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Climate Change, Nuclear Economics, and Conflicts of Interest

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Abstract Merck suppressed data on harmful effects of its drug Vioxx, and Guidant suppressed data on electrical flaws in one of its heart-defibrillator models. Both cases reveal how financial conflicts of interest can skew biomedical research. Such conflicts also occur in electric-utility-related research. Attempting to show that increased atomic energy can help address climate change, some industry advocates claim nuclear power is an inexpensive way to generate low-carbon electricity. Surveying 30 recent nuclear analyses, this paper shows that industry-funded studies appear to fall into conflicts of interest and to illegitimately trim cost data in several main ways. They exclude costs of full-liability insurance, underestimate interest rates and construction times by using "overnight" costs, and overestimate load factors and reactor lifetimes. If these trimmed costs are included, nuclear-generated electricity can be shown roughly 6 times more expensive than most studies claim. After answering four objections, the paper concludes that, although there may be reasons to use reactors to address climate change, economics does not appear to be one of them.

Keywords Atomic energy · Climate change · Conflicts of interest · Data-trimming · Economics · Electricity · Energy · Global warming · Greenhouse-gas emissions · Nuclear power · Renewable · Solar photovoltaic · Wind

Introduction

For many years bioethicists have recognized that conflicts of interest can skew biomedical research. An *Annals of Internal Medicine* study recently showed that

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98% of papers based on industry-sponsored studies reflected favorably on the industry's products (Rochon et al. 1994). A *Journal of the American Medical* Association article likewise concluded that industry-funded studies were 8 times less likely to reach conclusions unfavorable to their drugs than were nonprofit-funded studies (Campbell et al. 1998). Does something similar happen in electric-utility-related science?

Jonathan Porritt, chair of the UK Sustainable Development Commission and advisor to Gordon Brown, says it does. "Cost estimates from the [nuclear] industry have been subject to massive underestimates—inaccuracy of an astonishing kind consistently over a 40-, 50-year period" (Porritt, Chair of the UK Sustainable Development Commission 2006). A UK-government commission agrees, claiming virtually all nuclear-cost data can be "traced back to industry sources" (UK Sustainable Development Commission (UK SDC) 2006). University of Greenwich business professor, Stephen Thomas, says nuclear-industry sources "are notoriously secretive about the costs they are incurring" (Thomas 2005). Such charges suggest the need to scrutinize industry claims that, to address climate change, nuclear power is "the most cost-effective power source" (European Atomic Forum 2006).

Nuclear-Cost Studies

Apart from who is right about addressing climate change, how good is the science (therefore the ethics) behind studies claiming atomic energy is economical? One answer comes from assessing 30 prominent, international, nuclear-cost studies, all of which are original economic analyses, not merely summaries or derived from earlier nuclear-cost studies (Thomas 2005; World Nuclear Association (WNA) 2005, 2008, 2009; Scully Capital Services Inc. 2002; Du and Parsons 2009; PB Power 2006; Royal Academy of Engineering 2004; Performance and Innovation Unit 2002; Baker Institute for Public Policy 2000; Beutier 2005; Canadian Energy Research Institute (CERI) 2004; Tarjanne and Luostarinen 2002; University of Chicago (U Chicago) 2004; International Energy Agency(IAE)/Nuclear Energy Agency(NEA) 2005; Direction generale de l'energie et des matieres premieres (DGEMP) 2003; OXERA 2005; Department and of Trade, Industry (UK DTI) 2006; Ansolabehere et al. 2003; Deutsch et al. 2009; Lovins et al. 2008; Mariotte et al. 2008; Makhijani 2007; Diesendorf and Christoff 2008; Smith 2006; Thomas et al. 2007; Van Leuwen 2007; Brown 2008; International Atomic Energy Agency (IAEA) 2005; University of Sussex and NERA Economic Consulting (Sussex-NERA) 2006; Madsen et al. 2009). This list of 30 analyses includes all original nuclear-cost studies that are publicly available in scientific journals, books, NGO analyses, industry reports, and government documents since the year 2000. The list appears to be both balanced and comprehensive, as it includes all 7 studies listed and reviewed by the global nuclear-industry lobby group, the WNA or World Nuclear Association (World Nuclear Association (WNA) 2005), namely (Royal Academy of Engineering 2004; Canadian Energy Research Institute (CERI) 2004; Tarjanne and Luostarinen 2002; University of Chicago (U Chicago) 2004;

International Energy Agency(IAE)/Nuclear Energy Agency(NEA) 2005; Direction generale de l'energie et des matieres premieres (DGEMP) 2003; Ansolabehere et al. 2003); all 9 nuclear-cost studies listed and reviewed in a prominent 2006 UK-government report (University of Sussex and NERA Economic Consulting (Sussex-NERA) 2006), namely (Scully Capital Services Inc. 2002; Royal Academy of Engineering 2004; Beutier 2005; Tarjanne and Luostarinen 2002; University of Chicago (U Chicago) 2004; International Energy Agency(IAE)/Nuclear Energy Agency(NEA) 2005; OXERA 2005; Department and of Trade, Industry (UK DTI) 2006; Ansolabehere et al. 2003); and all 12 nuclear-cost studies listed and reviewed in a 2007 Greenpeace International report (Thomas et al. 2007), namely (Scully Capital Services Inc. 2002; PB Power 2006; Royal Academy of Engineering 2004; Performance and Innovation Unit 2002; Baker Institute for Public Policy 2000; Canadian Energy Research Institute (CERI) 2004; Tarjanne and Luostarinen 2002; University of Chicago (U Chicago) 2004; International Energy Agency(IAE)/Nuclear Energy Agency(NEA) 2005; OXERA 2005; Department and of Trade, Industry (UK DTI) 2006; Ansolabehere et al. 2003).

One of the interesting facts about these 30 prominent nuclear-cost studies is that a majority of them appear to trim nuclear-cost data in at least three ways. Subsequent paragraphs argue that a majority of these studies ignore taxpayer subsidies that reduce nuclear costs, ignore reactor-construction times and interest costs associated with nuclear-plant-construction capital, and inflate reactor capacity (or load-factor) and lifetime data.

Taxpayer Subsidies for Nuclear Costs

Consider first the way that most nuclear-cost studies ignore taxpayer subsidies that cover many nuclear costs. The largest of the ignored subsidies is for nuclear insurance. The European Commission (consistent with the WNA and Cato-Institute figures) recently showed that, if commercial reactors had to purchase full-insurance-liability coverage on the market, this would triple nuclear-generated-electricity prices (European Commission (EC) 2003; World Nuclear Association (WNA) 2008; Heyes 2002). Yet a majority of the nuclear-cost studies exclude full-insurance costs, presumably because they are not market costs but mainly government/taxpayer subsidies. Without these subsidies (and liability protection), however, utilities agree they would never use risky atomic energy, e.g. (Scully Capital Services Inc. 2002; Heyes 2002; Spurgeon 2008; Slocum 2008; American Nuclear Society (ANS) 2005; Rothwell 2002; Energy Information Administration (EIA) 1999; Brownstein 1994). Why not? Insurance rates reflect this high risk, given that the government-calculated, lifetime-core-melt probability for all US-commercial reactors is 1 in 5 (Makhijani 2007; Smith 2006; Shrader-Frechette 2007).

Reflecting various responses to this core-melt risk, commercial reactors fall into three camps regarding liability coverage. The vast majority of reactors are in the first camp (e.g., in China, India, Iran, Pakistan), where operator nuclear liability is 0. One-third of reactors (many in western Europe and the US) are in the second camp, where operator liability is minimal. US reactors have the highest (minimal) liability,

$10.8 billion—roughly 1.5% of government-calculated, worst-case-accident damages of $660 billion (Smith 2006; Shrader-Frechette 2007). The third camp includes 13% of reactors (in Germany, Japan, Switzerland), all having government-guaranteed, unlimited liability (World Nuclear Association (WNA) 2008; Schwartz 2006). All countries thus reduce nuclear-industry risks/costs by transferring them to the people, either directly, to those who live nearby, or indirectly, through taxpayer/government subsidies (Energy Information Administration (EIA) 1999).

Because a majority of the 30 nuclear-cost studies (mentioned above) trim taxpayer-subsidized, nuclear-liability-insurance costs from their energy-cost calculations, they may encourage flawed economic signals, inefficient markets, questionable research ethics, and unequal treatment. It seems inconsistent and unethical for assessors to trim (and not disclose) full-nuclear-liability costs that increase taxpayer risks (Heyes 2002; UK Department of Trade and Industry (UK DTI) 2007), while because of the associated financial risks, the US Securities and Exchange Commission requires disclosing lack of nuclear-liability limits to investors (Brownstein 1994).

Trimming Nuclear Costs by Using Only Overnight Costs

A second cost-trimming strategy of most nuclear-cost studies is to assume “overnight” plant-construction-capital costs, currently at least $12 billion in the US (Morris 2008). Overnight costs assume 0 interest rates and 0 construction times. For instance, the WNA states (pp. 5, 20) that “the case for nuclear energy is now solid on economics alone” and that “nuclear is the cheapest option in the majority of countries” (World Nuclear Association (WNA) 2005). Yet to support these claims, the WNA gives only “overnight costs” of nuclear power, costs that exclude construction time, finance charges, and interest charges on construction capital. WNA says (pp. 17–18) current overnight costs are “at and above ‘$2,000 per kW of capacity’ ” and claims these overnight “estimates have been produced by [nuclear-reactor] vendors and their partners”; attempting to justify this cost-trimming assumption of using overnight costs, WNA says “most studies of the competitiveness of nuclear power base their estimates of capital costs on data of construction costs of recent reactors in Asian countries [whose safety standards are weaker than in the West, as later paragraphs show] and use overnight costs” (World Nuclear Association (WNA) 2005).

Likewise, perhaps because official US national policy and the relevant federal agencies are pro-nuclear, even US-government agencies trim cost data on nuclear plants, as the Tennessee Valley Authority did recently. It used (p. 11) “overnight costs only” to quote prices for its reactors (Du and Parsons 2009).

Following most analysts, the authors of the 2009 MIT study also quote (pp. 5–6) total nuclear-plant costs as “overnight costs” and say that “this total [nuclear-power-plant] cost, which is exclusive of financing cost, is $4,706/kW”; noting that the earlier (2003) MIT analyses also compared overnight costs, “as described in the MIT (2003) *Future of Nuclear Power* study,” the 2009 MIT authors attempt to justify their interest-cost-trimming procedures by saying that using overnight costs "represents the standard basis for quoting comparable costs across different plants" (Du and Parsons 2009). Likewise, when the 2009 MIT authors assume a reactor-construction-time period, they again follow the 2003 MIT authors and say (p. 4) nuclear-plant "construction is planned to occur over a 5-year period" (Du and Parsons 2009).

However, most experienced nuclear operators, like Florida Power and Light, say US new-nuclear-plant-construction time is 12 years (Herbst and Hopley 2007), not the 5 years assumed by the MIT authors. Likewise, the US National Academy of Sciences estimates at least 11 years (Smith 2007). The average UK-nuclear-plant-construction time is 11 years (House of Commons Energy Select Committee 1990); in France, 14 years (International Atomic Energy Agency (IAEA) 2007); in Japan, 17 years (Stoett 2003); in Eastern Europe, 15 years (Bunyard 2006; International Energy Agency (IEA) 2001). Nuclear proponents admit that building the latest US reactors took 23 years (Herbst and Hopley 2007).

Trimming nuclear-interest rates to 0 also is misleading. Given plant delays, construction-cost overruns, equipment malfunctions, poor credit ratings, plant cancellations, and energy-market competition, most private investors/banks refuse all nuclear loans (Spurgeon 2008). Those few, that will loan, require 15% minimum-nuclear-interest rates (Thomas 2005; European Bank for Reconstruction and Development 1991, 2000, 2006; International Energy Agency (IEA) 2006; Froggatt 2001). Facing 15% rates, instead industry has successfully lobbied government, so that taxpayers subsidize nuclear-interest rates when markets will not. Proponents admit that in every nation, nuclear power is the most-subsidized energy technology (Herbst and Hopley 2007; Stoett 2003). Industrial-consulting firms showed that during 1947–1999, atomic energy received 96% of $150 billion total US subsidies for nuclear, wind, and solar (Goldberg 2000), and this trend continues (Smith 2006; Blair 2008).

Rather than 15% nuclear-interest rates, the WNA admits "most studies," e.g. (World Nuclear Association (WNA) 2008; Scully Capital Services Inc. 2002; Baker Institute for Public Policy 2000; OXERA 2005; Ansolabehere et al. 2003; Deutsch et al. 2009; Herbst and Hopley 2007; Berry 2007), including those from MIT (Du and Parsons 2009), assume overnight costs, that is, 0 nuclear-interest costs, 0 nuclear-interest rates, and 0 nuclear-construction times (World Nuclear Association (WNA) 2005). Even online, WNA calculations trim nuclear-construction times by excluding all "plants on which construction has stalled" (Thomas 2005). Yet 22 plants currently are under construction, mostly in the developing world, and 12 are "stalled"—suggesting WNA ignores a 35% construction-stoppage probability (Thomas 2005; International Atomic Energy Agency (IAEA) 2007).

What are the effects of interest-and-construction-time trimming? As the 2009 pro-nuclear MIT study warns, capital and financing costs (based on interest rate and construction time) "are the main components of the cost of electricity from new nuclear plants" (Deutsch et al. 2009). Atomic-energy proponents say each 5-year-reactor-construction period increases capital costs 100% (Cravens 2008). Thus, 10-year-nuclear-construction times increase capital costs 200%. Because capital costs are at least 75% of nuclear-operating costs (e.g. UK Sustainable Development Commission (UK SDC) 2006; Herbst and Hopley 2007), using 10-year, not 0-year, construction times increases nuclear-plant-operating costs 150% (0.750) (200). Amortization formulas likewise show that, with a typical 15% interest rate, 15-year loan, and quarterly payments, nuclear-construction costs are now $30 billion—250% higher than $12 billion overnight costs. Unsurprisingly, WNA admits that even low-interest rates double nuclear-construction costs (World Nuclear Association (WNA) 2008).

Trimming Nuclear Costs by Inflating Reactor Load Factors and Lifetimes

A third nuclear-cost-trimming strategy in a majority of the 30 studies is overestimating reactor lifetimes and nuclear-load or capacity factors (or plant output-percentages, compared to 100% output). For instance, the WNA report claims (pp. 21, 10) that nuclear plants "can offer electricity at predictable low and stable costs for up to 60 years of operating life," and that "capacity [or load-] factors of nuclear plants around the world have increased….Levels of 90% and above have been achieved by many plants in Europe and Asia for many years" (World Nuclear Association (WNA) 2005). Likewise the 2009 MIT study presupposes (p. 18) a "capacity factor of 85%" (Du and Parsons 2009). Yet what do actual empirical data say about current reactor lifetimes and nuclear-load factors?

If one assumes perfect plant components, routine refueling/maintenance, and flawless performance, at best reactors can achieve very-short-term, 90% load factors (Herbst and Hopley 2007). During the first 30 years of US-commercial-fission experience (beginning in the 1950s), proponents say nuclear-load-factor averages were 50% (Sweet 2006). With more reactors than other nations, the US has 104 plants. Nuclear proponents say their lifetime-load-factor average is 71% (Herbst and Hopley 2007). UK load factors are similar (Thomas 2005). Only 7 global reactors (1.7% of 414)—mostly those with lax design/standards/enforcement in developing nations—have ever eliminated original "bugs," then later achieved short-term, 90% load factors (Thomas 2005). Although reactor vendors claim a 79%, global-average-load factor, this figure excludes early-retirement (poorly performing) plants and reactors' early years of operation (Thomas 2005; Herbst and Hopley 2007; International Atomic Energy Agency (IAEA) 2007).

Rather than 71 or 79%, however, most nuclear-cost studies, like the WNA and MIT analyses assume 85–95% nuclear-load factors, e.g. (World Nuclear Association (WNA) 2005; Scully Capital Services Inc. 2002; Du and Parsons 2009; PB Power 2006; Royal Academy of Engineering 2004; Canadian Energy Research Institute (CERI) 2004; Tarjanne and Luostarinen 2002; OXERA 2005; Deutsch et al. 2009)—a lifetime-fleet average never achieved by any nation. When the pro-nuclear MIT (see later discussion) and US Nuclear Regulatory Commission studies recently reported US-nuclear-load factors of "about 90%," they admitted this figure covered only the last 5 years, included no new plants, and ignored lifetime-average data and early-shutdown reactors (Deutsch et al. 2009), all of which reveal the correct, lifetime-load average to about 70%. Obviously assessors should use national, lifetime-load averages, not short-term load factors, and neither those for the highest-performing reactors (that likely have deferred maintenance), nor those for the lowest-performing reactors (e.g., 14% load factor for the Fort St. Vrain, Colorado, reactor (Mariotte et al. 2008).

How does trimming nuclear-load factors cut costs? Pro-nuclear MIT scientists (see later discussion) calculate 1–1.5% in ratepayer-price savings per 1% load-factor improvement (Ansolabehere et al. 2003; Deutsch et al. 2009). Using the most common load-factor assumption (90–95%), not the average-US-nuclear-load factor (71%), thus cuts nuclear-ratepayer prices 19–36%.

Costs also drop when assessors lengthen reactor lifetimes. Current plants were designed to last 30 years, and some licenses have been extended longer (Smith 2006). However, the global-average lifetime of the 119 already-closed reactors is 22 years (Schneider 2008). 19 US fission plants (20%) retired before 30 years, and more than $20 billion was spent on 121 plants that were later cancelled (Herbst and Hopley 2007). Thus more US reactors (140) were closed prematurely or cancelled (amid construction) than those (104) now operating.

Rather than 22 years, however, virtually all nuclear-cost studies assume longer reactor lifetimes, partly because (as noted) industry data exclude early-retirement/cancelled plants, e.g. (International Atomic Energy Agency (IAEA) 2007). Some studies assume 60-year lifetimes, e.g. (Tarjanne and Luostarinen 2002); others assume 40, e.g. (World Nuclear Association (WNA) 2008; Scully Capital Services Inc. 2002; PB Power 2006; Royal Academy of Engineering 2004; University of Chicago (U Chicago) 2004; OXERA 2005; Department of Trade and Industry (UK DTI) 2006; International Atomic Energy Agency (IAEA) 2005). To their credit, MIT analyses assumed 25–40 years (Ansolabehere et al. 2003; Deutsch et al. 2009), and one UK-government study assumed 15–30 years (Performance and Innovation Unit 2002). Yet most studies assume operating-lifetimes of 40+ years. The result? The pro-nuclear MIT study calculated that increasing reactor lifetimes, from 25 to 40 years, would reduce overall nuclear-electricity costs 5% (Ansolabehere et al. 2003; Deutsch et al. 2009).

How does data-trimming affect fission-electricity prices? The preceding data show that including full-nuclear-liability-insurance expenses could alone increase atomic-energy costs 300% above most published nuclear-cost estimates—which were above $0.15/kWh in 2008, according to credit-rating firms (Finance 2008), and roughly $0.21/kWh in late 2009 (Lovins et al. 2008). Including full, 15%, not 0, nuclear-interest charges could alone raise costs 188%. Including 10-year, not 0, reactor-construction times could alone increase costs 150%. Using historical-average (71%), not hypothetical (90–95%), nuclear-load factors could raise costs 19–36%. Finally, using actual historical (22 years), not projected (40-year), nuclear-plant lifetimes could increase costs 5%. Provided various cost-increases are independent, this means correcting 5 types of nuclear-data-trimming arguably could increase atomic-energy costs 662–679% (300 + 188 + 150 + (19 − 36) + 5)—far above all published estimates. Yet even this figure may be too low because it excludes expenses such as full nuclear-waste storage, reactor decommissioning, and the 15% annual increase in nuclear-construction costs caused by labor/materials increases (Deutsch et al. 2009).

Studies That Do Not Trim Nuclear Costs

Because so many nuclear-cost analyses appear to trim the data, at least two obvious questions arise. "Do any studies get nuclear costs right?" "What can explain why so many nuclear-cost studies have erred so badly?"

Regarding the first question, many analyses do include complete nuclear costs. For instance, although most studies ignore massive nuclear subsidies, such as that for liability insurance, other studies, done by university professors and by NGOs, include them, e.g. (Thomas 2005; Lovins et al. 2008; Mariotte et al. 2008; Makhijani 2007; Diesendorf and Christoff 2008; Thomas et al. 2007; Van Leuwen 2007; University of Sussex and NERA Economic Consulting (Sussex-NERA) 2006). Authors from the University of New South Wales and the University of Melbourne, for example, claim (p. 2) that nuclear subsidies are "market distortions" and that taxpayer subsidies cover 60–90% of new nuclear-construction costs. In Britain, they say nuclear subsidies are about $2.6 billion annually. As a result, they note that "ignoring the huge subsidies from government to nuclear energy also makes the technology look less expensive," despite the fact that "the current economics of nuclear power make it an unattractive option for new generating capacity" (Diesendorf and Christoff 2008).

Similarly, regarding trimming interest costs and construction, many studies done by NGOs and by university professors note that "choosing an unrealistically low-interest or discount rate can make nuclear energy look much less expensive" (Campbell et al. 1998; Diesendorf and Christoff 2008). These authors avoid using only overnight costs (Thomas 2005; Lovins et al. 2008; Mariotte et al. 2008; Makhijani 2007; Diesendorf and Christoff 2008; Thomas et al. 2007; Van Leuwen 2007; University of Sussex and NERA Economic Consulting (Sussex-NERA) 2006). Instead they use full market-interest rates for nuclear construction, in part because many of them obtain data from banks and from Standard and Poor's, Moody's, and other credit-rating agencies. As one University of California, Berkeley, engineering Ph.D. claims (p. 169), nuclear plants "pay more on the margin for credit. Federal support of construction costs will do little to change that reality" (Makhijani 2007).

Likewise, regarding inflating load factors and nuclear-plant lifetimes, many university and NGO studies use historical-average load factors and nuclear-plant lifetimes. For instance, one Technical University of Eindhoven scholar criticizes (p. 9) the "very long operational lifetime [of a nuclear plant], as MIT proposes" in its nuclear-cost analyses (Van Leuwen 2007). He says (p. 37) instead that "only a few reactors in the world reached an operational lifetime of 24.6 FPY [full power years] today. Extensive refurbishments are required to reach even this lifetime….The reliability of the reactor vessel determines the operational lifetime of a NPP. The quality of the vessel deteriorates over time by corrosion and neutron capture" (p. 32). Thus (pp. 43, 54) "the lifetime of one reactor," even with extensive refurbishment, is "30–40 years" at best; "the average operational lifetime of the reactors to be decommissioned on the list of the UK Nuclear Decommissioning Authority…is 18.7 FPY" (Van Leuwen 2007).

As the previous examples show, a number of nuclear-cost studies appear to provide more reliable cost figures, based on historical-average data, bank estimates, and credit-rating figures. Some of the reliable data in these empirically based studies are difficult to obtain, however, for reasons that become clear, once we address the second question.

What May Explain Nuclear-Cost-Data-Trimming

Regarding the second question, what can explain why so many studies have erred so badly in underestimating nuclear-electricity costs? One reason is that current turnkey or fixed-price data for constructing nuclear plants are not available because no nuclear utilities have been willing to build turnkey plants, as they did with the earliest reactors; nuclear proponents say (p. 136) this is because every nuclear utility has had cost and construction-time overruns on all nuclear plants, and because every utility has lost money on turnkey plants (Morris 2008). Instead, nuclear "cost-plus" contracts have been the norm (MacKerron and 2007). Yet, given various types of cost overruns, it can be difficult to retrieve and account for all construction costs. A recent report by the US Congressional Budget Office revealed (p. 17) that average-US-nuclear-plant-cost overruns have been 207%; the reactors cost triple what was initially claimed (US Congressional Budget Office (US CBO) 2008). Although the Finnish reactor (now being built by the French-government-owned company Areva) is a turnkey plant, it is largely taxpayer subsidized (including interest); although it has had slightly more than 3 years of construction, by 2007 it already was 50% over budget and 3 years late (Lovins et al. 2008; Mariotte et al. 2008; Thomas et al. 2007, 2008). Yet this and another Areva plant are the only latest-design nuclear plants under construction in Western Europe or North America.

A second reason a majority of nuclear-economics studies may have underestimated costs is that nuclear utilities pay different groups for various nuclear-related components, at different stages of the nuclear fuel cycle. These different payments may cause confusion and allow for misstatement of costs. For instance, when a utility applies to build a nuclear plant or tries to show its cost-competitiveness, the utility quotes highly trimmed economic data that typically omit many charges, e.g., interest, transmission-system upgrades, none of which are paid to the reactor vendor. These trimmed data are (pp. 4–6) "how the cost is typically quoted by the [nuclear plant] vendor"; however, once the plant is built and ready to generate power, the utility quotes much higher costs to the Public-Service Commission, including inflation, interest, upgrades, cost overruns, etc., because "the regulated utility will be allowed [by the commission] to recover this total cost through customer charges." Yet as revealed earlier, interest charges alone double "the [nuclear-plant] vendor's EPC [engineering, procurement, and construction] overnight cost" that was quoted before the plant was built (Du and Parsons 2009). Moreover, the trimmed nuclear-cost figures, submitted to the commission to gain its approval to build a plant, typically have (p. 14) "all detailed information about this cost figure" redacted from the filings (Du and Parsons 2009). Thus nuclear-price data may be underestimated because they are quoted in different ways, depending on their audience and their use (either to convince utilities to purchase allegedly low-cost plants, or to convince public-service commissions to allow recovery from ratepayers of full nuclear costs.

A third reason for nuclear-cost underestimates is that the norm, for industry-provided, nuclear-price quotations is to trim cost data, probably because it is in the vendor's financial interest to underestimate nuclear costs, in order to sell reactors. As already mentioned, the 2009 MIT authors say (pp. 5–6, 14) that using overnight costs "represents the standard basis for quoting comparable costs across different plants"; they are "how the cost is typically quoted by the [nuclear plant] vendor" (Du and Parsons 2009). Given this norm and earlier comments on different nuclear audiences and data uses, there are no universally accepted, canonical studies for how every nuclear-cost analysis ought to be performed and what it ought to include.

Moreover, a fourth reason for underestimated nuclear costs is that many industry analyses do not make clear precisely what is included/excluded from their cost tabulations. Because of this fact, and because the nuclear industry controls most of the data, cost misrepresentation seems more likely. For instance, one prominent UK-government study, done at the University of Sussex, noted (p. 19) that although industry-funded studies (like Scully Capital Services Inc. 2002; University of Chicago (U Chicago) 2004; International Energy Agency(IAE)/Nuclear Energy Agency(NEA) 2005) exclude financing and other costs, often "it is not known" (e.g., in the pro-nuclear Finnish analysis (Tarjanne and Luostarinen 2002)), what costs are included or excluded (UK Sustainable Development Commission (UK SDC) 2006). Consequently, the Sussex University researchers noted (pp. 11–12) that even government nuclear-cost reports, e.g. (Department and of Trade, Industry (UK DTI) 2006) "leave no clear audit trail" (UK Sustainable Development Commission (UK SDC) 2006). Scientists from the University of Melbourne and the University of New South Wales agreed. They said (pp. 2–3) "published [nuclear] capital-cost estimates…derive from studies…from vendors of reactor systems….The data are supplied…by the nuclear industry itself and are not open to objective verification" (Diesendorf and Christoff 2008). More generally, the same Sussex University authors (of a UK-government report) criticize (p. 4) the "[cost] appraisal optimism" of most nuclear studies; under the heading of "capital costs," they note that "all of the [nuclear-capital cost] data is traced back to industry sources, usually reactor vendors, and the number of these sources is very few….Reactor vendors inevitably and legitimately have an interest in presenting costs in a way that maximizes their chances of commercial success" (UK Sustainable Development Commission (UK SDC) 2006).

A fifth reason for underestimated nuclear costs is that nearly all studies are either performed or funded by the nuclear industry, which has a financial incentive for minimizing costs. Of the 30 recent nuclear-cost studies analyzed here, at least 18 (World Nuclear Association (WNA) 2005, 2008, 2009; Scully Capital Services Inc. 2002; Du and Parsons 2009; PB Power 2006; Royal Academy of Engineering 2004; Performance and Innovation Unit 2002; Baker Institute for Public Policy 2000; Beutier 2005; Canadian Energy Research Institute (CERI) 2004; Tarjanne and Luostarinen 2002; University of Chicago (U Chicago) 2004; International Energy Agency(IAE)/Nuclear Energy Agency(NEA) 2005; Direction generale de l'energie et des matieres premieres (DGEMP) 2003; Department and of Trade, Industry (UK DTI) 2006; Ansolabehere et al. 2003; Deutsch et al. 2009; International Atomic Energy Agency (IAEA) 2005) of the 30 studies—60%—have clearly been either performed by or funded by the nuclear industry or by pro-nuclear (see later analyses) government committees, such as the US DOE. The cost studies *performed* by the nuclear industry itself include (World Nuclear Association (WNA) 2005, 2008, 2009; PB Power 2006; Royal Academy of Engineering 2004; Beutier 2005; Canadian Energy Research Institute (CERI) 2004; International Energy Agency(IAE)/Nuclear Energy Agency(NEA) 2005; International Atomic Energy Agency (IAEA) 2005). Those at least partly *funded* by the nuclear industry include (Du and Parsons 2009; Baker Institute for Public Policy 2000; Tarjanne and Luostarinen 2002; Ansolabehere et al. 2003; Deutsch et al. 2009). The cost studies funded by pro-nuclear government agencies, like the US DOE, include (Scully Capital Services Inc. 2002; Performance and Innovation Unit 2002; University of Chicago (U Chicago) 2004; Department and of Trade, Industry (UK DTI) 2006; Ansolabehere et al. 2003; Deutsch et al. 2009). For instance, the 2009 MIT study (Du and Parsons 2009) points out quite clearly (p. v) that it has been funded by the utility lobby group EPRI and by INEEL. Hence it is not surprising that these MIT authors later emphasize (p. 10): "It bears repeating, however, that none of the figures reported [by the nuclear industry] for these [nuclear] plants represent actual costs" (Du and Parsons 2009). Instead all of the cost figures are too low and have trimmed data.

A sixth reason for underestimated nuclear costs may be a consequence of the fifth reason (the fact that most nuclear-cost studies are funded/performed by the nuclear industry). This consequent reason is that nuclear-cost assumptions are often claimed to be privileged information and thus kept secret by the industry; or, if they are reported, they typically are counterfactual and favorable to the industry. Regarding the secrecy of assumptions, recall that the 2009 MIT authors reported earlier that, in Public-Service Commission filings, before nuclear-plant approval, nuclear-industry-cost figures (e.g., those provided by Georgia Power in 2009, when it considered building two nuclear plants) typically have (p. 14) "all detailed information about this cost figure" redacted (Du and Parsons 2009), despite the fact that taxpayers subsidize nuclear-electricity costs and ratepayers cover the remainder. Likewise a recent University of Greenwich nuclear-cost study noted (p. 25) that, for industry-performed or industry-funded studies, e.g. (Du and Parsons 2009; Tarjanne and Luostarinen 2002), "many of the [cost] assumptions are not fully specified, being classified as commercially sensitive" (Thomas 2005). The same university researcher charges (p. 26) that one pro-nuclear UK-government-commission study (Performance and Innovation Unit 2002) merely "reports the forecasts provided by [two nuclear companies,] British Energy and BNFL" and "uses BNFLs assumptions…[although] many of the assumptions, such as for construction cost, are categorized as commercially sensitive and not published….On load factor, the figures are also confidential, although the PIU (Performance and Innovation Unit 2002) states the assumed performance is significantly higher than 80%" (Thomas 2005). Yet, as already noted, actual, historical-average nuclear-load factors are 70%—not "significantly higher than 80%," as cited by the pro-nuclear government study. Another UK-government report, done by researchers at the University of Sussex, but not funded by the nuclear industry, says (p. 110) that many industry-dominated studies—including the earlier, pro-nuclear, UK-commission report (Performance and Innovation Unit 2002)—use nuclear-industry data but keep them confidential, to protect the industry (UK Sustainable Development Commission (UK SDC) 2006). For instance, the UK Royal Academy of Engineering report (Royal Academy of Engineering 2004), done by nuclear-industry contractors, PB Power (2006), states (p. 27) that "an allowance for [reactor] decommissioning cost is included in the capital cost, but it does not specify cost assumptions" (Thomas 2005). Both this Royal Academy report (Royal Academy of Engineering 2004) and the PB Power (2006) studies are based on Finnish nuclear-industry data (Tarjanne and Luostarinen 2002), but even MIT-based, nuclear-industry contractors admit (p. 9) that "there is no detail on what is included in this [Finnish cost] figure, and so it must be handled carefully" (Du and Parsons 2009). Such cost-concealments could be used to underestimate nuclear costs, particularly because they (pp. 11–12) "leave no audit trail" (UK Sustainable Development Commission (UK SDC) 2006). As the same UK-government report (UK Sustainable Development Commission (UK SDC) 2006) also emphasized, many studies (p. 19) "provide estimates of the overall generating cost of electricity using their own input assumptions," but "because [many industry-funded] published studies do not show the precise method by which different input costs are translated into generating costs, and because the assumptions made will vary and be of differing methodological quality, it is not possible" to evaluate their robustness (UK Sustainable Development Commission (UK SDC) 2006).

Moreover, when secret cost assumptions are revealed, typically they are counterfactual and favorable to the nuclear industry. For instance, in the industry-funded, Finnish, nuclear-cost study (Tarjanne and Luostarinen 2002), done at Lappeenranta University of Technology, the authors assume a counterfactual 5 (rather than the empirical 15) percent interest rate, as already mentioned. They assume a counterfactual 91 (rather than the historical-average 71) percent load factor, as already mentioned, and they assume a counterfactual 60 (rather than the historical-average 22) year lifetime, as already mentioned. Partly as a consequence of these counterfactual assumptions, the study (Tarjanne and Luostarinen 2002) arrives at low-nuclear-power costs. Nevertheless, as already mentioned, the Royal Academy (Royal Academy of Engineering 2004) and PB Power (2006) studies accept these implausible Finnish assumptions and their confidential data.

What do the preceding 6 reasons for possible nuclear-cost-study underestimates suggest? Recall that these reasons include (i) the *absence of fixed-price or turnkey reactor contracts,* that would reveal actual nuclear-plant costs, (ii) the *price discrepancy* between vendor-quoted, versus utility-quoted (to the Public-Service-Commission) nuclear costs, (iii) the vendor and industry *standard practice* of quoting trimmed prices, in the face of no canonical nuclear-cost studies, (iv) the fact that most *nuclear-cost data* are from the industry, without independent confirmation and detail about what is included/excluded, (v) the fact that most *nuclear-cost studies* are either funded by, or performed by, nuclear interests, and (vi) the fact that most nuclear-cost studies use *counterfactual assumptions* and confidential assumptions. The preceding reasons, especially (iv)–(vi), suggest that financial conflicts of interest (COI) also may help explain nuclear-cost underestimates.

Possible Conflicts of Interest (COI) in Nuclear-Cost Studies

To investigate whether financial COI appear to be at least partly responsible for some nuclear-cost underestimates, one needs to understand, at least, what constitutes a COI, (i) whether the nuclear-cost studies funded/performed by nuclear interests appear to be those that typically trim cost-data, and (ii) whether the studies, that are not known to be funded by nuclear interests, appear to be those that typically do not trim cost data. If the answers to (i) and (ii) are negative, then no COI may be involved in nuclear-cost studies. However, if the answers to (i) and (ii) are positive, then COI may be occurring. Although complete conclusions require a more extensive analysis than can be given here, this paper can provide some tentative, preliminary answers to (i) and (ii).

Consider first the nature of a COI. As defined (p. 6) in a classic 2009 US National Academy of Sciences report (Lo et al. 2009), "conflicts of interest are defined as *circumstances that create a risk that professional judgments or actions regarding a primary interest will be unduly influenced by a secondary interest*. Primary interests include promoting and protecting the integrity of research," the quality of scientific education, and the welfare of the public, whereas "secondary interests include not only financial interests…but also other interests, such as the pursuit of professional advancement." What happens when one applies this COI definition to nuclear-cost studies that are performed/funded by nuclear interests? The circumstances of the nuclear industry's performing/funding nuclear-cost studies (whose results could affect industry profits)—may "create a [COI, a] risk that professional judgments or actions regarding a primary interest," scientific integrity, may be "unduly influenced by a secondary interest," nuclear-industry financial interest.

To assess whether a nuclear-related COI may be involved in these 30 studies, consider the two questions just stated. (i) Are nuclear-cost studies, funded/performed by the nuclear industry, the ones that typically trim cost data? (ii) Are nuclear-cost studies, not known to be funded by the nuclear industry, the ones that typically do not trim cost data?

Regarding question (i), the preceding section of this paper showed that, of the 30 recent nuclear-cost studies, at least 18 analyses (World Nuclear Association (WNA) 2005, 2008, 2009; Scully Capital Services Inc. 2002; Du and Parsons 2009; PB Power 2006; Royal Academy of Engineering 2004; Performance and Innovation Unit 2002; Baker Institute for Public Policy 2000; Beutier 2005; Canadian Energy Research Institute (CERI) 2004; Tarjanne and Luostarinen 2002; University of Chicago (U Chicago) 2004; International Energy Agency(IAE)/Nuclear Energy Agency(NEA) 2005; Direction generale de l'energie et des matieres premieres (DGEMP) 2003; Department and of Trade, Industry (UK DTI) 2006; Ansolabehere et al. 2003; Deutsch et al. 2009; International Atomic Energy Agency (IAEA) 2005)—60%—have clearly been performed/funded by the nuclear-industry/pro-nuclear government committees (see later analyses), such as the US DOE—and that many of these studies trimmed the cost-data in various ways. Regarding question (ii), Section 6 of this paper showed that many nuclear-cost studies—that are done by university groups/non-governmental organizations (NGOs) that are not funded by the nuclear industry—appear to include most/all relevant nuclear costs and do not trim them. Building on this already-presented information, one can divide the 30 nuclear-cost studies into 4 groups, A–D, based on who funds them and what cost data they include or exclude. (Some studies do not list their funders, and they are categorized as such.)

- Group A (nuclear funders, pro-nuclear stance) consists of 18 analyses (World Nuclear Association (WNA) 2005, 2008, 2009; Scully Capital Services Inc. 2002; Du and Parsons 2009; PB Power 2006; Royal Academy of Engineering 2004; Performance and Innovation Unit 2002; Baker Institute for Public Policy 2000; Beutier 2005; Canadian Energy Research Institute (CERI) 2004; Tarjanne and Luostarinen 2002; University of Chicago (U Chicago) 2004; International Energy Agency(IAE)/Nuclear Energy Agency(NEA) 2005; Direction generale de l'energie et des matieres premieres (DGEMP) 2003; Department and of Trade, Industry (UK DTI) 2006; Ansolabehere et al. 2003; Deutsch et al. 2009; International Atomic Energy Agency (IAEA) 2005) that (to varying degrees) are pro-nuclear—and have been either performed by, or at least partly funded by, the nuclear-industry/pro-nuclear government agencies, like the US DOE.
- Group B (unknown funders, pro-nuclear stance) consists of 1 nuclear-cost analysis (OXERA 2005) that is pro-nuclear and whose funders are unknown because the study does not mention them.
- Group C (nonprofit-NGO funders, anti-nuclear stance) consists of 4 nuclear-cost studies (Lovins et al. 2008; Mariotte et al. 2008; Makhijani 2007; Madsen et al. 2009) that are critical of high nuclear costs and whose funders are nonprofit NGOs.
- Group D (university funders, anti-nuclear stance) consists of 7 nuclear-cost studies (Thomas 2005; Diesendorf and Christoff 2008; Smith 2006; Thomas et al. 2007; Van Leuwen 2007; Brown 2008; University of Sussex and NERA Economic Consulting (Sussex-NERA) 2006) that are critical of high nuclear costs and whose (at least partial) funders are universities, given that the lead authors of these studies are/were employed by universities.

Group A: 18 Studies with Nuclear Funders and a Pro-Nuclear Stance

One interesting fact about the Group A studies (World Nuclear Association (WNA) 2005, 2008, 2009; Scully Capital Services Inc. 2002; Du and Parsons 2009; PB Power 2006; Royal Academy of Engineering 2004; Performance and Innovation Unit 2002; Baker Institute for Public Policy 2000; Beutier 2005; Canadian Energy Research Institute (CERI) 2004; Tarjanne and Luostarinen 2002; University of Chicago (U Chicago) 2004; International Energy Agency(IAE)/Nuclear Energy Agency(NEA) 2005; Direction generale de l'energie et des matieres premieres (DGEMP) 2003; Department and of Trade, Industry (UK DTI) 2006; Ansolabehere et al. 2003; Deutsch et al. 2009; International Atomic Energy Agency (IAEA) 2005)—that are funded/performed by nuclear interests—is not only that they represent most (60%) of the nuclear-cost studies, 18 of 30, but also that typical industry, government, and NGO groups appear to take these pro-nuclear, largely industry-funded studies as dominant. For instance, a classic UK-government report (UK Sustainable Development Commission (UK SDC) 2006) lists only 9 nuclear-cost studies (Scully Capital Services Inc. 2002; Royal Academy of Engineering 2004; Beutier 2005; Tarjanne and Luostarinen 2002; University of Chicago (U Chicago) 2004; International Energy Agency(IAE)/Nuclear Energy Agency (NEA) 2005; OXERA 2005; Department and of Trade, Industry (UK DTI) 2006; Ansolabehere et al. 2003), all performed/funded by nuclear interests. The World Nuclear Association, a global nuclear-industry-lobby group, lists only 7 nuclear-cost studies (Royal Academy of Engineering 2004; Canadian Energy Research Institute (CERI) 2004; Tarjanne and Luostarinen 2002; University of Chicago (U Chicago) 2004; International Energy Agency(IAE)/Nuclear Energy Agency(NEA) 2005; Direction generale de l'energie et des matieres premieres (DGEMP) 2003; Ansolabehere et al. 2003)—and, again, all these studies were performed/funded by nuclear interests. Even environmental-group studies, like those of Greenpeace (Thomas et al. 2007), list only 12 nuclear-cost studies (Scully Capital Services Inc. 2002; PB Power 2006; Royal Academy of Engineering 2004; Performance and Innovation Unit 2002; Baker Institute for Public Policy 2000; Canadian Energy Research Institute (CERI) 2004; Tarjanne and Luostarinen 2002; University of Chicago (U Chicago) 2004; International Energy Agency(IAE)/Nuclear Energy Agency(NEA) 2005; OXERA 2005; Department and of Trade, Industry (UK DTI) 2006; Ansolabehere et al. 2003)—and all of them were performed/funded by nuclear interests. Thus, not only do most nuclear-cost studies appear to be performed/funded by pro-nuclear interests, but government, industry, and even environmentalists appear to take these studies as dominant.

Other interesting facts about these 18 studies are that all of them (a) appear to include no nuclear-cost data from credit-rating agencies, (b) appear to include no nuclear-cost data that include taxpayer nuclear subsidies, and (c) appear to use uncorrected, nuclear-industry-supplied cost data and assumptions that seem to contribute to overly optimistic conclusions about nuclear economics. To see the apparent flaws (a)-(c) in a typical Group A study, consider the 2009 MIT atomic-energy-cost analysis (Du and Parsons 2009).

On the positive side, as already mentioned, the 2009 MIT authors admit (p. v) their work is funded by the nuclear industry (Du and Parsons 2009), and they note (p. 11) that, because of cost-data-trimming, "none of the figures reported [by the nuclear industry] for these [nuclear] plants represent actual costs" (Du and Parsons 2009). These MIT authors also deserve credit for (pp. 10, 14, 15, iii) blowing the whistle on nuclear-industry failure to report actual costs, on industry secrecy about assumptions used to calculate costs, on overly optimistic nuclear-cost calculations, and on the doubling of overnight nuclear-construction costs between 2003 and 2008 (Du and Parsons 2009).

Despite these strengths, however, the industry-funded, 2009 MIT authors ignore problem (a), the high costs of nuclear energy calculated by credit-rating companies—and the challenges that (a) provides to their conclusions. Instead they follow overly optimistic, nuclear-industry assumptions that lead to low-nuclear-energy-cost conclusions, as will be shown below.

Regarding problem (b), excluding taxpayer-subsidy data from their nuclear-cost analyses, the 2009 MIT authors fail to take account of the many taxpayer subsidies that significantly reduce nuclear costs. They say (p. 9) their analysis "does not include any of the benefits from the production tax credits or loan guarantees…of 2005," that is, a specific class of 2005 US taxpayer subsidies (Du and Parsons 2009). Yet, they ignore the fact that their analysis incorporates many other cost subsidies which artificially lower their calculated nuclear-electricity costs. If the late MIT physicist Henry Kendall is correct (p. 131), US nuclear-power subsidies amount to about $20 billion annually (Shrader-Frechette 2002)—all of which are ignored by the MIT authors in their cost analysis. For instance, they ignore the billions of dollars in taxpayer subsidies needed for nuclear-waste storage, perhaps because these are not market costs. Instead the 2009 MIT authors assume (p. 21) that the total costs of spent fuel and waste disposal will be only "the statutory fee of 1 mil/kWh currently charged" by government to the utility (Du and Parsons 2009), which, over the last 10 years, amounts to only $5 billion total (Shrader-Frechette 2002). Given the average, 22-year lifetime of nuclear plants (see above), this statutory fee means the total collected from current US nuclear plants amounts to roughly $11 billion. Yet this is only a tiny portion of permanent waste-storage costs, most of which will be borne by taxpayers, per government agreement (Shrader-Frechette 2002; Congress 1999). While the nuclear industry would pay this $11 billion (which MIT authors have assumed are total US nuclear-waste costs), government and US National Academy of Sciences studies in 1996 placed the real US nuclear-waste-management costs at roughly $350 billion (US National Research Council 1996), and these costs have now risen to $1 trillion (Shrader-Frechette 2002; Congress 1999), most of which will be paid by taxpayers. Thus the MIT authors may be counting, as total nuclear-waste costs, only between 1% (assuming $1 trillion is needed) and 3% (assuming $350 billion is needed) of the total monies needed for US nuclear-waste management, because they ignore taxpayer nuclear-waste-management subsidies. More generally, the MIT authors (Du and Parsons 2009) assume that nuclear electricity includes no taxpayer-subsidized costs, although "federal subsidies cover 60–90% of the generation cost for new nuclear plants" (Lovins et al. 2008). As already documented, US federal nuclear subsidies have already amounted to about $150 billion. The MIT failure to take account of nuclear subsidies in nuclear costs is especially troublesome because utility executives say (p. 17) that because nuclear plants are so uneconomical, "without [low-interest, taxpayer-subsidized] loan guarantees, we will not build nuclear plants" (Madsen et al. 2009).

Regarding problem (c), the 2009 MIT authors also use mainly uncorrected nuclear-industry data, and they make many counterfactual nuclear-cost assumptions, the effect of which is to lower nuclear-cost estimates. They assume, for instance, that "the total cost" of a nuclear plant does not include financing or interest charges on construction capital, although they admit that utilities are allowed to recover these costs from ratepayers (pp. 4–6), and although they and earlier paragraphs (of this paper) showed that financing costs at least double nuclear-construction costs (Du and Parsons 2009). They also assume (p. 4) that nuclear-plant construction takes only 5 years (Du and Parsons 2009), although earlier paragraphs show historical-average nuclear-plant-construction time is 10–23 years. Likewise, the MIT authors assume (p. 18) that a nuclear-load or "capacity factor of 85%" is reasonable (Du and Parsons 2009), although earlier paragraphs showed that historical-average capacity factors are 71%. Likewise, the 2009 MIT authors assume (pp. 16, 19) that the annual inflation rate for future nuclear construction will be 3%, although they admit that, over the last 5 years, annual nuclear costs have increased by 23% per year (Du and Parsons 2009). They also assume (p. 22) that for nuclear energy, "the costs of capital [are] equal to those for coal." Yet this assumption appears wholly unrealistic, given that market-interest rates for nuclear loans, as already mentioned, are 15%, whereas coal loans are only about 25% of that figure. Moreover, as already noted, nuclear interest can add 250% to overnight reactor costs whereas, on the admission of the 2009 MIT authors, coal-plant interest charges add only roughly 17–21% to coal-plant overnight costs (Du and Parsons 2009). The MIT authors likewise assume (p. iii) that it is rational for them to claim to "update the cost of nuclear power," when their calculations of nuclear-electricity costs are only roughly half of those calculated by credit-rating firms like Standard and Poor's and Moody's (Du and Parsons 2009; Mariotte et al. 2008; Finance 2008). Moody's says that, even from 2008 to 2009, it has taken "a more negative view for those issuers seeking to build new nuclear power plants" because of "the substantial execution risks involved" (Moody's Corporate Finance 2009). The discrepancy between MIT and credit-rating-company figures arguably should have caused the 2009 MIT authors to question their industry-friendly economic assumptions that contributed to their low-nuclear-cost conclusions.

The earlier 2003 MIT nuclear-cost analysis (Ansolabehere et al. 2003) likewise was at least partly funded by the nuclear industry and perhaps, as a consequence, fell into similar counterfactual assumptions about nuclear costs. This study claims (p. vii) to be funded by the "Alfred P. Sloan Foundation,…MITs Office of the Provost, and [the MIT] Laboratory for Energy and the Environment" (Ansolabehere et al. 2003). However, "funding for this [laboratory that sponsored the] work comes from a variety of sources, including DOE, EPRI….INEEL" (MIT Laboratory for Energy and the Environment (LEE) 2003). Like the 2009 MIT studies, this one (a) appears to include no nuclear-cost data from credit-rating agencies, (b) appears to include no nuclear-cost data that include taxpayer-provided subsidies, and (c) appears to use uncorrected, nuclear-industry-supplied cost data. Regarding (b), this 2003 MIT report criticizes (p. 43) nuclear subsidies, yet proposes (p. 8) additional "modest" US subsidies for nuclear power, but then excludes (p. 82) the value of taxpayer subsidies from its cost accounting of nuclear power (Ansolabehere et al. 2003). Likewise, regarding (c), the MIT analysis assumes that nuclear-plant construction takes only 5 years (Ansolabehere et al. 2003), although earlier paragraphs showed historical-average nuclear-plant-construction time is 10–23 years. It assumes a nuclear-load-factor of 85% (Ansolabehere et al. 2003), although earlier paragraphs showed that historical-average load factors of 71%. Likewise, the 2003 MIT study assumes an 11.5 interest rate, although earlier paragraphs showed that 15% is the market rate. It assumes a 40-year lifetime for nuclear plants, although (as noted earlier) the historical-average lifetime is 22 years. Thus, these implausible and counterfactual nuclear-industry assumptions appear to have compromised the

MIT nuclear-energy-cost analyses. What about the other 12 nuclear-cost studies, those not known to be performed/funded by nuclear interests?

Group B: One Nuclear-Cost Study with Unknown Funders that Uses Uncorrected Industry Data

Group B studies consist of one nuclear-cost analysis (OXERA 2005), done by Oxera Consultants in the UK, whose funders are unknown (the study does not reveal them). Like the group A analyses, those in Group B (a) appear to include no nuclear-cost data from credit-rating agencies, (b) appear to include no nuclear-cost data that takes account of taxpayer nuclear subsidies, and (c) appear to use uncorrected, nuclear-industry-supplied cost data.

Regarding (a), the Oxera study says nothing about the high costs of nuclear power that are documented by credit-rating companies and that contradict the optimistic Oxera conclusions. Regarding (b), the Oxera analysis also fails to include any of the billions of dollars in subsidies that taxpayers have supplied to the nuclear industry. Instead, the Oxera authors say (p. 4) only that "economic investment [in nuclear power in the future] is likely to require government support" (OXERA 2005). Regarding (c), the Oxera study merely uses, and fails to correct, industry-based data and assumptions regarding costs of nuclear power. Its authors admit (p. 2) that their data/assumptions are "according to industry sources" (OXERA 2005). They specifically cite (p. 5) Westinghouse, one of the major global nuclear suppliers, as a source of their "related assumptions" (OXERA 2005). Hence, it is not surprising that, without any justification, the Oxera authors use (p. 3) the uncorrected nuclear-industry assumption that nuclear-load factor is 95% (OXERA 2005), although the historical-average nuclear-load factor is 71%, as shown earlier in this analysis. They also assume (p. 3) that the "cost inflation per year" for reactors is 2% (OXERA 2005), rather than the 23%, which has been the annual rate for the nuclear industry over the last 5 years (Du and Parsons 2009). Likewise, Oxera authors assume (p. 2) that "it takes at least 4 years for any reactor to be built and made operational" (OXERA 2005), not the historical-average 10–23 years, as shown earlier. Finally, Oxera authors assume (p. 3) that the "guaranteed debt interest rate" is 5% (OXERA 2005), rather than the 15% that is standard in the market for nuclear plants, as shown earlier. Given all these industry assumptions that minimize nuclear costs, it is not surprising that the Oxera study concludes (p. 4) that "the potential investment in nuclear new build is likely to bring positive returns" (OXERA 2005). What about other nuclear-cost studies?

Group C: Four Studies with NGO Funders and Completely Corrected Industry Cost Data

Group C analyses consist of four nuclear-cost studies (Lovins et al. 2008; Mariotte et al. 2008; Makhijani 2007; Madsen et al. 2009) whose funders are nonprofit NGOs, not nuclear interests. Group C includes a study (Lovins et al. 2008) from the nonprofit think-tank, the Rocky Mountain Institute (RMI). Regarding its funders, RMI claims that "half our support comes from individual donors and foundation grants…. The other half comes from earned revenue—from consulting for corporations and governments" (Rocky Mountain Institute (RMI) 2009). A second study (Mariotte et al. 2008), coming from the nonprofit NGO, Nuclear Information and Research Service (NIRS), says that says it relies on "contributions from citizens across the world to support our efforts" (Nuclear Information and Resource Service (NIRS) 2009). A third study (Makhijani 2007) comes from the nonprofit think-tank, the Institute for Energy and Environmental Research (IEER). The IEER website says IEERs work is "supported by grants from foundations, concerned individuals and public-interest consulting contracts. Foundation funders include Colombe Foundation, Ford Foundation, Livingry Foundation, New-Land Foundation, Ploughshares Foundation, Stewart R. Mott Charitable Trust, Town Creek Foundation, and the Wallace Global Fund" (Institute for Energy and Environmental Research 2009). The fourth study (Madsen et al. 2009) in this group is funded by the Maryland Public Interest Research Group or PIRG.

To see how differently nonprofit NGOs approach questions of nuclear-power costs, consider that all four of the group C studies (a) include nuclear-cost data from credit-rating agencies, (b) include nuclear-cost data that takes account of taxpayer nuclear subsidies, and (c) use completely corrected, nuclear-industry-supplied cost-data. For instance, consider the 2008 study done by the nonprofit NGO, RMI (Lovins et al. 2008).

Regarding (a), including nuclear-credit-rating data, the RMI study (p. 1) acknowledged the poor credit ratings of nuclear power and argued that "the private capital market isn't investing in new nuclear plants, and without financing, capitalist utilities aren't buying" (Lovins et al. 2008). Instead, said the study, poor credit ratings for nuclear plants mean that "the few [reactor] purchases, nearly all in Asia, are all made by central planners with a draw on the public purse" (Lovins et al. 2008). The RMI study also shows (p. 2) that, when one relies on "evidence-based studies" of nuclear costs, like those done by Moody's and Standard and Poor's, the capital costs of nuclear-generated electricity are more than 3 times higher than the estimated costs of the MIT study, which relies on industry data (Lovins et al. 2008).

Regarding (b), including taxpayer-subsidy data, the RMI study (p. 1) notes that even massive government subsidies have failed to make nuclear energy cost-effective, and that, once all taxpayer-nuclear-cost subsidies are counted, they approach full costs (Lovins et al. 2008). As a consequence, the RMI analysis (p. 11) shows that the nuclear industry relies mainly on taxpayer subsidies, not private investors:

> Taxpayers, who already bear most nuclear-accident risks…for decades have subsidized existing nuclear plants by ~1–5 ¢/kWh. In 2005, desperate for orders, the politically potent nuclear industry got those US subsidies raised to ~5–9 ¢/kWh for new plants, or ~60–90% of their entire projected power cost, including new taxpayer-funded insurance against legal or regulatory delays. Wall Street still demurred. In 2007, the industry won relaxed government rules that made its 100% loan guarantees (for 80%-debt financing)

even more valuable—worth, one utility's data revealed, about $13 billion for a single new plant, about equal to its entire capital cost. But rising costs had meanwhile made the $4 billion of new 2005 loan guarantees scarcely sufficient for a single reactor, so Congress raised taxpayers' guarantees to $18.5 billion. Congress will soon be asked for another $30+ billion in loan guarantees, or even for a blank check. Meanwhile, the nonpartisan Congressional Budget Office has concluded that defaults are likely (Lovins et al. 2008).

Regarding (c), correcting industry-based data and assumptions, consider how the RMI study challenges the nuclear-industry-funded studies (Lovins et al. 2008)—like those of MIT (Du and Parsons 2009; Ansolabehere et al. 2003), and the University of Chicago (2004)—that assume as much as 85–95% nuclear-load factors. The RMI authors say (p. 10) actual load factors are much lower because "even reliably operating nuclear plants must shut down," for roughly 8% of the time, "for refueling and maintenance, and unexpected failures" cause additional shutdowns for another "8% of the time." Thus even the most reliable reactors have average load factors of 84%, but not all reactors are reliable. Why not? Although 253 US reactors were ordered, only "132…52% of the 253 [reactors] originally ordered," were completed; reactors that were not completed (numbering 121) are typically excluded by industry from alleged load-factor averages. Industry data also exclude another 28 US reactors (21% of the US reactors that were built), because they were "permanently and prematurely closed due to reliability or cost problems." They likewise exclude "another 27% [36 of the US reactors actually built, because they] have completely failed for a year or more at least once. Although the surviving US nuclear plants," 68 in number and one-fourth of the total US reactors ordered, have short-term load factors of about 90%, RMI authors say this 90% figure is often quoted in industry studies. Yet they say these industry studies fail to reveal that the 90%, short-term figure represents only about 25% of US reactors and not all 253 reactors that were ordered. As already explained, the lifetime-average, nuclear-load factor for all reactors is only 71%. The RMI authors (p. 10) thus explain that these unrealistically high load-factor figures arise from excluding 73% of total reactors, the low-load-factor reactors (Lovins et al. 2008).

Likewise, the RMI authors show (p. 2) that when industry-funded, nuclear-cost studies exclude reactor-construction time and interest charges, this data-trimming can illegitimately trim nuclear-capital costs by more than 50% (Lovins et al. 2008). In reality, say (p. 1) the RMI authors, quoting *The Economist*, nuclear power "is now too costly to matter" (Lovins et al. 2008).

Group D: 7 Studies that are Partly University Funded and Use Completely Corrected industry Data

Other studies likewise challenge the counterfactual assumptions in many industry-performed/funded nuclear-cost studies. Group D consists of 7 nuclear-cost studies (Thomas 2005; Diesendorf and Christoff 2008; Smith 2006; Thomas et al. 2007;

Van Leuwen 2007; Brown 2008; University of Sussex and NERA Economic Consulting (Sussex-NERA) 2006) whose (at least partial) funders appear to be universities, as the lead authors of these studies are/were employed by universities. One such study (Thomas 2005) was done by a chemist working at the University of Greenwich, in London. Another nuclear-cost study (Brown 2008) says (p. 2) the author "wrote this paper when a Press Fellow at Wolfson College, Cambridge, during 2007/08." Still another nuclear-cost study (Smith 2006) was written by MIT physics Ph.D. Brice Smith, now Chair of the Physics Department at the State University of New York (SUNY) at Cortland.

Unlike industry-funded/performed studies, these 7 Group D university-funded analyses (a) include nuclear-cost data from credit-rating agencies, (b) include nuclear-cost data that takes account of taxpayer nuclear subsidies, and (c) use completely corrected, nuclear-industry-supplied cost-data. Consider the study done by physicist Smith from SUNY.

Regarding (a) the fact that credit-rating firms assess nuclear power as very costly, Smith repeatedly cites (pp. 44–45, 50–51, 97) credit-rating-firm data in his cost analyses. He quotes Moody's or Standard and Poor's to show that if utilities build nuclear plants, their credit is downgraded; that this downgrading prevents reactor construction; that nuclear plants always have cost overruns; that even subsidies will not make nuclear power economical; and that credit-rating firms do not support nuclear power (Smith 2006). Because of this poor credit rating, Cambridge University's Paul Brown likewise says (p. 32) that the high "cost of borrowing capital [for nuclear construction] in the open market" means that, "without government guarantees to hold down interest rates for new nuclear build," no new nuclear plants will be built (OXERA 2005).

Regarding (b), uncounted nuclear subsidies, SUNY physicist Smith notes (p. 7) that, throughout its history, nuclear power has had to be "pushed along by large government subsidies" (Smith 2006). After evaluating the costs of 4 new proposed US nuclear subsidies, he warns (p. 49) that "despite the magnitude of these proposed subsidies, they would still not be large enough to fully overcome the higher costs of nuclear power" (Smith 2006). Paul Brown concurs (p. 24), pointing out that "without subsidy no new nuclear power station has ever been constructed" (Brown 2008). He also notes (p. 31) that another "major public subsidy [of nuclear power in the UK and the US] is insurance against accident and the increasing bill for security" (Brown 2008). And in France, he says (p. 32), "the public pays for the nuclear industry twice, through its electricity bills and again through its taxes. The true cost of nuclear energy in France is a state secret and has never been disclosed" (Brown 2008). As already mentioned, taxpayer subsidies account for 60–90% of the cost of proposed new US reactors (Lovins et al. 2008).

Regarding (c), correcting nuclear-industry data and assumptions, SUNY physicist Smith criticizes (p. 53) the "highly optimistic assumptions" of nuclear-cost studies that are performed by, or funded by, the nuclear industry (Smith 2006). For instance, Smith criticizes (p. 40) the MIT assumption of a 5-year-reactor-construction time, given that the US National Academy of Sciences has shown that, for US reactors built after 1985, the construction time is 12.2 years (Smith 2006). Smith also shows (p. 41) that, given flawed interest-and-construction-time assumptions, the nuclear industry has underestimated reactor-construction costs by 75% (Smith 2006). Smith likewise shows (pp. 46–47) that in the overly optimistic MIT study, which assumed a nuclear interest rate of only 11.5%, MIT was able to show that interest costs represented only about 20% of the capital costs of a reactor; however Smith argued that, if one raised this nuclear-interest rate to 12.5%, interest costs would represent roughly 40% of nuclear-capital costs and would make nuclear power even less cost-effective (Smith 2006). Yet, as shown earlier, the market-interest rate for nuclear loans is 15%. Thus it is not surprising that after criticizing the "optimistic" nuclear-cost assumptions of the industry-funded Chicago and MIT studies, Smith concludes (p. 53) that "it is unlikely that any significant improvements to the economics of nuclear power could be sustained" (Smith 2006).

What conclusions can be drawn from the four classes of nuclear-cost studies (groups A–D), given that analyses in each group share comparable funding and make similar assumptions? One conclusion is that that the majority of nuclear-cost studies (the 18 of 30 analyses in Group A) appear to be either performed by, or funded by, pro-nuclear interests. A second conclusions is that, perhaps as a consequence, these Group A studies also constitute the majority of analyses that trim nuclear-cost data. A third conclusion is that these Group A, nuclear-funded studies are also the majority of studies that neglect to include evidence-based, credit-rating-firm data on (very high) nuclear costs and that fail to take account of how massive taxpayer subsidies reduce nuclear costs. Likewise, a fourth conclusion is that the majority of the 11 nuclear-cost studies (Groups C and D)—that include credit-rating-firm data and taxpayer-subsidized costs, and that use actual, empirical, historical-average data for assumptions about interest rates, construction times, load factors, and lifetimes—are the 7 Group D studies that are at least partly university funded. A fifth conclusion is that, whereas 4 of these 11 studies, the Group C studies, also include credit-rating-firm data, taxpayer-subsidized costs, and actual, empirical data for assumptions about interest rates, and so on—these 4 studies are funded by nonprofit NGOs. Thus, a sixth conclusion is that the majority of nuclear-cost studies (the 18 in Group A) appear to underestimate nuclear costs, perhaps because they are either performed by, or funded by, nuclear interests. A seventh conclusion is that a minority of nuclear-cost studies (the 4 in Group C and the 7 in Group D) appear to more accurately assess nuclear costs, largely because they use actual empirical data, rather than projections or assumptions, and perhaps also because they are not funded by those with obvious financial conflicts of interest, like those in the nuclear industry.

Moreover, although the majority of nuclear-cost studies that appear to "get things right" are the 7 university-funded studies, note that not all university studies are more error free. Rather, 6 of the 18 pro-nuclear-funded studies were done at universities (the University of Chicago (2004), Lapeenranta University (Tarjanne and Luostarinen 2002), MIT (Du and Parsons 2009; Ansolabehere et al. 2003; Deutsch et al. 2009), and Rice University (Baker Institute for Public Policy 2000)—and yet all of these studies neglect to include evidence-based, credit-rating-firm data on (very high) nuclear costs; fail to take account of how massive taxpayer subsidies reduce nuclear costs; use industry-projected (rather than historical-average) assumptions about interest rates, construction times, load factors, and lifetimes;

and thus draw arguably unrealistic conclusions about low-nuclear costs. Therefore, an eighth conclusion is that university-performed studies cannot protect against apparent bias, if these studies are funded by those with conflicts of interest, like the nuclear industry. However, a tenth conclusion is that, if university-based studies are not funded by those with obvious financial conflicts of interest, the university studies appear to be the most reliable.

Why Nuclear-Cost Studies May have Fallen into COI

Why do a majority of nuclear-cost studies apparently succumb to data-trimming and biased policy conclusions in favor of nuclear energy? The answer may not be merely that they are performed/funded by those with COI. Rather, part of the answer may be that COI are very difficult to handle, so as to protect the legitimate interests of all parties (Bird and Spier 2005, 2008; Roberts et al. 2001).

Another reason for faulty, data-trimmed conclusions may be that although traditional professional codes of ethics typically require professionals to protect the public, these codes do not require full disclosure of financial COI to the public. For instance, the US General Services Administration, in its Federal Acquisition Regulations (FAR), does not require that consultants' disclose COI to the public when they perform government-sponsored research. Instead FAR says (9.504(a)(2)) government officials should "avoid, neutralize, or mitigate significant potential conflicts [of interest,]" or obtain waivers for COI, when acquiring work from consultants or contracted scientists (Institute 2005). Rather than requiring full public disclosure of COI, especially in the consultant document, FAR requires (9.506(b)) only that if a "government contracting officer" decides that a particular action involves "a significant potential organizational conflict of interest, the contracting officer shall…submit for approval to the chief of the contracting office" a written analysis of the COI and how to mitigate or avoid it, so that the approving official can "approve, modify, or reject the recommendations in writing" (Institute 2005). Because the federal official is not required to disclose this COI to the public or to other potentially affected parties, the COI is handled privately, within government confines. Provisions like FAR may help explain the limited transparency and problematic assumptions in many nuclear-cost studies.

Likewise, US National Science Foundation (NSF) COI policies do not require public disclosure of COI in government-sponsored research. Instead NSF requires only that an institution, like a university, have a written COI policy and "manage" all COI prior to expending NSF funds—and that the scientist/engineer grantee disclose to a "responsible representative of the institution (e.g., the university) all significant financial interests of the investigator," so that this representative can certify to NSF that the COI has been mitigated or avoided. No disclosure of a COI need be made by the researchers, either in the resulting research, or to the public at large, or even to NSF. Indeed, NSF requires that it be informed only about any "unresolved conflict" of interest and that, otherwise, the institutional "representative" handle the matter (Stokes 2002).

Similarly, the ethics code of the National Society of Professional Engineers (NSPE) does not require disclosure to the public of any COI. Instead section II.4 of the NSPE ethics code requires merely that "Engineers shall disclose all known or potential conflicts of interest to their employers or clients by promptly informing them of any business association, interest, or other circumstances which could influence or appear to influence their judgment or the quality of their services" (Roberts et al. 2001). The Accreditation Board for Engineering and Technology (ABET) likewise requires (Guideline 1) no public disclosure of COI. Instead it requires that analysts do evaluations that are "consistent with…the safety, health, and welfare of the public and…disclose promptly factors that might endanger the public" (Accreditation Board for Engineering and Technology (ABET) 2009). Yet this disclosure does not include the public. Instead ABET requires (Procedures) only that "copies of the conflict of interest records will be provided" to officers selecting both the analysts and the evaluators of the analyses (Accreditation Board for Engineering and Technology (ABET) 2009). ABET also requires (Guideline 4) that analysts "keep confidential all…evaluations unless by doing so they endanger the public" (Accreditation Board for Engineering and Technology (ABET) 2009). If analysts knew, however, that their possible COI were disclosed publicly, they might be more cautious about making counterfactual or otherwise questionable assumptions in their work.

How Energy-Cost Studies Should Be Done

Given that scientific and engineering analysts deserve privacy and yet that clients and all affected parties (including members of the public) deserve to be protected from COI, how could the 30 nuclear-cost analyses (examined in this article) have been performed, so as to avoid both COI and some of their questionable assumptions? Although previous paragraphs explained why there is no canonical study of nuclear costs, nevertheless one can specify at least 5 necessary conditions that might make cost studies more reliable. Although one obviously cannot specify what is both necessary and sufficient for a defensible nuclear-cost analysis, it clearly is wrong to leave out costs, particularly when one has uncontested empirical data to support them.

Following the earlier brief discussion of COI, a first necessary condition for reliable nuclear-cost analyses is to attempt to avoid financial COI. US FAR, for instance, clearly say (9.505-2(b)(1)–9.508(a)–(e)) that analyses ought not be done by those who have personal or organizational COI (Institute 2005). FAR regulations specify that "contracts for the evaluation of offers for products or services shall not be awarded to a contractor that will evaluate its own offers for products or services"; that the same scientists/engineers/consultants who prepare "a work statement" for some system or analysis "may not supply the system"; that scientists who might, for instance, "provide systems engineering and technical direction" regarding a power plant, to a government agency, "should not be allowed to supply any power plant components"; or that the same consultants who "prepare data system specifications and…criteria….should be excluded from" supplying any "information technology" for that system (Institute 2005). In other words, US-government COI guidelines clearly try to avoid situations in which scientists/engineers—who assess some technology—are the same scientists with financial interests in it. Yet in the majority (18 of 30) of nuclear-cost studies examined here—as well as the majority of nuclear-cost studies listed by WNA (World Nuclear Association (WNA) 2005), the majority listed by the UK-government commission (University of Sussex and NERA Economic Consulting (Sussex-NERA) 2006), and the majority listed in the Greenpeace study (Thomas et al. 2007)—the same groups who assessed (or contracted for assessment) of nuclear costs were those with financial interests in nuclear power. Moreover, virtually all of these studies were used to help justify a type of partial government "acquisition" of nuclear power, or taxpayer subsidy of nuclear power. Because of these COI, it is not surprising that, as one UK-government study warned (p. 13), nuclear-industry "cost estimates need to be treated with some caution as the vendors' commercial incentive is clearly to estimate optimistically" (UK Sustainable Development Commission (UK SDC) 2006).

A second necessary condition, for all cost studies that cannot completely avoid COI, is to mitigate their effects by publicizing them. As the earlier discussion suggested, this requires at least reporting, in the study itself, the full personal and institutional financial ties of those who perform or who fund the analyses. Obviously, this disclosure is not sufficient to help protect against COI, but it clearly is necessary (Bird and Spier 2008). Especially for cost studies used to assess possible government subsidies, the public has a right to know about the quality of the studies and how taxpayer dollars might be used. Yet not all studies (funded by nuclear interests) reveal the full sources of that funding in the study documents themselves. For instance, in one MIT case (Ansolabehere et al. 2003), the study said funding came in part from an MIT lab. Yet the lab receives massive funding from the nuclear industry, and this fact was not disclosed in the study. If all such relevant financial ties (as in the lab case) are reported by analysts and their institutions, they will be more likely to perform studies that withstand scrutiny, and those who use the studies will be more likely to evaluate them more carefully. As a recent US National Academy of Sciences committee put it (pp. 1–2): "The disclosure of individual and institutional financial relationships is a critical but limited first step in the process of identifying and responding to conflicts of interest" (Lo et al. 2009).

A third necessary condition, especially for cost studies of various energy options, is for assessments to employ lifecycle-cost analysis. In the case of nuclear fission, such analyses should at least include costs associated with uranium mining, milling, conversion to uranium hexafluoride (UF6), enriching UF6, fuel fabrication, reactor construction, reactor operation, waste-fuel processing, fuel conditioning, interim waste storage, waste transport, permanent storage, and reactor decommissioning and uranium-mine reclamation. Yet typical economic analyses include only several of these stages, such as reactor construction and operation (Shrader-Frechette 2009). However, traditional codes of professional ethics, such as ABET (Guidelines 5(c)–6(a)), prohibit professionals from "omitting a material fact….from distorting or altering the facts….from any conduct that deceives the public" (Accreditation Board for Engineering and Technology (ABET) 2009). Arguably all the data-trimming of nuclear costs, as just analyzed, omits material facts, distorts the facts, and may deceive the public. Lifecycle-cost analysis is a way to help reduce these problems.

Doing full, lifecycle-cost analyses of all proposed energy systems also is important so as to use limited resources efficiently, to avoid flawed and misleading accounting, to obtain the highest energy and environmental value for the lowest cost, to make rational energy-policy decisions, and to make energy-decision-making transparent and cost-effective (Council 2001). In the US, the federal government says that lifecycle analysis is the necessary and best way to implement Executive Order 13101 ("Greening the Government through Waste Prevention, Recycling, and Federal Acquisition") and Executive Order 13423 ("Strengthening Federal Environmental, Energy, and Transportation Management") (Council 2001; Aabakken 2005). In part to satisfy these federal mandates and US executive orders, the US National Institute of Standards and Technology (NIST) has long had a software program, BEES (Building for Environmental and Economic Sustainability), that enables government purchasers and policymakers to make economic and environmentally sustainable decisions about acquiring products and services (Aabakken 2005). Lifecycle analysis is also mandated by the International Organization for Standardization (ISO) 14040 requirements for measuring environmental and economic performance (Aabakken 2005). For all these reasons, the US National Academy of Sciences (p. 4) says "many federal acquisition policies…require life-cycle costing," and it too has recommended life-cycle-costing in order to achieve "performance standards….preferable products," and "sustainable development and value engineering" (Council 2001) Without lifecycle analysis, public decisions about energy choices may ignore negative and positive externalities, even when they dominate the cost-and-benefit analyses. For instance, the International Energy Agency (IEA) points out that, because nuclear subsidies and *negative* externalities (e.g., taxpayer funding of most reactor-construction costs and permanent waste storage) are typically not included in *nuclear-cost* calculations, this causes nuclear-cost underestimates. Likewise, because the *positive* externalities (e.g., no fuel waste, no electricity-generation emissions, no catastrophic insurance needed) are typically not included in *renewable-energy-cost* calculations, IEA says this causes renewable-energy-cost overestimates. "Unrewarded [beneficial] environmental characteristics" of renewable-energy technologies, like wind, are 'the principal barrier to increasing the market share for renewable energy' " (Mariotte et al. 2008).

A fourth necessary condition for energy-cost studies is to be sure that energy-cost estimates are consistent with credit-rating and other data. When one uses nuclear-cost estimates that are based on credit-rating data, as many apparently reliable studies do, e.g. (Mariotte et al. 2008; Makhijani 2007), they are up to 350% higher than the nuclear-cost estimates from the industry itself, such as the WNA (World Nuclear Association (WNA) 2005), and nearly 200% higher than those from groups (like MIT), funded by the nuclear industry (Du and Parsons 2009). Regarding the importance of credit-rating data, US FAR (9.506(a)) note that if information is "necessary to identify and evaluate potential organizational conflicts of interest or to develop recommended actions [to mitigate COI]," government officials should seek information from both government groups, such as "audit activities and offices" and from non-governmental sources, such as "publications…credit-rating services, trade and financial journals" (Institute 2005).

A fifth necessary condition, for performing reliable nuclear-cost studies, also comes from the US FAR. They mandate (9.506(a)) that cost analyses should undergo reliable peer review by technical specialists and that federal officers who contract for studies, services, or products "should obtain the advice of counsel and the assistance of appropriate technical specialists in evaluating potential conflicts [of interest] and in developing any necessary…contract clauses" (Institute 2005). Yet, there is no evidence that any of the nuclear-cost-study contracting groups, like the US DOE—which funded the University of Chicago (2004), the Scully 10], and other nuclear-cost studies—had any of them evaluated by outside "technical specialists." (Part of the reason for this failure may be that, at least since 1990 and continuing since then, the US DOE itself has been repeatedly criticized by the US Congress, by US-government oversight agencies, and by the agency's own inspector general, for its pro-nuclear biases and poor science; the COI criticisms of DOE have been so severe that the US Office of Technology Assessment and the Congress have recommended either abolition of the US DOE or its regulation by an outside agency (Shrader-Frechette 2002; Congress 1999). Neither has occurred.

The Climate Importance of Nuclear-Cost Assessments

Given climate-change problems, getting nuclear costs "right" is especially important because society needs economically efficient, low-carbon solutions, not inefficient guesses based on trimmed economic-cost data. However, if faulty nuclear-cost analyses (like those just investigated) dominate climate-change discussions, this dominance could jeopardize using cheaper, cleaner technologies like wind (Mariotte et al. 2008; Makhijani 2007; Diesendorf and Christoff 2008). As a recent UK-government-commission notes (p. 45), "plans for new nuclear generation can therefore be expected the depress the market's appetite" for renewable-technology "investment, relative to what it otherwise would be," because there would be "a trade off between funding of nuclear power and funding of renewables" (UK Sustainable Development Commission (UK SDC) 2006). Given this tradeoff, it is especially important to get nuclear costs right.

Yet even without considering the data-trimming just surveyed, nuclear costs roughly triple those of wind. Credit-rating firms say nuclear-fission-electricity costs more than 15 cents/kWh in early 2008 (Finance 2008), and $0.21/kWh in late 2009 (Lovins et al. 2008). Yet the US DOE says US full-fuel-cycle wind prices, on average over the last 7 years, are 4.8 cents/kWh (Smith 2006; Cravens 2008; International Energy Agency (IEA) 2003), and global wind potential is 35 times greater than current global electricity use (Lovins et al. 2008). The International Energy Agency says wind costs have been dropping 18% (and solar-photovoltaic costs 35%) for every installed-capacity doubling, while atomic-energy costs have been increasing (US Department of Energy 2007). By 2015 (far sooner than reactors, ordered today, could be operational), even the pro-nuclear US DOE says full-fuel-cycle-centralized-solar-photovoltaic prices will be $0.05–0.10/kWh (depending on location), "competitive in markets nationwide," and much cheaper than nuclear (Energy Information Administration 2009). Solar photovoltaics, on only 7% of US land currently used for parking lots and buildings, could provide all the electricity needed for the US (Madsen et al. 2009). Given such data, it is not surprising that already, atomic energy has been losing private markets. By 2005, non-hydro-renewable energy was annually growing 7 times faster than nuclear (Thomas et al. 2007). In 2006, global added new wind capacity was 10 times greater than global added new nuclear capacity; in 2006, carbon-free renewable energy added 40 times more capacity globally than did nuclear (Lovins et al. 2008). In 2007, carbon-free renewable energy gained more than $90 billion in global investment, and in 12 nations, renewable energy now provides between 17 and 50% of total electricity needs (Lovins et al. 2008). US-government data, for the latest year available, likewise show that wind has been responsible for 60% of annual new-electricity capacity, as measured by peak summer demand (EIA 2009). By 2020, the US DOE says available renewable technology can provide 99% of US electricity (NREL 2006).

Objections

Objecting to the preceding conclusions, one might ask whether nuclear analyses should use actual, historical-average data (as done here), or projected (as industry does), cost-data based on new-reactor designs. However, projected data are hypothetical, untested, and provided by those who would profit from optimistic prices. Industry also admits that reactors always have 4–6 years of lower (50%) load factors, until "bugs" are removed (International Atomic Energy Agency (IAEA) 2007). Besides, if industry's projected-cost numbers were correct, most banks would make nuclear loans, and reactor vendors would guarantee specific lifetimes and nuclear-load factors for clients. Yet, they will not (Thomas et al. 2007). Also, after 50+ years of commercial implementation (as with fission), most technologies already have achieved all likely design/cost/efficiency improvements (Thomas 2005). For all these reasons, low-cost projections for new reactor-designs seem unrealistic.

Second, one might ask why countries use fission-generated electricity, if reactors are so expensive. However, most nations began this technology for military reasons, and (as discussed) all countries heavily subsidize it. China, France, India, Iraq, Israel, Pakistan, South Africa, the Soviet Union, UK, US, and other nations wanted "to open a nuclear-weapons option" (Sweet 2006). They have a "not too hidden agenda" of using commercial-nuclear technology so they can develop weapons; both the Joint Committee on Atomic Energy and nuclear scientists admit these facts (Makhijani 2007; Oppenheimer 1963).

Third, one might ask whether this analysis ignores the intermittency of renewable technologies, like wind and solar, whereas fission can supply baseload power. However, the earlier discussion revealed that, 30% of the time, nuclear energy cannot supply baseload power and thus is intermittent. Fission intermittencies also are expensive. The preceding analysis suggests that correcting nuclear-load-factor data-trimming could raise nuclear-ratepayer prices 19–36%. Yet the pro-nuclear UK government says alleviating wind intermittency increases costs only 6%, and wind is already much cheaper than atomic energy (Smith 2006). Besides, US-government agencies say that, until wind supplies more than 25% of US electricity, wind intermittency does not need to be considered and can be handled by the grid; besides, a dollar invested in wind energy would provide between 20 and 100 times more energy than that same dollar, invested in nuclear power (Madsen et al. 2009).

Fourth, one might ask whether it seems plausible for nuclear-cost research to have erred so badly. Yet as already noted, most atomic-energy-cost studies rely on trimmed, industry-supplied data. The errors in nuclear-cost studies likewise are consistent with four economic facts: Credit-rating companies downgrade ratings of utilities with nuclear plants (Makhijani 2007; Smith 2006; Thomas et al. 2007; Kennedy et al. 2006). Despite omitting costs like decommissioning, waste storage, and those discussed earlier, Moody's (credit-rating firm) says nuclear-generated-electricity costs are triple those of natural gas, and double those of scrubbed coal (MacKerron 2007). Also, the pro-nuclear, US-DOE-Scully-Capital study showed nuclear plants could provide typical electric-utility, investment-return rates, only if nuclear-construction costs did not exceed $1 billion (Scully Capital Services Inc. 2002). Yet construction costs are now $12–30 billion, as noted earlier. Finally, despite taxpayers' massive atomic-energy subsidies (Smith 2006; Slocum 2008), the industry itself admits that high costs will rule nuclear "out of consideration" in the future; by 2030, WNA says fission will decrease (from its current 16) to 9% of global electricity (World Nuclear Association (WNA) 2005).

The upshot? Just as drug-industry studies sometimes trim adverse-health-effects data, nuclear-industry studies may trim cost-data—especially data that hasten their predicted decline. Although there may be reasons to use atomic energy, economics is not one of them.

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