Chapter 15
The Nuclear Pipeline: Integrating Nuclear Power and Climate Change

Jen Schneider, Abraham S.D. Tidwell, and Savannah Avgerinos Fitzwater

Abstract This chapter focuses on nuclear scientists and engineers, and the effectiveness of small-scale interventions that could be made to prepare them to consider novel kinds of climate disruptions and how such considerations could affect plant design and operations. Events at Fukushima in 2011 prompted renewed attention to nuclear safety. Soon after, scientists recorded record-breaking global temperatures, particularly during the summer of 2012. Perhaps as a result of these two events, academics and the media have begun asking whether nuclear power plants are robust to natural events beyond the range of available historical data (beyond design basis), including climate-related events such as increasing drought and rising cooling-water temperatures. Science policy scholars, scientists, and engineers outside nuclear science and engineering have begun to pose such questions and model possible effects. This study demonstrates there is almost no public discourse and very little professional discourse within the nuclear science and engineering community on this topic. We posit that this is largely because of the insular culture and professionalization standards of nuclear science and engineering, which could limit the effectiveness of curricular interventions made in engineering education.

Keywords Nuclear engineering • Climate change • Nuclear power • Global warming • Engineering education

J. Schneider (✉)
Department of Public Policy and Administration, Environmental Research Building, Office 5135, Boise State University, 1910 University Drive, Boise, ID 83725, USA
e-mail: jenschneider@boisestate.edu

A.S.D. Tidwell
Consortium for Science, Policy and Outcomes, Arizona State UniversityTempe, P.O. Box 875603, Tucson, AZ 85287-5603, USA
e-mail: Abraham.Tidwell@asu.edu

S.A. Fitzwater
Liberal Arts and International Studies, Colorado School of Mines, 301 Stratton Hall, 1005 14th Street, Golden, CO 80401, USA
e-mail: savannah.fitzwater@gmail.com

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Introduction

The research in this chapter emerged from a larger project that asked the question: can engineering education be reformed to better prepare engineering students to incorporate climate variability, as a result of climate change, in their engineering design work? The focus of this work has been on infrastructure resilience in particular: if increasingly severe flooding will adversely affect engineered structures such as dams and levees, for example, should not engineers be thinking differently about design bases, assumptions, and their interactions with other experts, policymakers, and the public?

Initial work from the project took the form of ethnographic interviews with faculty members in engineering and the sciences at our university, the Colorado School of Mines (CSM). Findings from that study suggested that there were tremendous challenges facing efforts to reform engineering education in order to better integrate climate change, not the least of which were complex faculty attitudes toward the topic itself, but also institutional disincentives and barriers (Lucena et al. 2011). In fact, there was a significant absence of climate-change related curriculum in the university as a whole. This initial work may give us some context for understanding why nuclear science and engineering educators are ignoring climate change as it relates to plant vulnerability: it simply is not yet part of institutional cultures.

Furthermore, in 2011, there was a dearth of scholarly approaches to thinking about the resiliency of nuclear power plants in response to climate change. The authors of this chapter, along with other students involved in the initial stages of this research project, were only able to find one or two articles in peer-reviewed sources dealing with the subject (e.g., Kopytko and Perkins 2011). The majority of other sources on the topic, such as websites and blog entries, treated the topic in a fairly non-academic fashion. The Fukushima Dai-ichi crisis happened in the spring of 2011, and pundits and nuclear experts alike were renewing their focus on nuclear plant resilience, but little of that seemed to be translating into scholarly assessments of U.S. plants and climate change.

The year 2012, however, was to teach us differently. Climate scientists reported that they were recording the highest global temperatures on record. Droughts became increasingly severe in already-dry parts of the globe; rising sea levels and increasingly intense floods struck other parts. The summer was intensely hot in Western Europe and the Eastern United States, areas with high concentrations of nuclear power plants. Blogs, press releases, news stories, and articles in the scientific press (such as *Science Magazine* and *Nature Climate Change*) began reporting that increasing numbers of nuclear power plants were being shut down because their cooling waters were too hot, either for intake or for discharge. Clearly, there was something to this issue, despite first appearances.

This study emerged from these initial experiences, and the "failure" of our initial research into this topic. Science policy scholars, scientists, and engineers outside of nuclear science and engineering have begun to think critically about nuclear plant responses to climate disruptions. This chapter demonstrates, however, that there is almost no public discourse and very little professional discourse within the nuclear science and engineering (NSE) community on this topic. We posit that this is largely because of the insular culture and professionalization standards of nuclear science and engineering, which – along with material obstacles, such as access to specifics of plant design and security restrictions – limit the effectiveness of curricular interventions made in engineering education at the undergraduate and graduate levels.

Methodology

One emphasis of this chapter is on performing a literature review of relevant policy and nuclear science and engineering journals on the topic of nuclear power and climate change. The Center for Science, Technology, and Policy Research (CSTPR) has identified a list of influential journals in science and environmental policy. We used this as a starting point for conducting a search on nuclear power and climate change, focusing our work on those journals from the list that look specifically at environmental policy. We also chose to search the journals *Nature* and *Science Magazine* because of their stature and wide readerships, particularly in relation to climate science and policy commentary. We limited our initial search of the journal *Nature* to "Research" articles: future work will need to expand to include the hundreds of commentaries and news pieces related to our topic. The publications we searched are listed below.

1. *Nature*
2. *Science Magazine*
3. *Climatic Change*
4. *Environmental Research Letters*
5. *Global Environmental Change*
6. *Weather, Climate, and Society*

We conducted a general search for any original research articles containing the phrases "nuclear power" or "nuclear energy" in the text. From these articles, the search was further refined to focus on those articles that refer to nuclear power and energy in the context of climate change. We also chose to review two types of publications in nuclear science and engineering: the five English-only journals with the highest rated impact factors according to the Web of Science, and more operations-oriented publications produced by the American Nuclear Society (ANS), a professional organization of scientists, engineers, and other professionals devoted to the peaceful applications of nuclear science and technology. ANS has 10,500 members in 46 countries, and its publications are widely read by practicing nuclear scientists, engineers, and students, (http://www.new.ans.org/about/history/).

What became immediately clear is that highly theoretical research published by the top journals in nuclear science does not address the primary concerns of power plant operators. These top journals were searched and, yielding no results, eventually excluded. On the other hand, it seemed possible that ANS publications might address climate change as affecting nuclear power plant production in some way. Because the focus of the paper is on electricity generation, we focused our search to articles that addressed the nexus of climate change and commercial-scale nuclear power plant production or small modular reactor (SMR) design. The following ANS publications were also searched using the keywords “climate change,” “global warming,” “climate disruption,” and “climate variability”:

1. *Fusion Science and Technology*
2. *Nuclear Science and Engineering*
3. *Nuclear Technology*
4. *Nuclear News* (magazine)

Finally, we also searched the websites of the two most prominent nuclear industry organizations, the World Nuclear Association (WNA) and the Nuclear Energy Institute (NEI) for articles addressing nuclear plant resilience to climate change. Both organizations have a strong web presence, and a core mission of communication with the public. Both could be described as industry front or trade groups.

We read abstracts for all articles that resulted from these searches, and then conducted a keyword search for “nuclear” within the article to determine its relevance to our topics and hypotheses and to look for repeating patterns, approaches, and attitudes toward nuclear. Articles that were irrelevant to our topic, or which only addressed climate change and nuclear power tangentially, were excluded. Policy modeling papers that explored nuclear power more thoroughly, particularly in relation to emissions targets, were included.

Articles were coded by summarizing each relevant article and then we organized these notes by thematic unit in order to determine relevant categories (Frey et al. 2000). For example, as we searched the policy journals, we looked for articles that addressed how nuclear power was understood as a response to climate change. In some of these cases, nuclear power took on the role of being a key decarbonization technology. In others, the articles reflected policy scholars’ concerns about public resistance to nuclear power plant builds. Therefore, we added a category titled “public acceptance of nuclear power as a response to climate change.” We added categories in this way as they emerged from the coding and then organized articles into categories in order to understand general patterns in the literature.

Nuclear Power as Climate Policy

In their 2004 *Science Magazine* article “Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies,” Stephen Pacala and Robert Socolow famously argue that the challenges posed by climate change could be solved in the “first half of this century simply by scaling up what we already know how to do (Pacala and Socolow 2004). Pacala and Socolow demonstrate how this could be done by dividing carbon emissions into a series of seven “wedges,” with the wedges representing avoided carbon emissions resulting from technological and social improvements in energy efficiency or development. Accomplishing the reduction implied by the wedges would limit atmospheric CO_2 to 500 parts per million (ppm) – an amount the authors argue "would prevent most damaging climate change."

Pacala and Socolow identify at least 15 strategies for accomplishing the wedged reductions that involve scaling up existing energy production or consumption technologies. In retrospect, we now see that some wedges are more feasible than others. For example, the authors argue that society could accomplish one wedge of CO_2 reductions by replacing 1,400 GW of low-efficiency coal-fired power plants with gas plants. Unlike some of the other strategies – the ones requiring significant performance from CO_2 Capture and Storage (CCS) facilities, for example – this particular strategy might prove to be economically and politically feasible depending on the development of shale gas, which in turn faces substantial public opposition.

Pacala and Socolow's article was historically significant in part because it galvanized discussions about concrete climate policy action, and because its central assumptions are representative of persistent climate policy debates. For example, their work forces us to ask whether we can accomplish climate goals using technologies we have, or whether we must launch a "Manhattan Project" for new energy research and development. This is arguably an unresolved and ongoing climate policy debate. The Pacala and Socolow proposal also focuses on mitigation strategies, as opposed to adaptation strategies, another contentious area of debate. Ongoing research regarding the feasibility of their ideas continues (e.g., see Pielke 2010; Socolow 2011).

Pacala and Socolow's article is interesting as context: it is typical of how those concerned with policy think about nuclear power, which is as a mitigation response to climate change. Nuclear fission is a stand-alone strategy on Pacala and Socolow's list; the authors argue that doubling our current nuclear capacity to 700 GW would accomplish the reduction of one wedge of CO_2 emissions by 2054. This optimistic outlook for nuclear seems both unrealistic and unreasonable now; however, this article was written before the meltdowns at the Fukushima Daiichi reactors in 2011 and the consequent reduction in German and Japanese electricity production from nuclear power. The article was also published before the 2008 global recession, making it still possible for US and European utilities or states and developing-world economies to imagine investing billions in building large-scale nuclear reactors. Such building continues in China, of course, but at a somewhat less aggressive pace than before (Yiyu 2012).

Despite these concerns, the promise of nuclear power as a response to climate change persists. It is appealing because it promises to provide massive amounts of baseload power, if we continue with large-scale plant building, while emitting a reasonably small amount of CO_2 into the atmosphere, particularly when compared with coal or gas plants. It does not face the same storage problems that renewable technologies such as wind and solar face, and it is easily transmitted over existing power distribution networks. Furthermore, many of the licensing hurdles that nuclear plants have faced since the 1980s promise to be reduced by an improved and streamlined regulatory regime, which might improve building efficiencies and therefore reduce cost overruns. In addition, SMRs are receiving increasing attention as a possible response to the problems posed by huge power plants; they may be more economical and more easily maintained and licensed than large plants, and answer a philosophical resistance to large-scale energy production (e.g., Winner 1986). Arguments such as we have listed here in favor of the nuclear solution are frequently made by those arguing for a "moonshot" approach to energy development and climate policy (e.g., Bryce 2010).

A wide swath of thinkers and scholars think of nuclear power as a climate mitigation strategy. Advocates of the "nuclear renaissance" – including some formerly notable anti-nuclear environmentalists such as Patrick Moore (Madrigal 2007) and Gwyneth Cravens (2007) – tout nuclear as the truly environmental response to climate change, and a relatively safe technology in comparison with fossil fuel electricity production. Similarly, policy scholars also see nuclear power as a key decarbonization strategy, particularly in cases where stringent emissions targets have been set. There are a few minor exceptions and corollaries to this generalization, but it is notable that, in general, scholars assume nuclear is a feasible and/or necessary climate solution (Bosetti et al. 2009; Bush and Harvey 1997; Buttel et al. 1990; den Elzen et al. 2008; Green 2000; de Lucena et al. 2010; Luderer et al. 2012; Mander et al. 2007; Mohnen et al. 1991; Myhrvold and Caldeira 2012; Riahi et al. 2011; Rosenberg and Scott 1994; Schultz et al. 2003; Urban et al. 2009). The industry groups – WNA and NEI – also beat this drum exceptionally loudly. WNA and NEI mention climate change frequently on their websites, but only in the context of justifying a nuclear renaissance.

In critical policy terms, however, one could argue that the future of nuclear is anything but bright, and the possibility of a nuclear renaissance looks bleak. There is no doubt that, if we did not have social, economic, or ethical concerns, nuclear power would be an excellent technological response to climate change, but such a world in which power plants operate separate from their socio-political context does not exist. Nuclear opponents are, of course, stridently opposed to such expansion of nuclear power. Furthermore, there is some concern or suspicion among a number of policy scholars as to how countries will meet seemingly unrealistic emissions targets and/or avoid catastrophic climate change when prevailing trends against nuclear are unfavorable, and the immense number of reactors that would be required to successfully meet such targets are economically infeasible (Collier and Löfstedt 1997; Davis et al. 2010; Pielke 2009a, b; Webber 2007; Yue and Sun 2003). Other scholars suggest that while nuclear power might be a promising decarbonization technology, political and social forces may prevent its implementation. Public views on these two issues – nuclear power and climate change – are incredibly complex (Bostrom et al. 2012; Carr-Cornish et al. 2011; Pidgeon et al. 2008; Rayner 1993; Truelove and Greenberg 2012; van Vuuren et al. 2007).

Yet only a few policy scholars openly critique nuclear power as a response to climate change, citing concerns over its technocratic nature, which has implications for social justice and community engagement, or its inability to respond quickly and with flexibility to changing climate policies (McEvoy and Wilder 2012; Trancik 2006). Scholars are more likely to take a social constructionist view of nuclear power, examining when and how it is invoked or used in the context of climate change (Rogers-Hayden et al. 2011).

Does Climate Change Pose a Risk to Nuclear Power?

The nuclear industry, generally speaking, invokes climate change primarily as a justification for supporting a nuclear renaissance in the United States and abroad. Popular books on the subject, including Gwyneth Cravens' *Power to Save the World* (2007), Herbst and Hopley's *Nuclear Energy Now* (2007), and Charles Ferguson's *Nuclear Energy: What Everyone Needs to Know* (2011) make this argument, and industry websites such as those of the WNA and NEI frequently speak about nuclear power's value in mitigating climate change. Referring to climate change is a central component of contemporary nuclear renaissance discourse. The study of how nuclear power plants will respond to climate change itself, however, is still clearly in its infancy. Engineers, scientists, regulators, and policymakers who are involved in designing and maintaining the existing environment across multiple sectors are struggling with how to retrofit, plan around, or otherwise prepare for climate disruptions, which are still uncertain and difficult to predict at local scales. Nuclear plant design, construction, and maintenance are no different in terms of facing similar challenges. Yet we can begin to identify some vulnerabilities that nuclear plants in particular face as a result of increasing global temperatures and disruptions, and which are being addressed in the policy literature:

Ability to Discharge Cooling Water This is the most prominent concern expressed in the literature (Aaheim et al. 2012; Golombek et al. 2012; Rübbelke and Vögele 2012; Van Vliet et al. 2012; Vine 2012). During the 1970s, nuclear power plants came under intense public and environmental scrutiny due to their contributions to the "thermal pollution" of rivers and lakes used to discharge cooling water. As a result, governments created regulations that required plants not to exceed certain temperatures when discharging their cooling water. However, as global temperatures rise, the temperature of rivers and lakes may also rise. Power plants may not be able to discharge warm cooling waters into rivers and lakes or risk exceeding temperature levels. Consequently, some regulators are actually raising the allowable temperatures for discharge to accommodate the plants (Godoy 2006).

Access to Cooling Water There is some concern among experts outside of NSE that, as droughts get more severe and access to water more contested, nuclear plants may have to undergo extensive retrofitting measures (such as having intake pipes lowered), endure closures (temporary or otherwise), or politically maneuver for water rights in highly contested policy terrains (Rübbelke and Vögele 2012; Stillwell et al. 2011; Van Vliet et al. 2012). There has been some public concern about how rapidly changing ecosystems may affect oceanic cooling waters. For example, some have predicted a "jellyfish apocalypse": As ocean waters warm, scientists expect species such as jellyfish to thrive. Jellyfish are also easily sucked into intake pipes, fouling up cooling water mechanisms for power plants (Attrill et al. 2007; see Eng 2012). However, in general the policy literature there is mostly concern about drought and water availability.

Siting Problems Some scholars are also concerned about how shifting climate patterns or melting permafrost will affect the buildings of the plants themselves, or change the way plant builders have historically chosen sites, i.e., near bodies of water that have historically been replenished by significant snowfall (Bulygina et al. 2011; Nelson et al. 2001).

The significance of nuclear plant shutdowns or efficiency losses resulting from climate disruptions is presently hard to quantify, and even harder to predict for the future. Yet, some research suggests that the frequency and/or severity of nuclear plant efficiency losses or shutdowns are increasing as the climate warms because of the reasons described above. Van Vliet et al. (2012), suggest that the Southern and Eastern US will be most vulnerable, along with the Southwestern and Southeastern parts of Europe (p. 2). These authors argue that substantial losses in efficiency in Europe occurred in 2003, 2006, and 2009, and in the US in 2006–2007 (p. 1). Recent news reports also tell of efficiency losses or shutdowns in US plants, occurring in 2011 and 2012, at plants that had not seen such shutdowns before.

The elements identified above form the framework of the paradox in understanding the relationship between nuclear power and climate change. As Rübbelke and Vögele put it in a 2011 article in *Climatic Change*:

> Nuclear energy is frequently regarded as a vehicle to reduce CO2 emissions and thus to combat global warming. Yet, there is also a reverse interrelation: the nuclear power sector is negatively affected by climate change, since cooling processes of power plants are likely to be impaired by climate-change related extreme weather events like droughts and heat waves.

For reasons discussed below, the nuclear industry does not seem to be paying much attention to this paradox.

Industry Responses

Those in the nuclear industry are clearly aware of these issues, but according to our research, frame them as falling under typical operations and maintenance. One example is illustrative. The NEI features a blog called "NEI Nuclear Notes." It was in this blog that we found the *only* nuclear science, engineering, or industry responses to nuclear power plant resilience and climate change. On the blog, the author responds to concerns about rising temperatures of cooling waters with the following points ("The Truth" 2006):

1. These issues are not particular to nuclear plants but to all thermoelectric plants, which "account for over 80 % [sic] of all electricity generated on the planet;"
2. Usually, nuclear plants don't have to shut down altogether, like wind power generation did during the 2006 heat waves (because the wind wasn't blowing);

3. And nuclear plants can be designed to “minimize water usage” and therefore not suffer from droughts.

These responses are not wholly satisfying: they do not address our central paradox, which is that the industry has represented itself as a meaningful solution to climate change, yet has not adequately or meaningfully addressed its vulnerabilities to significant climate disruption. Furthermore, while plants *may* be designed to minimize water usage, that does not mean they *can* currently operate in that way, especially in areas not historically accustomed to drought-like conditions, but which may encounter them as the global climate continues to change. Instead, existing nuclear plants have primarily been designed using historical environmental and climate data rather than predictive data.

In a related post on *NEI Notes*, the author writes that nuclear is being held to an unfair standard compared with coal-fired or gas-fired plants; these plants are also vulnerable to supply disruptions, particularly when overwhelmed with peak loads, such as during a heat wave, or even during an exceptionally harsh winter. The author also notes that environmental regulations for thermal pollution are probably “over-conservative and not based on today’s best available science,” though no link to this science is provided (Countering More Propaganda 2006). Again, this answer seems unsatisfying, perhaps because the nuclear industry has made so much of efficiency gains and high capacities, and of their ability to mitigate climate change. Furthermore, risks of nuclear accidents increase with extensive wear and tear of infrastructure, and the scale of a potential nuclear accident may far exceed that of a gas-fired or coal accident. If a nuclear plant must be shut down for a long period of time due to water-related issues, then questions about when to begin the very expensive decommissioning process must be raised.

Finally, in a third blog post, *NEI Notes* provides a meaningful answer to our paradox when it briefly suggests that the industry is attempting to respond to the thermal pollution problem, in some cases by building “small cooling towers to pre-cool discharge water.” Still, the author does not explore this in depth, and soon returns to the problems with wind power’s intermittency and coal and natural gas’s inability to address meaningfully the climate problem (Revisiting Nuclear 2012).

Though neither scholarly nor complete, at the very least these blog posts acknowledge the problems raised by van Vliet et al., and attempt to respond. By contrast, in our study of the scholarly literature and the literature produced by the ANS we found *not one instance* of scholars, scientists, or engineers addressing in research articles or public discourse the potential challenges posed to nuclear plants by climate change.

Discussion and Conclusion

The research above reveals a possible discourse gap between those concerned about nuclear power plant resilience and those who design and operate nuclear power plants but who do not seem to be discussing resilience in terms of climate change at all. Here, we attempt here to describe why this discourse gap might be occurring, proposing these possible explanations in a spirit of humility and inquiry. It is possible, for example, that our methodology is not sound; we acknowledge that those who operate and maintain nuclear power plants may be having these discussions, as might industry insiders, behind closed doors. The Nuclear Regulatory Commission (NRC), the regulatory body within the U.S. responsible for the safe use of radioactive materials for civilian use, may be accounting for climate disruptions out of the public eye, and may be doing so using terms other than "global warming" or "climate change." When we presented our research to energy policy experts and to the NSE students and faculty at CSM, however, none raised the possibility that we missed important publications or venues where these discussions were happening. To the contrary, their impressions matched our own: these discussions are *not* occurring in nuclear science and engineering. The possible reasons for *why* they are not occurring are many. They are outlined here.

Climate Skepticism First, research emerging from this research project confirmed what many of us who had worked as engineering educators for years already suspected: engineers, generally speaking, may be more resistant to "believing in" or taking seriously climate change and climate change research. These findings are discussed in detail in Lucena et al. (2011).

Furthermore, it seems important to acknowledge that not *all* scientists support the consensus on anthropogenic climate change; some scientific disciplines, including Physics, may be more likely to be skeptical of this consensus. Most NSE programs have some foundation in Physics or Mechanical Engineering programs. Myanna Lahsen (2008), Laura Nader (1981), and others have convincingly argued that physical scientists and engineering, as disciplines, encourage skepticism as a cultural value. In fact, a number of prominent physicists – particularly those who made their careers during the postwar era – have also emerged as strong doubters of climate change theory. It seems possible, if not likely, that nuclear scientists and engineers might absorb this culture from professors and mentors, and that such beliefs might translate into an unwillingness to engage in discussions about nuclear power plant resilience to climate change.

Disciplinary Factors Another possible explanation grapples with the nature of the development of the nuclear engineering discipline and curriculum itself. According to Sean F. Johnston, the peculiar nature of the development of nuclear engineering as a discipline made nuclear engineers subservient to the state and the technology that brought them into existence. Consequently, nuclear engineers had little opportunity to establish social and economic relationships common to other professions; develop a coherent and cross-cutting curriculum; and, in the case of the United Kingdom, play a major part in the industry they were created to serve. Summarizing the current status of the nuclear engineering discipline, Johnston (2012) states:

> If the field of nuclear engineering were considered in the framework of development psychology, the neutron's children [nuclear engineers] might be perceived as suffering from arrested development, peculiar idiosyncrasies and worldview, insecure self-image, weak communication skills, and poor socialization with their peers. The gradual estrangement of

> their governments and the traumatic experiences of Three Mile Island, Chernobyl, and Fukushima furthered shaped their identity.

Without the opportunity to properly develop as a discipline, nuclear engineering, as the segment of NSE that deals most directly with nuclear plant operations, possibly never developed the educational capacities necessary to grapple with the challenges posed by climate change.

Climate Change as a Wicked Problem A third explanation for this discourse gap, in addition to the cultural ones outlined above, is the nature of climate change itself. As many scholars have noted, climate change is particularly difficult to communicate and plan for because it is a diffuse and ubiquitous threat; it evolves relatively slowly compared with the rapid pace of human news and policy cycles; and its effects will be uneven and unpredictable at the local scale. This makes it a so-called "wicked" problem. These characteristics could lead to any number of responses from scientists and engineers. One response could be fatalism: if climate change is going to be as bad as some scientists predict, then nuclear power plant efficiency will be low on the totem pole of priorities. Another response might be denial; the scope and the severity of the climate problem is so great, it is perhaps easier to discount it as the delusional ramblings of greedy climate scientists. Or, perhaps, a third response – and one that we feel is quite likely – is that nuclear scientists and engineers might see climate change as just another engineering problem. They believe they know how to engineer for severe weather, earthquakes, even terrorists crashing jetliners into plants. Increasing drought or rising sea levels can be dealt with as well. This also appears to be the position the NRC took when recently responding to public concern about potential rising sea levels at a plant applying for re-licensing. The correspondence from the NRC to a concerned letter-writer in response to these sea level concerns was as follows (Nuclear Regulatory Commission 2012):

> The NRC has multiple processes to evaluate the adequacy of current plant operations and licensing bases. Should the NRC become aware at any time of information calling into question the continued safe operations of any nuclear power plant … the NRC will take the appropriate actions as part of the agency's ongoing safety oversight, regardless of whether those plants have sought or are seeking a renewed license.

This response further supports the argument that scientists and engineers within the nuclear field believe that impacts from climate change can be tackled like any other engineering problem. Furthermore, the NRC does not appear to be concerned about the impacts from climate change until they pose specific threats, which does not indicate much concern for long term planning.

There is also a tendency in NSE to argue that nuclear *has* addressed concerns such as drought, cooling water temperatures, and safety, primarily through the development of Generation-IV designs which do not require water for coolant, or which can be developed and deployed on a local scale in the form of small modular reactors (SMRs). In our experiences, face-to-face discussions about plant resilience almost always end up focused on these future, not-yet-implemented technologies. However, such future technologies are yet to be deployed on a utility-scale, potentially face numerous social, economic, and political challenges, and do nothing to address the vulnerabilities of the more than 400 plants that already exist worldwide. This rhetorical shift to future technologies also serves to emphasize the supremacy of technical discourse and the technological fix, ground upon which scientists and engineers often feel most comfortable (see Weinberg 1994).

Political Economy A fourth explanation for the discourse gap has to do with politics and economics. On a practical level, the costs of adaptation to climate change might be tremendous. Retrofitting plants for risks that *may* occur but that are not accounted for in a plant's existing design basis is unpalatable from an industry perspective. Fluctuations in the economy exacerbate financial concerns, particularly in the wake of the 2008 financial crisis. Furthermore, following the Fukushima crisis and the push to denuclearize electricity production in many parts of the world, the industry has seemingly more pressing concerns. In the words of one colleague from NSE, "We [the industry] just have other priorities right now." Such a sentiment is congruous with political approaches to risk in the United States in general, where we tend to be reactive when crisis hits, rather than proactive in trying to head off the crisis to begin with.

Similarly, while climate change might provide a positive justification for building more nuclear power plants (the "nuclear renaissance" reasoning) there are strong disincentives to explore the downsides climate change might pose. From a public relations perspective, it is difficult to argue that climate change is both good for the industry *and* bad for it, and the industry is not likely to point out its potential weaknesses in this regard. Furthermore, many utilities own not only nuclear power plants but also coal-fired and gas-fired power plants, which are a primary source of the very greenhouse gases that are accelerating climate change to begin with. The industry and its public relations organizations must be careful in how they address this paradox.

The NSE Pipeline A fifth explanation might unite all of those presented above, and, from our point of view, is most compelling. This explanation is largely an instrumental one, and suggests that, quite simply, there is just no space in NSE to meaningfully take up climate change and plant resiliency as a research question. When Jen presented this research to a group of NSE students at CSM, one asked, "Why don't you start an academic journal about this?" She replied, "Why don't *you*?" The discussion that ensued suggested that such a thing was atypical of the culture of NSE. There are no panels at the annual ANS conference on such topics; no publication venues; no funding opportunities; no classes; no publications. There do not even seem to be casual side conversations on the topic.

If this is true, then there are significant ramifications for those interested in engineering reform that advocates introducing climate change more meaningfully into these engineering students' curricula. If not meaningfully addressed by their professors, colleagues, future employers, journal editors, or conference organizers, climate change becomes just another concern of the liberal arts professor, and a dodgy one at that. If the entire professional pipeline of NSE, from diploma to retirement, is built to shut out such concerns, what hope do micro-interventions or modest reforms have? Such classroom interventions will only be successful if integrated into "pipeline" efforts that target practicing scientists and engineers, professors, employers, and policymakers, in addition to undergraduate and graduate students.

Which brings us to our last possibility, which is the possibility that climate change really does not pose much of a threat to nuclear power plants, especially when compared to other concerns we might have. We acknowledge that this may be the case. Yet, we would make the case to nuclear scientists and engineers that their voices are needed at the table of this particular discussion in order to determine if inaction is the best course. We would encourage them to propose a panel at ANS, to write an editorial on the subject, to post blog entries, and to push their colleagues and professors to address the question. Perhaps the answer is an easy one, perhaps not. In any event, the question of whether nuclear power plants are resilient to climate change is being asked by the public, the media, and experts outside of NSE; pretending that the question has not been posed is not a good strategy and, at worst, could backfire on the industry the way so many issues of public concern have in the past.

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Jen Schneider Ph.D. in Cultural Studies from Claremont Graduate University. Associate Professor, Public Policy and Administration, Boise State University, USA. Co-author with Juan Lucena and Jon Leydens of *Engineering and Sustainable Community Development*. Past projects have addressed the role communication plays in environmental crises such as climate change and engineering for development work. Current projects address the role of rhetoric, media, and communication in energy controversies in the United States, with a special focus on fossil fuel production and consumption. Jen is completing a co-authored book titled *Under Pressure: Coal Industry Rhetoric in the Age of Neoliberalism*.

Abraham S.D. Tidwell B.S. Chemical Engineering, Virginia Tech. M.S. in the Master of International Political Economy of Resources (MIPER) program at the Colorado School of Mines. Ph.D. student at Arizona State University. At the Colorado School of Mines, Abraham worked on a multitude of topics including public lands management and policy, uranium milling policy in Colorado, and communication studies of nuclear energy controversies. Abraham's master's thesis work examined the controversy surrounding a proposed uranium mill in western Colorado – the first of its kind in 30 years – and how this controversy adds to our understanding of the intersection of nuclear technology and society in the twenty-first century American West, a space he has termed *The New Nuclear West*. In addition, Abraham co-authored an entry in *American Political Culture: An Encyclopedia* on nuclear power and U.S. politics with Jen Schneider and Savannah Avgerinos Fitzwater.

Savannah Avgerinos Fitzwater B.S. in Nuclear Engineering from Missouri S&T and currently pursuing an M.S. in Nuclear Engineering and Masters in International Political Economy of Resources at Colorado School of Mines. Research interests include the politics of nuclear weapons, the education of nuclear engineers and the associated long term impacts, and the intersection of nuclear weapons and national identity. Co-authored an entry focusing on nuclear power and U.S. politics for *American Political Culture: An Encyclopedia* with Jen Schneider and Abraham S.D. Tidwell.