HOLISTIC CLIMATE CHANGE GOVERNANCE: TOWARDS MITIGATION AND ADAPTATION SYNTHESIS

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Climate change already has begun destabilizing natural systems, prompting unprecedented heat waves, droughts, floods, and severe storms. While scientists admonish us that greenhouse gases must be cut deeply and quickly to avoid the worst impacts, past emissions have committed the planet to some further warming. Resulting physical changes will require a legal system that functions amidst extreme weather, rising seas, and scientific uncertainty about the stability of natural systems upon which we relied in designing institutions and infrastructure. An effective response requires both substantial reductions in greenhouse gas emissions to limit the harm ("mitigation") and significant adaptation. Scholars and policymakers have largely treated mitigation and adaptation as distinct strategies, overlooking critical interactions between the two issues. This Article addresses the resulting gap in scholarship.

Adequate preparation for climate change requires fundamentally rethinking systems and infrastructure designed for more stable conditions. Part of this rethinking process includes evaluating whether legal measures designed to reduce

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greenhouse gas emissions will ultimately aid or hinder adaptation. Using a case study of one proposed mitigation measure—expanded reliance on nuclear power—this Article illustrates how disconnected approaches to adaptation and mitigation can undermine both efforts. The Article then offers a preliminary framework for holistic climate change governance that directs mitigation investment toward adaptive and adaptable infrastructure that reduces human risks, decreases reliance on complex networks, and moderates the extent of scientific uncertainty that legislators and administrative agencies will face in an unpredictable future environment.

INTRODUCTION

"We are all used to talking about these impacts coming in the lifetimes of our children and grandchildren. Now we know that it's us. . . . Mitigation has got[ten] all the attention, but we cannot mitigate out of this problem. We now have a choice between a future with a damaged world or a severely damaged world."[1]

Climate change has begun destabilizing natural systems that we have long taken for granted. Impending physical changes will require a legal system that functions amidst extreme weather, rising sea levels, and generally high levels of scientific uncertainty about the stability of natural systems upon which we relied in designing institutions and infrastructure. An effective response requires both substantial reductions in greenhouse gas (GHG) emissions to limit the extent of warming and thoroughgoing planning to help humans, animals, and ecosystems adapt to a changing climate.

Unfortunately, the need for climate change adaptation can no longer be ignored. While scientists admonish us that GHG

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[1] Martin Parry, Co-chair, Intergovernmental Panel on Climate Change, *quoted in* David Adam, *How Climate Change Will Affect the World*, THE GUARDIAN, Sept. 18, 2007, http://www.theguardian.com/environment/2007/sep/19/climatechange.

production trajectories must be cut deeply and quickly to avoid the worst impacts,[2] past emissions already have committed the planet to at least some further warming.[3] Consequently, even under the best emissions scenarios, this century will see more frequent and severe storms, flooding, heat waves, droughts, and fires.[4] Sea level is anticipated to rise, possibly abruptly, although projections vary dramatically.[5] Researchers expect that these changes will exacerbate security risks, alter food production, shift disease vectors, and prompt human migrations, among other phenomena.[6]

In light of these impending changes, this Article argues that effective climate change governance requires fundamentally rethinking physical and regulatory infrastructure that was designed for historically more stable climatic conditions. The legal system should direct investment toward adaptive and adaptable infrastructure that reduces human risks, decreases reliance on complex networks, and curbs (or at least does not exacerbate) the degree of scientific uncertainty that legislators and administrative agencies will face while regulating in an unfamiliar and evolving physical environment. Part of this rethinking process asks whether legal mechanisms designed to mitigate climate change by incentivizing GHG emissions reductions will aid or hinder adaptation. The most effective policy will synthesize both efforts, favoring coordinated over unilateral approaches to either issue.

Initially, legal scholarship on climate change focused heavily on mitigation.[7] Although not a subject of analysis until

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[2] *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: SYNTHESIS REPORT 73 (Larry Bernstein et al. eds. 2008) [hereinafter IPCC SYNTHESIS REPORT], *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf. ("Many impacts can be reduced, delayed or avoided by mitigation. Mitigation efforts and investments over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels. Delayed emissions reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts.").

[3] *See Climate Change Inevitable in 21st Century, Sea Level Rise to Outpace Temperature Increase, News Releases*, UNIV. CORP. FOR ATMOSPHERIC RESEARCH (Mar. 17, 2005), http://www.ucar.edu/news/releases/2005/change.shtml.

[4] IPCC SYNTHESIS REPORT, *supra* note 2, at 48.

[5] *See infra* Part I.B.1.

[6] *See* IPCC SYNTHESIS REPORT, *supra* note 2, at 48.

[7] *See infra* Part II.A.

recently, and by some accounts a formerly "taboo" topic, scholars have begun turning attention to strategies for adapting to a changed climate.[8] While mitigation aims to limit the extent of global warming (for example, by reducing fossil fuel combustion or sequestering carbon dioxide), adaptation reduces harm to humans, animals, and ecosystems from the warming that does occur. Adaptation measures could include, for example, shifting populations away from coastal areas that are vulnerable to rising seas.[9] The increasing attention to adaptation likely stems from recognition that some degree of warming and ecosystem change is now inevitable; hence mitigation can limit, but not eliminate, adverse impacts.

Analyses of mitigation and adaptation in the United States have largely occurred on parallel tracks.[10] Scholars have extensively debated the best design of mitigation regimes—focusing predominantly on proposals to incentivize GHG emissions reductions through market mechanisms such as cap-and-trade.[11] With the recent entry of adaptation into legal scholarship, academics have asked how to promote ecosystem resilience and reduce harm to human populations.[12] They have also evaluated how environmental and natural resources law should change to give agencies new decision-making tools and increased flexibility.[13] However, with few exceptions, scholars have not yet considered the intersection of these two issues. Up to now, federal policymakers have similarly analyzed

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[8] J.B. Ruhl, *Climate Change Adaptation and the Structural Transformation of Environmental Law*, 40 ENVTL. L. 363, 367 (2010) (describing how, in the 1990s, "talk of adaptation became taboo for fear it might throw the mitigation train off its tracks and lead to complacency").

[9] *See, e.g.*, ANNE SIDERS, COLUMBIA LAW SCH. CTR. FOR CLIMATE CHANGE LAW, MANAGED COASTAL RETREAT: A LEGAL HANDBOOK ON SHIFTING DEVELOPMENT AWAY FROM VULNERABLE AREAS i (2013), *available at* http://web.law.columbia.edu/sites/default/files/microsites/climate-change/files/Publications/ManagedCoastalRetreat_FINAL_Oct%2030.pdf ("Already we are beginning to see the effects of [climate] change along our coasts. Rising seas and more frequent hurricanes present a dynamic environment that threatens infrastructure long thought to be safe. . . . Some areas will be too vulnerable, despite our best efforts to hold back the sea. Infrastructure and homes will need to be moved away from the threat . . . .").

[10] *See infra* Parts II.A, II.B (describing scholarship on climate change adaptation and mitigation); *but cf.* Lesley McAllister, *Adaptive Mitigation in the Electric Power Sector*, 2011 BYU L. REV. 2115 (2011) (discussed *infra*).

[11] *See infra* Part II.A.

[12] *See infra* Part II.B.

[13] *Id.*

mitigation and adaptation separately.[14]

This Article connects these disparate discussions by asking how proposed mitigation technology and supporting legal regimes affect adaptive capacity in the United States.[15] Mitigation regimes aim to redirect investment in critical infrastructure, particularly transportation and energy systems.[16] They will undoubtedly shape the built environment; create economic, political, and property interests; and drive the development of regulatory institutions. If developed without attention to the impending climatic changes, this

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[14] Nascent adaptation planning at EPA focuses on developing procedures to address climate change impacts on regulation and enforcement of existing programs, but does not incorporate mitigation analysis. *See generally* U.S. ENVTL. PROT. AGENCY, CLIMATE CHANGE ADAPTATION PLAN (June 2012). President Obama's recently established Interagency Adaptation Task Force has similarly considered its mandate in isolation from emissions reductions programs. *See* INTERAGENCY ADAPTATION TASK FORCE, FEDERAL ACTIONS FOR A CLIMATE RESILIENT NATION: PROGRESS REPORT OF THE INTERAGENCY CLIMATE CHANGE ADAPTATION TASK FORCE 2 (2011) [hereinafter TASK FORCE REPORT], *available at* http://www.whitehouse.gov/sites/default/files/microsites/ceq/2011_adaptation_progress_report.pdf. The closest Congress has come to enacting comprehensive climate change legislation was when the House of Representatives passed the American Clean Energy and Security Act of 2009 (ACES), H.R. 2454, 111th Cong. (2009), *available at* http://www.c2es.org/docUploads/hr2454_house.pdf, a bill that subsequently died in the Senate. *See H.R. 2454 (111th): American Clean Energy and Security Act of 2009*, GOVTRACK.US, http://www.govtrack.us/congress/bills/111/hr2454 (last visited Feb. 15, 2014) (giving bill history). ACES would have established a national cap-and-trade program to incentivize emissions reductions. It included numerous complementary provisions as well—for increased energy efficiency in buildings, reductions in GHGs from mobile sources, incentives for studying carbon capture and sequestration, and promotion of green jobs, among other things. The bill's brief adaptation section addressed only information gathering and dissemination to prepare states and localities to better predict and withstand physical impacts. The bill did not address the relationship between mitigation-driven infrastructure and adaptation.

[15] This Article focuses on adaptation challenges within the United States to assess how this issue intersects mitigation policy. However, it is worth noting that other countries, particularly developing and island nations, will confront even more dramatic challenges.

[16] *See* J.R. DeShazo & Jody Freeman, *Timing and Form of Federal Regulation: The Case of Climate Change*, 155 U. PA. L. REV. 1499, 1502 (2007) ("The regulatory burden of addressing climate change will fall most heavily on the transportation and electric power sectors, since they are responsible for most domestic greenhouse gas (GHG) pollution . . . ."); *see also* Katherine Trisolini, *All Hands on Deck: Local Governments and the Potential for Bidirectional Climate Change Regulation*, 62 STAN. L. REV. 669, 695, 703–07, 715–16 (2010) (describing the predominant mitigation proposals as targeting fossil fuel use in electricity generation and transportation but also identifying local climate change plans that revise building and zoning codes to reduce fuel demand (and hence future GHG emissions)).

infrastructure, along with these interests and institutions, may work at cross-purposes with the need to adapt. Therefore, mitigation options should be evaluated not only for their potential to reduce emissions but also for their impact on future regulators and policymakers.

This Article uses a case study of one proposed mitigation measure—expanded deployment of nuclear power—to illustrate under-appreciated ways in which lack of integration with adaptation can hinder both efforts. Recent debate over the merits of nuclear power has pitted climate benefits against long-recognized general drawbacks[17] but has largely ignored the impact on adaptation.[18] Indeed, as discussed below, legal changes designed to promote nuclear power limit regulators' ability to respond to future climatic changes.[19]

Given that changing conditions on the ground will require not only physical but also regulatory adaptation, this Article directs attention to the limits of legal institutions' adaptive capacity. Legal scholars have proposed important procedural changes to environmental and administrative law to enhance agencies' responsiveness to climate change impacts.[20] They have also proposed new decision-making and management approaches to accommodate future complexities.[21] This Article argues that some of the onus must also be on the substance of proposed mitigation technologies. Just as societies and

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[17] *See* Joseph P. Tomain, *Nuclear Futures*, 15 DUKE ENVTL. L. & POL'Y F. 221, 237–38 (2005) (describing how contemporary debate is framed as a choice between nuclear promotion for climate mitigation and nuclear precaution to avoid environmental, security, and accident risks).

[18] While this Article does question the adaptability of large-scale nuclear power plants, particularly under the current regulatory structure, it should not be understood to simply track a traditional anti-nuclear stance. Indeed, some of the maladaptive aspects of nuclear power (such as scale and reliance on long-distance transmission) apply to all large, centralized power facilities including large-scale renewables. Rather than reiterating nuclear power's risks for their own sake, the Article uses them to exemplify how climate change can affect the calculus, particularly when planning both for adaptation and mitigation. The nuclear regulatory structure also illustrates the critical interplay between law and adaptability.

[19] While the Fukushima accident and increased access to natural gas have dampened investor enthusiasm for nuclear power, some have continued to seek new licenses. Moreover, if the energy economics shift in the future to make nuclear power more appealing, investors will find that national law and policy ensure substantial taxpayer support for the nuclear industry. This may mean that a large portion of our mitigation dollars will be directed to this technology.

[20] *See infra* Part II.B.

[21] *Id.*

ecosystems have limits to their ability to adapt to new circumstances, so do agencies and other legal institutions.

The discussion proceeds as follows: Part I reviews anticipated climate change impacts and consequent governance challenges. Part II describes trends in legal scholarship and argues for a synthesized approach to adaptation and mitigation. It proposes a preliminary framework for analyzing the adaptation implications of mitigation options. Areas of analysis include: the speed and extent of potential emissions reductions; interaction with the (evolving) physical environment; systemic vulnerabilities; and governance burdens. Part III provides a case study of one proffered mitigation approach— expanded nuclear power—and discusses how adaptation considerations affect assessment of this option. Part IV reflects on how the case study informs holistic climate policy and provides sample strategies that serve both mitigation and adaptation goals.

I. CLIMATE CHANGE GOVERNANCE CHALLENGES: EVOLVING PHYSICAL AND SOCIAL CONDITIONS WITH SUBSTANTIAL UNCERTAINTIES

The following Part briefly reviews anticipated physical impacts from climate change as well as several consequent social and regulatory challenges. This background frames subsequent discussion of scholarship trends and supports the case for an integrated approach to adaptation and mitigation.

A. Why Mitigate?

In the context of climate scholarship, mitigation has a specific meaning referring to actions designed to reduce net emissions of GHGs.[22] Atmospheric accumulation of these heat-trapping gases is increasing average global temperature[23]—

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[22] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: MITIGATION OF CLIMATE CHANGE, CONTRIBUTION OF WORKING GROUP III TO THE FOURTH ASSESSMENT REPORT OF THE IPCC 3.5.1 (B. Metz et al. eds., 2007) [hereinafter IPCC, MITIGATION OF CLIMATE CHANGE], *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4_wg3_full_report.pdf.

[23] *See* U.S. ENVTL. PROT. AGENCY, INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990–2010, ES-3 (2012) [hereinafter EPA INVENTORY], *available at* http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2012-ES.pdf. Although carbon dioxide is by far the most

hence the term "greenhouse gases." Human activities since the last century—particularly fossil fuel combustion—have raised atmospheric GHG concentrations far beyond naturally occurring levels.[24] Indeed, current carbon dioxide concentrations exceed anything found for the last 800,000 years.[25] Without mitigation, these levels will continue to increase. The Intergovernmental Panel on Climate Change (IPCC)[26] anticipates that, without effective mitigation, growing emissions will cause global temperature to rise by 0.2 degrees Celsius per decade.[27] If emissions continue along a business-as-usual trajectory, models project that atmospheric concentrations of GHGs will double by 2050.[28]

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ubiquitous GHG, several other gases (such as methane, ozone, nitrous oxide, and chlorofluorocarbons, among others) contribute to global warming, and in fact more effectively trap heat. At the most extreme, one metric ton of sulfur hexafluoride has the same heating effect (referred to as "radiative forcing") as 23,900 tons of carbon dioxide. In order to create a common metric for evaluating the effect of these gases, scientists assign a value of one to the radiative forcing caused by carbon dioxide and describe other gases' effects in terms of equivalence to carbon dioxide over a certain time period. This allows GHG inventories to evaluate the greenhouse effect of all gases combined by providing the total in terms of metric tons of carbon dioxide equivalent (MT CO_2e).

[24] *See* LISA ALEXANDER ET AL., WORKING GROUP I CONTRIBUTION TO THE IPCC FIFTH ASSESSMENT REPORT, CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, SUMMARY FOR POLICYMAKERS SPM-7, 9 (2013) [hereinafter IPCC 2013 SUMMARY FOR POLICYMAKERS], *available at* http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf. The report expresses very high confidence that "the mean rates of increase in atmospheric concentrations [of carbon dioxide, methane, and nitrous oxide] over the past century are . . . unprecedented in the last 22,000 years." *Id.* at 9. The authors further explain: "Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions . . . ." *Id.*

[25] *Id.*

[26] *See generally Organization*, IPCC, http://www.ipcc.ch/organization/organization.shtml (last visited Nov. 10, 2012). The IPCC was established by the United Nations Environment Program and the World Meteorological Organization with the endorsement of the U.N. General Assembly to "provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts." *Id.* The organization reviews and synthesizes the most recent scientific, technical and socio-economic studies but does not conduct its own research. Its reports reflect the work of thousands of scientists and its reports must be adopted and approved by all 195 member countries.

[27] IPCC SYNTHESIS REPORT, *supra* note 2, at 44, 72.

[28] JOHN HAWKSWORTH, PRICEWATERHOUSECOOPERS LLP, THE WORLD IN 2050: IMPLICATIONS OF GLOBAL GROWTH FOR CARBON EMISSIONS AND CLIMATE CHANGE POLICY 6 (2006), *available at* http://www.foresightfordevelopment.org/sobipro/54/777-the-world-in-2050-implications-of-global-growth-for-carbon-emissionsand-climate-change-policy.

The longer emissions continue to rise, the more difficult warming will be to reverse. In addition to higher absolute levels, this trajectory could trigger adverse feedback mechanisms, such as release of frozen methane (a potent GHG) from melting permafrost and a shift from radiation-reflecting surface ice to darker heat-absorbing ocean water.[29] Moreover, natural processes that have muted the warming effect of past emissions—such as ocean absorption of carbon dioxide—will soon reach a saturation point rendering future emissions more effective at heating the globe.[30] Thus, mitigation actions are necessary to break this trend and to prevent climate change impacts from escalating.

B. Why Adapt?

Even if emissions could be immediately stabilized, warming would continue for several decades because some of the heating effect is delayed. Scientific models show that past emissions have already committed the globe to at least another 0.5 degrees Celsius of warming by 2100.[31] Moreover, even before potential melting of the Arctic, Antarctic, or Greenland ice sheets is factored into the calculus, past emissions will cause sea level to rise by another four inches solely from thermal expansion of water.[32] Thus, even with aggressive emissions cuts, humans, animals, and ecosystems will face new environmental conditions requiring adaptation.

1. Extreme Weather and Unpredictably Rising Seas

What changes do researchers expect in the physical environment that would require adaptation? While there is a high degree of scientific consensus that GHG emissions from

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[29] *See* Kevin Shaeffer, et al., *Policy Implications of Warming Permafrost* 18, U.N. Doc. DEW/1621/NA, U.N. ENV'T PROGRAMME (UNEP), *available at* http://www.unep.org/pdf/permafrost.pdf (last visited Mar. 7, 2013).

[30] *See* Holli Riebeek, *The Ocean's Carbon Balance*, NASA EARTH OBSERVATORY (June 30, 2008), *available at* http://earthobservatory.nasa.gov/Features/OceanCarbon/.

[31] *Climate Change Inevitable in 21st Century, Sea Level Rise to Outpace Temperature Increase*, UNIV. CORP. FOR ATMOSPHERIC RES. (Mar. 17, 2005), *available at* http://www.ucar.edu/news/releases/2005/change.shtml (describing study).

[32] *Id.*

human activities are causing the average global temperature to rise,[33] models differ as to the exact extent of warming that correlates with specific emissions levels.[34] Complex interactions between multiple systems render it difficult to predict impacts with geographic specificity.[35] Nonetheless, documented changes that already have occurred and consensus on general predictions for the future can provide a starting place for analysis.

Changing weather patterns have already begun to affect the United States. President Obama's Interagency Climate Change Adaptation Task Force (Adaptation Task Force) reported that in April 2011 the United States "experienced record-breaking floods, tornadoes, drought, and wildfires all within a single month."[36] By September of that year, the country set a new annual record for damaging weather events, with ten costing more than a billion dollars each.[37]

International and national researchers anticipate that climate destabilization will continue to cause extreme weather, including heat waves, intense storms, and unpredictable precipitation patterns that will damage infrastructure, cause weather-related deaths, and alter water supplies. According to the IPCC, "[i]t is *very likely* that hot extremes, heat waves and heavy precipitation events will become more frequent."[38] The

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[33] *See* IPCC 2013 SUMMARY FOR POLICYMAKERS, *supra* note 24, at SPM-12 ("[E]vidence for human influence has grown since [IPCC's 2007 Synthesis Report]. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century.").

[34] *Id.* at 14 ("No best estimate for equilibrium climate sensitivity can now be given because of a lack of agreement on values across assessed lines of evidence and studies."). This should not be terribly surprising given the interplay of multiple ecological systems that influence average global temperatures. *See id.* ("The rate and magnitude of global climate change is determined by radiative forcing, climate feedbacks and the storage of energy by the climate system.").

[35] *See* Alan Krupnick & David McLaughlin, *Valuing the Impacts of Climate Change on Terrestrial Ecosystem Services*, RESOURCES FOR THE FUTURE WORKSHOP 1 (Jan. 27–28, 2011), *in* 3 CLIMATE CHANGE ECONOMICS 4, 1 (Nov. 2012), *available at* http://yosemite.epa.gov/ee/epa/eerm.nsf/vwan/ee-0566-119.pdf/$file/ee-0566-119.pdf ("However, these models lack geographic specificity [and] must make hugely simplifying assumptions to capture the myriad effects caused by climate change . . . .").

[36] TASK FORCE REPORT, *supra* note 14, at 3. The Adaptation Task Force further reports that "NOAA estimates the total damage of property and economic impacts for all weather-related disasters during the spring and summer of 2011 at more than $45 billion." *Id.*

[37] *Id.*

[38] IPCC SYNTHESIS REPORT, *supra* note 2, at 46.

IPCC also finds it likely that the twenty-first century will see more intense typhoons and hurricanes (with higher peak wind speeds and heavier precipitation) than the prior century.[39] The Adaptation Task Force similarly anticipates "more frequent and intense" heat waves as well as potential water shortages from reduced snowpack that will adversely affect human health, agriculture, and ecosystems.[40]

In 2009, the EPA found that anthropogenic climate change impacts sufficiently endanger public health and welfare to trigger GHG regulation under the Clean Air Act.[41] The Agency concluded that global warming will increase the incidence of heat-related deaths while extreme weather, hurricanes and floods will destroy infrastructure and also cause deaths.[42] Meanwhile, reduced mountain snowpack and altered precipitation patterns will reduce water supply in some areas sufficiently to harm ecosystems and undermine food production.[43]

Scientists also anticipate that climate change will continue to raise sea-levels due to melting ice sheets in the Arctic, Antarctic, and Greenland as well as warming-induced expansion of seawater.[44] Obviously, these effects will threaten infrastructure. The Adaptation Task Force found that sea level rise, "especially in combination with storm surge, will increasingly inundate United States' coastal communities and threaten coastal ecosystems and infrastructure."[45]

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[39] *See id.* These events pose direct threats to human health through heat-related deaths and severe storms. They are further projected to disrupt electricity and water supply. *Id.*

[40] TASK FORCE REPORT, *supra* note 14, at 2 ("Heat waves are expected to become more frequent and intense, posing a threat to human health and agriculture. For rivers fed by snowpack, runoff will continue to occur earlier, with reduced flows late in the summer, and the potential for water shortages that can affect the supply of water for drinking, agriculture, electricity production, and ecosystems.").

[41] *See* Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act, 74 Fed. Reg. 66,496 (Dec. 15, 2009) (codified at 40 C.F.R. ch. 1. pt. 1).

[42] Am. Elec. Power, Inc. v. Connecticut, 131 S. Ct. 2527, 2533 (2011) (citing 74 Fed. Reg. 66,496, 66,524–35 (Dec. 15, 2009)).

[43] *Id.*

[44] *See* RICHARD Z. POORE, RICHARD S. WILLIAMS, JR. & CHRISTOPHER TRACEY, USGS FACT SHEET 002-00: SEA LEVEL AND CLIMATE (Jan. 2000), *available at* http://physics.oregonstate.edu/~hetheriw/projects/energy/topics/doc/environment/climate/sea.level.changes.USGS.FS.002-00.html.

[45] TASK FORCE REPORT, *supra* note 14, at 2.

Despite concurring that global warming will raise the sea level, scientists have found it difficult to precisely predict future levels. In 2007, the IPCC projected end-of twenty-first century levels ranging from 0.18 to 0.59 meters based on models corresponding with low to high future emissions scenarios.[46] However, due to the insufficiency of published literature on such critical drivers as ice-sheet flow, the report "[did] not assess the likelihood, nor provide a best estimate or an upper bound for sea level rise."[47] In 2012, the Adaptation Task Force predicted that sea levels would increase by two to three and a half feet over the same period.[48] Climate scientist James Hansen anticipates larger changes:

> How far can it go? The last time the world was three degrees warmer than today—which is what we expect later this century—sea levels were 25m higher. So that is what we can look forward to if we don't act soon . . . I think sea-level rise is going to be the big issue soon, more even than warming itself.[49]

Thus, the United States will undoubtedly face some rise in sea level sufficient to necessitate adaptive action in the coming decades.[50]

2. Social Stability and Security Threats

In addition to physical changes, researchers anticipate that changes to the physical environment may further destabilize already volatile regions. Studies from well-respected think tanks, governmental bodies, and academic institutions have identified increased threats to national

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[46] IPCC SYNTHESIS REPORT, *supra* note 2, at 45.

[47] *Id.*

[48] TASK FORCE REPORT, *supra* note 14, at 2.

[49] Jim Hansen, *Climate Change: On the Edge*, INDEPENDENT, Feb. 17, 2006, http://www.independent.co.uk/environment/climate-change-on-the-edge-466818.html.

[50] Indeed, relatively modest sea level rise caused by global warming in the nineteenth century has already damaged coastlines. In 2007, the Supreme Court found the ten to twenty centimeter rise in sea levels during the nineteenth century had sufficiently injured Massachusetts to serve as a basis for standing to sue in *Massachusetts v. EPA*, 549 U.S. 497, 521–23 (2007).

security stemming from climate change.[51] While the precise nature of the threats is impossible to predict, researchers anticipate that reduced agricultural productivity, severe water shortages, flooding, and human migration will destabilize regimes and exacerbate existing conflicts across Asia, Africa, and the Middle East.[52] Instability, hunger, and resource conflicts in these areas could strengthen terrorist movements and prompt unanticipated changes in political regimes.[53]

These and other global impacts make climate change a "threat multiplier."[54] As one security analyst explains, even under the lower-impact scenarios, climate change "indirectly pose[s] very real national security concerns" and will "complicate American foreign policy in a wide variety of ways."[55] This will require a complex and multi-faceted response.[56]

The unpredictable nature of security stressors combined with the uncertainties regarding physical impacts generally

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[51] *See, e.g.,* Jody Freeman & Andrew Guzman, *Climate Change and U.S. Interests*, 109 COLUM. L. REV. 1531, 1575–83 (2009); TASK FORCE REPORT, *supra* note 14, at 2–3 ("Economic, social, and natural systems are also inter-connected on a global scale, meaning that climate impacts in other regions of the world can pose serious economic and security risks to the United States. Increases in extreme weather and climate events will contribute to food and water scarcity, which can intensify existing tensions over access to life-sustaining resources."). *See generally* GREGORY F. TREVERTON ET AL., RAND CORP., THREATS WITHOUT THREATENERS? EXPLORING INTERSECTIONS OF THREATS TO THE GLOBAL COMMONS AND NATIONAL SECURITY (2012).

[52] Freeman & Guzman, *supra* note 51, at 1579–83.

[53] *Id.* at 1576–77. Security stresses likely will be exacerbated by climate refugees' movement away from areas that have been rendered uninhabitable. *See id.* at 1583–87.

[54] *Id.* at 1576 (citing *National Intelligence Assessment on the National Security Implications of Global Climate Change to 2030: Joint Hearing Before the H. Select Comm. On Energy Independence and Global Warming and the H. Permanent Select Comm. on Intelligence*, 110th Cong. 4–5 (2008) (statement of Thomas Fingar, NIC Chair)).

[55] Carolyn Pumphrey, *Introduction*, *in* STRATEGIC STUDIES INST., GLOBAL CLIMATE CHANGE: NATIONAL SECURITY IMPLICATIONS 8 (Carolyn Pumphrey ed. 2008).

[56] *See* IPCC SYNTHESIS REPORT, *supra* note 2, at 13 ("Climate change, as a security problem, needs to be addressed at multiple levels. First, there is the root problem—the changing climate. Second, there is the human misery it will engender—we are talking of such things as poverty, disease, displacement, and social inequality. Third, there is the instability and/or changing strategic picture that will spring from all of the above. Simply put, our response needs to encompass at least three things: slowing down the rate of climate change and preparing to adapt to changes that cannot be avoided; taking steps to alleviate social distress; and preparing to cope with potential conflicts.").

will complicate future governance. Mitigation and adaptation planning efforts should recognize that future policymakers will face much less predictable physical, social, and security landscapes than currently exist.

C. Governance Under Uncertainty

The uncertainty as to what precisely this country will confront in the future complicates adaptation planning. Laws and regulations will be made and enforced without a static physical baseline for reference, and regulators will face unprecedented levels of uncertainty. Environmental lawmaking is typically undertaken with some degree of scientific uncertainty; agencies often contend with incomplete and evolving science. Yet climate change presents particularly daunting uncertainties. Scientists predict significant changes in the physical environment in the coming decades that will continue into the next century and beyond.[57] Because impacts will unfold over a long time horizon, climate change is unlikely to be resolved in a generation (the way, for example, lead exposure has been dramatically reduced in the twentieth century).[58] Although the broad outlines of future changes can be discerned, many details remain hazy.

While the IPCC identified a number of impacts in its 2007 Synthesis Report, it also recognized the limits of current knowledge.[59] Data are missing in certain regions and it is often difficult to reliably simulate and attribute "observed temperature changes to natural or human causes at smaller than the continental scales."[60] Despite modeling improvements between 2007 and 2013, the IPCC continues to describe limits in identifying impacts with geographical specificity.[61]

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[57] IPCC SYNTHESIS REPORT, *supra* note 2, at 46 ("Anthropogenic warming and sea level rise would continue for centuries . . . even if GHG concentrations were to be stabilised.").

[58] *See* CTRS. FOR DISEASE CONTROL & PREVENTION, FOURTH REPORT ON HUMAN EXPOSURE TO ENVIRONMENTAL CHEMICALS, E-S 5 (2009), *available at* http://www.cdc.gov/exposurereport/pdf/FourthReport_ ExecutiveSummary.pdf.

[59] IPCC SYNTHESIS REPORT, *supra* note 2, at 51 ("Barriers, limits, and costs of adaptation are not fully understood, partly because effective adaptation measures are highly dependent on specific geographical and climate risk factors as well as institutional, political and financial constraints.").

[60] *Id.* at 72.

[61] IPCC 2013 SUMMARY FOR POLICYMAKERS, *supra* note 24, at SPM-10–11 (describing improvements in modeling temperature and precipitation but

Not only do we not know for sure what future emissions will be, but also we do not know how a given level of emissions correlates with specific impacts. As a 2009 MIT report explained, climate change presents a "cascade of uncertainties" that policymaking models fail to capture.[62] This modeling difficulty applies to such basic issues as future emissions; the relationship between emissions levels and the degree of warming; and the environmental impacts that various levels of warming will cause.[63] Perhaps most seriously, models vary in their projection of different feedback impacts and the potential for "tipping points" to induce irreversible (at least by human action) warming.[64] As Cass Sunstein explains, the potential for irreversible catastrophic consequences must influence policy choices:

> The risk of irreversibility is especially troublesome in light of massive uncertainty about the actual damage from climate change. Suppose that we project, with the [IPCC], warming between 1.8 and 4.0 C by 2100. There is a large difference between adverse effects at 1.8 C and adverse effects at 4.0 C. Even at a specified increase in temperature, it is exceedingly difficult to know the extent of the harm . . . . There is some risk of catastrophe, and once that risk is incorporated into the analysis, the assessment of what to do changes dramatically.[65]

Common decision-making tools used in environmental regulation, such as risk analysis and front-end environmental impact analysis, are rendered especially unreliable because models currently cannot predict the likelihood of "low-

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nonetheless noting continuing uncertainties at less than the continental scale).

[62] MORT WEBSTER ET AL., MIT JOINT PROGRAM ON THE SCI. & POLICY OF CLIMATE CHANGE, REPORT NO. 180, ANALYSIS OF CLIMATE POLICY TARGETS UNDER UNCERTAINTY 37–38 (2009), *available at* http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt180.pdf.

[63] *See id.*

[64] *See id.*; *see also* IPCC SYNTHESIS REPORT, *supra* note 2, at 2; Timothy M. Lenton et al., *Tipping Elements in the Earth's Climate System*, 105 PROC. NAT'L ACAD. SCI. 1786, 1786 (2008), *available at* http://www.pnas.org/content/105/6/1786.full.pdf.

[65] Cass R. Sunstein, *Two Conceptions of Irreversible Environmental Harm*, John M. Olin Law & Economics Working Paper No. 407 (2d Series) 2 (May 2008), *available at* http://www.law.uchicago.edu/files/files/407.pdf.

probability/high-impact events."[66] Unlike quantifiable risks—which can be analyzed fairly effectively with the statistical tools currently employed to inform agency decision-making—climate change is rife with "uncertainty."[67]

As Dan Farber explains: "True uncertainty involves risks that are not well understood, where the range of outcomes is potentially very large, and where probabilities cannot be assigned with confidence."[68] Conventional risk analysis—which deals in probabilistic harm—frequently presumes that "extreme harms are highly unlikely," an assumption that causes models to inaccurately characterize potential outcomes from climate change.[69]

Finally, this process will play out over a long period of time, indeed for centuries. Multiple generations likely will face the need to mitigate and adapt to climate change. Administrative challenges are exacerbated by the need to forecast far into the future. Moreover, new institutions will need to remain robust over a long period of time through changing conditions.

In sum, adaptation planning should anticipate a destabilized physical environment that includes extreme temperatures, more frequent and severe storms, increased numbers of droughts and floods, and rising sea levels. Adaptation plans will be more robust if they anticipate costly social disruption and increased security threats. Finally, adaptation proposals should recognize that future lawmakers and agencies will contend with unprecedented levels of uncertainty (as opposed to mere risk) in preparing for effects that may occur over very long time horizons. Given this set of

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[66] IPCC SYNTHESIS REPORT, *supra* note 2, at 51 ("Understanding of low-probability/high-impact events and the cumulative impacts of sequences of smaller events, which is required for risk-based approaches to decision-making, is generally limited.").

[67] *See* Daniel A. Farber, *Uncertainty*, 99 GEO. L.J. 901, 906 (2011) ("[T]his Article does not address the garden-variety policy issues that involve well-understood processes, confined ranges of possible outcomes, and risks that can be translated in a meaningful way into quantitative probabilities. Many risks do fit those categories—otherwise, life would be difficult indeed for insurance companies, among other entities. True uncertainty involves risks that are not well understood, where the range of outcomes is potentially very large, and where probabilities cannot be assigned with confidence. Climate change . . . exhibit[s] these characteristics.").

[68] *Id.*

[69] *See id.* at 904–05.

physical and administrative challenges, investment in mitigation should be informed by consideration of how physical and regulatory infrastructure will interact with an evolving future environment. However, such a synthetic approach to adaptation and mitigation has not yet received sufficient attention. This Article argues that the most effective policy will integrate these efforts.

II. HOLISTIC GOVERNANCE

This Part describes major themes in mitigation literature and illustrates its general agnosticism toward adaptation. It then discusses adaptation scholarship. The latter has highlighted the complex demands that future policymakers will face in an unfamiliar and evolving environment. In response, scholars have proposed new decision-making tools and administrative procedures to advance agencies' adaptation efforts. This Part proposes a preliminary framework for evaluating mitigation options in light of complexities that future regulators will face.

A. Mitigation Scholarship

Until recently, both legal scholarship and policymaking have focused on mitigation. While significantly advancing understanding of potential emissions-reduction strategies, this discussion largely has treated mitigation as independent from adaptation. As discussed below, policy proposals have emphasized market mechanisms, assuming price will drive the most efficient selection among potential mitigation technologies. However, this Article argues that adaptation needs are unlikely to be adequately captured in mitigation mechanisms unless explicitly incorporated.

1. Selecting Among Technological Options

Scientists, academics, and policymakers agree that there is not one technology that will single-handedly reduce emissions sufficiently to stabilize atmospheric concentrations of GHGs at a level that will prevent "dangerous climate change."[70] Rather,

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[70] IPCC, MITIGATION OF CLIMATE CHANGE, *supra* note 22, at 41.

policymakers will need to employ a suite of technological and behavioral changes.[71]

Although new approaches are under development, policymakers do not need to wait for new technologies to mature; the existing tools provide many possible options. To illustrate that existing mature technologies can achieve sufficient mitigation, Princeton scientists Pacala and Sokolow developed a "Wedge" model which provides a non-exclusive list of fifteen sample policies, any seven of which could be combined to reduce projected 2050 emissions sufficiently to progress toward climate stabilization.[72] In the energy sector, the model lists such things as efficiency measures and technologies for lower-carbon fuel supplies, including expanded electricity production from nuclear fission.[73]

A multitude of sources produce GHG emissions but certain economic sectors produce the large majority of the United States' emissions. The United States' roughly one-quarter share of global GHG emissions[74] stems predominantly from fossil fuel combustion in energy production and

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[71] *Id.* at 10.

[72] S. Pacala & R. Socolow, *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies*, 305 SCIENCE 968, 968–69 (2004). These Princeton scientists divided the reductions necessary to flatten the business-as-usual (BAU) trajectory into seven conceptual wedges of one billion $MTCO_2eq$. [metric tons of carbon dioxide equivalent] emissions that, taken together, equaled the triangular space between an upward sloping line representing BAU emissions and a flat line representing climate stabilization levels. Each wedge thus represented one-seventh of the global emissions reduction target for 2050, which, they argued, could be accomplished through existing, readily available technology. *Id.*

[73] *Id.* at 969–70. Four potential wedges stem from efficiency and conservation through improved fuel economy, reduced reliance on cars, and improved power plant and building efficiency. Nine wedges from technologies for decarbonizing electricity and fuel include: substituting natural gas for coal; carbon capture and storage in coal, hydrogen and synfuel plants; and electricity generation from wind, solar photovoltaic, nuclear fission, renewable hydrogen, and bio-fuels. Other potential wedges stem from forest management and agricultural soil management.

[74] On a per capita basis, the United States far exceeds every other country's emissions (with the exception of Australia), producing nearly a quarter of the world's GHG emissions. *See Each Country's Share of CO2 Emissions*, UNION OF CONCERNED SCIENTISTS, http://www.ucsusa.org/global_warming/science_and_impacts/science/each-countrys-share-of-co2.html (last visited Mar. 18, 2014), with only 5 percent of the population, *see* POPULATION REFERENCE BUREAU, 2009 WORLD POPULATION DATA SHEET 2 (2009), *available at* http://www.prb.org/pdf09/09wpds_eng.pdf.

transportation.[75]

Globally, the energy supply sector has been responsible for the largest growth in GHG emissions between 1970 and 2004, increasing by 145 percent.[76] Among practices that must be reformed to mitigate climate change, carbon intensive electrical power production tops the list.[77] The IPCC has thus identified decarbonizing the power supply as an essential component of climate change mitigation.[78] The IPCC identifies numerous means of generating needed reductions, including both existing and soon-to-be-available technologies. Currently available approaches identified by the IPCC include: improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power from hydropower, solar, wind, geothermal, and bioenergy; combined heat and power; and early applications of carbon capture and storage (CCS). Key mitigation technologies that it projects to be commercialized by 2030 include: "CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and waves energy, concentrating solar, and solar PV."[79]

Although aggressive emissions reduction will require a multi-faceted approach, policymakers still will need to select among the options to create a mitigation package. Broadly speaking, two selection approaches have emerged.[80] In the first, governments pre-determine specific technologies or behavioral strategies to promote through direct regulation, incentives, or other means. The second approach allows price—either through a cap-and-trade regime or a carbon tax—to signal which technologies or behavior changes to adopt, presuming that this will allow the private sector to create the most efficient reductions.[81] Because they seek to allow the

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[75] *See* EPA INVENTORY, *supra* note 23, at ES-4, ES-7.

[76] IPCC, MITIGATION OF CLIMATE CHANGE, *supra* note 22, at 3.

[77] *See id.*

[78] *Id.* at 10.

[79] *Id.* at Table SPM.3.

[80] *See* Ann E. Carlson, *Designing Effective Climate Policy: Cap-and-Trade and Complementary Policies*, 49 HARV. J. ON LEGIS. 207, 209 (2012) (distinguishing between two mechanisms, cap-and-trade and "complementary" policies, that differ in terms of the governmental role in selecting mitigation technologies).

[81] *See* Joseph E. Aldy & Robert N. Stavins, *Using the Market to Address Climate Change: Insights from Theory & Experience*, 141 DAEDALUS, Spring 2012, at 5 ("Market-based policies can support *cost-effective* attainment of policy goals.").

market to determine how reductions are achieved, market mechanisms are technology-neutral by design.[82]

2. Direct Selection

Although scholars favor market mechanisms, numerous policies have been adopted by various governmental bodies that favor specific mitigation mechanisms.[83] Among other things, the federal government has promoted lower carbon electricity technologies by providing tax credits for renewable energy projects[84] and new nuclear power generation.[85] Credits lower electricity generation costs, thereby enabling chosen sources, at least theoretically, to compete more effectively for market-share. The Environmental Protection Agency has begun regulating mobile and stationary source GHG emissions pursuant to its authority under the Clean Air Act.[86] Meanwhile, forty-three states (and several territories) have adopted renewable portfolio standards (RPS)[87] that require utilities to include a minimum percentage of renewable sources in their generation mix.[88] While the details of RPS programs differ, the general approach is the same; by defining a set of electricity generation sources that meet the "renewable" definition, states ensure demand for these technologies even if they would not otherwise be price competitive. Local

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[82] *See id.* ("A carbon tax and cap and trade establish a common price for emitting a ton of CO2, and the private sector has the flexibility to identify and exploit least costly ways of reducing emissions. This approach is vastly superior to command-and control regulatory mandates . . . .").

[83] See Carlson, *supra* note 80, at 209–10 (describing efforts at various levels of government).

[84] Roberta F. Mann & E. Margaret Rowe, *Taxation, in* THE LAW OF CLEAN ENERGY: EFFICIENCY AND RENEWABLES 146 (Michael B. Gerrard, ed., 2011).

[85] *See infra* Part III.

[86] *See Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards*, 75 Fed. Reg. 25,324 (May 7, 2010) (codified at 40 C.F.R. 85, 86, 600); *Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule*, 75 Fed. Reg. 31,514 (June 3, 2010) (codified at 40 C.F.R. pts. 50, 51, 70, 71).

[87] *See Rules, Regulations & Policies for Renewable Energy*, DSIRE, http://www.dsireusa.org/summarytables/rrpre.cfm (last visited Feb. 28, 2014).

[88] *"Renewable Portfolio Standards (RPS)," Glossary*, DSIRE, http://www.dsireusa.org/glossary/ (last visited Feb. 28, 2014) ("Renewable portfolio standards (RPSs) require utilities to use or procure renewable energy or renewable energy credits (RECs) to account for a certain percentage of their retail electricity sales—or a certain amount of generating capacity—according to a specified schedule.").

governments have used building codes and incentives,[89] proprietary municipal utilities,[90] and purchasing power[91] to advance specific climate mitigation mechanisms.

Unlike the much-lauded policy of technological neutrality embodied in market mechanisms (described further in the next section), these programs specifically select technological winners. As Ann Carlson explains, this creates an inherent tension that will surface if the federal government enacts a cap-and-trade program:

> If the central premise behind cap-and-trade is to allow market mechanisms to work in as unfettered a manner as possible in order to find the most cost-effective emissions reductions, complementary policies that designate in advance which emissions should occur will interfere with that promise.[92]

A similar tension can occur between market mechanisms and adaptation efforts. As this Article argues, effective adaptation will require reconsideration of existing infrastructure systems that have supported investments in energy, transportation, and other sectors. From the private sector perspective, it may be most efficient to perpetuate reliance on this infrastructure because of sunk costs (e.g., machinery adopted for power grid connection, trucks purchased for highway goods transport).

3. Indirect Selection Through Market Mechanisms

Following the contemporary preference for market mechanisms over traditional "command-and-control" regulation,[93] numerous proposals incentivize emissions

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[89] *See* Trisolini, *supra* note 16, at 705 (discussing the types of incentives cities offer for energy efficiency and identifying cities that mandate green building standards).

[90] *Id.* at 727–28 (describing municipally-owned utilities' initiatives to increase reliance on renewable sources).

[91] *Id.* at 725 ("Local governments can and have targeted a long list of energy-consuming activities, ranging from lighting, fleets, direct energy purchase. . . .").

[92] Carlson, *supra* note 80, at 210.

[93] *See* Jonathan B. Wiener, *Radiative Forcing: Climate Policy to Break the Logjam in Environmental Law*, 17 N.Y.U. ENVTL. L.J. 210, 236–37 (2008) ("A generation ago, the debate raged between advocates of command-and-control technology standards and advocates of market-based incentives. Today this question has largely been settled with broad acceptance of incentive

reductions by placing a price on GHG emissions. Scholars and policymakers have favored cap-and-trade[94] proposals as a United States mitigation strategy, although carbon taxation has proponents as well.[95] As discussed below, these proposals signal selection among options by price. Proponents believe this approach will reduce emissions more efficiently and effectively than either direct emissions regulation or incentives for specific low-carbon technologies.[96]

Scholars have promoted market mechanisms and argued over various models' benefits predominately with reference to efficiency, effectiveness, administrative ease, and political feasibility. Academics and policymakers describe the primary benefits of cap-and-trade as certainty about total emission levels and economically efficient reductions.[97] Prominent

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instruments . . . .").

[94] In a cap-and-trade system, policymakers set an overall cap on emissions levels and then distribute the right to pollute up to the cap among various parties. Generally, one emissions allowance is required per ton of carbon dioxide (or its equivalent) emitted during a compliance period. Because the system caps emissions but does not mandate specific means for containing emissions, the flexibility allows firms to find reductions in any way possible while the price creates an incentive. Presumably, parties that can efficiently eliminate their emissions will do so and sell their allowances to others for whom emissions reductions are more costly, spawning innovation and allowing the reductions to be accomplished at the lowest cost. Over time, the cap is ratcheted down for progressively lower emissions. *See, e.g.*, Carlson, *supra* note 80, at 209.

[95] *See, e.g.*, Victor B. Flatt, *Taking the Legislative Temperature: Which Federal Climate Change Proposal is "Best"?*, 102 NW. U. L. REV. COLLOQUY 123, 135–36, 142 (2007) (analyzing legislative proposals); *see also* Joseph E. Aldy et al., *Designing Climate Mitigation Policy*, RESOURCES FOR THE FUTURE 16 (May 2009), *available at* http://www.rff.org/RFF/Documents/RFF-DP-08-16.pdf (arguing that a well-designed carbon tax is preferable but acknowledging that a well-designed cap-and-trade system could mimic the benefits of a tax).

[96] *See,* Aldy & Stavins, *supra* note 81, at 51 (describing market-based approaches as "vastly superior to command-and-control regulatory mandates" and describing a renewable electricity standard as "even less cost effective because it proscribes some low- and zero-emissions technologies from the set of compliance options.").

[97] Flatt, *supra* note 95, at 136 ("Cap and trade can be an efficient pollution reduction mechanism because the trading allows the private sector to control emissions at the lowest possible cost (to the private sector) and also encourages innovation."); *see also* Byron Swift, *U.S. Emissions Trading: Myths, Realities, and Opportunities*, 20 NAT. RESOURCES & ENV'T 3 (2005) (arguing that the flexibility of cap-and-trade encourages innovation and reduces costs). However, the accepted wisdom about cap-and-trade is not without its critics. *See, e.g.*, David M. Driesen, *Free Lunch or Cheap Fix?: The Emissions Trading Idea and the Climate Change Convention*, 26 B.C. ENVTL. AFF. L. REV. 1, 46 (1998) (questioning the assumption regarding innovation and instead finding a perverse incentive: "The broader the universe of trading opportunities, the greater the potential to find cheap fixes that

models eschew supplemental standards-based regulations, viewing these additions as inefficient, except to the extent they are necessary to correct specific market failures.[98]

Scholars propose both geographic scale and regulatory targets designed to best capture efficiencies and ensure reduction levels.[99] While some envision a United States-based system, others have argued that only a global cap-and-trade system would be efficient and cost-effective.[100] Aside from scale issues, debate over design of cap-and-trade regimes has focused on the effect that allowance allocation,[101] offsets,[102] and price

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avoid long-term investments.").

[98] Carlson, *supra* note 80, at 248 ("Cap-and-trade has emerged as a promising mechanism to tackle the reduction of greenhouse gases. . . . If a policymaker's sole goal is to establish the most cost-effective greenhouse gas emissions reduction policy . . . then we should not use any complementary policies in conjunction with cap-and-trade *unless* market failures exist that would inhibit the proper functioning of the cap-and-trade system."). *See also* Robert N. Stavins, *Addressing Climate Change with a Comprehensive U.S. Cap-and-Trade System*, 24 OXFORD REV. OF ECON. POL'Y 298, 304 (2008). Stavins argues that regulatory standards offer no additional benefits to a cap-and-trade regime and instead simply create inefficiencies. *Id.* at 314–15. Thus, cap-and-trade should displace regulatory emissions standards (except to the extent standards are necessary to overcome specific market failures). *Id.* at 315.

[99] Stavins, *supra* note 98, at 302. Stavins argues that a United States cap-and-trade regime that is upstream (i.e., targeting fossil fuel suppliers) and economy-wide "provides the greatest certainty that national emission targets will be achieved" and allows for international trading coordination. *Id.* at 304.

[100] *See, e.g.*, Richard B. Stewart & Jonathan B. Wiener, *The Comprehensive Approach to Global Climate Policy: Issues of Design and Practicality*, 9 ARIZ. J. INT'L & COMP. L. 83, 103–04 (1992). Wiener and Stewart proposed that a "full accounting" of all anthropogenic causes of climate change could serve as the basis for an international agreement limiting GHG emissions while giving individual nations the flexibility to use their unique assets to create the most cost-effective reductions. *Id.* Wiener and Stewart argued that "piecemeal" efforts by individual nations acting alone (or incomplete policies encompassing only some sectors or only some GHGs) would likely produce perverse results and undermine the possibility of agreement. *Id.* at 96, 98–99. Wiener also has argued that anything less than a geographically comprehensive regime would incentivize emitting activities to shift or "'leak' to unregulated areas over time." Jonathan B. Wiener, *Think Globally, Act Globally: The Limits of Local Climate Change Policies,* 144 PA. L. REV. 1961, 1967–70 (2007). Although researchers disagree about the potential for leakage to undermine emissions reductions, leakage has been frequently discussed in the cap-and-trade scholarship. *See, e.g.,* IPCC, MITIGATION OF CLIMATE CHANGE, *supra* note 22, at 665–66.

[101] *See* Flatt, *supra* note 95, at 139.

[102] Offsets would allow firms to get credit for emissions reductions from outside of the trading system's geographic area (e.g., by subsidizing reforestation in another country) or to outside of the covered industries (e.g., by subsidizing domestic farming activities that reduce emissions). Advocates say that offsets enhance efficiency and flexibility while critics argue that they encourage gaming

controls[103] would have on the overall political feasibility of a cap-and-trade program.[104] Some scholars argue that a carbon tax provides a better market tool for prompting greenhouse gas reductions.[105] Advocates emphasize the availability of existing administrative infrastructure to implement a carbon tax[106] and the superior price certainty that a tax system provides (as compared to cap-and-trade).[107] Critics view a tax-based system as politically infeasible[108] and fear that even if a tax could be adopted, emissions reductions would be too uncertain.[109]

This literature has significantly advanced understanding

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and may create false credits. *See id.* at 142.

[103] To reduce price volatility, some designs include options for firms to bank allowances or borrow from future years. Critics question system efficacy (for example, banking and borrowing from future years' allowances could undermine certainty about the level of the cap while offsets raise the prospect of false reductions) and fairness (giving away credits or grandfathering existing polluters violates the polluter pays principle and in fact rewards polluters). *See*, *Containing the Cost of Climate Policy* PEW CTR. ON GLOBAL CLIMATE CHANGE (Nov. 2008), *available at* http://www.c2es.org/publications/containing-costs-climate-policy (summarizing these issues).

[104] *See, e.g.*, Flatt, *supra* note 95, at 138.

[105] *See generally* SHI-LING HSU, THE CASE FOR A CARBON TAX: GETTING PAST OUR HANG-UPS TO EFFECTIVE CLIMATE POLICY (2011); *see also* Flatt, *supra* note 95, at 138–39 (describing this view).

[106] *See, e.g.*, Gilbert E. Metcalf, *Cost Containment in Climate Change Policy: Alternative Approaches to Mitigating Price Volatility*, 29 VA. TAX REV. 381, 402 (2009) ("We have a time-tested administrative structure for collecting taxes that can ramp up a carbon tax in relatively short order. Firms that would be subject to a carbon tax are already registered with the Internal Revenue Service ("IRS") and have whole departments within their firms that carry out the record keeping and reporting for tax payments. . . . In contrast, we have no administrative structure for running an upstream carbon cap-and-trade program."); *see also* Flatt, *supra* note 95, at 138–39 ("Economists generally favor a tax because it internalizes any efficiencies of a trading system . . . without having to monitor a complicated trading system. . . . A tax system is probably superior with respect to enforcement and fairness.").

[107] Flatt, *supra* note 95, at 139. *See also* Reuven S. Avi-Yonah & David M. Uhlmann, *Combating Global Climate Change: Why a Carbon Tax is a Better Response to Global Warming than Cap and Trade*, 28 STAN. ENVTL. L.J. 3, 8 (2009) (identifying a potential tradeoff between the "price certainty" benefit of a carbon tax and the "benefit certainty" of a cap-and-trade regime, but ultimately favoring a carbon tax because it will be "simpler to implement, more transparent, and less vulnerable to abuse.").

[108] *See* Flatt, *supra* note 95, at 138 ("The main objection to a tax system seems to be the belief that the American public abhors any 'tax' and will punish any legislator who proposes or votes for one . . .") (citing to David Leonhart, *Auto's Friend Shifts Tune on Climate,* N.Y. TIMES, Sept. 5, 2007, at C1).

[109] *See* Flatt, *supra* note 95, at 138 ("There is also some concern that the appropriate level of 'tax' will not be selected to reach the intended reduction target, a problem that one need not worry about in cap-and-trade.").

of the benefits and tradeoffs at issue in designing market-based tools. Little attention, however, has been given to how these approaches would intersect with the demands of adaptation. The analysis has largely overlooked the adaptability of the physical and regulatory infrastructure that will develop in response to the price incentives.

While market mechanisms that place a price on GHG emissions likely will be critical mitigation tools, they are (at least in theory) adaptation-neutral, showing indifference to the technologies or behavioral changes adopted in response to price. Indeed, the purpose is to allow least-cost avoiders in the private sector to determine strategies on the theory that market incentives (rather than government agencies) can more efficiently select among emissions reduction options.[110] Thus, generally speaking, neither a cap-and-trade program nor carbon taxes necessarily promote or discourage adaptive behavior. No doubt, specific legislative proposals under either system could be designed to include adaptive elements and revenues from market mechanisms could be used to fund adaptation efforts. Price signals also would encourage some adaptive behaviors, such as increased use of building insulation that would protect inhabitants from extreme temperatures.[111]

Nonetheless, market mechanisms undoubtedly would drive technology and infrastructure investment in numerous other ways that have not been evaluated. Scholarship has yet to assess how the technology (and infrastructure incentivized by market mechanisms) will perform in an era of extreme weather, multiple security threats, higher sea levels, and shifting regulatory baselines. A carbon price enacted with the current energy infrastructure will shape future investment, creating technological winners and losers. While deterring

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[110] *See supra* Part II.A.1.

[111] To the extent pricing carbon encourages increased efficiency to reduce energy costs, this will produce a residential adaptation benefit indirectly. Better insulated homes will help buffer the effects of extreme heat and cold, particularly important if these events are coupled with storms that cause power outages. Of course this raises the question of whether or not price incorporates the risk of failing to adapt. While I suspect that it does not fully do so for a number of reasons (such as short time horizons for decision-making, lack of knowledge, public rejection of science, short term incentives of business managers and politicians, inertia and psychological tendencies to presume a static environment) the important point here is that scholars have not considered this issue.

future use of highly polluting coal-fired power plants is a highly desirable outcome, a price signal could also incentivize investment in maladaptive technologies or maladaptive locations. For example, commentators expect that nuclear power would be a "big winner" under a cap-and-trade regime because it does not emit GHGs when generating electricity.[112] However, as discussed below, large-scale nuclear power plants—particularly those located along the coasts—increase climate vulnerability in numerous ways.

Given what we know about impending climate change impacts, mitigation plans should not be agnostic as to whether power plants lie in the likely path of rising seas and intensifying hurricanes, rely on vulnerable transmission lines, or increase use of hazardous materials. More importantly, the plans should consider how mitigation choices now will affect future governance.

Of course, reducing the current emissions trajectory is absolutely essential to keeping climate change within a range to which we can adapt. Pricing carbon likely will be essential for achieving adequate mitigation. However, to advance adaptation, these price signals will need supplemented by measures limiting technology choice, reforming systemic vulnerabilities, and giving regulators the ability to redirect prior investment that subsequently proves maladaptive as impacts unfold. Such supplemental measures inevitably reduce private sector choice. Thus, some might view these additional policies as undermining the efficiency of a market mechanism. However, some loss of efficiency and choice may be the inevitable cost of doing business in physically unstable conditions.

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[112] *See e.g.*, Arnold W. Reitze, Jr., *Electric Power in a Carbon Constrained World*, 34 WM. & MARY ENVTL. L. & POL'Y REV. 821, 881–82 (2010) ("If federal legislation to control carbon emissions that is similar to the pending cap-and-trade program in ACES is enacted, a big winner will be the nuclear power industry. The benefits to the nuclear industry can be calculated in various ways. Regardless of the approach, the benefits are in the billions . . . ."); Keith Johnson, *Nuclear Obama: Will Cap-and-Trade Plans Spur Nuclear Revival?*, WALL ST. J. BLOGS (Mar. 11, 2009, 3:50 PM), http://blogs.wsj.com/environmentalcapital/2009/03/11/nuclear-obama-will-cap-and-trade-plans-spur-nuclear-revival/ ("The idea that the climate-change imperative will give fresh legs to nuclear power isn't entirely new; that's what's pushing once-hostile environmentalists toward the pro-nuclear camp. And a carbon tax or at least expensive emissions in a cap-and-trade program would go a long way toward improving nuclear power's currently grim economics.").

Incorporating adaptation into mitigation selection will shift the balance away from some options that appeared favorable on a mitigation-only analysis and toward others which may have been overlooked or undervalued. It will also require critically examining the broader infrastructure systems. Mitigation choices will invariably affect investment in critical infrastructure, such as power systems and transportation networks,[113] which likely will be in place for decades. Thus, this Article proposes a holistic approach that considers both the adaptability of mitigation technologies individually and their role in broader infrastructure networks.

B. Adaptation Scholarship

Although the belated entry of adaptation into climate change literature has led some to refer to an "adaptation deficit,"[114] the pace of scholarship on this issue has been accelerating.[115] As discussed below, legal scholars have emphasized procedural changes—such as new decision-making models, modified administrative procedures to enhance agency flexibility, and revised regulatory goals—to accommodate the demands that climate change will place on administrative agencies. This Article proposes that a holistic approach will evaluate which mitigation technologies are substantively best equipped to adapt and to accommodate regulators' future constraints.

Scholars have advocated new decision-making methodologies that de-emphasize front-loaded analysis in favor of ongoing evaluation that acknowledges the depth of uncertainties.[116] Daniel Farber, for example, proposes

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[113] *See* DeShazo & Freeman, *supra* note 16, at 1502.

[114] *See* Ruhl, *supra* note 8, at 363, 372 (quoting Ian Burton, *Climate Change and the Adaptation Deficit*, in THE EARTHSCAN READER ON ADAPTATION TO CLIMATE CHANGE 89, 90–92 (E. Lisa F. Schipper & Ian Burton eds., 2009).

[115] *See, e.g.*, Robert L. Glicksman, *Climate Change Adaptation: A Collective Action Perspective on Federalism Considerations*, 40 ENVTL. L. 1159, 1164–65 (2010); Alejandro E. Camacho, *A Learning Collaboratory: Improving Federal Climate Change Adaptation Planning*, 2011 BYU L. REV. 1821 (2011); Victor B. Flatt, *Adapting Laws for a Changing World: A Systematic Approach to Climate Change Adaptation*, 64 FLA. L. REV. 269 (2012); Holly Doremus, *Adapting to Climate Change with Law That Bends Without Breaking*, 2 SAN DIEGO J. CLIMATE & ENERGY L. 45 (2010).

[116] *See, e.g.*, Robin Kundis Craig, *"Stationarity is Dead"—Long Live Transformation: Five Principles for Climate Change Adaptation Law*, 34 HARV.

replacing current models with robust decision making (RDM) models that run plans through scenarios with numerous different potential future environments.[117] RDM, he contends, offers a better approach to dealing with deep uncertainties surrounding climate change.[118] Others have advocated placing much more emphasis on adaptive management rather than focusing too heavily on pre-project planning,[119] so that agencies engage in an iterative process, revising plans and regulations in light of observed effects.[120]

Scholars also propose increasing regulators' flexibility to adapt to shifting baselines.[121] Administrative law should be changed by reducing procedural requirements to give agencies "breathing room" to address the demands of climate change adaptation.[122] Robin Craig, for example, envisions a system of "principled flexibility" which allows for climate change adaptation exemptions for existing laws to accommodate the impossibility of returning to pre-climate change states.[123]

Both Craig and J.B. Ruhl argue that the aims of

ENVTL. L. REV. 9 (2010); Farber, *supra* note 67, at 907 ("Conventional risk assessment, which is the dominant mode in the United States, requires quantification of probabilities and hence is not well adapted to true uncertainty . . . [and] functions more as a source of sound advice [rather] than as a method of analysis."); Ruhl, *supra* note 8, at 420.

[117] Farber, *supra* note 67, at 933.

[118] *Id.* at 934 ("Robert Verchick has emphasized the importance of scenario analysis—and of the act of imagination required to construct and consider these scenarios—in the face of nonquantifiable uncertainty.").

[119] Pre-project environmental impact assessment has formed a foundation of environmental law since passage of the National Environmental Policy Act (NEPA) (42 U.S.C. §§ 4321–4370 (2014)) in 1969. NEPA aims make environmental impacts part of the pre-decisional analysis for every agency. 42 U.S.C. § 4332. Agencies must adopt procedures to incorporate environmental factors in decision-making "to the fullest extent possible." *Id.* However, it does not create ongoing review after the project has been approved. *See* Daniel A. Farber, *Adaptation Planning and Climate Impact Assessments: Learning from NEPA's Flaws,* 39 ENVTL. L. REP. NEWS & ANALYSIS 10605, 10610 (2009).

[120] *See* Craig, *supra* note 116, at 65.

[121] *See id.* at 17–18.

[122] *Id.* at 66–67 (Limited procedures could alter land management, for example, as follows: "[P]ublic lands managers may need some form of general planning requirements coupled with abbreviated administrative procedures for specific implementation decision, periodic rather than continual judicial review for rationality, the ability to rely on post-decisional evaluations rather than pre-decisional justifications, or increased emergency authorities in order to achieve true capacity for adaptive management.").

[123] *Id.* at 17, 64 (advocating agency flexibility when responding to climate change impacts but more rigidity when preventing pollution and other environmental stressors).

environmental and natural resources law must be revised because the current preservationist approach presumes a stationary baseline that "no longer reflects ecological realities."[124] Thus, adapting environmental and natural resources law requires an "across the board shift in legal objectives, from preservation and restoration to the improvement of resilience and adaptive capacity."[125]

This literature highlights the complex demands that future administrators will face. Craig, for example, argues that resource agencies will need to promote adaptation through multiple avenues: ongoing study and monitoring of ecosystems; aggressively reducing non-climate stressors to ecosystems (such as air and water pollution, overfishing, habitat loss); and engaging in planning with increased coordination across media, sectors, interests, and governments.[126] This latter task will require governmental entities to treat climate change as a mainstream concern at "all levels of governmental planning."[127]

These changed procedures, new decision-making tools, and revised goals likely will prove to be important aspects of climate change adaptation. At the same time, it also will be important to ensure that the physical and regulatory infrastructure adopted to slow climate change does not exacerbate adaptation challenges.

C. Towards Synthesis

Adaptation and mitigation scholarship have largely

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[124] *Id.* at 17. *See also* Ruhl, *supra* note 8, at 364, 366.

[125] Craig, *supra* note 116, at 18.

[126] *Id.* at 15–17 ("[C]limate change alters baseline ecosystem conditions in ways that are currently beyond immediate human control, regardless of mitigation efforts. . . . [E]xisting environmental and natural resources laws are preservationist, grounded in the old stationarity framework that no longer reflects ecological realities. In contrast, the new climate change adaptation law needs to incorporate a far more flexible view of the natural world, because both the identity of the regulatory objects—the things such as rivers that such statutes are trying to protect—and the regulatory objectives will themselves be continually transforming, especially at the ecosystem level.") (footnotes omitted).

[127] *Id.* at 57. Craig's statement that "adaptation measures must embrace all aspects of human society simultaneously" may suggest an unnecessarily tall order. *Id.* at 29. While complex overlaps (between, for example, food production and water supply) would ideally be evaluated together, adaptive changes, at least those that do not strongly undermine efforts in other areas, could occur in an interactive process that allows some tradeoffs and experimentation but eventually enhances overall resilience.

occurred on parallel tracks. Indeed some scholars have explicitly conceptualized these as alternative strategies for responding to climate change, with adaptation emerging as the "second-best imperative" in the face of political and social forces that have prevented sufficient mitigation.[128]

In the one exception to this pattern identified in a literature review, Lesley McCallister has recognized adaptation and mitigation as potentially complementary strategies.[129] She emphasizes three impending changes in the physical environment—water scarcity, extreme events, and an overall increase in environmental stressors—that should be considered in developing "adaptive mitigation" in the electricity sector.[130] She proposes three policy measures to advance adaptive technologies for mitigation: information dissemination about projected impacts, incorporation of adaptation issues into pre-project review under NEPA or similar mechanisms, and expanded use of adaptation planning.[131]

This Article contributes to what hopefully will become a burgeoning literature on holistic climate change governance by examining previously unrecognized interactions between adaptation and mitigation policies. Most importantly, this Article highlights the impact present mitigation choices may have on future governance. The case study of nuclear power demonstrates how laws intended to prompt mitigation can limit future governmental bodies' responsiveness to climate change impacts. In addition, this Article proposes a preliminary framework for evaluating mitigation proposals'

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[128] A. Dan Tarlock, *Takings, Water Rights, and Climate Change,* 36 VT. L. REV. 731, 733–34 (2012) ("There are two strategies to address the projected adverse impacts of climate change: mitigation and adaptation. Most domestic and international efforts have focused on the theory of mitigation—the reduction of greenhouse-gas emissions—through either a cap-and-trade system or a carbon tax. However imperative it may be to roll back greenhouse-gas emission levels, mitigation is largely an illusion in an era of constrained budgets, an increasingly dysfunctional American political system, the weakness of international environmental law, and the resistance of large segments of the energy industry to switching to a non-carbon-based future. . . . Furthermore, even if there were to be an effective international mitigation regime, the benefits will not manifest themselves for centuries. The result is that adaptation—taking projected adverse impacts as a given—has emerged as a second-best imperative.") (footnotes omitted).

[129] Lesley McCallister, *Adaptive Mitigation in the Electric Power Sector*, 2011 BYU L. REV. 2115, 2122 (2011).

[130] *See id.* at 2128–43.

[131] *See id.* at 2144–50.

impact on adaptation.

D. A Preliminary Framework

A holistic approach to climate change law and policy begins with several empirical assumptions that shape the relevant inquiry. First, emissions must be quickly and significantly reduced to avoid the worst impacts (and to retain a habitable planet). Second, mitigation will occur in evolving physical circumstances due to climatic changes that have already begun and will continue to change the environment. Third, extreme weather, sea-level rise, fires, and other climate change impacts will increasingly disrupt energy, transportation, and other systems absent robust adaptation. Finally, future governments and administrative agencies have limited adaptive capacity. A holistic approach thus places some of the adaptation onus on the substance of mitigation technologies and the infrastructure on which they rely rather than presuming that future governments can adapt around the built environment if given sufficient legal tools.

The following list of factors stems from these empirical assumptions. Mitigation measures should be evaluated for (1) the potential implementation speed and potential extent of GHG reductions, (2) interactions with anticipated climatic changes to the physical and social environments, (3) the extent to which the measure relies on vulnerable systems or expands investment in such systems, and (4) the degree to which the physical and regulatory infrastructure reduces or exacerbates future administrative burdens.

1. Speed and Extent of Emissions Reductions

Mitigation and adaptation are interdependent because "[l]ess action on mitigation raises the risk of greater climate-change-induced damages to economic development and natural systems and implies a greater need for adaptation."[132] Hence, the speed and extent of emissions reductions must factor into an evaluation of proffered measures. Dramatic reductions relative to projected business-as-usual emissions will be necessary for adaptation because, as the IPCC warns,

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[132] IPCC, MITIGATION OF CLIMATE CHANGE, *supra* note 22, at 226.

unmitigated climate change likely will exceed the human ability to adapt.[133] Moreover, earlier and deeper GHG emissions cuts reduce the likelihood of triggering pernicious feedback mechanisms and crossing thresholds for irreversible changes.

As discussed below, the catastrophic potential harm of failing to mitigate climate change has weighed heavily in favor of using carbon-free nuclear power generation to meet projected future demand, engendering substantial support for the technology. However, analysis of this option cannot stop with speed and depth of reductions given potential interactions with changes to the physical environment, systemic vulnerabilities, and governance demands.

2. Interaction with the Physical Environment

Mitigation technologies will interact with the future physical environment in at least two directions—what I call "inputs" and "outputs." The changing environment can have inputs into the mitigation technologies that can affect their efficacy. A 2013 report from the Department of Energy (DOE) extensively describes energy sector vulnerabilities from climate change impacts that will undermine many forms of electricity generation, including nuclear power and the renewable technologies favored in RPS standards.[134] For example, increasing temperatures reduce the efficiency of solar photovoltaic generation.[135] Drought conditions significantly reduced hydropower generation at certain sites over the last decade, an effect that DOE expects will increase as climatic changes accelerate.[136]

Interactions with the changing physical environment can

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[133] *See id.* at 197.

[134] *See* U.S. DEP'T OF ENERGY, U.S. ENERGY SECTOR VULNERABILITIES TO CLIMATE CHANGE AND EXTREME WEATHER 12 (2013) [hereinafter DOE 2013], *available at* http://energy.gov/downloads/us-energy-sector-vulnerabilities-climate-change-and-extreme-weather.

[135] *Id.*

[136] *See id.* at 3 (describing power reductions of 23 percent at Lake Mead in 2010 and about 50 percent at the North Platte Project in 2006); *see also id.* at A-7 ("Although wet regions will generally become wetter and dry regions will become drier, changes in streamflow are projected to vary spatially and seasonally. . . . Under higher emissions scenarios, widespread drought is projected to become more common over most of the central and southern United States.") (internal citations omitted).

go in the other direction as well. Climatic changes can also lead to outputs into the environment that exacerbate ecological stressors and challenge responders and regulators. In the case of nuclear power, for example, rising seas, flooding, or fires may undermine the integrity of spent fuel pools at reactor sites, causing release of hazardous materials. Thus, evaluation of potential physical environment interactions should consider both inputs to and outputs from the measure.

3. Systemic Considerations

Choices among mitigation technologies will influence infrastructure development and create path dependencies in energy, transportation, and other systems. Selection should account for physical and systemic vulnerabilities to the extent possible. A holistic approach asks how physical and regulatory infrastructure designed for a stable climate will function in the less predictable future.

Because existing infrastructure is part of a complex system that has sunk costs and path dependencies, technologies that fit into existing systems likely will appear to be more cost-effective than others that require broadly rethinking the systems themselves. Hence market mechanisms likely will prompt investment that reduces emissions while largely perpetuating existing energy, transportation, and other infrastructure systems. The alternative of government-directed technology selection is not immune from this effect either given that it may focus on individual technologies in isolation from systemic context. For example, renewable portfolio standards favor investment in specific technologies but still require grid-tying.

The potential interaction between complex systems and adaptation is well illustrated in the United States energy system. Mitigation proposals aim to redirect infrastructure investment in the high-emitting United States power sector.[137] As discussed below, the current highly centralized infrastructure is vulnerable to climate change impacts. To the

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[137] Aldy & Stavins, *supra* note 81, at 54 ("Any meaningful climate policy will increase energy prices, particularly with regard to energy derived from coal combustion and, to a lesser extent, petroleum and natural gas combustion. Mitigation policies would also benefit firms (and some regions) with zero-carbon technologies . . . .").

extent mitigation choices rely on and perpetuate this system, they will be similarly maladaptive.

In their classic analysis of the United States power system, Amory Lovins and L. Hunter Lovins argued that the United States has evolved to create a "brittle" structure.[138] They identified multiple aspects of the United States power system that create vulnerability, contrasting those with alternatives that could be used to promote resilience.[139] Although Lovins and Lovins focused on security risks from accidents or sabotage and not from global warming, their considerations prove critical for climate change adaptation.

First, United States power plants rely on dangerous materials—such as flammable, explosive, and radioactive fuels[140]—with large quantities stored in centralized locations, making them easy targets and heightening the risk of large-scale accidents.[141] Second, many aspects of the system render it susceptible to disruption that can create a ripple effect, undermining power delivery.[142] Supply centralization necessitates long-distance transport to end-users;[143] hence transportation delays can disrupt power delivery. Large power plants are built with limited substitutability of fuel, heightening the impact from supply chain disruptions.[144] Finally, continuous delivery of electricity depends upon grid operators' meticulous balancing of power generation and usage to prevent component damage and power outages.[145]

Interactions between energy delivery systems exacerbate vulnerabilities. For example, oil and gas furnaces often employ electric pilot lights and electric blowers, rendering heat

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[138] AMORY B. LOVINS & L. HUNTER LOVINS, BRITTLE POWER 1 (2001) ("The United States has . . . gradually built up an energy system prone to sudden, massive failures with catastrophic consequences. The energy system that runs America is brittle—easily shattered by accident or malice. . . . It poses, indeed, a grave and growing threat . . . [that] comes not from hostile ideology but from misapplied technology.").

[139] *Id.* at 31–42.

[140] *Id.* at 31–32.

[141] *Id.* at 34–35.

[142] *Id.*

[143] *Id.* at 36.

[144] *Id.* at 36–37.

[145] *Id.* at 38–39. Lovins explains that, because electricity is difficult to store, "the central supply of electricity requires a continuous direct connection from source to user." *Id.* at 38. Moreover, the grid "carries electrons in a particular, precisely defined time pattern of variation that is *synchronous throughout the grid*." *Id.* at 39.

unavailable if electricity is disrupted.[146] The aftermath of "Superstorm Sandy" in October 2012 illustrates how delivery system interdependence heightens vulnerability to ripple effects. After the storm downed power lines, leaving millions of homes without electricity and heat, residents found themselves unable to purchase gasoline to run generators (or cars to leave the area) because gas stations lacked the necessary electricity to pump fuel from underground storage tanks.[147] As Lovins and Lovins explained, the "sheer complexity of many technical systems" renders prediction of all potential causes of failure nearly impossible.[148]

Although *Brittle Power* focused on security risks, the analysis aptly addresses climate impacts. Climate change impacts will substantially exacerbate the system's brittleness. Fires, hurricanes, heavy snowstorms, and rain can also take out transmission lines, disabling the electrical system over large geographic areas. Extreme weather increases accident risk, particularly when components were formulated for past weather conditions.[149] Because large-scale energy facilities are highly capital intensive and require long lead times before producing power,[150] their sunk costs render it difficult to adapt to changing circumstances.[151] Meanwhile, increased security threats[152] warrant caution in relying on dangerous materials.

Future systemic vulnerabilities should factor into the present selection of mitigation technologies. For example, this factor weighs against large-scale, centralized power plants that rely on vulnerable long-range transmission or long-distance fuel transportation. As DOE warns:

> Climate change and extreme weather risks facing the U.S. energy sector are varied, complex, and difficult to project. . . . Climatic conditions are already affecting energy

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[146] *Id.* at 42.

[147] *See* Andrew Mach, *After Sandy, a Desperate Search for Power*, NBC NEWS (Oct. 31, 2012), http://usnews.nbcnews.com/_news/2012/10/31/14835919-after-sandy-a-desperate-search-for-power?lite.

[148] LOVINS & LOVINS, *supra* note 138, at 19.

[149] *See* DOE 2013, *supra* note 135, at 46 ("Current energy technologies were in large part developed to meet design specifications that do not address the full set of challenges posted by climate change and extreme weather.").

[150] *Id.* at 43–45.

[151] *Id.* at 45.

[152] *See supra* Part I.B.2.

> production and delivery in the United States, causing supply disruptions . . . . [T]he magnitude of the challenge posed by climate change on an aging and already stressed U.S. energy system could outpace current adaptation efforts, unless a more comprehensive and accelerated approach is adopted.[153]

Mitigation choices could rely on the current transmission and fuel transport systems while concurrently seeking to have these improved. Yet, continuing to build large-scale infrastructure before the system becomes more resilient is a risky strategy both because financing these upgrades will be subject to political conflict and because the uncertainty about climate change impacts makes systemic resilience a moving target. A better strategy will rely on full utilization of more adaptive approaches (such as energy efficiency, distributed generation, and urban cooling, discussed in Part IV.B) before employing brittle technologies to meet emissions reductions goals.

4. Governance and Administrative Burdens

Climate change policy should anticipate that future governments will face unprecedented circumstances[154] while trying to ensure public safety, regulate risk, and maintain infrastructure. Adaptation scholarship has proposed important procedural mechanisms to help accommodate these increased demands. However, procedural changes alone likely will be insufficient to ensure that agencies and officials can deliver critical services.

The legal regimes that we adopt now to incentivize mitigation will shape the regulatory landscape and the physical infrastructure that will constrain future policymakers' options. The following Part uses a study of nuclear power to illustrate how legal structures designed to incentivize investment in mitigation can interact with the demands of adaptation. It demonstrates that adaptation and mitigation must be considered together to be most effective.

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[153] DOE 2013, *supra* note 135, at 46.

[154] *See supra* Parts I.B, I.C.

III. CASE STUDY: NUCLEAR POWER

In the last two decades, the federal government has adopted new legal incentives for investment in nuclear power, justifying these policies in part by the need to reduce GHG emissions from electricity production.[155] Yet policymakers have not considered how this technology and the regulatory context affect the United States' ability to adapt to climate change impacts. Critically, as described below, legal changes designed to promote nuclear power undermine future regulators' ability to respond nimbly to climate change impacts. A holistic approach accounts for these adaptation implications in selecting among mitigation technologies and in designing regulatory regimes.

A. Nuclear Power as Mitigation

The following Part provides regulatory background and discusses specific legal changes the federal government has made to induce expansion of nuclear power. It then identifies nuclear power's value as a mitigation tool. Finally, it discusses how an adaptation perspective informs assessment of nuclear power as a mitigation tool and how this perspective should influence regulatory choices.

1. Background

The Atomic Energy Act of 1954 established the Atomic Energy Commission and gave it authority over both civilian and military nuclear technology development.[156] The Energy Reorganization Act of 1974 created a successor agency, the Nuclear Regulatory Commission (NRC or Commission)[157] and vested it with regulatory power over civilian nuclear power producers (while shifting military oversight to other agencies).[158] The Commission is charged with supervising producers to ensure public health and safety, environmental quality, and security.[159]

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[155] *See infra* Part III.A.2.

[156] *See* 42 U.S.C. § 2011 (2014).

[157] 42 U.S.C. § 5801 (2014); 42 U.S.C. § 5842 (2014); 42 U.S.C. § 5381 (2014).

[158] 42 U.S.C. § 2140 (2014).

[159] *See* OFFICE OF THE FED. REGISTER, NAT'L ARCHIVES & RECORDS ADMIN.,

Despite the Commission's central role, nuclear power also involves multiple agencies at lower levels of government. While the federal government exclusively controls questions of radiological safety and plant licensing, states retain their traditional authority over electric utilities' supply, reliability, and ratemaking.[160] Local governments must respond in an emergency requiring evacuation, although case law leaves them little power to control plant siting or otherwise to influence safety; courts have maintained a sharp division of responsibilities, repeatedly holding that federal law preempts any efforts by states or localities to address plant safety through regulatory or tort avenues.[161] State and local efforts to regulate storage or transport of radioactive materials into their regions are also preempted.[162]

The NRC's decision to approve an operating license creates a long-term infrastructure commitment. The NRC grants initial operating licenses for a period of forty years,[163] and twenty-year renewals can be requested at the expiration of the initial period.[164] The Commission has granted renewals for

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U.S. GOVERNMENT MANUAL 432 (July 2013), *available at* http://www.gpo.gov/fdsys/pkg/GOVMAN-2013-11-06/pdf/GOVMAN-2013-11-06.pdf#page=443.

[160] Pac. Gas & Elec. Co. v. Energy Res. & Dev. Comm., 461 U.S. 190, 191 (1983) ("From the passage of the Atomic Energy Act in 1954, through several revisions, and to the present day, Congress has preserved the dual regulation of nuclear-powered electricity generation: the Federal Government maintains complete control of the safety and 'nuclear' aspects of energy generation, whereas the States exercise their traditional authority over economic questions such as the need for additional generating capacity, the type of generating facilities to be licensed, land use, and ratemaking.").

[161] *See, e.g.*, Skull Valley Band of Goshute Indians v. Nelson, 376 F.3d 1223, 1246 (10th Cir. 2004), *cert. denied* 546 U.S. 1060 (2005); United States v. Kentucky, 252 F.3d 816, 824 (6th Cir. 2001) (holding that although states retain authority to regulate solid waste, federal law preempts state efforts to control radioactive components of solid waste); *In re* TMI, 67 F.3d 1103, 1107 (3d Cir. 1995) (holding that the Federal Atomic Energy Act preempts inconsistent state tort claims); Suffolk Cnty. v. Long Island Lighting Co., 728 F.2d 52, 59 (2d Cir. 1984) (holding that a tort action based on state law was preempted because it raised safety issues and challenged NRC enforcement decision); United States v. Manning, 434 F. Supp. 2d 988, 996–97 (E.D. Wash. 2006) (finding that federal law preempts state efforts to regulate releases of radioactive substances).

[162] *See, e.g.*, United States v. Manning, 527 F.3d 828, 836–37 (9th Cir. 2008) (holding that a Washington statute mandating cleanup at Hanford site before addition of new waste was preempted by federal law); *Skull Valley*, 376 F.3d at 1246 (holding that state regulation of spent nuclear fuel storage and transport was preempted by federal law).

[163] 42 U.S.C. § 2133(c) (2014).

[164] 10 C.F.R. § 54.31(b) (2014).

most of the applications that it has received,[165] making the de facto period sixty years. The infrastructure lifetime commitment extends well beyond the licensed operating life of the plant to include up to sixty years for decommissioning and possible onsite storage of spent nuclear fuel.[166]

As of 2011, the United States had 104 operating commercial nuclear reactors generating 19 percent of the country's electricity.[167] Because most nuclear capacity in the United States was built in a relatively short time period, current plants' licenses (based on an initial forty years with twenty-year renewal) will begin to expire in 2029, although the NRC purportedly is considering extending existing plant licenses beyond the sixty-year period by allowing a second twenty-year renewal.[168]

A complete drop-off in license applications for new plants after 1978 led commentators to presume that nuclear power was on the way out, and many anticipated that existing plants would soon be decommissioned.[169] In addition to public reaction

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[165] *See Status of License Renewal Applications and Industry Activities*, U.S. NUCLEAR REGULATORY COMM'N, http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html (last visited Oct. 14, 2013). As of October 2013, eighty-eight plant owners had applied for renewals and seventy-three renewals had been granted. *Id.* NRC was reviewing nine more and had received eleven letters of intent to submit renewals. *Id.*

[166] *See* U.S. NUCLEAR REGULATORY COMM'N, NUREG-1437, VOL. 1, GENERIC ENVIRONMENTAL IMPACT STATEMENT FOR LICENSE RENEWAL OF NUCLEAR PLANTS 7.2.2 (June 2013), *available at* http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1437/v1/part07.html#_1_173 (describing three methods NRC developed for plant decommissioning with time periods ranging from nine to 300 years but noting that available options are currently restricted by regulatory limits of sixty years); *see also Waste Confidence—Continued Storage of Spent Nuclear Fuel*, 78 Fed. Reg. 56776, 56799 (proposed Sept. 13, 2013) (describing the Commissions' conclusion that spent nuclear fuel can be safely stored in onsite fuel pools "for at least 60 years beyond the licensed life for operation").

[167] U.S. ENERGY INFO. ADMIN., DOE/EIA-0383(2013), ANNUAL ENERGY OUTLOOK 44 (2013) [hereinafter EIA 2013], *available at* http://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf.

[168] *See* NUCLEAR ENERGY INST., SUBSEQUENT LICENSE RENEWAL: CREATING THE FOUNDATION FOR NUCLEAR POWER PLANT OPERATION BEYOND 60 YEARS 1 (Feb. 2013), *available at* http://www.nei.org/CorporateSite/media/filefolder/NEI-White-Paper-Subsequent-License-Renewal.pdf?ext=.pdf ("The Nuclear Regulatory Commission and nuclear industry are studying whether extending nuclear plants' operating lives beyond 60 years is safe, manageable and economical. The current nuclear plants' 60-year licenses will begin expiring after 2029. Many years ahead of that date, companies must begin planning either to continue operating those plants or to develop new baseload power.").

[169] *See* Stephen Maloney, *Nuclear Revival: The Sequel,* POWERGRID INT'L-ELEC. LIGHT & POWER (Jan. 1, 2008), http://www.elp.com/articles/

to the accidents at Three-Mile Island and Chernobyl, cost overruns plagued construction efforts for the initial generation of United States nuclear plants.[170] Regulatory changes, public opposition, and other factors caused delays that combined with high interest rates to create extremely high costs.[171]

This history and several intrinsic difficulties in constructing large nuclear power plants deters investment in nuclear power. Costs are heavily front-loaded[172] and the construction process requires a select group of highly specialized workers. This "complex operation . . . can take more than a decade to complete."[173] Because of this complexity and cost, private parties hesitate to invest in new builds,[174] particularly if they suspect that shifting regulatory requirements and litigation will cause delays.

2. Federal Efforts to Promote the Industry: Overcoming Investor Reluctance

Both Congress and the NRC have taken steps to revitalize the industry and prompt investors to build new plants. As part of its effort to stimulate investment, Congress promoted nuclear power with direct subsidies to the industry and other measures to reduce investor risk in the Energy Policy Act of 2005. Debates show that climate change mitigation was an important factor in a number of legislators' support for nuclear

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print/volume-86/issue-1/sections/risk-management/nuclear-revival-the-sequel.html ("Unfortunately for the industry, the fire at Browns Ferry in 1975 called attention to weaknesses in electrical standards. The dynamic and static loads on essential safety structures in a design basis accident constantly changed as accident analyses became more robust. Resolutions to other generic and unresolved safety issues were backfit on plants in the midst of construction. As a result, construction periods doubled and even tripled. The costs for many plants would grow three to five times above original estimates. The Three Mile Island accident in 1979 halted progress on the few plants still under construction and triggered several rounds of costly safety backfits that continued into the mid- to late 1980s. Some argue that Three Mile Island also killed off the nuclear construction boom.").

[170] *See id.*

[171] *See* JOHN M. DEUTCH ET AL., MASS. INST. OF TECH. ENERGY INITIATIVE, UPDATE OF THE MIT 2003 FUTURE OF NUCLEAR POWER 8 (2009), *available at* http://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf.

[172] EIA 2013, *supra* note 167, at 45 ("Nuclear power plants are among the most expensive options for new electric generating capacity.").

[173] *Id.*

[174] *See id.* In recent years, low natural gas prices have further deterred investors.

industry.[175] Senator McCain, for example, stated:

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[175] For House debates, *see, e.g.*, 151 CONG. REC. H2401 (daily ed. Apr. 21, 2005) (statement of Rep. Burgess, TX) ("Nuclear power will help provide the electricity that our growing economy needs without increasing emissions. This is truly an environmentally responsible source of energy."); 151 CONG. REC. H6952 (daily ed. July 28, 2005) (statement of Rep. Stupak, MI) ("[I]f we are really concerned about global climate change and climate change here in this country, we must revisit the issue of nuclear energy, and I am pleased this bill provides incentives to make the United States once again a leader in this area, and protect our environment, protect our climate and get America less dependent on foreign oil."); 151 CONG. REC. H6962 (daily ed. July 28, 2005) (statement of Rep. Murphy, PA) ("Nuclear power is a vital part of the energy mix in this country and in our State. The Energy Policy Act of 2005 will encourage this clean-burning energy source by promoting the construction of new nuclear reactors."). For Senate debates, *see, e.g.*, 151 CONG. REC. S6883 (daily ed. June 21, 2005) (statement of Sen. Isakson, GA) (speaking in support of the Hagel-Pryor Amendment designed to incentivize low-carbon technologies) ("As we talk about the need to protect our environment and ensure that greenhouse gases don't run away from us and that we preserve all that we have, we have to understand that we have to incentivize every part of the energy sector and the energy segment, and as we develop new technologies, we also ought to reuse and reintroduce those great technologies of nuclear and others that have produced clean, efficient, reliable energy without the production either of carbon or the greenhouse gases."); 151 CONG. REC. S6885 (daily ed. June 21, 2005) (statement of Sen. Domenici, NM) ("If people want to move with nuclear power, which is the cleanest—right now, as my friend from Tennessee [Alexander] has reminded me, 70 percent of the carbon-free emissions in America come from the nuclear power plants [sic]. That is rather astounding. We run around thinking we have done so much cleanup, but these very old—old in that we have not built one in 23 years—these nuclear power plants are the ones that are cleaning up right now."); 151 CONG. REC. S6892 (daily ed. June 21, 2005) (statement of Sen. McCain, AZ) (discussing McCain-Lieberman Amendment—to give construction subsidies to nuclear plants) ("In this amendment we encourage technology in order to reduce greenhouse gas emissions and make energy use more efficient, and we are trying at the expense of some support to recognize that nuclear power is a very important contributor to our energy needs in the coming years, particularly since 20 percent of our energy supply is already supplied by nuclear power and those power plants are going out of business fairly soon."); 151 CONG. REC. S6998 (daily ed. June 22, 2005) (statement of Sen. Lieberman, CT) (discussing McCain-Lieberman Amendment) ("I know there are some who are concerned about the mere mention of nuclear. The fact is, today 20 percent of electric power generated in America comes from nuclear plants. They are functioning safely. . . . We do not want to close the door on any technology that will give us the power to run our society and help us deal with the greenhouse gas global warming problem, and that includes but is not limited to, as we say, nuclear."); 151 CONG. REC. S7010-11 (daily ed. June 22, 2005) (statement of Sen. Brownback, KS) ("In Sweden, they have switched to nuclear production and away from traditional sources of power like coal. I believe nuclear power needs to play a greater role in our own power generation, and I think it will lead clearly to reductions in greenhouse gas emissions."); 151 CONG. REC. S7017 (daily ed. June 22, 2005) (statement of Sen. Talent, MO) ("In 2003, U.S. nuclear power-plants avoided the emission of 679 million metric tons of carbon dioxide, from the fossil fuels that would have been burned to generate power in the absence of nuclear energy. . . . Without nuclear energy, U.S. electric sector carbon emissions would

> As nuclear plants are decommissioned . . . we must make efforts to maintain nuclear energy's level of contribution, so that this capacity is not replaced with higher-emitting alternatives. I, for one, believe it can and should play an even greater role . . . for the very simple reason that we must support sustainable, zero-emission alternatives such as nuclear if we are serious about addressing the problem of global warming.[176]

Similarly, Senator Alexander stated:

> [T]he bill . . . puts a focus on the one way today that we create carbon-free electricity far and above everything else, and that is nuclear power. If we are worried about global warming, the solution is nuclear power. Nuclear power produces 70 percent of our carbon-free electricity. We know how to do it, we invented it. . . . If we care about low-carbon, no-carbon electricity, after we have aggressive conservation, we should make it easier to produce nuclear power, and in a variety of ways this legislation does that.[177]

The Energy Policy Act extended, until 2025, the Price-Anderson Act's[178] cap on private companies' nuclear accident liability and federal reinsurance for accidents.[179] The Energy Policy Act also created a production tax credit for new nuclear capacity, regulatory risk insurance, and federal loan guarantees for up to 80 percent of construction costs.[180] The Act allowed new builds to qualify for up to $18.5 billion worth of loan guarantees and a production tax credit of $18.00 per megawatt hour of electricity generated during a reactor's first

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have been approximately 30 percent higher.").

[176] 151 CONG. REP. S7023 (daily ed. June 22, 2005) (statement of Sen. McCain, AZ) (quoting a New York Times writer, McCain stated: "It's increasingly clear that the biggest environmental threat we face is actually global warming and that leads to a corollary: nuclear energy is green.").

[177] 151 CONG. REP. S6623 (daily ed. June 15, 2005) (statement of Sen. Alexander, TN).

[178] 42 U.S.C. § 2210 (2005) (Price-Anderson not only caps total liability but also provides a mechanism for consolidating claims in a single federal court proceeding).

[179] Energy Policy Act of 2005, 42 U.S.C. 15801–16538 (2014).

[180] Mark Holt, CONG. RESEARCH SERV., 17–22 NUCLEAR ENERGY POLICY, (Nov. 25, 2011), *available at* http://fpc.state.gov/documents/organization/168680.pdf.

eight years of production.[181]

Augmenting these financial incentives, the NRC has completed three regulatory initiatives that began in the 1990s: a provision for early site permits, a design-certification process, and a combined construction and operating license.[182] These revised licensing provisions encourage investment in nuclear power by reducing regulatory and litigation risks for investors.[183] The early site permit process resolves in advance all on-site environmental issues associated with plant licensing,[184] thus reducing subsequent regulatory hurdles. Combined permits allow operators to accomplish in one step what had formerly required two permitting processes—one for construction and another for operation.[185] Design certification allows the industry to garner off-the-shelf approval for plant models before ever applying them to a particular setting.[186]

These changes not only reduce administrative procedures but significantly reduce litigation risk for plant operators. In the past, plants have been scuttled by litigation delays.[187] The

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[181] EIA 2013, *supra note* 167, at 45.

[182] *See* Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Reactors, 54 Fed. Reg. 15372, 15378–79 (Apr. 18, 1989) (codified at 52 C.F.R. subpart A) (requirements for early site permits), 15382–83 (codified at 52 C.F.R. subpart B) (describing the design certification process), 15383 (codified at 52 C.F.R. subpart C) (requirements for combined licenses).

[183] *See The COL Leagues,* NUCLEAR ENGINEERING INT'L (Dec. 10, 2005), http://www.neimagazine.com/story.asp?storyCode=2033035 ("In the 1980s the NRC [Nuclear Regulatory Commission] took steps to streamline the licensing system, developing the framework for a one-step process (combined construction and operation), instead of the former two-step process (construction, then operation). Crucially, this removes the fear that a plant could be built, but then be found unacceptable for operation – a worst-case financial scenario. [Investor] activity was fuelled by President George Bush's Energy Policy Act, which brought in new legislation to introduce tax credits for the first 6000MWe of new nuclear capacity. The act also enabled the DOE to provide loan guarantees and created a fund to reduce a constructing utility's financial exposure to planning and litigation delays. The acceptance by the NRC of early site permit (ESP) applications, whereby a potential constructor could establish the validity of a site for a new reactor far in advance of an actual commitment to build, has further streamlined the process.").

[184] *See* 10 C.F.R. § 52.17 (application and technical information), § 52.39 (finality) (2014) (effective Sept. 27, 2007).

[185] *See* 10 C.F.R. § 52 Subpart C (2014) (effective Sept. 27, 2007); *see also* 54 Fed. Reg. 15,372, 15,379 (Apr. 18, 1989) (rejecting the view that the statute requires a two-step process and arguing that the NRC is authorized to combine construction and operating permits).

[186] *See* 10 C.F.R. § 52.41 (2014).

[187] *See* Justin Guandlach, *What's the Cost of a New Nuclear Power Plant? The*

new regulations strictly limit when challenges can be raised in the licensing process.[188] Moreover, because these new licensing procedures allow NRC to pre-approve reactor designs and to resolve many environmental issues before operators have even selected a site, potential local opponents will not even know to mobilize opposition until after NRC has already finalized permits.[189] Thus, permits will preclude local opponents from raising many environmental and design issues when challenging the placement of nuclear plants in their communities.

The financial and regulatory incentives created by Congress and the NRC induced the industry to begin moving forward with developing new operating units and renewing licenses at existing plants. Proposals for up to thirty-one new operating units had been made by 2011.[190] Between June 2010 and February 2013, NRC renewed fourteen licenses.[191] The Commission expects fifteen renewal applications between 2013 and 2019.[192]

3. Climate Benefits Versus General Risks

Since the initiation of United States nuclear power programs, critics have emphasized waste disposal, accident risk, and security concerns along with high costs as basis for rejecting it as a source of domestic electrical power.[193] The

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Answer is Gonna Cost You: A Risk-Based Approach to Estimating the Cost of New Nuclear Power Plants, 18 N.Y.U. ENVTL. L.J. 600, 642 (2011).

[188] *See id.* at 667; *see also* Citizens Awareness Network, Inc. v. United States, 391 F.3d 338, 348 (1st Cir. 2004) (upholding changes to adjudicatory process established in 69 Fed. Reg. 2182, 2193 (January 14, 2004) which grant NRC more control over licensing adjudication).

[189] Neal Lewis, *Interpreting the Oracle: Licensing Modifications, Economics, Safety, Politics, and the Future of Nuclear Power in the United States*, 16 ALB. L.J. SCI. & TECH. 27, 33 (2006) ("Local public interest groups are unable to oppose at this licensing stage because there is no connection between their local interests and the proposed design. . . . [I]t is unlikely that these groups will muster the resources to challenge a particular design when they are unable to demonstrate to their constituents that the design will be built locally.").

[190] Holt, *supra* note 180, at 2–3.

[191] *Id.*

[192] *See* EIA 2013, *supra* note 167, at 45.

[193] *See, e.g.*, AMORY LOVINS, SOFT ENERGY PATHS: TOWARDS A DURABLE PEACE 212 (1977) ("Phasing out nuclear power should make our electricity cost not more but less."); Louis J. Sirico, *Stopping Nuclear Power Plants: A Memoir*, 21 VILL. ENVTL. L.J. 35, 38 (2010) ("Although the questionable safety of nuclear plants held center stage, a number of related issues generated serious discussion,

renewed interest in nuclear power—based in no small part on the desire to address climate change—has led to a debate over whether the climate benefits outweigh these previously identified risks.[194] (A subset of this discussion has focused on the conflicting empirical analyses of the degree of risk.)[195] While some critics dispute nuclear energy's potential to significantly reduce GHG emissions, many former opponents have changed sides in light of climate change risks, embracing this technology as an important tool for generating carbon-free electricity.

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including waste disposal, the lack of sufficient insurance coverage, worker safety, inadequate evacuation plans, the presence of alternative energy sources, and the questionable financial wisdom of investing in nuclear power.").

[194] Charles de Saillan, *Disposal of Spent Nuclear Fuel in the United States and Europe: A Persistent Environmental Problem*, 34 HARV. ENVTL. L. REV. 461, 472 (2011) (describing extensive risks of waste disposal and high costs of current United States' policy requiring DOE to take title); LISBETH GRONLUND ET AL., UNION OF CONCERNED SCIENTISTS, NUCLEAR POWER IN A WARMING WORLD: ASSESSING THE RISK, ADDRESSING THE CHALLENGES 2–7 (2007), http://www.ucsusa.org/assets/documents/nuclear_power/nuclear-power-in-a-warming-world.pdf (discussing nuclear power's continuing safety and security risks with reference to waste disposal, accidents and terrorism); AMORY B. LOVINS ET AL., NUCLEAR POWER: CLIMATE FIX OR FOLLY? 1 (2008), http://rmi.org/images/PDFs/Energy/E0901_NuclPwrClimFixFolly1i09.pdf (arguing that nuclear power is too expensive to be worthwhile and wastes mitigation dollars better spent elsewhere); Amory Lovins, Imran Sheikh & Alex Markevich, *Forget Nuclear,* SOLUTIONS, Spring 2008, at 1, 25, http://www.rmi.org/Content/Files/SolutionsJournalSpring2008.pdf; Benjamin Sovacool & Christopher Cooper, *Nuclear Nonsense: Why Nuclear Power is No Solution to Climate Change and the World's Post-Kyoto Energy Challenges*, 33 WM. & MARY ENVTL. L. & POL'Y REV. 1, 1–2 (2008) ("Nuclear power plants are a poor choice for addressing energy challenges in a carbon-constrained, post-Kyoto world. Nuclear generators are prone to insolvable infrastructural, economic, social, and environmental problems. They face immense capital costs, rising uranium fuel prices, significant lifecycle greenhouse gas emissions, and irresolvable problems with reactor safety, waste storage, weapons proliferation, and vulnerability to attack. Renewable power generators, in contrast, reduce dependence on foreign sources of uranium and decentralize electricity supply so that an accidental or intentional outage would have a more limited impact than the outage of larger nuclear facilities. Most significantly, renewable power technologies have environmental benefits because they create power without relying on the extraction of uranium and its associated digging, drilling, mining, transporting, enrichment, and storage. As a result, renewable energy technologies provide a much greater potential for substantial carbon emissions reductions than significant investments in new nuclear power generation.").

[195] Guandlach*, supra* note 187, at 601.

a. Climate Benefits

Nuclear power has several upsides as a source of electricity generation. Most importantly for climate change mitigation, production does not produce GHG emissions.[196] Based on this fact, some scientists have urged that the dangers of nuclear power are insignificant when compared with the threats from failing to reduce GHG emissions. James Lovelock, for example, has argued:

> I am a green and would be classed among them, but I am most of all a scientist; because of this I entreat my friends among the greens to reconsider . . . their wrongheaded objection to nuclear energy. Even if they were right about its dangers, and they are not, its use as a secure, safe, and reliable source of energy would pose a threat insignificant compared with the real threat of intolerable and lethal heat waves and sea levels rising to threaten every coastal city of the world.[197]

Energy scholar Donald Zillman similarly states, "[G]lobal warming can produce as catastrophic harms to the earth as significant radiation release from a nuclear accident. Increased use of nuclear energy may be the most practical current method of reducing consumption of fossil fuels."[198]

The advantages of nuclear power are not illusory, particularly when compared with coal-powered electricity generation. Even considering the full fuel cycle (as opposed to just production), nuclear power emits far fewer GHG emissions than coal.[199] Nuclear power production also avoids emission of the criteria pollutants associated with fossil fuel combustion that reduce air quality and impact public health.[200]

Nuclear power plants can generate large quantities of

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[196] *See, e.g.*, Fred Bosselman, *The Ecological Advantages of Nuclear Power*, 15 N.Y.U. ENVTL. L.J. 1, 41 (2007).

[197] JAMES LOVELOCK, THE REVENGE OF GAIA: EARTH'S CLIMATE IN CRISIS AND THE FATE OF HUMANITY 11 (2006).

[198] Donald Zillman, *Nuclear Power*, *in* ENERGY LAW AND POLICY FOR THE 21ST CENTURY 10–12 (James E. Hickey, Jr. 2000).

[199] *See* VACLAV SMIL, ENERGY AT THE CROSSROADS: GLOBAL PERSPECTIVES AND UNCERTAINTIES 313 (2005) (estimating nine grams of carbon dioxide per kilowatt hour).

[200] *See* Bosselman, *supra* note 196, at 31–35.

electrical power.[201] They also benefit from a relatively abundant supply of fuel (as compared to fossil fuels).[202] MIT scientists conclude that world supplies of uranium ore are "sufficient to fuel the deployment of 1000 reactors over the next century."[203] Some have argued that with appropriate reprocessing, uranium provides an almost infinite supply of fuel.[204]

Once incorporated into the grid, nuclear power plants provide *baseload* power,[205] that is, a steady, predictable flow that is important to balancing other less predictable sources.[206] Fred Bosselman, author of a leading energy law textbook, argues that because nuclear provides baseload power (unlike intermittent wind and solar), any reduction in nuclear capacity will be replaced not with clean wind and solar but with dirtier sources of baseload power, particularly coal.[207] Coal-fired

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[201] *See* U.S. ENERGY INFO. ADMIN., ANNUAL ENERGY REVIEW 2011 224, table 8.2a, *available at* http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf (last visited Nov. 2, 2012). The average nuclear plant in the United States produces approximately 12.2 billion kilowatt-hours (kWh). *Frequently Asked Questions*, U.S. ENERGY INFO. ADMIN., http://www.eia.gov/tools/faqs/faq.cfm?id=104&t=3 (last visited Oct. 14, 2013) (based upon a total of 790 billion kilowatt-hours (kWh) generated in 2011 from sixty-five nuclear power plants, with a total of 104 reactors).

[202] *See* DAVID BODANSKY, NUCLEAR ENERGY: PRINCIPLES PRACTICE AND PROSPECTS 225 (2d. ed. 2010).

[203] DEUTCH ET AL., *supra* note 171, at 12 (quoting MASS. INST. OF TECH., THE FUTURE OF NUCLEAR POWER: AN INTERDISCIPLINARY MIT STUDY (2003), *available at* http://web.mit.edu/nuclearpower/pdf/nuclearpower-summary.pdf).

[204] *See* Fletcher T. Newton & Byron Little, *Why Nuclear Energy Will Prevail and Not Merely Survive*, *in* ROCKY MT. MIN. L. FOUND., URANIUM EXPLORATION AND DEVELOPMENT, at 1A-2 (Nov. 2, 2006) (describing uranium as a fuel that is "for all practical purposes, inexhaustible").

[205] U.S. ENERGY INFO. ADMIN., FUEL COMPETITION IN POWER GENERATION AND ELASTICITIES OF SUBSTITUTION, 2, 3 (June 2013) *available at* http://www.eia.gov/analysis/studies/fuelelasticities/pdf/eia-fuelelasticities.pdf. "Historically, most of the baseload power demand in the United States has been supplied by coal and nuclear generation units, owing to their low costs of operation. Generation fueled by natural gas and petroleum supplemented the baseload generators during peak and intermediate periods of demand . . . ." *Id.* at 2. "The elasticity of substitution between these two fuels and coal was generally found to be insignificant, for the most part because the price of coal ensured its position as a primary fossil fuel used for baseload generation." *Id.* at 6.

[206] *See* MATHEW CORDARO & THE NEW YORK AFFORDABLE RELIABLE ELEC. ALLIANCE, UNDERSTANDING BASE LOAD POWER: WHAT IT IS AND WHY IT MATTERS 2 (Oct. 7, 2008), *available at* http://www.area-alliance.org/documents/base%20load%20power.pdf.

[207] *See* Bosselman, *supra* note 196, at 52 (According to Bosselman, the gap will not be filled by natural gas because of price volatility and unreliable supplies).

plants share many of the same downsides as nuclear plants—large-scale infrastructure, harmful waste, and a potential for supply disruptions—while also generating large quantities of both GHGs and other pollutants.[208] Bosselman argues that coal combustion's serious environmental and health harms may be underappreciated because they are incremental.[209] Meanwhile, the single event, catastrophic nature of a nuclear meltdown leads the public to overestimate its risk.[210] Thus, for these commentators, the prospect for low carbon electricity outweighs other concerns.

b. General Drawbacks

Opponents of nuclear power have long argued that the risk of serious accidents outweighs the benefits of nuclear power. The serious accident at Three Mile Island, Chernobyl, and Fukushima heightened these concerns. Critics contend that policymakers underestimate the risk of public exposure to dangerous radiation levels.[211] Meanwhile, supporters argue that the public overestimates both the likelihood of accidents and the potential extent of harm; they also emphasize the comparative harms from continued fossil fuel use and tout carbon-free nuclear electricity generation as essential for avoiding dangerous climate change.[212] However, this risk versus risk discussion has largely ignored the adaptation question;[213] it has not asked how various technologies will fare in a climate-altered future and how the agencies tasked with oversight can effectively govern the industry to ensure safety.

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[208] *Id.* at 30–35.

[209] *Id.* at 50–51.

[210] *Id.*

[211] *See, e.g.*, LOVINS & LOVINS, *supra* note 138, at 162–64 (stating that "most of the literature" understates the radiological consequences of major releases).

[212] *See, e.g.*, Bosselman, *supra* note 196, at 24 ("Examining coal and nuclear power solely from an ecological standpoint, the advantages of nuclear power are clear."); DEUTCH ET AL., *supra* note 171, at 4 ("Nuclear power [is an] important option[ ] for achieving electricity production with small carbon footprints. . . . The sober warning is that if more is not done, nuclear power will diminish as a practical and timely option for deployment at a scale that would constitute a material contribution to climate change risk mitigation.").

[213] *But cf.* Natalie Kopytko & John Perkins, *Climate Change, Nuclear Power, and the Adaptation-Mitigation Dilemma*, 39 ENERGY POLICY 318, 318 (2011) (examining "several ways in which climate change has already affected water in ways that create problems for existing nuclear power plants.").

Similarly, little attention has been paid to how increased security threats prompted by climate change could complicate efforts to prevent terrorist attacks on domestic plants. Yet this has been a longstanding concern even in more stable conditions.[214]

Climate change also will complicate another longstanding regulatory challenge for nuclear power—waste disposal. As of 2011, the United States had generated over 75,000 metric tons of spent nuclear fuel and high-level nuclear waste, currently stored at eighty different sites in thirty states.[215] The vast majority of spent fuel is "temporarily" stored at power plants in water pools originally constructed for cooling spent fuel before transport to a permanent repository.[216] These pools require constant supervision to prevent uncontrolled nuclear reactions (known as "criticality") that can occur when water levels get too low.[217] Pool storage was never intended to be a long-term waste disposal method. Since the 1970s, the federal government has planned to bury spent fuel at an underground site.[218] For

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[214] *See, e.g.*, Christopher E. Paine, *The Nuclear Fuel Cycle, Global Security, and Climate Change: Weighing the Costs and Benefits of Nuclear Power Expansion*, 44 U. RICH L. REV. 1047, 1098, 1108 (2010) ("If ensuring nuclear safety remains a challenge even for advanced industrial states with highly-developed safety cultures, these demanding safety requirements become a significant concern when one considers that some of the countries interested in producing nuclear power . . . have very high indices of both industrial accidents and official corruption. . . . Nuclear reactors and their associated spent fuel pools and fuel cycle facilities can [also] become targets in wartime [as seen with conflicts between Iraq, Iran, Israel, and Syria].").

[215] *Nuclear Waste: Disposal Challenges and Lessons Learned from Yucca Mountain: Hearing Before the H. Subcomm. on Env't & the Economy, Comm. on Energy & Com.*, 112th Cong. 1 (2011) (statement of Mark Gaffigan, Managing Dir. Natural Res. and Env't, General Accounting Office).

[216] Charles de Sailan, *Disposal of Spent Nuclear Fuel in the United States and Europe: A Persistent Environmental Problem*, 34 HARV. ENVTL. L. REV. 461, 472 (2011).

[217] *Id.* at 477 (discussing some of the dangers of inadequate supervision and cooling issues). The NRC has also authorized the use of dry cask storage in concrete or steel containers when plants exceed pool capacity although this method currently accounts for only a small proportion of storage. *Id.* at 473–74. High costs for constructing and operating dry cask storage facilities combined with additional licensing requirements likely account for limited adoption of this approach. *See* Michael A. Mullett, *Financing for Eternity the Storage of Spent Nuclear Fuel: A Crisis of Law and Policy Precipitated by Electric Deregulation Will Face New President*, 18 PACE ENVTL. L. REV. 383, 411 (2001) (describing industry-sponsored studies showing multi-million dollar costs).

[218] *See* Megan Easley, *Standing in Nuclear Waste: Challenging the Disposal of Yucca Mountain*, 97 CORNELL L. REV. 659, 665, 667 (2012) ("[F]ederal agencies began to officially address the need for a comprehensive waste management

decades the NRC has assumed optimistically that long-term disposal would soon be available.[219] On this basis, NRC promulgated a generic rule governing environmental impact analysis in all licensing proceedings that presumed zero-release of disposed waste, precluding opponents from raising these impacts during licensing proceedings.[220]

Congress has also long assumed that waste-disposal solutions were imminent. The Nuclear Waste Policy Act of 1982 (NWPA)[221] required DOE to site a national repository and to take title to spent fuel by 1998.[222] The NWPA mandated that utilities contract with DOE for high-level waste disposal in exchange for a statutory fee.[223] When DOE did not accept waste by the statutory deadline, utilities began to sue (successfully) for the cost of onsite storage.[224]

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scheme in the 1970s . . . Owners pay the fees into the Nuclear Waste Fund, which Congress created to finance the development and construction of a deep geologic repository").

[219] *See* Farber, *supra* note 67, at 910–11 ("The government decided to *assume* that the waste disposal problem would eventually be solved completely, an approach that dealt with all potential uncertainties by the simple expedient of ignoring them."); *see also* Lawrence Flint, *Shaping Nuclear Waste Policy at the Juncture of Federal and State Law,* 28 B.C. ENVTL. AFF. L. REV. 163, 166 (2006) (initiation of nuclear power program was premised on assumption that safe disposal would be developed).

[220] In *Balt. Gas & Elec. v. Natural Res. Def. Council*, the Supreme Court upheld NRC's application of this generic zero-release finding for purposes of analyzing environmental impacts from a future waste disposal in licensing proceedings. 462 U.S. 87, 97 (1983). However, a 2012 First Circuit decision was less deferential to NRC's optimistic assumptions about future waste disposal given the decades long failure to establish a federal repository. The court rejected the NRC's finding that waste rules would not significantly affect the environment because a repository would be available "when necessary." As the court explained: "The Commission apparently has no long-term plan other than hoping for a repository." New York v. Nuclear Regulatory Comm'n (NRC), 681 F.3d 471, 478 (1st Cir. 2012).

[221] 42 U.S.C. § 10101–10270 (2014) (effective 1982; amended 1987).

[222] 42 U.S.C. § 10222(a)(5) (1983).

[223] 42 U.S.C. § 10131 (2014) (effective 1983).

[224] *See* KIM CAWLEY, CONG. BUDGET OFFICE, THE FEDERAL GOVERNMENT'S RESPONSIBILITIES AND LIABILITIES UNDER THE NUCLEAR WASTE POLICY ACT (2010) (Courts have held the agency liable for breach of contract and determined that the appropriate remedy was damages). *See, e.g.*, S. Cal. Edison Co. v. United States, 93 Fed. Cl. 337, 341 (Fed. Cl. 2010) (as of June 2010, electric utilities had filed over seventy cases seeking to recover storage costs) (Fed. Cir. 2011); *see also* Ind. Mich. Power Co. v. Dep't of Energy, 88 F.3d 1272, 1277 (D.C. Cir. 1996) (finding DOE had contractual duty to accept waste by 1998); Entergy Nuclear Fitzpatrick v. United States, 1711 F.3d 1382, 1383 (C.A. Fed. 2013) (describing appeal as "the latest in a line of attempts by the government to raise the 'unavoidable delays' defense in breach of contract actions stemming from its

Thus far, DOE has failed to establish a permanent repository and the decades-long attempt to do so has been fraught with legal and political conflict.[225] After years of conflict over a potential site, DOE withdrew its license application for a permanent underground waste repository at Yucca Mountain, Nevada prompting suits by state and local governments.[226] Meanwhile, the D.C. Circuit ordered NRC to continue evaluating the Yucca Mountain waste repository application despite frankly acknowledging that Congress has simultaneously both mandated and yet virtually defunded this plan.[227] Collapse of the Yucca Mountain process prompted the General Accounting Office to report "restarting the search [for a permanent site] would likely take decades and cost billions of dollars."[228] As discussed below, climate change impacts will exacerbate these governance challenges.

B. Nuclear Power and United States Adaptation

The following discussion analyzes the impact of large-scale nuclear power on climate change adaptation with reference to the preliminary framework outlined in Part II.[229] It considers: the speed and extent of emissions reductions; interactions with the evolving physical environment; energy system vulnerability; and future governance.

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failure to accept Spent Nuclear Fuel (SNF) from the nation's nuclear utilities" and rejecting defense).

[225] *See NRC*, 681 F.3d at 473–74, 478 (stating that "[t]his is yet another in the growing line of cases involving the federal government's failure to establish a permanent repository for civilian nuclear waste. . . .[d]espite years of 'blue ribbon' commissions, congressional hearings, agency reports, and site investigations" and commenting that "[w]e share petitioners' considerable skepticism as to whether a permanent facility can be built given the societal and political barriers"); *see also,* Alex Funk & Benjamin K. Sovacool, *Resolving the Impasse in United States Nuclear Waste Policy*, 34 ENERGY L.J. 113, 122–23 (2013) (describing fifteen year process leading to designation of Yucca Mountain, Nevada as a repository site, Congressional legislative efforts to override the State's opposition to the plan, and lawsuits filed by Nevada).

[226] *In re* Aiken County, 645 F.3d 428, 436 (D.C. Cir. 2011) (finding challenge not yet ripe).

[227] *In re* Aiken County, 725 F.3d 255, 266–68 (D.C. Cir. 2013) (ordering agency to restart analysis but stating "we would certainly hope that Congress would step in before the [remaining insufficient funds] are expended").

[228] Gaffigan, *supra* note 215.

[229] *See supra* Part II.D.

1. Emissions Reductions: How Fast and How Deep?

Because unmitigated emissions that continue on current trajectories likely will render effective adaptation impossible, nuclear energy's potential to reduce emissions should be taken seriously. As described above, nuclear power plants generate electricity with very few GHG emissions. In addition, one plant can produce large quantities of power from apparently abundant uranium fuel, offering significant savings over electricity generated from fossil fuels.

Although construction can take a decade, the technology is mature and available. These qualities favor nuclear power because it significantly can contribute to mitigation in a moderate time frame, at least more quickly than proffered measures that are still in research phases. This potential to quickly and deeply reduce emissions must be understood as benefitting not only mitigation but also adaptation efforts. Failure to mitigate will undermine and possibly preclude effective adaptation and earlier emissions reductions will ease the adaptation burden.

However, the efficacy of the reductions must be evaluated in light of changes in the environment. New plant licensing presumes extremely long lifetimes—up to sixty and possibly eighty years—of power generation with up to sixty more years for decommissioning. Because of this timeframe, infrastructure will be on the ground during periods of significant environmental change and sea level rise. Even mere renewals of existing plants' licenses will have them operating into the middle of this century. Mitigation benefits offered by nuclear power may be undermined by future climatic changes. As discussed in the next Part, anticipated climate change impacts likely will interfere with plant productivity, undercutting the presumption that nuclear power can provide carbon free, baseload power over a plant's lifetime.

2. Nuclear Power in a Changing Physical Environment: Inputs and Outputs

Mitigation technologies can interact with the physical environment in two directions, creating both inputs and outputs. Climate change can have "inputs" into technological processes that undermine their efficacy. In the case of large nuclear power plants, extreme weather and fires can be anticipated to down power lines more frequently than in the past, preventing electricity from reaching end users.[230] Storm surge and flooding can damage reactors or require a shutdown to avoid damage, either of which prevents electricity generation.

Over the last decade, extreme weather, flooding, and storm surge have increasingly rendered plants unsafe to operate, requiring temporary shutdowns.[231] For example, three plants were shut down in the wake of Hurricane Sandy, leaving many people without power for extended periods of time in cold weather.[232] Plant location will play a critical role in determining vulnerability to climate change impacts; plants along low-lying coastal areas will be particularly vulnerable to storm surge and hurricanes. Indeed, large plants located along the coast may be rendered permanently unusable due to sea level rise. If so, these large plants will not be moveable and other power generation sources will be substituted.

Climate change can undermine production in more modest ways; for example, warmer temperatures increase cooling needs and hence electricity and water requirements. At the same time, climate change will reduce water availability in some areas. DOE thus reports that this impact could reduce capacity by 12 to 16 percent at thermoelectric power plants that depend on these water supplies for cooling.[233]

Power plants also can have outputs into the physical environment. Existing and proposed plants on the coast will experience more severe storms, hurricanes, and sea level rise. Rising sea levels and storms increase accident risk[234] and potential releases of waste stored in on-site pools. This is not a far-fetched scenario given that, even under current conditions,

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[230] *See generally* McCallister, *supra* note 129, at 2134–45 (discussing the increased risk of outages in the electric sector).

[231] *See* DOE 2013, *supra note* 135, at 2–3 (listing shutdowns and power curtailments over the last decade due to excessive heat and flooding).

[232] *See* Evan Osnos, *Sandy, Fukushima, and the Nuclear Industry*, NEW YORKER, Nov. 2, 2012, http://www.newyorker.com/online/blogs/evanosnos/2012/11/sandy-fukushima-and-the-nuclear-industry.html.

[233] DOE 2013, *supra* note 135, at 24.

[234] Kopytko & Perkins, *supra* note 213, at 330 (“Safe operations during extreme climate events remain a challenge. Regardless of design parameters, storms at coastal locations continue to be a problem because they often lead to the failure of multiple systems, and despite previous experience, failures in alarm and communication systems continue to occur.”).

a Category 3 hurricane could cause "considerable flooding" at Turkey Point Nuclear Facility in Florida.[235] By the end of the century, a Category 2 storm could be expected to cause the same impacts.[236] The DOE has identified numerous power plants (including nuclear and other forms of generation) that are vulnerable to flooding along the coasts and in low-lying inland areas.[237] In addition to requiring a shut down that interrupts power delivery, flooding creates a serious risk for accidental releases because it can interrupt power to safety systems as happened at Fukushima.[238] These potential safety issues will require increasing administrative oversight, complicating agencies' tasks in ensuring public safety in a complex and uncertain context.

Outputs also include more modest impacts. For example, cooling water released from nuclear plants (and other power generators) into rivers exacerbate the harms biota sensitive to temperature change have already experienced due to waters already warmed by changing temperatures.[239]

3. Nuclear Power in the Energy System

The energy system into which nuclear power is incorporated currently has several maladaptive features. In general, electricity in the United States is "delivered through a long, intricate chain of events and equipment. . . . All these processes depend on massive, highly capital-intensive, long-lead-time facilities which are extremely complex, both technically and socially, and which operate continuously under precise controls."[240] The system's technical complexity (due to the system components) renders it prone to failures.[241] Meanwhile, systemic complexity (due to intricate connections

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[235] *See* DOE 2013, *supra* note 135, at 34.

[236] *See id.*

[237] *See id.* at 34–35 (describing increased flood risks for the "numerous thermoelectric plants [that] line the coasts" and for inland facilities that draw upon river water).

[238] *See* MILLER ET AL., U.S. NUCLEAR REG. COMM'N, RECOMMENDATIONS FOR ENHANCING NUCLEAR SAFETY IN THE 21ST CENTURY: THE NEAR-TERM TASK FORCE REVIEW OF INSIGHTS FROM THE FUKUSHIMA DAI-ICHI ACCIDENT 9 (July 12, 2011), *available at* http://pbadupws.nrc.gov/docs/ML1118/ML111861807.pdf.

[239] *Id.* at 321–22.

[240] LOVINS & LOVINS, *supra* note 138, at 30.

[241] *Id.*

between various parts of the energy system) increases the likelihood of unpredictable interactions.[242]

Large nuclear power plants suffer from many of the downsides of centralized production identified by Lovins and Lovins. Because they depend on long-distance transmission lines, power line damage can disrupt power delivery.[243] Fires, floods, and extreme storms will increasingly damage power lines and undermine delivery.[244] While such considerations also apply to "green" technologies (such as large solar installations and wind farms), the presumption that nuclear power can provide reliable *baseload* power may need to be re-evaluated in light of transmission line vulnerability.

Transmission line vulnerability also increases risks associated with continued on-site storage of spent fuel. More frequent flooding, fires, and grid failures could disrupt the external electricity supply necessary to maintain water levels in spent fuel pools and prevent criticality.

The nuclear power plant models currently being licensed by NRC are particularly large-scale projects.[245] The high upfront investments do not allow for rapid design evolution. While estimates differ dramatically as to the cost per kilowatt hour of electricity generated by nuclear power and its consequent cost-effectiveness,[246] no one disputes that new

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[242] *Id.*

[243] *Id.* at 36–39.

[244] *See* DOE 2013, *supra* note 135, at 7.

[245] Although smaller modular reactors are being developed that offer increased flexibility and lower cost, they have not yet been approved for licensing given remaining technical, policy, and administrative issues. *See* EIA 2013, *supra* note 167, at 46. Assuming these become commercially and legally viable, they could provide a different model for nuclear power better suited to the demands of adaptation. Because small modules would not necessitate that same level of initial investment as large-scale plants, they would create fewer sunk costs. *See* Holt, *supra* note 180, at 28 ("[T]heir ability to be constructed in small increments could reduce financial commitment and risk to electric utilities."). Moreover, if designed as envisioned for factory assembly with transport to utility sites, *see id.*, modular reactors could potentially be relocated if climate change impacts rendered former sites unsuitable.

[246] *Compare The Economic Future of Nuclear Power*, UNIV. OF CHICAGO S-4, S-14 (2004), *available at* http://www.mcs.anl.gov/~anitescu/EXTRAS/READING/NuclIndustryStudy-Summary.pdf (stating "[o]vernight cost estimates from different sources have ranged from less than $1,000 per kW [kilowatt] to as much as $2,300 per kW" but finding that new plants could be competitive if government provides investment and production tax credits), *with* Travis Madsen et al., *The High Cost of Nuclear Power: Why America Should Choose a Clean Energy Future over New Nuclear Reactors*, MARYLAND PIRG FOUND. 10–12, 31 (2009),

plant construction creates large upfront costs.[247] These sunk costs can lock in approaches that prove maladaptive later, particularly for plants that are poorly sited.

The typical contents of a nuclear power plant also exemplify the technical complexity that contributes to systemic vulnerability:

> Some fifty miles of piping, held together by twenty-five thousand welds; nine hundred miles of electrical cables; eleven thousand five hundred tons of structural steel . . . . Countless electric motors, conduits, batteries, relays, switches, switchboards, condensers, transformers, and fuses are needed. Plumbing require[s] . . . innumerable valves, seals, drains, vents, gauges, fittings, pipe hangers, hydraulic snubbers, nuts, and bolts. Structural supports, radiation shields, ductwork, fire walls, equipment hatches, cable penetrations, emergency diesels, and bulkheads must be installed. Instruments . . . [to] monitor temperatures, pressures, chain-reaction power levels, radiation levels, flow rates, cooling-water chemistry, equipment vibration, and the performance of all key plant components.[248]

The technical complexity of power plants and other aspects of the broader system render it impossible to anticipate all potential problems, an often underappreciated fact.[249] Both individual plant and systemic complexity create vulnerability to power delivery disruption. These disruptions can harm end-

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available at http://www.uspirg.org/sites/pirg/files/reports/High_Cost_of_Nuclear_Power_ MDPIRG.pdf (describing "skyrocketing" cost estimates and stating that "[n]uclear power is one of the least cost-effective ways to address America's energy problems.").

[247] EIA 2013, *supra* note 167, at 45. *See also*, UNIV. OF CHICAGO, *supra* note 246, at xii ("Capital cost is the single most important factor determining the economic competitiveness of nuclear energy.").

[248] LOVINS & LOVINS, *supra* note 138, at 19–20.

[249] *Id.* at 20 (explaining "[n]ot surprisingly, the sequence of human and mechanical events leading to the two most serious power reactor failures in the U.S. [at Browns Ferry, where a technician testing for air leaks with a candle caused a fire that burned sixteen hundred electrical cables, and at Three Mile Island] were excluded from . . . analysis in the most comprehensive study of reactor safety ever undertaken. Clearly it is possible to construct systems sufficiently complex that all probable states of the system are not foreseeable. Recent reactor failures "must give pause to one's acceptance of any claim of high reliability for a particular system, based solely on probabilistic analysis [which tries to foresee all the ways in which it can fail].").

users because people rely on this energy system to meet not only the demands of daily life but also for survival needs.[250] Climate change will exacerbate this complexity by changing the environmental conditions in which power plants operate. Components may be subject to new stressors from water, heat, cold and wind.

As discussed above, a classic risk model that presumes risk to be quantifiable (and hence subject to balancing against other factors) does not sufficiently capture these potential occurrences. Climate change does not just increase risk but also *uncertainty*.[251] Because of uncertainties, it is hard to calculate these potential impacts using existing modeling procedures.

4. Nuclear Power Governance

In some respects, nuclear power is not administratively difficult. Unlike some proposed mitigation measures, expanding the United States' nuclear power production does not require creation of a new regulatory agency or assignment of novel programs to an existing agency. The basic technology is not new. The NRC will be tasked with licensing new plants and relicensing old ones, a job it has been performing since 1974. The agency has long experience with this task. Nonetheless, nuclear power does require substantial multi-level and multi-agency oversight that changing climate conditions could drastically complicate. NRC and other agencies will have to ensure safe and effective operations under the shifting and unpredictable environment. Unfortunately, these future regulators' need for legal flexibility and adaptable infrastructure conflicts with current investors' incentives. Federal policymakers have tried to encourage investment in nuclear power by reducing the substantial financial and regulatory risk associated with large-scale nuclear plants. However, some of these efforts work at odds with the need to adapt.

As described above, in the last two decades NRC has

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[250] *Id.* at 38–39 (Electricity is supplied indiscriminately of end use). Thus, the system must be reliable enough to power hospitals and police stations regardless of whether most of the electricity serves less critical functions, such as powering televisions.

[251] *See* Farber, *supra* note 67, at 906.

streamlined licensing by allowing for early site permits and combined construction and operating permits. Both limit agency adaptability by making it more difficult for the Commission to impose new requirements on operators as conditions change. These rules, designed to encourage new plant construction, hinder administrative adaptability by allowing owners and operators to establish permit conditions much earlier in the process than before and placing the burden on the NRC to demonstrate that new information requires permit changes, even when multiple decades have passed.

The regulations promulgated in 2007 finalized procedures for early site permits, which give "approval of a site for one or more nuclear power facilities . . . ."[252] Permits last for no less than ten and no more than twenty years, although they can be renewed for similar periods.[253] Once obtained, these early site permits insulate the holder from subsequently enacted regulations and orders. Regulations limit Commission discretion to backfit requirements and place the burden on the agency to demonstrate that changes are necessary:

> [T]he Commission may not change or impose new site characteristics, design parameters, or *terms and conditions, including emergency planning requirements*, on the early site permit unless the Commission:
>
> (i) Determines that a modification is necessary to bring the permit or the site into compliance with the Commission's *regulations and orders applicable and in effect at the time the permit was issued*; [or]
>
> (ii) Determines the modification is necessary to assure adequate protection of the public health and safety or the common defense and security.[254]

While NRC could determine that changes are necessary for adequate protection, this determination will be subject to challenge and judicial review.[255] Because the Commission

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[252] 10 C.F.R. § 52.12 (2014).

[253] *Id.* § 52.33.

[254] *Id.* § 52.39 (emphasis added).

[255] 42 U.S.C. § 2239 (2014) (subjecting the Commission's final orders in licensing proceedings to judicial review).

assesses adequate protection on a case-by-case basis[256] rather than by prescribed parameters, it is not clear how this standard will be interpreted in the context of the evolving physical conditions presented by a changing climate. Given the uncertainties in climate science regarding such things as projections of sea-level rise or the geographic location of impacts, it may be difficult for the agency to justify a precautionary approach (presuming it is inclined to do so). More importantly, these new regulations place the burden on NRC to justify changes to licensing conditions that may have been established decades earlier.

With limited exceptions, early site permits—which may be procured long before application for construction, operating, or combined licenses—also preclude the agency or interested parties from raising a number of safety design issues when the Commission adjudicates these latter licenses: "[I]f the application for the construction permit or combined license references an early site permit, the *Commission shall treat as resolved those matters resolved in the proceeding on the application for issuance or renewal of the early site permit* . . . ."[257] These regulations limit NRC's flexibility to adapt to changing circumstances on the ground. While they do allow for changes due to new circumstances, they place the burden on the agency to demonstrate the need for the changes. Absent such a showing, very early determinations can limit future agency discretion for multiple decades.

Because licensing anticipates long plant life-times (forty to eighty operational years with up to sixty years for decommissioning) regulatory agencies will inevitably be required to ensure plant safety under new climatic circumstances.

As discussed earlier, researchers anticipate that climate change will be a "threat multiplier," creating a more complex security picture than previously existed.[258] Although the nonspecific nature of this future threat makes it impossible to quantify security risks, the current legal structure mal-

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[256] *See* Union of Concerned Scientists v. U.S. Nuclear Regulatory Comm'n, 880 F.2d 552, 557 (D.C. Cir. 1989) (holding that NRC is not required to establish objective standards for adequate protection and can instead determine the answer on a case-by-case basis).

[257] 10 C.F.R. § 52.39(a)(2) (2014) (emphasis added).

[258] *See supra* Part I.B.2.

adaptively reduces the NRC's and plant operators' incentives to sufficiently account for security threats.

Although nuclear power plants provide a potential target for terrorist acts, NRC's 2007 revision of its "design-basis threat" rule[259] exempted licensees from protecting against September 11th type attacks.[260] The Ninth Circuit upheld regulations allowing plant operators and the NRC to rely on other governmental agencies to prevent attacks;[261] therefore new plants can forego available design option features to physically prevent reactor or spent pool breach by a commercial aircraft.[262] The Third Circuit upheld NRC's refusal to even consider potential airborne terrorist attacks in environmental analysis for plant relicensing, accepting the Commission's contention that NEPA imposes no duty on NRC to evaluate these impacts.[263] Despite noting that "the NRC controls whether equipment within the facility . . . could withstand an accident," "it has no authority over the airspace above its facilities which is largely controlled by Congress and the Federal Aviation Administration."[264] While NRC eventually conceded to require these features for new applicants, it studiously avoided "backfitting" these requirements on existing plants, insisting that these features were not necessary for adequate protection.[265] Other decisions allow the agency to

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[259] *See* 10 C.F.R § 73.1 (2014) (defining threats against which plants must be protected).

[260] *See* Public Citizen v. Nuclear Regulator Comm'n, 573 F.3d 916, 920 (9th Cir. 2009) (upholding the NRC refusal to include air-based terrorist attacks in "design-basis" threats against which nuclear power plants should be passively protected despite studies showing "that nuclear facilities were not designed to withstand the impact of a commercial jet plane.").

[261] *See id.* at 926 (stating that "[i]t is not implausible for the Commission to determine that most attacks will be prevented in the first instance by the coordinated efforts of multiple Federal agencies").

[262] *Id.* at 920.

[263] N.J. Dep't of Envtl. Prot. v. Nuclear Regulatory Comm'n, 561 F.3d 132, 133 (3d Cir. 2009).

[264] *Id.* at 139.

[265] *See Consideration of Aircraft Impacts for New Nuclear Power Reactors,* 74 Fed. Reg. 28112, 28115 (June 12, 2009) (codified at 10 C.F.R. pts. 50 & 52) ("The Commission believes that it is prudent for nuclear power plant designers to take into account the potential effects of the impact of a large, commercial aircraft. The Commission has determined that the impact of a large, commercial aircraft is a beyond-design-basis event. . . This rule should result in new nuclear power reactor facilities being more inherently robust with regard to an aircraft impact than if they were designed in the absence of this final rule. This final rule provides an enhanced level of protection beyond that which is provided by the existing

presume that local governments will evacuate local residents in an emergency in the face of express statements to the contrary.[266]

Current regulations allow the nuclear industry to externalize security risks by forgoing available protective technologies while expecting non-NRC agencies to prevent terrorist attacks. This structure imposes additional uncertainties on other governmental bodies that will be facing increasing complexity over the coming decades due to climate change impacts.

The long lead times and large capital investment required before operation create risks that investors want to avoid.[267] Congressional efforts to induce new plant development by limiting owner and operator liability for accidents also conflicts with the needs of adaptation. As discussed above, Congress extended the Price-Anderson Act's limits on total liability and the public funding of insurance for nuclear accidents in the Energy Policy Act of 2005. Yet these changes reduce investors' incentives to fully account for climate change impacts in new plant development and relicensing of existing plants. Critics of Price-Anderson have identified several perverse incentives created by the Act.[268] First, because the owners, operators, and contractors do not have to insure for accident risks, they are

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adequate protection requirements, which all operating power reactors are required to meet. . . . NRC is making it clear that the requirements are not meant to apply to current or future operating license applications for which construction permits were issued before the effective date of this final rule. . . . Applying the final rule to operating license applications for which there are existing construction permits could result in an unwarranted financial burden to change a design for a plant that is partially constructed. Such a financial burden is not justifiable in light of the fact that the NRC considers events to which the aircraft impact rule is directed to be beyond-design-basis events and compliance with the rule is not needed for adequate protection to public health and safety or common defense and security.").

[266] *See, e.g.*, Long Island Lighting Co. v. Suffolk Cnty., 628 F. Supp. 654, 658–61 (E.D.N.Y. 1986) (describing ongoing conflict where state, county, and town claimed that no adequate plan could be developed for Shoreham but that LILCO operators would simulate plan without local officials' participation and finding local restrictions on simulation to be preempted).

[267] LOVINS & LOVINS, *supra* note 138, at 45.

[268] *See* Sean Hecht, *The Story of the Price-Anderson Act: How Congress Made Nuclear Power Financially Viable in the U.S. by Eliminating Accountability for Risk*, LEGAL PLANET (May 10, 2011), http://legal-planet.org/2011/05/10/the-story-of-the-price-anderson-act-how-congress-made-nuclear-power-financially-viable-in-the-u-s-by-eliminating-accountability-for-risk/.

less likely to take them into consideration.[269] Second, the Act treats all plants the same—regardless of age, design, location, or safety record.[270] To the extent the industry contributes to insurance pools (for a comparatively small portion of potential payouts), accident costs are spread evenly across the industry.[271] This discourages proper consideration of plant-specific risks and "tips the scales in favor of terrible decisionmaking [sic]."[272]

In sum, while nuclear power has the potential to produce large quantities of low-carbon power under current conditions, this benefit could easily be undermined by climate change impacts to individual plants and disruptions in the electrical grid more broadly. Despite NRC's extensive administrative experience, climate change will significantly increase administrative complexity of handling waste and other safety issues that have already proven difficult to manage in a stable climate. Moreover, laws enacted to promote investment in nuclear power undercut adaptation by constraining agency flexibility and externalizing risks. The expanded use of nuclear power and its regulation as a mitigation measure should be assessed with these adaptation implications in mind.

IV. ADVANCING ADAPTIVE PHYSICAL AND LEGAL INFRASTRUCTURE

A. *Reflections on the Case Study*

Existing technologies could be assembled to achieve the necessary reductions to avert dangerous anthropogenic climate change. Assuming sufficient political will can be garnered to address this issue, the question becomes how to select among the options. Potential implications for future adaptation have received insufficient attention as criteria for selecting mitigation measures and designing legal regimes to prompt mitigation.

This Article argues that mitigation options should be

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[269] *Id.*

[270] *See id.* ("Act created a retroactive common pool that requires all nuclear plant operators to share the liability equally, without regard to fault, if there's an accident at any nuclear facility, up to a specified limit.").

[271] *See id.*

[272] *Id.*

analyzed for their potential impact on adaptation and proposes a preliminary set of factors for this analysis. It also urges that anticipated adaptation constraints facing future regulators should influence the selection of mitigation technologies and design of mitigation legal regimes.

As the example of nuclear power shows, systemic vulnerabilities affect the viability of mitigation. In the coming decades, storms can be expected to increasingly down transmission lines, making it impossible for the power generated at any centralized plant, such as a nuclear one, to reach end users and rendering it far less useful as a source of baseload power. Plants can be more directly incapacitated by rising sea levels that allow storm surge to enter power plants. Particularly in light of the high variability in models of projected sea-level rise and the remaining uncertainties, this issue is critical to address before continued licensing of coastal nuclear plants. Otherwise, nuclear and other power plants will be rendered less effective at producing power and more likely to add to cumulative environmental harms from climate change.

Although nuclear power presents unique risks, DOE has identified vulnerabilities for other types of generation, including coal and gas-fired plants, some forms of solar, and hydropower.[273] Systemic vulnerabilities apply to many sources because transmission or fuel transportation failures can undermine delivery from any source.

Proposed mitigation that does not anticipate future warming may impede adaptation if it overlooks systemic brittleness. This observation applies beyond the energy sector to a broad range of issues, such as transportation, goods movement, land use, and population. Adaptation may require discouraging human settlement and development in areas particularly susceptible to fires, excessive heat, or sea level rise. A mitigation measure's reliance on complex and vulnerable systems should weigh against its adoption. Analysis of vulnerabilities should be extended to current transportation, communication, and energy systems to ensure that mitigation efforts do not excessively expand reliance on complex systems better suited to more stable climatic conditions.

Although nonspecific, repeated warnings from experts

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[273] *See* DOE 2013, *supra* note 135, at 9–12, 32–34.

about heightened security threats should be taken into consideration when evaluating mitigation options.[274] In the case of nuclear power, these warnings could be counted against expansion generally. Alternatively, if other factors weighed heavily in favor of using nuclear-generated power, regulations allowing plant operators to avoid available defensive measures may need revision. In general, anticipated increases in security stressors warrant caution in exacerbating existing power-system vulnerabilities.

Smaller and more decentralized power options may prove easier to reconfigure or redesign as well as less costly to abandon if regions become uninhabitable. All things being equal, the intensive use of mitigation or adaptation capital in one industry or geographic region may be less desirable than a mitigation strategy that can create equal reductions without concentrating sunk costs in one industry. In general, adaptation favors an approach that avoids path dependencies and maintains flexibility.

Even if the sunk costs and reduced flexibility are deemed warranted because of other benefits of nuclear power, the maladaptive elements of the current regulatory approach will need revision. While the high sunk costs for new plant construction make investors wary of regulatory delay, laws that pacify investors by locking in early environmental and safety decisions hamstring agencies' abilities to respond to new circumstances.

Finally, a holistic strategy recognizes that residents rely on governments to respond in emergencies, research and regulate technological risks, and plan infrastructure development. Future administrative agencies will face unprecedented levels of uncertainty that render risks difficult to predict and complicate emergency response. All other things being equal, approaches that require less ongoing administrative oversight to ensure public safety will be most adaptive.

B. Illustrations: Strong Synergies

Approaches that synthesize climate change adaptation and mitigation should receive highest priorities for funding and implementation. Such options do exist. To illustrate the

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[274] *See supra* Part I.B.2.

availability of holistic strategies, the following briefly discusses three underutilized options—energy efficiency, urban cooling through materials-choices, and distributed power—that mitigate climate change while creating adaptive infrastructure and potentially easing future governance burdens.

1. Energy Efficiency

Enhanced energy efficiency mitigates climate change by reducing electricity demand and, consequently, GHG emissions. Many of the same measures also provide adaptation benefits. The mitigation potential is quite large and can be accomplished while also easing burdens on future governance structures.

As I have discussed elsewhere, cost-effective energy-efficiency improvements in buildings can substantially mitigate climate change, but these enhancements are nonetheless dramatically underutilized.[275] Residential and commercial buildings use over two-thirds of the electricity generated in the United States,[276] generating 38 percent of the country's carbon dioxide emissions.[277] Up to half of this demand could be reduced with existing, mature, and available technology[278] at a cost-savings.[279]

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[275] *See* Trisolini, *supra* note 16, at 697–98.

[276] *Why Build it Green*?, U.S. ENVTL. PROT. AGENCY, http://www.epa.gov/greenbuilding/pubs/whybuild.htm (Dec. 19, 2012).

[277] *Id.*

[278] Energy efficiency can be increased substantially with mature technologies through improvements to a building's thermal envelope, heating system, and lighting systems. Other available options include: reducing the cooling load through such methods as reflective roofs and shade trees; using passive and low energy cooling techniques; building energy management systems; using solar energy for power, heat, and hot water; daylighting (using natural light); and using highly efficient appliances, electronics, and office equipment, among other things. IPCC, MITIGATION OF CLIMATE CHANGE, *supra* note 22, at 395–403.

[279] *See id.* at 389. (The IPCC found "a global potential to reduce approximately 29% of the projected baseline emissions by 2020" in a cost-effective manner. The report's authors concluded that: "Substantial reductions in CO_2 emissions from energy use in buildings can be achieved over the coming years using mature technologies for energy efficiency that already exist widely and that have been successfully used. . . . A significant portion of these savings can be achieved in ways that reduce life-cycle costs . . . ."). Other studies report even higher potential efficiency savings from buildings. Based on extensive modeling that factored in both industry and climatic zone, the National Renewable Energy Laboratory reported mature, available technologies for commercial buildings that can cost-effectively reduce energy demand compared with those built to commonly

A 2012 report by the American Council for an Energy Efficient Economy (ACEEE), a well-respected non-partisan think tank, comprehensively analyzed the potential long-term energy efficiency available in the United States' economy.[280] ACEEE's projections rely on feasible efficiency improvements in residential and commercial buildings, industrial processes, and transportation implemented over the next forty years.[281] The report concludes that by 2050, efficiency measures could reduce United States' energy consumption to half of its 2010 level.[282] This represents a 59 percent decrease from projected energy consumption in 2050, reduced entirely through efficiency measures.[283] Moreover, ACEEE's analysis demonstrates substantial economic benefits from these measures.[284]

Many mitigation proposals recognize the need to improve building energy efficiency and a number of jurisdictions have raised standards in building codes.[285] However, few, if any, analyze what could be accomplished with the level of institutional and financial investment that has been extended

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adopted standards. It found, for example, that grocery stores, general merchandise stores, highway lodgings, and medium-sized office buildings could cost-effectively cut their energy demand by 50 percent. *See generally* MATTHEW LEACH ET AL., U.S. DEP'T OF ENERGY, GROCERY STORE 50% ENERGY SAVINGS, TECHNICAL SUPPORT DOCUMENT (2009), *available at* http://www.nrel.gov/docs/fy09osti/46101.pdf; ELAINE HALE ET AL., U.S. DEP'T OF ENERGY GENERAL MERCHANDISE 50% ENERGY SAVINGS, TECHNICAL SUPPORT DOCUMENT, (2009), *available at* http:// www.nrel.gov/docs/fy09osti/46100.pdf; W. JIANG ET AL., U.S. DEP'T OF ENERGY, TECHNICAL SUPPORT DOCUMENT: 50% ENERGY SAVINGS DESIGN TECHNOLOGY PACKAGE FOR HIGHWAY LODGING BUILDINGS (2009) *available at* http://www.pnl.gov/main/publications/external/technical_reports/PNNL-18773.pdf; B.A. THORNTON ET AL., U.S. DEP'T OF ENERGY, TECHNICAL SUPPORT DOCUMENT: 50% ENERGY SAVINGS DESIGN TECHNOLOGY PACKAGES FOR MEDIUM OFFICE BUILDINGS (2009), *available at* http://www.pnl.gov/main/publications/external/technical_reports/pnnl-19004.pdf. Where payback periods were estimated, all were under twenty years and some much shorter, such as that for office buildings, which could be under five years. JIANG ET AL., *supra*, at 6.1; THORNTON ET AL., *supra*, at 5.1.

[280] JOHN A. LAITNER, ET AL., AM. COUNCIL FOR AN ENERGY EFFICIENT ECON., THE LONG-TERM ENERGY EFFICIENCY POTENTIAL: WHAT THE EVIDENCE SUGGESTS 2–3 (2012), *available at* http://aceee.org/research-report/E121 (summarizing the Release of ACEEE's New Report).

[281] *Id.* at 3.

[282] *Id.*

[283] *Id.*

[284] *Id.*

[285] *See* Trisolini, *supra* note 16, at 703–07 (describing rapid diffusion of green building standards).

to nuclear power. While the United States has reduced the energy intensity of its economy over the last few decades, numerous studies show that much greater reductions are technologically feasible.[286] Even though many of these available technologies are cost effective, they are underutilized because of barriers to adoption.[287] A price signal alone would be unlikely to fully capture these mitigation benefits.[288]

Energy efficiency improvements in buildings can be highly adaptive. Improved insulation in private residences, for example, shields residents from dangerous impacts of supply disruption by slowing indoor temperature changes during severe temperatures. Because building energy efficiency relies on existing technology, it can be implemented quickly once policymakers adopt appropriate legal mandates and incentives. Moreover, many efficiency measures reduce regulatory complexity and uncertainty. Although efficiency regulations require initial oversight, once measures are built into a building's structure they do not generally require ongoing oversight from agencies.

While energy efficiency encompasses a broad range of technologies, many of these also will increase resilience to climate change impacts. In general, efficiency measures reduce

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[286] Substantial potential to reduce emissions from improvements in energy efficiency are indicated by a National Academy of Engineering Study that finds that other industrialized countries have far lower energy intensity levels. *See* Lester B. Lave, *The Potential of Energy Efficiency: An Overview*, 39 THEBRIDGE 2 (2009), *available at* http://www.nae.edu/Publications/Bridge/EnergyEfficiency 14874/ThePotentialofEnergyEfficiencyAnOverview.aspx.

[287] *See* Trisolini, *supra* note 16, at 698–701 ("[E]ven with adequate information, improper incentives may act as a barrier. Landlords have little financial incentive to pay for energy efficiency when tenants realize the benefits through reduced energy bills. Similarly, developers have little motivation to pay for efficiency features that will reduce costs for future owners unless they are certain that the added cost can be more than recouped. Homeowners also may be deterred from investing in more expensive retrofitting if it exceeds their anticipated duration of ownership—on average seven to ten years. Nonetheless, most homeowners fail to invest in simple measures with quick payback periods, likely stemming from inadequate information combined with a general bias against up-front costs. Other barriers arise from inadequate institutional development. Within the building industry, a lack of trained professionals and the fragmentation of the design and construction process into many professions, trades, work stages, and industries render the necessary collaboration to construct green buildings difficult. Within both the industry and governmental agencies that regulate construction, inertia and familiarity with established practices also likely impede adoption of new approaches.").

[288] *See* Carlson, *supra* note 80, at 227.

reliance on electrical transmission and fuel distribution that are likely to experience increased disruption due to climate change impacts. Moreover, efficiency measures avoid the need for increased production that often relies on flammable, explosive, or toxic materials.

2. Cooling Urban Infrastructure

Reducing urban heat islands by employing reflective materials and shade trees provides another holistic strategy. Urban areas experience a heat island effect—with air temperatures averaging from 1.8 to 5.4 degrees Fahrenheit warmer than the surrounding countryside—due to dark colored roofs, dark pavement, and other materials that absorb heat.[289] Materials and methods already exist for dramatically reducing the heat island effect, including such simple measures as painting dark roofs lighter colors, building with more reflective paving and roofing materials, and adding shade trees.[290] Cool materials have enormous (and untapped) mitigation potential because they counteract global warming in two ways: by reducing demand for air conditioning in buildings and cars and directly cooling the planet by reflecting solar radiation. Scientists at Lawrence Berkeley National Laboratory (LBL) estimate that a global effort to increase the reflectivity of roofs and pavement could counteract the warming effect of 44 gigatons of carbon dioxide equivalent emissions.[291] To give some perspective on the enormous impact such a cooling effect could have, consider that total global emissions of GHGs totaled fifty gigatons in 2012.[292] Importantly, domestic-only urban cooling efforts offer significant mitigation. For example, LBL scientists concluded that retrofitting 80 percent of the roofs on commercial buildings in the United States would yield annual carbon dioxide savings equating to emissions from 25.4

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[289] U.S. ENVTL. PROT. AGENCY, REDUCING URBAN HEAT ISLANDS: A COMPENDIUM OF STRATEGIES, Ch. 1, 1 (2008) [hereinafter HEAT ISLANDS]. *See also* Kenneth Chang, *Scientists Watch Cities Make Their Own Weather*, N.Y. TIMES, Aug. 15, 2000, *available at* http://www.nytimes.com/2000/08/15/science/scientists-watch-cities-make-their-own-weather.html.

[290] HEAT ISLANDS, *supra* note 289, at 1.

[291] Hashem Akbari et al., *Global Cooling: Increasing Worldwide Urban Albedos to Offset CO_2*, 94 CLIMATIC CHANGE 275, 278–80 (2009).

[292] *Emissions Gap Report,* UN ENV'T PROGRAMME (Nov. 2012), ES-1, http://www.unep.org/publications/ebooks/emissionsgap2012/.

peak power plants (and offsetting the annual sulfur dioxide emissions of 815 facilities).[293]

Cooling communities also provide particularly adaptive health benefits by reducing health threats from heat waves and warming-induced air pollution. Because heat catalyzes ozone formation, global warming exacerbates urban air pollution.[294] As one researcher explains: "[f]or many North American cities . . . persistent air quality issues may prove to be the most tangible—and threatening—symptom of a warming world."[295]

Cooler cities also will help reduce the serious, but widely underappreciated health threats from increasingly frequent and intense heat waves.[296] A model developed by DOE and LBL scientists showed a potential to reduce summer temperatures in Los Angeles up to 3 degrees Celsius simply by increasing the reflectivity of roofing and paving materials and increasing tree canopy cover.[297]

Finally, these measures also prove administratively adaptive because urban cooling measures offer an off-the-rack mitigation strategy. Because cooling methods for roofing and paving require only that builders change the materials used in existing home-building and road-building processes, they are relatively simple. Moreover, given that the materials will be incorporated into the built environment, they will require little ongoing oversight.

As of yet, the law has been minimally used to mandate or incentivize this strategy.[298] When the full benefits of this

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[293] Ronnen Levinson & Hashem Akbari, *Potential Benefit of Cool Roofs on Commercial Buildings: Conserving Energy, Saving Money, and Reducing Emission of Greenhouse Gas and Air Pollutants*, 3 ENERGY EFFICIENCY 53, 78 (2010).

[294] Brian Stone Jr., *Urban Heat and Air Pollution: An Emerging Role for Planners in the Climate Change Debate*, 71 J. AM. PLANNING ASS'N 13, 13 (2005).

[295] *Id.*

[296] *See* Ann Carlson, *Heat Waves, Global Warming, and Mitigation*, 26 UCLA J. ENVTL. L. & POL'Y 169, 186 (2008) ("Despite the fact that heat waves kill more people annually, on average, than any other natural disaster, they receive little public attention relative to their more dramatic counterparts like hurricanes and earthquakes.").

[297] Stone, *supra* note 294, at 21.

[298] *See Green Building Programs*, COOL ROOF RATING COUNCIL, http://coolroofs.org/documents/Cool_Roof_Ratings_Codes_and_Programs021710.pdf (last visited Oct. 30, 2013). Only eleven states have code provisions that address cool roofs and some of these have limited scope, applying only to new commercial buildings or state-funded projects. Ten states have some loan provisions for cool roofs. *See Rebates and Codes*, COOL ROOF RATING COUNCIL, http://coolroofs.org/

strategy are considered, it should be an institutional development and funding priority.

3. Distributed Renewables and Microgrids

While supply centralization arose organically as long-distance transmission became available,[299] United States energy policy has evolved to further concentrate power supplies.[300] Under existing energy law, future demand will largely continue on this model, emphasizing large-scale electricity generation.[301] However, as described above, centralization and excessive reliance on large-scale facilities creates vulnerabilities that climate change exacerbates. In contrast, decentralized, small-scale electricity generation ("distributed power") offers both mitigation and adaptation benefits.

Dramatically expanding distributed renewable power offers substantial potential to mitigate climate change while also increasing the energy system's resilience. Small-scale power generation—such as rooftop solar panels—can be quickly deployed and, if widely adopted, can displace large amounts of fossil fuel.[302] Because these sources are closer to end users, they do not rely on long transmission lines that may be downed in extreme weather events. Hence, end users' vulnerability to power outages is substantially reduced or eliminated.

This approach can be extended beyond single individual or business projects that use power on site (or in some jurisdictions, feed it back into the grid). Sara Bronin argues that renewable energy law should be substantially revised to support "small-scale, low voltage distributed generation" that she refers to as "microgrids."[303] These would allow neighborhood-scale generation, reducing the need for long distance transmission lines and large centralized energy production.[304]

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resources/rebates-and-codes (last visited Dec. 12, 2013).

[299] *See* Garrick Pursley & Hannah Wiseman, *Local Energy*, 60 EMORY L.J. 877, 886 (2011); *see also* LOVINS & LOVINS, *supra* note 138, at 34.

[300] LOVINS & LOVINS, *supra* note 138, at 35.

[301] EIA 2013, *supra* note 167, at 72.

[302] *See* Pursley & Wiseman, *supra* note 299, at 900.

[303] Sara C. Bronin, *Curbing Energy Sprawl with Microgrids*, 43 CONN. L. REV. 547, 549 (2010).

[304] *See id.* at 579.

Because microgrids require far less infrastructure than large centralized facilities, they will be much more flexible if populations need to shift in response to climate impacts.[305] Large, centralized-power generation creates large sunk costs and hence are not readily modified.[306] Finally, Bronin notes that some microgrids can "incorporate plug-and-play technology [that] provide[s] greater flexibility for users, who can move equipment and modify systems as circumstances require."[307] Microgrid technology already exists. However, implementing microgrids requires changes to the legal system because "the biggest barrier . . . is contradictory, unclear, or hostile law."[308] States can adopt model codes to allow and support microgrids, a move that could be catalyzed by federal incentives or mandates.[309]

Developing law to support expanded use of distributed renewables and microgrids provides another straightforward step towards synthesizing the demands of adaptation and mitigation. These technologies avoid the sunk costs of centralized power and reduce systemic vulnerability. They also open up innumerable generation sites that could avoid the permitting and financing delays associated with large-scale renewable projects.

At the same time, distributed renewable and microgrids could require more governmental oversight than efficiency and community cooling strategies because government agencies need to ensure the safety of technology design, manufacturing, and installation. Nonetheless, because this approach is unlikely to involve large quantities of dangerous materials or rely on grid tying, it should be far less complex than large-scale, centralized facilities. Moreover, to the extent legal changes advance adoption, the lack of large sunk costs permits rapid experimentation that can more quickly produce high quality, standardized technology.

In sum, a number of options exist that synthesize adaptation and mitigation. Properly weighing the adaptive aspect of these measures in conjunction with their efficacy as mitigation measures should cause policymakers to prioritize

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[305] *See id.* at 562.
[306] *See id.*
[307] *Id.*
[308] *Id.* at 566.
[309] *Id.* at 575.

their adoption.

CONCLUSION

While this Article argues for a holistic approach that integrates mitigation and adaptation, this should not be read to downplay the critical importance of cutting emissions quickly and deeply. Debate over regime design should not be an excuse for doing nothing. This is so, because of the pressing need for emissions reductions and the simple fact that any form of mitigation aids adaptation by reducing future impacts. Indeed, the IPCC concludes that "[u]nmitigated climate change would, in the long term, be *likely* to exceed the capacity of the natural, managed, and human systems to adapt."[310] The depth and speed of emission reductions are critical because the longer mitigation is delayed, the more adaptation will be required. Delay and half measures allow emissions to build up in the atmosphere. Moreover, earlier reductions may be more important than later ones due to the impending saturation of natural carbon sinks (e.g., oceans and forests) and the potential for triggering feedback mechanisms that render warming irreversible.

However, we now know that the planet is committed to some degree of additional warming regardless of mitigation. Given this reality, we are tasked with finding ways to both mitigate and adapt to climate change. To effectively do both, we will need to harmonize these efforts to avoid working at cross-purposes.

While mitigation is complex, challenging, and politically daunting, at least its focus is relatively clear: reducing emissions and consequent atmospheric concentration of GHGs. Adaptation, in contrast, must be implemented "while the ground is literally and figuratively shifting under society's feet."[311] Thus, the goals shift as the adaptive process itself is being implemented. Incorporating what we do know about impending environmental changes into mitigation selection and consequent infrastructure development will help to ease the significant demands this shifting environment will place on future governments.

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[310] *See* IPCC SYNTHESIS REPORT, *supra* note 2, at 65.

[311] *See* Craig, *supra* note 116, at 29.

The analysis need not be binary, leading to recommendations to either surely adopt or definitely reject specific proposals. Rather, it may counsel for modifying mitigation proposals to make them more adaptive and for paying attention to governance demands of future proposals. Recognizing the maladaptive aspects of large-scale nuclear power, for example, does not necessarily counsel for entirely rejecting it as an option. However, it does counsel for a very different legal framework and shows that it should be a much lower priority than combined approaches. A holistic approach requires that policymakers prioritize the most adaptive options, recognize potential administrative burdens, and avoid creating legal structures that impede agencies' ability to respond to changing circumstances.

The examples I consider are likely at two ends of a spectrum. Nuclear power plants are large and centralized, with the risks that attend such enterprises (plus a few that are unique to nuclear power). They also can produce significant power from one plant. In contrast, building energy efficiency, cooling communities, and distributed power are dispersed and their climate benefits are cumulative. They do not have the safety risks associated with nuclear power and have several adaptation benefits.

Other strategies fall somewhere between these options. For example, large-scale solar production would likely have far fewer safety concerns or waste disposal complexities than nuclear power, but large-scale solar production implicates transmission and grid-tying issues as well as potential power failures. A synthesized analysis that combines adaptation and mitigation inquiries will provide the best information for weighing these options.

Creating holistic climate change governance in the United States will facilitate future adaptation for the population and governmental institutions. This Article provides a step in that direction.