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Nuclear Power: Is It Worth the Risks?

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The major challenge of a green energy economy lies in finding "promising new technologies" that can replace fossil fuels. Thus, a major question arises, "Can we label nuclear power a promising new technology?" or "Is nuclear power 'green' and thus a valuable part of the technology portfolio that should replace fossil fuels?"

Advocates of nuclear power point to its ability to generate electricity with low-carbon emissions, its established role as a base-load power source in nu-merous countries, its plentiful supplies of fuel, and they argue the existence of new technology and operational practices that render nuclear power clean, green, cost-effective, and safe. Thus, nuclear power deserves a prominent place in the green energy economy. Opponents question claims of low-carbon emissions over the total nuclear fuel cycle and life cycle of the plant, as well as assertions about cost-effectiveness and safety. Nuclear power in this school of thought deserves no, or at most a minimal, role in the green energy economy.

Because of its large scale and capital intensity, questions about the inclusion of nuclear power in the green energy economy demand a "yes" or "no" answer, not "maybe" or "sort of." The middle path is not feasible. As a result, govern-ments considering the nuclear option face Hamlet's pivotal dilemma—"to nuke or not to nuke."

To grasp the arguments surrounding this dilemma requires understanding the history of nuclear power in the United States, the country that shaped and led the evolution of this technology. The most important feature of this history is that decision making on nuclear power has never been simply a matter of science and engineering. While technical matters always occupied a place in debates about nuclear power, value judgments and politico-economic factors have also played important roles. Moreover, even the scientific and engineering communities never reached a consensus on the methods for evaluating the technology. Today's debates are no different. Decision makers and citizens continue to face the same morass of technical and nontechnical issues that have always bedeviled nuclear power.

After reviewing the history of this technology, this chapter provides a critical analysis of examples of policy recommendations that favor or oppose, respectively, nuclear power as an important component of the world's new energy economy. Each of these assessments shows how the respective policy recommendations considered or failed to take into account the lessons from the history of nuclear power.

Finally, the chapter suggests an integrated framework—Political Ecology—that can incorporate qualitative and quantitative data in discussions of nuclear power. Political Ecology will not lead to a scientifically unambiguous answer about nuclear power. However, the framework encompasses the lessons of history, value judgments, concerns about safety, financial investment, and electrical production, allowing political and business leaders and citizens to better understand the dilemmas surrounding energy choices and to more well-informed choices.

Changing Patterns in Decision Making on Nuclear Power, 1939–Present

As described below, decision making about nuclear energy occurred in six phases in the United States, each marked by a shift in policies and politics or in the economic and social contexts surrounding governmental control and promo-tion of nuclear technologies.

Phase I: The Beginning of the "Atomic" Age, 1939–1954

Seldom has a scientific discovery moved from the laboratory bench to a world-altering technology as fast as the discovery that the uranium atom could fission, releasing huge amounts of energy. That part of the nuclear story began in 1939 and culminated in the dropping of atomic bombs in 1945. Under the Atomic Energy Act of 1946, the Atomic Energy Commission (AEC) launched efforts to vastly expand the nuclear arsenal of the United States and to explore the potential for electrical generation. In 1951, the United States became the first country to generate electricity from this energy source. By 1957 two commercial scale plants had come on line: Santa Susana, CA (20 MWe maximum output) and Shippingport, PA (60 MWe).[1]

This early history of nuclear power in the United States established a number of features about decision making that persist to this day: (a) a high reliance on federal government support in the form of research, subsidies, and regulation; (b) close links between civilian and military issues, due to commonality of technical skills, and because the fission of uranium fuel inevitably produces plutonium, a component of nuclear weapons; (c) an aura of secrecy and security concerns about the technology; and (d) a vision that prowess in nuclear technology confers diplomatic, military, and commercial strength in both the domestic and interna-tional political arenas.

Decision making during Phase I focused primarily on the desire for weapons, followed by the pursuit of international leadership in nuclear technology for electric power. Issues of energy security, pollution from competing fuels, or climate change, while present, had no significant voice in the military/political machinery that created the US program in nuclear energy.

Phase II: Origins of Nuclear Power as a Private-Public Partnership, 1954–1962

The Atomic Energy Act of 1954 allowed the US government to share secrets with private companies as a way to promote the development of nuclear power.[2] Despite high expectations for the new law, the eight years following its passage brought only small progress toward the envisioned new era of electricity gen-erated by nuclear fission.

One challenge stemmed from the inability and unwillingness of most private companies to accept the liability for accidents that might release significant amounts of radiation. Industry spokesmen made it clear that neither manufacturers nor utilities would embrace this new technology unless the federal government indemnified them from that liability. As a result, in 1957, the Price-Anderson Nuclear Industries Indemnity Act amended the Atomic Energy Act of 1954 and limited the liability claims from an accident to $560 million.[3] Private insurance held by the reactor owners/operators covered the first $60 million; Congress would pay additional damages up to $500 million (1957 dollars). Compensation for any damages beyond that level would require further action by Congress.

Congress then asked the AEC to estimate the maximum damage that might occur from an accident with a nuclear reactor. In 1957, AEC reported that a major accident could lead to up to 3,400 deaths, 43,000 injuries, or property damages valued at up to $7 billion.[4] AEC scientists felt an accident of such magnitude was extremely unlikely; still, they shied away from estimating the actual chances of such an event.

The legacy Phase II includes the public-private partnership as the major pattern of ownership in the US nuclear power industry. While public entities do operate a few of the nuclear power plants in the United States (Tennessee Valley Authority (TVA), for example), government supported private industry has dominated and looks to continue doing so into the foreseeable future.

Second, the inherent safety problems of the technology became known. Knowledgeable scientists predicted catastrophic nuclear accidents; their projections were confirmed years later by accidents at Three Mile Island, Chernobyl, and Fukushima. Even so, passage of the Price-Anderson Act signaled that a majority in Congress believed that the probabilities of major accidents were low enough to proceed. Private insurers have been less confident. As a result, renewable of the Price-Anderson Act persists as a fundamental condition for private investment in nuclear power.[5]

Third, the light water reactor (using water as the reaction moderator) became the predominant technology for the US industry. Despite continued efforts by the engineers to develop radically different designs, light water reactors continue to be the preferred technology.

Phase III: Nuclear Power Enjoys a Boom and Suffers a Bust, 1962–1978

By early 1962 only a handful of commercial plants had begun operations: Dresden I (867 MW per unit, outside Chicago, 1959), Yankee Rowe (600 MW, in northwestern Massachusetts, 1960) and Indian Point I (275 MW, outside New York City, 1962).[6] The AEC's Congressional overseer, the Joint Committee on Atomic Energy, became impatient with the pace of developments and persuaded President John F. Kennedy to ask the AEC for a forward-looking document. The ensuing report, *Civilian Nuclear Power . . . a Report to the President—1962* dramatically changed the atmosphere surrounding nuclear power and catalyzed the transformation of AEC into a vigorous proponent of nuclear power.[7]

The AEC proposed nuclear power as the answer to soaring national demand for electricity. Between 1960 and 2020, total electricity consumption was expected to increase twelve-fold.[8] Nuclear proponents envisioned 50 percent of total US electricity coming from nuclear power by the year 2000, and about 90 percent by 2020. In addition, a new "breeder reactor" would generate more fuel than it burned, vastly enhancing supplies of uranium fuel, and reducing problems of waste disposal through spent fuel reprocessing.

The pace of construction picked up remarkably. During the "boom" of the US nuclear power industry from 1967 to 1978, the AEC issued ninety-eight construction permits and oversaw the construction of a fleet of 133 power reactors. However, no commercially successful breeder reactor has yet come on line.

Despite the apparent success of the nascent industry, a period that began with high hopes for a new technology ended with bickering, dissolution of the AEC, and civil disobedience at construction sites. The industry never came close to transforming the US electrical industry to predominantly nuclear technology. In fact, the experiences with the construction of nuclear power plants highlighted a number of challenges that collectively devastated the confidence of investors, many political leaders, and substantial numbers of citizens. First, companies and utilities rapidly scaled-up reactor sizes from less than 100 MW in the 1950s, to near or more than 1,000 MW by the mid-1960s. They sought to capture important economies of scale through increased size, but instead outran the skill base of construction workers and the knowledge of regulators.[9] As a result, many projects floundered in re-work, lengthy delays, and budget overruns as contractors tried to meet the AEC's changing requirements.

Environmental issues created problems. Nuclear power had been viewed as cleaner than existing coal-fired operations, which were coming under pressure to reduce emissions by the Clean Air Act of 1970. However, by mid-1971, concerns about thermal pollution of discharges from nuclear plants surfaced. Thermal pollution could have been resolved by the installation of cooling towers for dissipating the waste heat from the reactors. But even today, only 62 of 104 operating reactors rely on cooling towers.

A lack of confidence in engineered safety features also generated complaints. No person knowledgeable about nuclear technology had denied the potential for catastrophic risk, but proponents had argued that the combination of (a) remote siting; (b) redundant engineered safety features; and (c) proper design, construction, operation, and maintenance made the risks "acceptably" low.

The AEC attempted to demonstrate the acceptability of these risks by devel-oping a new method for assessing them: probabilistic risk assessment (PRA). Before PRA, the AEC mandated sites and reactor designs that would not expose any *real person* to radiation above the limits considered tolerable in emergencies. Proponents of PRA suggested that regulations should aim to reduce the proba-bility of serious injury or death to a *statistical person* below a level considered insignificant. "Safe enough" became a calculated probability of harm that political leaders could accept as "low enough."[10]

Other problems lay in the radically changing energy outlook in the 1970s. Electrical industry and utility analysts wrongly assumed that the rate of high growth of the 1950s and 1960s would continue indefinitely. When actual growth rates dropped, companies cancelled or delayed new nuclear construction. Sixty-three nuclear plants fell by the wayside even after having received construction permits.

New frameworks for thinking about energy also emerged in the 1970s and partially eclipsed the framework upon which *Civilian Nuclear Power* had relied. The Ford Foundation study, *A Time to Choose* (1974), identified efficiency as the most important factor in planning for the energy economy.[11] Spurred by the Arab oil embargo of 1973, *A Time to Choose* argued that energy policy should focus first on minimizing demand, not maximizing supply. The virtually un-limited supply of electricity generated by nuclear power was no longer the key consideration in discussions about energy.

Finally, controversies swirling around the AEC as both champion and watch-dog of the nuclear industry led Congress to break the agency into two parts in 1975. The Nuclear Regulatory Commission (NRC) would regulate, while the Energy Research and Development Administration (later the Department of Energy) would promote nuclear power.

Significant segments of the public voiced concern over the legacies of Phase III. The security of one's health, family, home, community, and place, all could be threatened by a nuclear accident. Costs and efficiency affected individual pock-et-books directly, in utility bills, or indirectly, through government and tax-payer subsidies to the industry. In addition, low investor confidence challenged the premise that nuclear power should be (or could be) a public-private partnership. These issues from Phase III continue to play prominent roles in today's nuclear energy debates.

Phase IV: Accidents and Waste Management Tarnish the Image of Nuclear Power, 1979–1988

Two major nuclear accidents occurred during Phase IV. In 1979, Three Mile Island—2, near Harrisburg, PA, suffered a major loss of coolant accident, partial core meltdown, and release of considerable radioactivity, mostly in the form of gases. In 1986, Chernobyl—4 near Kyiv, Ukraine, suffered a spike in reactivity followed by steam and/or hydrogen explosions, and fire. Massive amounts of radioactive debris contaminated Ukraine, Belarus, Russia, and many countries of central and Western Europe. An Exclusion Zone approximately the size of Rhode Island surrounds the ruined reactor to this day.

The Nuclear Waste Policy Act of 1982 acknowledged a growing problem associated with the disposal of spent fuel from nuclear reactors and the need to "promote public confidence in the safety of disposal of such waste."[12] The Act outlined the responsibility of the US government to select and develop the site(s) for a permanent waste disposal facility. Yucca Mountain, NV ultimately emerged as the first choice site for the spent-fuel repository. As of this writing, however, political opposition from the State of Nevada and the President has left the choice of repository site unresolved.

The major legacies of Phase IV were the preeminence of safety concerns and the intractability of waste management. Earlier knowledge of large acci-dents stemmed from theoretical studies, modeling, and statistical calculations of risks. Three Mile Island and Chernobyl provided empirical verification of the catastrophic potential of mishaps. Still, proponents of nuclear power in the United States rationalized the outcomes of the accidents by claiming that Three Mile Island demonstrated that safety features, especially containment buildings, worked as planned. United States and Western European proponents dismissed the significance of Chernobyl, because the reactor had no containment building and because the accident stemmed from an ill-advised and ill-timed experiment, not commercial operation. Proponents of nuclear power put their faith in engi-neered safety features and technical solutions to waste disposal problems. Many members of the general public, however, did not embrace this faith.

Phase V: New Policies Fail to Promote New Plants, 1989–2005

By 1989, proponents of nuclear power again saw steady increases in the overall US demand for electric power as motivation for the revival of the quies-cent nuclear industry. First, they needed to remove two barriers to this goal: the lack of standard designs for nuclear power plants, and the cumbersome process under which utilities needed to obtain a construction permit first, and apply for an operating license only once the construction ended. Proponents believed that standardized designs and a one-step licensing process would relieve the uncer-tainties and risks of building new plants.

The NRC already had begun establishing a process to standardize designs. The agency believed that nuclear engineers would submit a handful of designs for advanced certification. The designs would be for essentially complete, except for necessary site-specific elements, such as cooling water intake structures. Up front safety reviews and public hearings would produce certified designs from which utilities could choose.[13]

In 1992 Congress followed with amendments to the Atomic Energy Act of 1954 allowing early site approval and the issuance of combined construction and operating licenses.[14] Utilities would first get approval regarding the hydrological, geological, seismic, and meteorological features of a proposed site. Subsequent application for the construction-operation license, combined with selection of a standard, pre-approved design, would lead to faster and cheaper completion of safer plants.

Contrary to expectations, by 2005 not a single company had stepped forward to build a new nuclear power plant. Instead, utilities met increased demand by investing in projects to improve efficiency of electricity use and to increase the capacity factor of existing plants. Companies built some new power plants during this period, but they used coal, natural gas and, in a few places, wind, solar, and geothermal resources. Advocates of a “nuclear renaissance” remained frustrated.[15] Resumption of active construction of new nuclear plants required still something else to bring utilities back to nuclear power.

Consumers and citizens mostly forgot about the nuclear industry after the 1990s. Fears inspired by Three Mile Island and Chernobyl faded from memory, and most people outside the nuclear and utility industries had little knowledge or curiosity about the source of their electricity.

Phase VI: More New Policies Stimulate Proposals for New Plants, 2005–Present

The presidential election of 2000 generated more change in nuclear power than the industry had seen since the late 1970s. President George W. Bush appointed Vice President Dick Cheney to head a task force to forge a new national energy policy. Their report, dated May 2001 and entitled *National Energy Policy Report of the National Energy Policy Development Group: Reliable, Affordable, and Environmentally Sound Energy for America’s Future*, strongly embraced the project of invigorating the American nuclear industry.[16] Before the end of 2001, the US Department of Energy followed with its report, *A Roadmap to Deploy Nuclear Power Plants in the United States by 2010*.[17] *A Roadmap* recommended financial incentives to motivate design and construction projects. It also put into place a 50–50 cost sharing program to help the first movers demonstrate the NRC's revised site permitting and reactor licensing procedures.

NuStart Energy Development, a company formed in 2004 by ten power com-panies and two reactor vendors, sought to devise standard methods for preparing applications for the permits needed for constructing new nuclear power plants. As a result, NuStart received $260 million under the Department of Energy's cost sharing program as a "first mover."

In spite of the promotional steps advanced by the Bush-Cheney Administra-tion, additional stimulus had to be added to generate investment commitments in new nuclear power plants. The Energy Policy Act of 2005 (EPAct) contained a number of initiatives that finally prompted applications for construction-operating licenses.[18] One of these was a production tax credit of 1.8 cents per kilowatt-hour for the first 6,000 megawatts of installed capacity, provided the application for construction-operation arrived by the end of 2008 and construc-tion began before 2014.

Next, the EPAct again renewed the Price-Anderson Indemnity Act of 1957 and extended its expiration date to December 31, 2025. Under the new revision, nuclear power plant operators had to obtain $300 million per plant in liability insurance and contribute another $10 million annually to an industry pool. Con-gress would supplement the funds available by indemnifying all other liability up to approximately $10 billion.

The EPAct also created a "delay risk insurance" policy for the power compa-nies. It authorized the Department of Energy to cover part of the cost of delays due to changing regulations and lawsuits brought by opponents of nuclear power. This protection against delays would equal up to $500 million for the first two new nuclear power plants, and up to $250 million for each of the following four new plants.

The final incentive from EPAct came in 2007: loan guarantees. As initially conceived, the federal government would insure loans to the builders of new plants for up to 80 percent of the total financing for a plant—the Department of Energy later amended this amount to 100 percent of the debt obligation for the plant.[19] This provision reduced the risks to lenders, a strong incentive for private funds to flow into the nuclear enterprise once again. Financial analysts convinced Congress that, without loan guarantees, banks and Wall Street investors would not support construction of new plants.

Retrospectively, loan guarantees almost certainly were the missing link in federal policy from 1989 to 2005.[20] Before the existence of the loan guarantee program, no applications for construction-operation permits arrived at the NRC. After the loan guarantee program came into effect, applications began to arrive. The Department of Energy issued the first loan guarantee for $8.3 billion in Feb-ruary 2010, for Georgia Power's project to build two new AP1000 Westinghouse pressurized water reactors at the Vogtle Nuclear Power Plant near Waynesboro, Georgia.[21]

Guaranteed financing, in the form of loan guarantees or Construction Work in Progress financing (CWIP), also provided the incentive for some utilities to take interest in the construction of new nuclear power plants. For example, Progress Energy Florida was able to garner support for its plans to charge Florida customers in advance of its nuclear plant construction. As of January 2009, Progress Energy has been recovering costs for its planned Levy County facility—costs including those related to the construction of the plant itself, nuclear related transmission expenses, and the annual expensing of pre-construction costs, such as costs related to site selection.[22] Since Progress Energy did not apply for loan guarantees from the DOE, being able to recoup some of the costs up front was crucial for the construction plans to move forward.

The legacies of Phase VI lie in the institutional world of power companies, reactor manufacturers, the finance industry, the US Department of Energy, the US Nuclear Regulatory Commission, and state utility regulatory agencies. Overwhelmingly, the evidence indicates that the private finance industry will not touch investment in new nuclear power plants unless the financial risks are reduced to close to zero. Federal loan guarantees accomplish this by assuring the lenders that, in the event of default, the lenders will still receive their money back from taxpayers. Even without federal loan guarantees, a utility company can finance a plant provided their state regulatory agency allows the company to increase rates to cover the expected costs. In essence, the utility obtains the necessary funds from customers with no requirement to pay any interest.

The legacies left by Phases I–VI still shape the assessment of nuclear power. Four driving features are particularly noteworthy: (a) Nuclear power plants operate under an all-encompassing shroud of public policy; no major investments in nuclear power would have ever been made without strong support from government. (b) The transferal of health and financial risks associated with nuclear accidents from the power plant owners and operators to taxpayers and citizens became a part of the industry standard with passage of Price-Anderson in 1957; the industry has insisted on this transfer ever since. (c) The transfer of the nuclear investor's financial risks to taxpayers and utility customers emerged after 1978 as the only way to obtain new investment capital into this industry. (d) Taxpayers and customers generally have little specific knowledge of the nuclear power industry, and the fears of accidents fade from memory; many remain firmly convinced that nuclear power creates unacceptable dangers, but many others accept the benefits of nuclear power for electrical generation.

Current Assessments of Safety and Costs: The Nuclear-Accepting Position

The legacies of Phases I–VI underlie the nuclear Hamlet's dilemma: should we, or should we not, embrace nuclear power? Two recent studies, both of which accept nuclear power as potentially valuable or even essential, offer valuable insights, yet both suffer important gaps in their analyses of nuclear power.

The first study, from the National Academy of Sciences, assesses all energy issues facing the United States to 2035 and beyond: *America's Energy Future: Technology and Transformation* (2009).[23] The second example, *Beyond Smoke and Mirrors: Climate Change and Energy in the 21st Century* (2010), was written by Burton Richter, the Paul Pigott Professor of Physical Sciences *Emeritus* at Stanford University and recipient of the Nobel Prize in Physics.[24]

First, consider the issue of safety as portrayed in the two studies. Both *America's Energy Future* and the Richter book recognize the safety of nuclear power as a fundamental issue that, if ignored, can scuttle the entire nuclear power industry. In both, the management of safety lies in design, proper operations of plants, careful monitoring of component parts, and a strong regulatory system. *America's Energy Future* briefly mentions the use of PRA, which predicts lower frequencies of core-damaging accidents in newer plants, and which has become part of NRC's "risk-informed" regulatory processes.

America's Energy Future contains a passing mention of the Chernobyl accident and no mention of Three Mile Island. Richter's book, in contrast, discusses both of these accidents. In neither case, however, do the respective authors incorporate accidents, their severe disruptions of life, and the potential for health-related problems as critical components of safety. Instead, both studies implicitly assume that safety can be "managed" satisfactorily. In essence, accidents result from bad handling of a good technology. Past catastrophic accidents and the ever-present potential for future catastrophes tend to be ignored. In both books, engineers learn from past mistakes so that "such a thing will never happen again." In short, accidents are peripheral, not central, to the concept of safety.

We maintain, in contrast, that the potential for calamitous accidents associated with nuclear power must be integral to the concept of its safety and pose the question, "Should the intrinsic potential for catastrophe affect the final decision to adopt or not adopt nuclear power?" We also assert that if consideration of accident potentials evokes only a discussion of good engineering and the regulatory principles to avoid them, and fail to consider the wider impacts of accidents, then the concept of safety remains incomplete and inadequate for decision making.

A similar deficiency attends treatment of the costs of electricity from nuclear power and other sources. These comparisons rely heavily on calculations of levelized costs, which place the costs of nuclear power in or near the range of power generated from advanced coal and biomass.[25]

America's Energy Future defines the levelized cost of electricity as ". . . the average cost of generating a unit of electricity over the generating facility's service life. The levelized cost is computed by dividing the present value of the estimated full life-cycle costs of the generating facility by its estimated lifetime electricity production. The result is usually expressed in terms of cents per kilo-watt-hour."[26] Thus, levelized cost of electricity appears to provide an objective, quantitative, scientific method for comparing the economic costs of generating electricity by different technologies.

While levelized costs can be useful for comparing technologies, the limitations of the method pose serious problems for decision makers. A key concern revolves around life-cycle costs and, more importantly, those costs not included.

The cost estimates in *America's Energy Future* include (a) capital construction, (b) financing, (c) operation and maintenance, (d) fuel, and (e) decommissioning. Useful as these costs are, they do not provide all necessary information, because the list excludes two vital issues: insurance costs and those resulting from damages due to accidents involving any significant releases of radioactive material.

As noted previously, nuclear power plant operators must obtain $300 million per plant in liability insurance from a private insurer and contribute $10 mil-lion annually to the industry pool. Federal taxpayers absorb liability damages above that level. Are the liability costs covered by private insurance adequate? Cleanup, compensation payments, and other costs associated with the accident at Fukushima in 2011 may reach $250 billion, so the amount not covered by private insurance could be considerable.[27] Levelized cost calculations do not account for these extra costs.

Justifying the omission based on the difficulty of estimating monetary costs of serious accidents will not reassure skeptics of nuclear power. True, damages are not easily monetized, but omitting them, and remaining silent about the omission, undermines the argument that calculated low, levelized costs of nuclear power make it preferable to other sources of electrical generation.

Other problems also plague calculations of levelized costs. The analyst must compute a "present value" of full life-cycle costs, yet calculating present values entails selecting a discount rate. Unfortunately, no objective means exist to pick the proper discount rate. Too high a rate will reduce present value and thus yield low estimates of costs. Too low a rate will inflate present values and thus the estimates of levelized costs. The analyst could use a range of discount values and the associated range of costs, but that approach runs the risk of letting decision makers justify their already-made decision using costs that might not reflect real world conditions.

A more subtle problem of using levelized costs in decision making stems from a bias in the basic approach. The method assumes a lower cost is preferable and asks, "What is the customer/citizen willing to pay for electricity?" Implicitly, the use of levelized costs of electricity assumes that as long as the cost of a technology is lower than competing technologies, the customer/citizen will be happy.

Unfortunately, the method ignores a different question that is equally important: "What is the customer/citizen willing to accept for the damages and risks imposed by the technology?"[28] This question focuses inquiry on the often unacknowledged dark side of all energy technologies and asks what the cus-tomer/citizen would voluntarily accept as compensation for the harms and risks. Omission of this question prematurely closes the analysis and leaves decision makers without important information about the public's willingness to accept or reject nuclear power.

As discussed earlier, nuclear power has always been a child of the state. Both *America's Energy Future* and the Richter study acknowledge the importance of public policy, but neither of their respective assessments covers the political tensions stemming from the necessity of heavy governmental involvement as a force for nuclear power's survival.

Similarly, neither of the two assessments discusses the important fact that US policy for the nuclear industry transferred risks to health and to economic well-being from the private sector to citizens and taxpayers. Price-Anderson in 1957 and federal loan guarantees after 2005 socialize risk while leaving potential profits privatized. These transfers, therefore, leave important ethical questions unexamined. Similarly, neither assessment fully embraces the need to assess the impacts of potential catastrophic accidents.

The common failing of each of these two assessments is their lack of historic frameworks for analysis. They ignore lasting legacies of history that are impossible to quantify. As a result, they fail to incorporate a full consideration of both safety and costs associated with nuclear power. Unfortunately, many decisions to proceed with nuclear power rely on such incomplete assessments.

Current Approaches to Costs and Safety: The Nuclear-Skeptic Positions

Two non-governmental organizations (NGOs) also assessed nuclear power in recent years but drew substantially different conclusions than the studies discussed above. Neither flatly rejects nuclear power, but both remain very skeptical about it. The Natural Resources Defense Council (NRDC), organized in 1970, has long worked on issues of energy.[29] Its methods of analysis incorporate physical science, but NRDC emphasizes economics, law, and litigation. The Union of Concerned Scientists (UCS), also organized in the early 1970s, has focused on nuclear power and on climate change.[30] Its methods include public policy analysis with an emphasis on scientific considerations. Even so, both NGOs have been very attentive to the qualitative factors that formed the history of nuclear power.

Proponents of nuclear power argue that nuclear stands out among existing technologies in the battle against climate change because of its ability to provide base-load power without emitting carbon dioxide or other greenhouse gases. Unfortunately, as the NRDC pointed out in its 2005 position paper and subse-quent fact sheets, that statement overlooks an important fact: it will be years, if not decades, before that electrical power could be on line in the United States to help reduce emissions. In addition, despite the flurry of applications to the NRC in 2007 and 2008, only two have received their construction-operating license to build two new reactors.[31]

The NDRC and UCS both fault nuclear power for the lack of a long-term geologic repository for its waste, whether from the mining and milling of ore or from the production of electricity. The US fleet of reactors discharges spent fuel at a rate of about 2,000 metric tons per year.[32] The spent fuel sits in cooling pools for five to ten years before being moved to large steel and concrete casks filled with inert gas. The accident at Fukushima highlighted the vulnerability of the spent fuel pools at each reactor location—cracks in the pools or a lack of adequate cooling water can lead to releases of radioactive material. The radioactive decay and heat generation inside the dry casks and the forces of nature outside may weaken the casks before a permanent storage solution is found.

In contrast to other green energy options, like wind and solar power, which can be added in small increments, current US nuclear power plant designs call for units that produce 1,200 to 1,600 MW each. Electrical capacity added in large, lumpy increments leads to extended periods of excess capacity in the system. Thus, although current capacity factors of nuclear power plants may exceed 90 percent, that number may drop as more units come on line. A decrease in the capacity factor will drive up the levelized cost of nuclear power.

Publications from the Union of Concerned Scientists primarily address the safety of nuclear power plants and the cost of building new ones. For the for-mer, the UCS examined the fourteen special inspections launched by the NRC in 2010 in response to safety equipment problems, security issues, and special events at the plants. It found that even after forty years of operating experience, US nuclear power plants continue to experience problems with safety related equipment and worker errors that increase the risk of core damage.[33] Many of the problems arise from known but misdiagnosed or unresolved issues. This implies the plants either do not have the technical expertise to correctly identify the causes of problems, or that they do not have the proper impetus to fix them in a timely manner. Indeed, many repairs are delayed until scheduled refueling outages, allowing them to worsen before they get fixed.

The UCS also looked closely at the subsidies for existing and new reactors. They argue that subsidies must be taken into account when comparing commercial nuclear power to other options for combating climate change, because of their impact on the cost of electricity produced.[34] For example, all nuclear facilities benefit from artificially low costs of uranium—companies pay no royalties for mines on public lands in the United States, and the industry receives a special depletion allowance equal to 22 percent of the ore’s market value.[35] Reactor owners pay little for the massive volumes of water they consume, often receive priority access to water supplies, and in return, alter stream flows and tempera-tures with their discharges. All reactors also benefit from the Price Anderson cap on accident liability. Moreover, new reactors will benefit from (a) federal loan guarantees, which lower the cost of debt; (b) accelerated depreciation—a tax break of $40–$80 million per year; (c) the ability in some areas to charge ratepayers now for power plants in construction; and (d) production tax credits. All of these subsidies have the effect of transferring the risks of nuclear power from the owners and operators of power plants, to ratepayers and/or taxpayers. The owners/operators do not pay the full cost of nuclear power but do reap the financial rewards.

Additional concerns about safety stem from proposals for the use of new reactor designs that have yet to be tested under production conditions: the Westinghouse AP1000 or AREVA's Evolutionary Power Reactor, for example.[36] Proponents stress the enhanced safety from passive safety features. But will all these engineered safety features really function as expected? Engineered safety features of designs from the 1960s and 1970s were also predicted to be essen-tially without risk on the basis of models,[37] but Three Mile Island and Fukushima demonstrated that they were not.

Despite the sensitivity the NRDC and UCS have shown to the legacies of nuclear power's history, they and other skeptics of nuclear power rarely provide full analyses of the engineering, ethical, and political-economic challenges of supplying a steady stream of base-load electricity to the US grid with renew-able energy. For example, solar and wind power generate electricity where and when the sun is shining or the wind is blowing, generally in places far removed from consumption centers. In addition, solar and wind installations require large land areas. Proponents of nuclear power often cite the low amount of land required for a plant that can generate a steady stream of 1,000 MW or more of electricity: about 245 hectares. In contrast, the land area needed to generate the equivalent of 1,200–1,600 MW from solar or wind would be much larger: over thirty-eight thousand hectares.[38] Large solar or wind installations provoke conflict and litigation based on aesthetic concerns (huge transmission structures or unsightly turbines) and destruction of habitat for endangered species (such as the desert tortoise).

Hydropower faces a similar problem. Many good hydropower sites are already developed. Proposals for new plants endure intense criticisms due to forced relocations of people and destruction of wildlife habitat. For example, the Three Gorges Dam in China will generate about 18,000 MW, but has required the relocation of 1.2 million people.[39] In the Pacific Northwest, conflicts over fish habitat led to dam removal, and it is highly unlikely that any large, new hydroelectric facilities will be built in the United States.

Finally, the manufacture of wind turbines and energy-saving compact fluorescent bulbs and electric vehicles requires rare earth elements, the production of which results in toxic wastes.[40] Moreover, China currently supplies about 93 percent of the rare earth materials used in the United States, so reliance on these materials currently generates concerns about the security of US energy supplies.

The NRDC and UCS have improved upon existing analyses of nuclear power by reflecting on history and including a more comprehensive analysis of safety and costs, the factors that proponents of nuclear power generally shortchange. However, they shortchanged the analysis of the downside of the options to nuclear power. Thus, a major lesson for both sides of the nuclear debate is to of nuclear assess the strengths and the weaknesses of *all* energy technologies. We propose the use of a Political Ecology framework as one way of doing just that.

Political Ecology: A New Framework for Assessing Nuclear Power

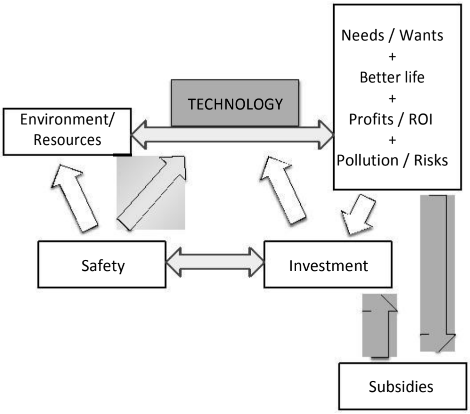
"Political Ecology"[41] encompasses both quantitative and qualitative parame-ters, but does not result in a bottom-line single number, such as a levelized cost or the risk of failure, that can be used in decision making. Instead, the framework produces a narrative that illuminates the critical issues involved in resolving Hamlet's dilemma: should we or should we not embrace nuclear power in a new energy economy?

Historically, purely quantitative methods never have been the basis for decisions about nuclear power. More importantly, purely quantitative measures *should not* be the sole basis for decision making about nuclear power, because such an approach will inevitably omit considerations that lie at the heart of public concerns about the technology. As discussed above, some attributes cannot be fully quantified and/or monetized in any meaningful way.

Political-Ecological assessment incorporates the usual factors of electrical supply and demand, available technologies, and the two major attributes of nuclear power often overlooked: safety and its complete range of costs. It yields a multi-dimensional narrative that introduces the need to make value judgments and not to rely solely on numbers to guide decisions. Political Ecology will not produce an unambiguous conclusion about the wisdom of using or avoiding nuclear power. Rather, it forces decision makers to think about many facets of nuclear power and thus guides them to a more comprehensive assessment.

The Political-Ecological framework (see Figure 1 below) begins with a focus on technology, which links nature and natural resources to people and their material

Figure 1
The Political-Ecological Analytical Framework



**Note*: "ROI" is return on investment

wants and needs. As described by Greenberg and Park in 1994, Political Ecology is an exploration of (a) the conflicts between people, their productive activities, and nature, and (b) the influence of culture and political activity on all three.[42] For energy technologies, "environment/resources" includes the natural resources or supplies of fuels to power electrical generation (natural gas, uranium, coal, wind, solar radiation, water, and land). Technology (power plants, wind turbines, solar panels) allows people to turn natural resources into electricity to satisfy human needs and wants. Access to electricity brings about a better life, and profits and return on investments (ROI), but also pollution and risks. The double-headed arrow under "technology" suggests the mutual interactions be-tween human wants and needs and natural resources: satisfying a want or need using technology makes no sense if the required natural resource is not accessi-ble, does not exist, or if no practical or affordable technology exists. Similarly, no need exists to develop a technology to harvest a natural resource if nobody wants or needs the electricity produced.

Figure 1 draws attention to the idea that both "safety" and "investment" affect choices of technology. Furthermore, safety and investment interact: increased safety usually costs money, and failure to include safety measures puts the in-vestment at greater risk and thus results in a higher cost. "Safety" also affects "environment/resources," because gaining access to any natural resource inevi-tably disturbs the environment and, in the case of coal or uranium mining, puts people's health at risk.

Finally, Figure 1 draws attention to the interactions among needs and wants, subsidies, and investment. Investors will not supply money unless they perceive low risks and/or adequate returns on their investment. Through various means, government may step in with a subsidy that catalyzes the investment. Subsidies draw money from other activities, through the tax and regulatory systems, into projects that otherwise would die for lack of private investment support. As an alternative, government can become the investor, but again the funds will inevitably come through the tax and regulatory systems. Nuclear power is not unique in its reliance on government subsidies, but many scholars have concluded that subsidies to nuclear power are of overwhelming importance to the existence of the technology.[43] Nuclear power would never have emerged from private investors alone without those subsidies.

For nuclear power, the Political-Ecological framework draws immediate attention to the two factors most prominently incomplete in positive assessments of nuclear power: safety and costs/investment/subsidies. Within the Political-Ecological framework, a calculation of levelized cost of electricity will appear as a necessary—but by no means sufficient—tool for comparing the costs of nuclear power with alternatives. Similarly within this framework, it will be impossible to ignore the important subsidies that underlie nuclear technology.

Assessment of renewable technologies such as biofuels, hydropower, wind, and solar also will benefit from use of the Political-Ecological framework. Issues of subsidies, investments, and safety also attend these technologies, and any valid assessment must develop a narrative to capture these issues. For each renewable energy source the narrative will be different. For example, an examination of wind or solar would highlight the engineering challenges of providing a steady, stable supply of electricity to the grid. The discussion would include the loan guarantees, low interest rates, and tax breaks helping to fund the large solar installations and wind farms.[44] Although neither wind nor solar generates the type of toxic and radioactive spent fuel associated with nuclear power, the narrative might discuss the use and disposal of hazardous chemicals used in equipment manufacture. Understanding the multitude of characteristics for each energy technology will help us all make better decisions about the future of the energy economy.

Conclusions

Finding technologies that can replace fossil fuels remains a challenge for the green energy economy. Devising a quantitative tool that can capture the ethical, economic, and political problems created by these different energy systems presents an additional challenge. The Political Ecology framework, described here for the case of nuclear power, allows for a more complete assessment and comparison of various technologies than do calculations of levelized costs or return on investment. First, the entire energy economy comes into consideration, as questions of which technology to use leads to questions about harvesting natural resources and how best to address needs and wants. Safety and risks also become decision-relevant factors that can lead to rejecting or accepting a candidate technology.

Finally, energy technology appears not as a disembodied physical process but as a component of a socio-technical system in which the *context* of the physical technology is as important as the *technical system* itself.

As for Hamlet's dilemma: should we, or should we not, embrace nuclear pow-er as a necessary green energy technology? Those who promote nuclear power have yet to demonstrate that this choice justifies billions of dollars in investment. Those who oppose nuclear power have yet to find a clean technology capable of providing base-load power. Using a Political Ecology framework may help us all find the mix of technologies that will best meet the social and environmental needs in an ever-changing world.

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