very different from the IEA's projected intermediate-term contractions.

The SRES scenarios are global scenarios based on a global process – an open invitation that resulted in 28 authors from around the world and six modelling teams from three continents (Asia, Europe, and North America) doing the analysis. They have been subjected to the most thorough and documented expert and governmental reviews of any scenario set we know of. And they are relatively transparent, with extensive qualitative and quantitative results available at http://www.grida.no/climate/ipcc/emission/. Given their international authorship and comprehensive review by governments and scientific experts, the SRES scenarios are the state of the art in long-term energy scenarios.

SRES developed four narrative storylines, each representing a different coherent set of demographic, social, economic, technological, and environmental developments. For each storyline, several different quantifications, or scenarios, were then developed by the six modeling teams. The result is 40 scenarios grouped in four "families" (A1, A2, B1, and B2) corresponding to the four narrative storylines. Economic objectives dominate in the "A" storylines, while environmental objectives dominate in the "B" storylines. The "1" storylines emphasize globalization, while the "2" storylines are better characterized by regionalism. The following summaries are almost verbatim from the SRES report.

[5] IPCC (Intergovernmental Panel on Climate Change), 2000: *Special Report on Emission Scenarios*. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

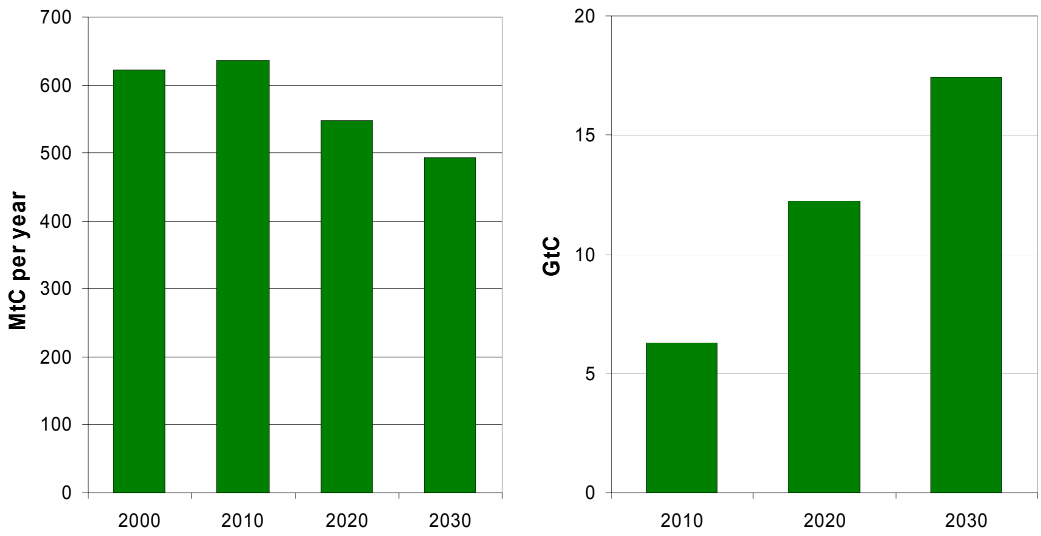

Figure 3. Projected carbon emissions avoided annually (left panel) and cumulatively from 2000 (right panel) by nuclear power using the reference scenario of the "World Energy Outlook 2002."

- The A1 storyline and scenario family describe a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.
- The A2 storyline and scenario family describe a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.
- The B1 storyline and scenario family describe a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental challenges, including improved equity, but without additional climate initiatives.
- The B2 storyline and scenario family describe a world in which the emphasis is on local solutions to economic, social, and environmental challenges. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the storyline is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

For each of the A2, B1, and B2 storylines we use a single "marker" scenario representative of central tendencies within the scenario family. For the A1 storyline, SRES projections showed that greenhouse gas emissions (the principal focus of SRES) vary greatly depending on the technologies assumed to progress most quickly. We use the A1T Scenario, which assumes that advances in non-fossil technologies – renewables, nuclear, and high-efficiency conservation technologies – make them most cost-competitive.

The left panel of Figure 4 projects the carbon emissions avoided by nuclear power in each of the four selected SRES scenarios as adjusted to match actual 2000 electricity generation data in the *World Energy Outlook 2002*. All four project increased carbon avoidance attributable to nuclear power corresponding to their projections of increasing nuclear electricity generation. One reason that the SRES scenarios differ from the IEA is that they minimize total energy system costs looking ahead 100 years. They thus take greater account of the projected depletion of low-cost fossil fuels and give greater weight to long-term returns than do current deregulating energy markets – which form the basis for the IEA reference scenario. From the longer-term perspective of SRES, nuclear power is a more attractive investment than from the near-term perspective of the IEA.

But although the SRES scenarios generally project nuclear expansion, they don't push the envelope. They don't explore the full potential for large reductions in GHG emissions through aggressive expansions of nuclear energy. The IAEA has developed for each of the four SRES scenarios in the left panel of Figure 4 an aggressive-nuclear variant that assumes improvements in nuclear technologies, relative to alternatives, at faster rates than those assumed by the original SRES modeling teams.[6] Faster technological improvements mean greater economic competitiveness, which in term means greater market shares and faster expansion. The resulting projections for carbon avoidance from nuclear power are given in the right panel of Figure 4.

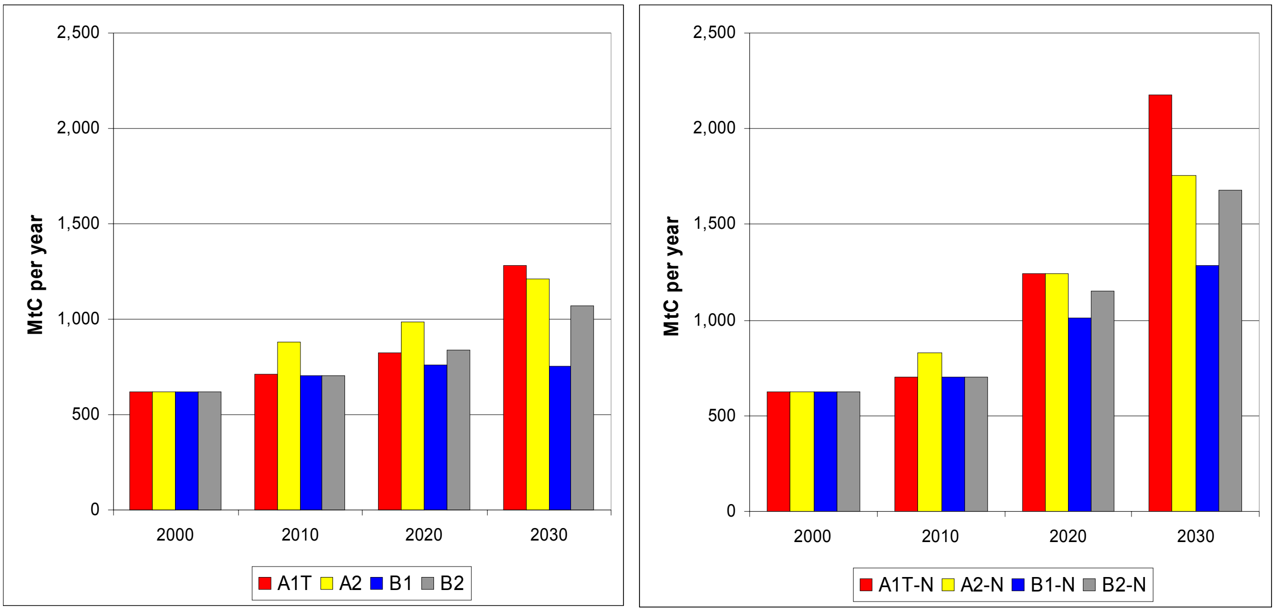

Figure 4. Projected carbon emissions avoided annually by nuclear power for four SRES scenarios (left panel) and their aggressive-nuclear variants (right panel).[7]

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[6] Alan McDonald, Keywan Riahi, and Hans-Holger Rogner, "Elaborating SRES Scenarios for Nuclear Energy," Risø International Energy Conference on Energy Technologies for post Kyoto Targets in the Medium Term, Risø National Laboratory, Roskilde, Denmark, May 19-21 2003.

[7] For these results the selected SRES scenarios were first adjusted to be consistent with actual data for 2000 from the IEA *World Energy Outlook 2002*.

Because it is not so much annual emissions but cumulative carbon emissions that drive climate change, Figure 5 shows the cumulative carbon emissions avoided by nuclear power (from 2000 forward) both for the selected SRES scenarios and the aggressive-nuclear variants.

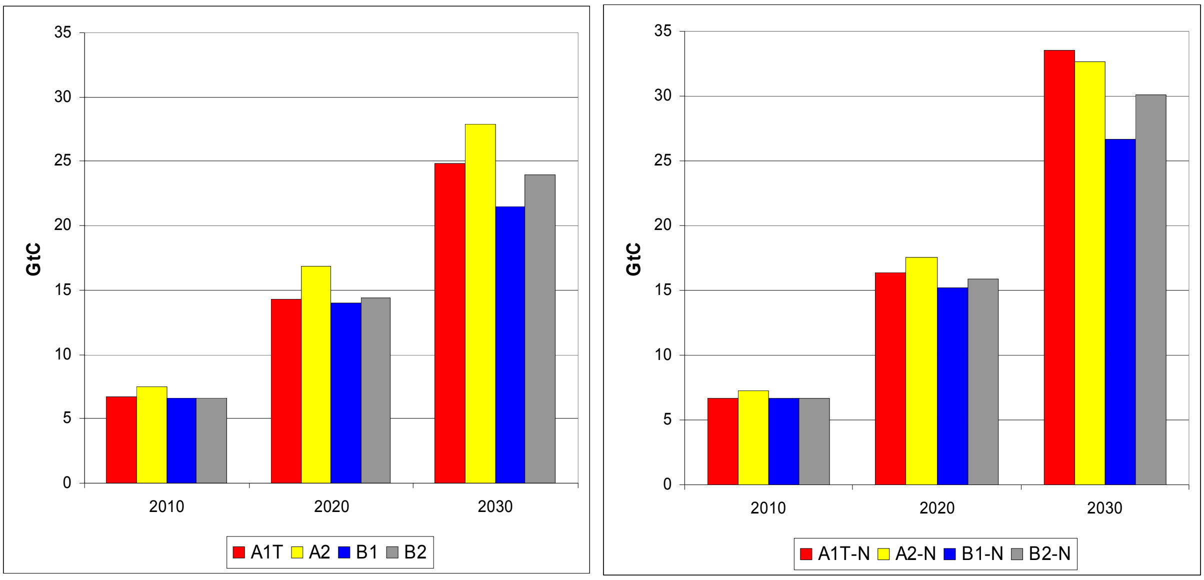

Figure 5. Projected cumulative carbon emissions avoided by nuclear power for four SRES scenarios (left panel) and their aggressive-nuclear variants (right panel).

Re-focusing just on the near-term, Figure 6 compares carbon avoidance due to nuclear power with that promised by the Kyoto Protocol. The protocol requires that by 2010, Annex I countries collectively reduce their carbon emissions by 5.2% relative to 1990 levels. Assuming that without the protocol, emissions would rise according to the projections in the IEA's reference scenario, estimated reductions in annual carbon emissions in 2010 due to the protocol amount to less than 350 MtC – perhaps as little as 220 MtC if Russia sells all its unused emission allowances to countries that need them. Thus nuclear power *already* contributes reductions more than twice the likely reductions from the Kyoto Protocol seven years down the road.

The full comparison is shown in Figure 6. The bottom bar equals the emission reductions mandated by the Kyoto Protocol, relative to its 1990 baseline, from Annex I countries minus the United States, which is no longer participating in the protocol. The bar above it shows mandated reductions relative to the 1990 baseline including the United States, as originally expected. The third bar shows reductions in 2010, relative to the IEA reference scenario, without the United States and assuming that all unused emission allowances are sold to countries that need them. The fourth bar describes they same situation, but with no sales of unused emission allowances. The top bar is the avoided carbon emissions, already in 2000, due to a single year's operation of the world's nuclear power plants.

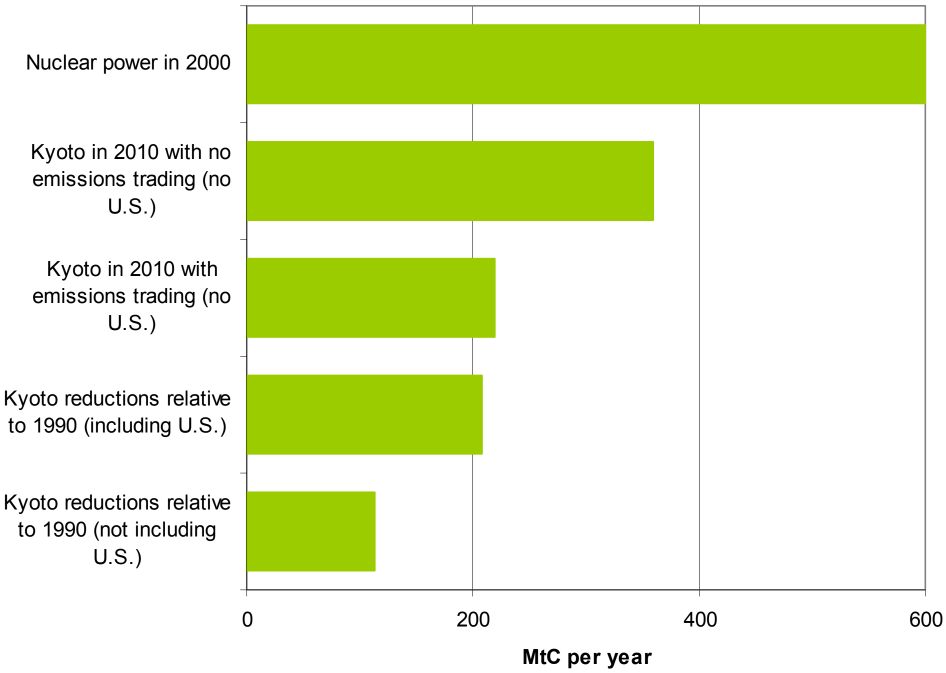

Figure 6. Estimated reductions in global carbon emissions from the Kyoto Protocol and from nuclear power in 2000.

Nuclear Power in the Kyoto Protocol

However far you want to push the envelope, from the IEA's cautious intermediate-term projections to the most expansive of the aggressive nuclear scenario variants in Figures 4 and 5, all show that nuclear energy reduces GHG emissions. In the context of climate change, in the context of this meeting, and in the context of the ratification decision facing the Russian government, nuclear energy is exclusively positive. It has no adverse impacts on the climate, and the more it is used the more GHG emissions are avoided.

Yet nuclear power is currently excluded from joint implementation projects under the Kyoto Protocol and from the CDM, and there continue to be proposals to further exclude nuclear power from the menu of climate change mitigation options. Again, this is not because nuclear power is bad for the climate; it's undeniably benign. Indeed, countries with high shares of nuclear electricity have the lowest per capita GHG emissions. But among the countries working hard to limit GHG emissions there are those who also oppose nuclear power for other reasons. That is their right. But their arguments for excluding the nuclear option must be examined carefully and independently, and the question of whether the categorical exclusion of nuclear power, or of any technology, should be inserted in international climate change agreements must be answered objectively.

The stated non-climate-related concerns about nuclear power are that it is too expensive, too dangerous, or too conducive to weapons production and terrorist attacks, and that a solution to the accumulation of high level wastes is still too remote. But international agreements on climate change are not the appropriate place to deal with any of these issues. If reactor safety is the worry, the focus should be on those few old-style reactors that fall short of current standards; not summarily precluding new, state-of-the-art reactors from future carbon markets. If proliferation is the concern, consider the near-universal adherence to the Non-Proliferation Treaty, and devote your efforts first to advancing the growing adherence to the Additional Protocol, which further strengths safeguards agreements under this Treaty. Efforts to better address proliferation concerns and waste management could, in our view, also include the consideration of restrictions on the use of weapon-usable material (plutonium and high enriched uranium) in civilian nuclear programmes, and limitations on the processing of such material – and the production of new material through reprocessing and enrichment – to international centres, under appropriate rules of transparency, control and assurance of supply. Such an approach, by strengthening transparency and control over sensitive nuclear fuel cycle facilities, would go a long way towards strengthening the non-proliferation regime.

In addition, as national waste strategies continue to evolve, it may also be of benefit to consider multinational approaches to the management and disposal of spent fuel and other radioactive waste. Not all countries have the appropriate conditions for geologic disposal – and, for many countries with small nuclear power programmes, the financial and human resource investments required for research, construction and operation of a geologic disposal facility are intimidating. Considerable economic, safety, security and non-proliferation advantages may accrue from programmes to collaborate on the construction and operation of international waste repositories.

Particularly with respect to concrete actions to strengthen non-proliferation, I should recall President Putin's speech at the UN Millennium Summit in 2000 in which he called for the development of new technologies that could generate nuclear power without requiring or producing weapons grade material, and for a parallel focus on emerging technology to burn long lived wastes from spent fuel. Among other consequences, his call gave impetus to the Agency's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), which has developed guidance for long-term nuclear improvements.

All these efforts to strengthen non-proliferation safeguards and make further progress on waste disposal are valuable and important whatever the politics and science of climate change. And they are advanced not at all by efforts to prohibit nuclear power from expanding its contribution to reducing climate change risks.

The argument that climate change agreements should legislate against nuclear energy because it is too expensive makes no sense. A more logical approach to concerns about high nuclear capital costs is to liberalize energy markets and then let the markets decide. If nuclear power proves more expensive than alternatives, it simply will not be built in competitive markets. But if the industry can reduce nuclear capital costs below alternatives, then countries and companies should be allowed to choose nuclear power. To promote cost-effectiveness, climate change agreements should make it easier for markets to operate freely, not try to centrally plan their outcomes for the next 100 years either in favor of nuclear power or against it.

Entry into force of the Kyoto Protocol would be an important step towards internalizing the external costs of GHG emissions. Nuclear energy, like most renewable energy sources, produces virtually no greenhouse gases. But this advantage of nuclear power and renewables has been invisible to investors because it has not been convertible to cash on the bottom line. Except for a very few instances, there have been no restrictions or taxes on greenhouse gas emissions and thus no economic value to their avoidance. The Kyoto Protocol represents important progress towards widespread, coordinated restrictions on greenhouse gas emissions, and thus towards attaching a tangible economic value to the avoidance of such emissions – whether through efficiency improvements, new renewables, cleaner fossil technologies, or nuclear power.

Exclusion from climate change agreements of any technology with clear climate benefits can only limit options, flexibility, and cost-effectiveness. The best chance for sustainable development – for meeting the needs of the present without compromising the ability of future generations to meet their needs – lies in allowing those future generations to make their own decisions about energy options, and allowing all options to compete on a level playing field on the basis of cost-effectiveness, greenhouse gas reductions, environmental health and protection, security, and safety.