Greenhouse Emissions and Nuclear Energy

a report by
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Hopes of Using Nuclear Power to Reduce Climate Change

In 2009, a pro-nuclear Massachusetts Institute of Technology (MIT) report claimed that atomic energy is "a practical and timely option for deployment at a scale that would constitute a material contribution to climate change risk mitigation".[1] Similarly, the Intergovernmental Panel on Climate Change (IPCC) noted that nuclear power could make "an increasing contribution to carbon-free electricity and heat in the future".[2]

Eager to reduce greenhouse gas emissions (GHGEs) by curtailing the use of fossil fuels, many people agree with the MIT and IPCC claims. Consequently, they propose tripling the number of atomic energy plants from about 450 to 1,000–1,500 globally so that they would supply roughly 20% of global electricity by 2050; proponents say that this is the largest reasonably achievable nuclear expansion.[3] Urging this fission increase, many advocates say that there is a new 'nuclear renaissance'.[4]

High Costs Undercut Any Nuclear Renaissance

Since the beginning of commercial atomic energy in the early 1950s, every nation with reactors has provided massive taxpayer nuclear subsidies that have been far higher than those for other energy technologies.[5] Despite this fact, the MIT report noted that today "there are only few firm commitments" to new nuclear plants, mainly in China, India and Korea; in the US, "no new nuclear units have begun construction" since the completion of the last reactors, ordered in 1974.[1] The World Nuclear Association (WNA), the main industry lobby group, confirms the fission downturn. It says that global atomic energy has been decreasing since the 1990s and, by 2030, nuclear-generated electricity will decline from 16 to 9% of global electricity.[4]

What can explain the failure of most nations to use increased atomic energy to help address climate change? One reason may be costs. According to credit-rating firms, even if one ignores heavy expenses such as reactor decommissioning, permanent waste storage and full insurance coverage, fission-generated electricity still costs three times more than energy from new natural gas plants and two times more than energy from scrubbed coal plants; credit-rating firms say fission-generated electricity costs at least 15 cents/kWhr.[6] However, atomic-energy proponents such as the US Department of Energy (DOE) state that on average over the last seven years, actual US wind prices are 4.8 cents/kWh, or more than three times cheaper, than nuclear power. By 2015, long before any commercial reactor could be completed if construction were begun in 2009, the DOE says that solar photovoltaic (PV) energy will cost 5–10 cents/kWh, be economically competitive with all energy technologies and be far less expensive than commercial fission.[7] Even now, renewable-energy technologies (such as wind), conservation and efficiencies are all much cheaper than nuclear power.[8]

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Of course, a carbon tax could make atomic energy more economically competitive with fossil fuels. However, such a tax would not improve nuclear economics compared with those of renewable energy technologies such as solar and wind power.

Citing poor nuclear credit ratings, high nuclear construction costs, numerous plant cancellations, equipment malfunctions, a competitive energy market and a long history of reactor cost over-runs and delayed plants, the World Bank,[9] the European Bank for Reconstruction and Development (EBRD),[10] the Asian Development Bank (ADB),[11] the African Development Bank (AFDB), the European Investment Bank (EIB), the Inter-American Development Bank (IADB) and most other market lenders say nuclear power is 'uneconomic'; as a matter of policy, most refuse nuclear loans or investments.[12] Consequently, all nations who seek fission-generated electricity must heavily subsidise it. Credit-rating companies also say they downgrade the ratings of any utilities with nuclear plants; they claim that even large, continuing taxpayer subsidies may not make commercial reactors economical.[13,14]

The Emissions Argument for Using Nuclear Power

Besides questions about costs, there is the issue of whether atomic energy should replace scrubbed coal plants. Is nuclear power a good (low-carbon) way to generate electricity? As noted, the MIT and IPCC reports suggest so. The US DOE, the UK Environment Secretary and others make the 'emissions argument'. They say that atomic energy must be tripled because it is 'carbon-free'.[8,15] Official US government, Nuclear Energy Institute and World Energy Council documents, respectively, claim that more nuclear power is necessary because it is "clean" and "emission-free", "does not emit greenhouse gases" and is "not a source of carbon dioxide".[16–18] However, subsequent paragraphs suggest that this argument is erroneous. It trims nuclear-related GHGE and ignores analyses showing that renewable energy technologies produce fewer emissions.

Trimming Greenhouse Emissions from the Nuclear Fuel Cycle

To understand how the emissions argument is erroneous in claiming that atomic energy is emission-free, one must recognise that the nuclear-fuel cycle has 13 stages: uranium mining, milling, conversion to uranium hexafluoride (UF6), UF6 enrichment, fuel fabrication, reactor construction, reactor operation, waste processing, waste conditioning, radioactive waste storage during its high-temperature period, nuclear waste transport to permanent management facilities, perpetually storing radioactive waste and reactor decommissioning and uranium-mine(s) reclamation

When emissions argument proponents say nuclear energy is carbon-free, they ignore the GHGEs from most of the 13 nuclear-fuel-cycle stages. They trim the data and typically calculate emissions only from stages seven and sometimes four or five. As a consequence, they claim that atomic energy produces minimal/no GHGEs. However, even under optimal, low-pollution conditions, only fuel-cycle stage seven is typically carbon-free.[19]

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Nuclear-fuel-cycle Greenhouse Gas Emissions

Each of the 13 nuclear-fuel-cycle stages creates high levels of GHGEs in using mainly fossil fuels for raw materials, product output and radioactive waste storage transport. Each stage releases many GHGEs because most processes rely mainly on coal-generated electricity.

Consider nuclear-fuel-cycle stages two to four – uranium milling, conversion and enrichment. Stage two (milling) requires roughly 1,000 metric tons of uranium ore to produce 1 ton of yellowcake using mainly coal-generated electricity to grind ore into small particles, chemically leach it and process it.[20,21] Stage three (conversion and purification of yellowcake into UF6) also releases substantial GHGEs because it employs mostly fossil-based electricity for extraction/fluorination/fractionation processes and because yellowcake is often 20% impure and only about 60% uranium ore.[22]

Stage four (UF6 enrichment and concentration into roughly 5% U-235) releases substantial GHGEs because it uses mainly coal-generated electricity; because UF6 is only about 0.7% usable, fissionable U-235,[23] and because it creates a lot of radioactive waste that must be reclaimed, secured and shipped for storage. Processing 1,000 metric tons of UF6 in a modern gaseous-diffusion (enrichment) plant produces 124 tons of enriched UF6 and 876 tons of radioactive waste tailings, and requires 951,542,500kWhr electricity. Thus, obtaining 1kg of enriched UF6 at nuclear-fuel-cycle stage four requires 7,674kWhr of electricity that virtually all comes from fossil fuels.[24]

Because each reactor annually uses about 149 metric tons of enriched UF6,[23] each therefore requires roughly 19,230MWhr/year of largely fossil-fuelled electricity just for fuel-cycle-stage four production. For all 104 US commercial reactors, stage four electricity needs alone are (104)(19,230) or 1,999,920MWhr/year, or about 2,000,000,000kWhr per year, and are largely met by fossil fuels.[24] However, each kWhr of US coal-generated electricity produces (on average) more than 2lb (0.91kg) of CO_2.[25] Consequently, because nuclear-fuel-cycle stage four relies mainly on coal-generated electricity, its CO_2 emissions alone are 4,000,000,000lb (1,814,369,000kg) annually. Similar GHGEs, waste products and transport needs characterise all 13 nuclear-fuel-cycle stages, helping to explain why each reactor takes 11 years to 'pay back' energy used prior to start-up; pay-back for natural gas plants is only six months.[23]

Calculating Total Nuclear-fuel-cycle Greenhouse Gas Emissions

What are total nuclear-fuel-cycle GHGEs? If one excludes all fuel lifecycle GHGE analyses that rely on secondary sources, are unpublished or fail to explain GHGE estimation/calculation methods, 103 fuel-lifecycle GHGE studies remain. These calculate nuclear-fuel-cycle GHGEs ranging from 1.4 to 288g CO_2-equivalent emissions per kWh of generated electricity (gCO_2/kWh). Nuclear industry studies typically give total GHGE as 1.4g/kWh, but consider only one to three nuclear-fuel-cycle stages, typically stages four, five or seven. Some environmental groups give total GHGEs as 288g/kWh, but appear to count some GHGEs twice. The mean total GHGEs calculated by all 103 studies (described above) is 66gCO_2/kWh, which is roughly what independent university scientists (funded by neither industry nor environmental groups) calculate at places such as Columbia, Oxford and Singapore.[19,26–28]

Moreover, the preceding university analyses use current, refereed, published, empirical data on nuclear facility lifetimes: efficiency (load factors), enrichment methods, plant types, fuel grades and so on. Their calculations (fairly consistent across universities) reveal ratios for mean full-fuel-lifecycle GHGEs across different energy technologies. This ratio for coal:combined-cycle natural gas:nuclear:solar PV:wind is 1,010:443:66:32:9 – roughly 112 coal: 49 gas: 7 nuclear: 4 solar: 1 wind. If preceding university calculations are correct, they suggest atomic energy fuel cycles emit about 16 times fewer GHGEs than coal, about two times more GHGE than solar and about seven times more than wind.[29]

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Trimming Nuclear-fuel-cycle Emissions via Kyoto Conventions

Because emissions argument proponents ignore most atomic energy fuel cycle emissions, they commit a fallacy of composition. That is, they make a logically invalid inference about GHGEs from some (one to three) to all (13) of the nuclear-fuel-cycle stages. However, trimming data on nuclear-fuel-cycle GHGEs may arise partly from Kyoto Protocol conventions. These conventions assess carbon content from fission fuels only at their consumption point (electricity generation). As a

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consequence, they ignore full nuclear-fuel-cycle carbon-equivalent emissions content.[30]

Trimming Nuclear-fuel-cycle Emissions via Unrealistic Assumptions

Emissions argument proponents also often trim atomic-energy-related GHGEs by making unrealistic assumptions about empirical factors that influence emissions levels. One problematic assumption is that nuclear GHGEs arise only from higher-grade (roughly 0.1% yellowcake) and not low-grade (≤0.01% yellowcake) uranium ores. However, cleaner, higher-grade ores are nearly gone, and the lower-grade, higher-emissions ores are widely used.[13]

Nuclear-fuel cycles using 10 times less concentrated uranium ore (<0.01% yellowcake) have total GHGEs equal roughly to those for natural gas fuel cycles; all other things being equal, such nuclear fuel cycles (using lower-grade uranium ore) release 12 times more GHGEs than solar cycles and 49 times more GHGEs than wind cycles.[31] Thus, when reactors use lower-grade uranium ores, the full fuel cycle GHGE ratio is 112 coal: 49 natural gas: 49 nuclear: 4 solar: 1 wind. With lower-grade uranium ores, nuclear energy emits 12 times more GHGEs than solar power and 49 times more than wind power. Some scientists even claim that lower-grade uranium ore fuel cycles could require more energy than they produce.[27,32]

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Trimming Comparative Greenhouse Gas Emissions by Ignoring Low-emissions Renewable Energy

If the preceding university data are correct, solar and wind power appear to be more effective (than nuclear energy) at helping to reduce GHGEs. However, most industry, government and even the classic MIT reports analyse comparative GHGEs only from coal, natural gas, petroleum and fission.[1,30] When they use such limited comparative analyses, emissions argument proponents are inconsistent. Claiming that atomic energy releases fewer GHGEs than coal, natural gas and petroleum, they propose increasing the number of reactors in order to reduce climate change risks. However, if their goal is reducing GHGEs, consistency requires that they compare all major low-carbon energy technologies, otherwise trimmed comparative analyses appear to be biased in favour of nuclear power.

It is especially important that GHGE comparisons include all major low-carbon energy technologies because classic Princeton University studies show that more than seven options (including technological efficiencies, conservation, natural gas, wind, solar PV, biomass and hydrogen) could alone cost-competitively ("at an industrial scale") supply as much energy as nuclear tripling. "None of the options is a pipe dream or an unproven idea," say the authors. "Today one can buy electricity from a wind turbine, PV array, gas turbine"; "every one of these options is already implemented at an industrial scale and could be scaled up further over 50 years".[3]

Wind already generates 20% of Danish electricity.[33] By 2020, Britain will use wind to supply six times more (and solar to supply three times more) electricity than that from six proposed new nuclear plants.[27,34] As already mentioned, the US DOE says that wind now costs three times less than nuclear and by 2015 solar PV will be much cheaper than atomic energy.[13,35] By 2005, the annual global growth rate of non-hydro-renewable energy was seven times greater than that of nuclear energy,[36] partly because many renewables are less expensive than nuclear and can be paid off in just 10 years.[37] US government data for the latest year available show that wind energy has been responsible for 60% of annual added new electricity capacity, as measured by peak summer demand.[38] Thus, the market seems to agree that the DOE, Princeton and British studies are correct. Regardless, all other things being equal, scientists should assess and promote the cheapest and least-carbon-intensive energy technologies first. They should not ignore any major technologies.

Consequences of Trimming Nuclear-related Greenhouse Gas Emissions – Undermining Renewable Energy

Nuclear fission not only has higher GHGEs than wind and solar energy, but also may be detrimental to using them. Why? Economic studies show that capital-intensive, heavily subsidised nuclear plants make energy capital scarce and undermine funding for renewable-energy and energy efficiency programmes; as a consequence, they delay more effective and cheaper electricity production technologies for reducing GHGEs.[34]

Germany's Oko Institute shows that wind energy, gas co-generation and energy-efficiency programmes all have negative costs of GHGE avoidance. This is because they either cut energy demand or are cheaper than the electricity they replace, or both.[39] Consistent with the German findings, the pro-nuclear US DOE, the US National Academy of Sciences and the US Office of Technology Assessment all say that using energy efficiencies alone "the US could cut carbon emissions to 1990 levels by 2010 with no net cost to the nation's economy".[40] Thus, one question is why one should promote nuclear energy if it is more expensive and less effective (than many renewable energy technologies) at reducing GHGEs.

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Objections

Of course, GHGEs are not the only consideration relevant to energy choices. Reasonablew energy policies require assessing many conflicting claims, many of which have not been investigated here. Consider several objections to the preceding analysis.

One might object that because renewable energy technologies such as wind and solar energy are intermittent, nuclear power is needed "to generate baseload electricity".[8,41] However, the pro-nuclear UK government says that baseload power is not an issue; intermittency increases wind-generated-electricity costs only by about 6% and wind is already much cheaper than atomic energy.[8] Besides, nuclear power has its own intermittency problems. The UK and US lifetime average nuclear load factors (the percentage of time plants operate compared with 100%) is only 71%.[42] However, the European Renewable Energy Council and Shell Oil say renewables can cost-competitively supply 50% of global energy by 2040–2050.[43,44] The US DOE goes even further, claiming that renewable technology could provide 99% of US electricity by 2020.[45] How? Wind and solar intermittencies can be solved by mixed power sources and wide geographical distributions of energy facilities so that, somewhere, wind is blowing or sun is shining. Offshore winds virtually always blow. Wind is often also available at night, while solar is often available in daytime.[13,33]

A second objection is that if nuclear power is expensive, why have many nations embraced it? History suggests that the US began nuclear-generated electricity for the same reason as China, France, India, Iraq, Israel, Pakistan, South Africa, the Soviet Union, the UK and other nations: "to open a nuclear weapons option".[37] Physicists say that the US had a "not-too-hidden agenda" of using commercial nuclear technology to develop nuclear weapons.[13] US government officials (such as the Chair of the Joint Committee on Atomic Energy) and nuclear scientists (such as J Robert Oppenheimer) admit that the US wanted a 'peaceful' excuse for continued nuclear weapons development.[13]

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Conclusions

Regardless of why nations began pursuing atomic energy, nuclear proponents say more taxpayer subsidies are needed "to demonstrate the economic viability of nuclear" energy.[1] Are they right? The preceding analysis suggests that (because of data trimming, fallacies of composition and inconsistency in nuclear assessments) atomic energy appears to be neither as cost-effective nor as low in GHGEs as many renewable-energy technologies. A remaining question is whether other considerations outweigh the economic and emissions data presented here.[46] ■

For more information please see Kristin Shrader-Frechette's website (www.nd.edu/~kshrader). Several photos are available at www.nd.edu/~shrader/personal/

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