*Getting the politics of a messy situation right may make it easier to get the science right, too.*

# Decision Strategies for Addressing Complex, "Messy" Problems

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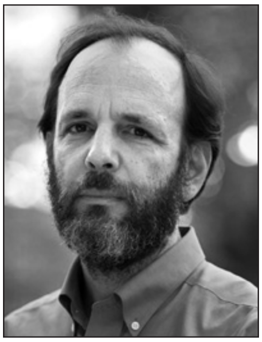

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More than a half-century ago, two social scientists, James D. Thompson and Arthur Tuden, advanced what has come to be called the "contingency theory" of decision making (Thompson and Tuden, 1959). They argued that there is a connection between two properties of problems—the degree of uncertainty and the extent of disagreement over trade-offs among important values—and the strategies appropriate for addressing those particular challenges. Although Thompson and Tuden developed a set of hypotheses about how different types of problems are solved, their theory is fundamentally normative: depending on the attributes of the problem at hand, some strategies are suitable for solving it and others are not.

One class of problems, termed messy, wicked, or ill-structured, is characterized by (1) a high degree of uncertainty about how options are linked to outcomes and (2) substantial controversy over trade-offs among values. Examples of messy problems include preventing the spread of nuclear weapons, regulating the production and use of chemicals, and reforming health

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[1] Affiliation is presented for identification purposes only. The views expressed in this paper are those of the authors and do not represent the views of the Nuclear Waste Technical Review Board.

care. Addressing such problems often requires a mix of scientific research and engineering practice, which, by necessity, must be undertaken in a context of political disagreement.

In this article, we begin with a brief discussion of the Thompson-Tuden contingency theory and a description of decision strategies for addressing well-structured problems. We then examine specific strategies that are appropriate, according to the theory, for tackling messy problems. We conclude by offering some general observations about disentangling messy challenges.

## Decision Strategies for Addressing Well-Structured Problems

*Programmed Decision Making*

If the level of uncertainty inherent in a problem is low and there is a strong consensus on values, decisions can be computed, sometimes even programmed. In such cases, choices follow directly from pre-established rules. Familiar forms of this decision-making strategy include cost-benefit analyses and optimization methods, such as the methods used in operations research. Among the problems amenable to this strategy are determining a firm's tax liability or an individual's eligibility for welfare payments.

Although programmed decision making is always vulnerable to the criticism that it does not make allowances for exceptional or ambiguous cases or account for how (and by whom) costs and benefits are determined, this strategy is often sought by decision makers because it places great emphasis on efficiency.

*Bargaining*

If uncertainty is low but there are disagreements about trade-offs, bargaining is the appropriate decision-making strategy. Bargaining can be effective in such cases because the understanding about connections between options and outcomes is sufficient for decision makers to appreciate how different alternatives affect salient values.

Common examples of this strategy include logrolling by legislators, compromises in negotiations, and sensitivity testing in multi-attribute utility analyses. This strategy is also used in the writing of regulations, in deliberations on appropriations bills, and in adjusting Social Security payments to reflect inflation. Because value trade-offs are inherently subjective, the stability of a bargain is, perhaps, the best measure of its success.

*Incremental, Adaptive, Stepwise, or Trial-and-Error Strategies*

An incremental strategy, otherwise known as adaptive, stepwise, or trial-and-error decision making, is fitting for addressing problems characterized by substantial uncertainty and by a general consensus on values. Incremental strategies rely on a "cybernetic" feedback model (Steinbruner, 1974). A decision is made, and its impacts are closely monitored. When deviations from the desired (and agreed to) outcome are discovered, adjustments (typically "small") are made. This process is repeated until the desired outcome is reached. Of course, irreversible outcomes at any stage doom this strategy.

The effectiveness of an incremental approach depends on how well problem solvers can detect when actual outcomes deviate from the desired outcomes and how well they can find ways of making mid-course corrections. Consequently, the behavior of the problem solvers and their organizations is more important in this strategy than in programmed decision making or bargaining.

*Messy problems are characterized by an incomplete understanding of how options are linked to outcomes and by conflicts over values.*

## Addressing Poorly Structured Problems

Messy, or poorly structured, problems are characterized by a very incomplete understanding of how options are linked to outcomes and by intense conflicts over values. In these situations, people are likely to disagree not only on what actions to take but also on what the results of those actions are likely to be and what constitutes progress.

These complex challenges are usually closely connected with other issues; are constrained by politics, economics, and ideology; have significant gaps in both information and understanding; and are resistant to change, even when evidence has shown that the status quo is untenable. In addition, the views of key actors about uncertainty and value trade-offs tend to be mutually exacerbating, that is, substantial uncertainty promotes conflicts over ends, and such conflicts, in turn, heighten awareness of the many sources of uncertainty.

*Some Proposed Approaches for Dealing with Messy Problems*

According to Thompson and Tuden, "inspiration" is the appropriate "strategy" for addressing demanding situations like the ones just described. They also acknowledge, however, that its success may depend largely on the emergence of a charismatic leader. In fact, almost as soon as they advance the strategy, Thompson and Tuden question its efficacy. "The most likely action in this situation, we suspect, is the *decision not to face the issue* . . . . If forced to choose, however, an organization is likely to dissolve—unless an innovation can be introduced" (Thompson and Tuden, 1959, p. 202; emphasis added).

*A transformation in the way a problem is conceived may be a prerequisite for solving it.*

In other words, if the political situation *requires* action, decision makers may reach a consensus about a mutually tolerable intervention but they are unlikely to "solve" the problem. Instead, the intervention will probably defer a solution or, at best, keep the problem from becoming intolerable. This phenomenon is known colloquially as "kicking the can down the road." Over the years, we have seen such outcomes for Social Security reform, immigration policy, resolving ethnic conflicts, and other complex issues.

Other scholars have argued that messy problems can be addressed using "heuristic decision making" (Gigerenzer and Gaissmaier, 2011) or creating an "organized anarchy," while adopting a "garbage-can" approach wherein solutions go looking for problems (Cohen et al., 1972).

As should be evident just from the terminology, these "strategies" are unlikely to offer policymakers much practical guidance, especially when dealing with large-scale messy problems. In our opinion, such strategies are poorly defined and difficult to implement, a weakness of more than academic interest. Our interest here is in describing a more practical and potentially formal way of approaching messy, complex problems.

*Transformation as a Strategy*

In many cases, and perhaps increasingly often, addressing messy problems cannot wait until divine guidance or political expediency saves the day. Nor can such problems be deferred indefinitely in the hope of fortuitously avoiding unacceptable consequences. Based on the cases we discuss below, problem solvers seem to have discovered, *at least implicitly*, approaches that offer some hope of success in tackling messy problems.

The essence of these approaches is the transformation of ill-structured challenges into well-structured ones. Such transformations, whether they are brought about by political or technical means, are always provisional and are generally contested, often vigorously, and whether a transformation can be made to endure remains an open question. Nevertheless, it seems that a durable transformation in the way a problem is conceived may be a prerequisite for solving it.

To illustrate this conclusion, we consider two archetypically messy problems, the management of high-activity radioactive waste and efforts to deal with global climate change.

**Managing High-Activity Radioactive Waste**

A strong consensus prevails in the international scientific community that the preferred method for ensuring the isolation and containment of high-activity radioactive waste is to dispose of it in a deep-mined geologic repository. Since the mid-1970s, more than a dozen countries have attempted (in some cases many times) to site such a facility, but only three of those efforts have culminated in the identification of a potentially suitable location and are still on track. The most important uncertainty related to siting is projecting repository behavior and performance for long periods of time, in some cases as long as a million years.

Depending on the nation, a variety of key values may be involved, such as how the development of a repository might affect the future production of nuclear-generated electricity, how the risk will be distributed between the host community and the rest of the country, and how questions associated with intergenerational equity will be answered.

We first examine how Sweden has addressed questions of uncertainty and value trade-offs. We then turn our attention to the experience in the United States.

*Sweden*

In the early 1970s, more than 50 percent of the energy used in Sweden was supplied by nuclear power. Thus, on a per capita basis, Sweden had made one of the largest commitments to nuclear power. By the mid-1970s, however, commercial nuclear power had emerged as a contentious political issue, with national parties staking out well-defined positions for and against.

The parliamentary election in 1976 brought into office a new coalition government that, at the beginning of the next year, passed the Nuclear Power Stipulation Act.[2] Among other things, the law mandated that, as a prerequisite for operations, the owners of power plants under construction *show how* and *where* the high-activity waste could be disposed of with *absolute safety* (see Sundqvist, 2002).[3]

Even after the passage of the Stipulation Act, however, the national debate over the future of commercial nuclear power continued unabated. In 1979, after the partial meltdown of the Three Mile Island reactor in the United States, all of Sweden's political parties endorsed an advisory referendum in which three policy options were put to the voters:

- The six reactors under construction or not yet operating would be allowed to start up, but nuclear power would be phased out "at a pace compatible with satisfying the need for electricity and maintaining employment and welfare" (Sundqvist, 2002, p. 94). No time limit was specified for the phaseout.
- Reactor start-ups would be permitted, but all reactors would have to be phased out within 25 years.
- The six reactors under construction or not yet operating would not be permitted to start up, and all operating reactors would have to be shut down within 10 years.

The first two options together received about 60 percent of the vote, the third slightly less than 40 percent. Interpreting the results of the referendum, Government decided that all plants could be started up but would have to be shut down by 2010. Notwithstanding the large minority that had supported an early shutdown of operating reactors and a moratorium on new ones, the referendum established a consensus on values that has persisted for more than three decades.[4]

The first test of the Stipulation Act was in December 1977, when an application was made to fuel the Ringhals 3 reactor located on Sweden's west coast. The Swedish Nuclear Fuel and Waste Management Company (SKB), which had been set up by reactor owners to develop a deep-mined geologic repository, engaged more than 450 scientists and engineers in a nine-month-long effort to demonstrate that its spent-fuel disposal concept would satisfy the requirements in the Stipulation Act.

*A national referendum in Sweden established a consensus about nuclear reactors that has persisted for more than three decades.*

This disposal concept, which was marginally modified over the next few years,[5] envisions the placement of high-activity waste in copper canisters. The canisters would be set in oversized boreholes drilled in the floor of the granite basement rocks that underlie most of Sweden. Bentonite clay would be used to fill the gaps between the canisters and the rock, and the repository itself would be sealed by backfilling the underground workings with bentonite.

Based on the laws of thermodynamics under the electrochemical conditions of the groundwater suffusing the

[2] Of the coalition's three parties, only one, the Centre Party of the new prime minister, Thorbjörn Fälldin, was committed to shutting down operating reactors, halting construction on new reactors, and shelving plans for future reactors. The coalition fell apart in October 1978, primarily because of disagreements about nuclear energy policy.

[3] In 1984, the Nuclear Power Stipulation Act was replaced by the Nuclear Activities Act. Instead of "absolute safety," the new law provided for the establishment of dose constraints and risk targets to be met for as long as $10^6$ years.

[4] Over that period, it became clear that there were few, if any, alternative sources for the production of baseload electricity. Two reactors, situated directly across the Öresund strait from Copenhagen, were shut down, but no action was taken with respect to the remaining ten plants. Then, recognizing that nuclear-generated electricity did not produce climate-changing gases, Parliament, by an overwhelming majority, lifted the ban on the construction of new nuclear reactors. After the vote, the leader of the Centre Party was quoted as saying, "I'm doing this for the sake of my children and grandchildren. I can live with the fact that nuclear power will be part of our electricity supply system in the foreseeable future" (*Guardian*, 2009).

[5] Among other things, the original concept anticipated the disposal of vitrified waste from the reprocessing of spent nuclear fuel. The concept finally adopted is based on the disposal of unprocessed spent nuclear fuel.

granite, the copper should not corrode. A natural analogue, elemental copper nodules in granitic formations that are tens of millions of years old, further increased confidence in the fundamental validity of the concept. And even if the containers did degrade, the bentonite clay would adsorb any radioisotopes that might migrate from them.

*The Swedish waste management company established a long-term presence in the selected communities and formed bonds of trust.*

In the late 1970s and again in 2000, this concept was rigorously peer-reviewed by both Swedish and international experts. Although questions have been raised recently about SKB's arguments with respect to copper corrosion, and other residual uncertainties persist, an international peer review just released by the Nuclear Energy Agency concluded that the concept was technically defensible (NEA, 2012).

In October 1978, the government coalition rejected the Ringhals 3 application under the Stipulation Act because SKB had failed to identify a *specific site* for the repository. However, the alliance left open the possibility that SKB could conduct supplemental geologic studies to demonstrate "that there exists a sufficiently large rock formation at the required depth and with qualities that the [SKB] safety analysis . . . gives as necessary prerequisites" (quoted in Sundqvist, 2002, p. 87). Any revised application would then be evaluated by the regulatory authority, then the Swedish Nuclear Power Inspectorate (SKI).

SKB immediately undertook additional investigations at two sites. Data from one of them, Sternö, on the southeast coast, were included in the amended application, which was submitted in February 1979. Notwithstanding a number of concerns raised by a technical advisory group empanelled by the regulators, the commissioners of SKI voted overwhelmingly a month later to approve SKB's request.

Although SKB had satisfied *in principle* the requirements of the Stipulation Act, thereby paving the way for the last six reactors to begin operation, selecting a suitable site *in practice* would take another 30 years. During that long process, the question of how to distribute risk between a host community and the rest of the nation—a key value trade-off—was gradually settled.

Shortly after the national referendum on nuclear power in 1980, a new nationwide search was initiated to find the best available geology for the final disposal of Sweden's nuclear waste. Test drillings conducted throughout the country, however, quickly gave rise to widespread local protests. By the end of the decade, SKB had reformulated its siting strategy, after recognizing that communities held a near-absolute veto over the development of a deep-mined geologic repository within their borders. In 1992, SKB sent a letter to all 286 Swedish municipalities, asking whether any of them would be interested in allowing "feasibility studies." The letter stressed that any expression of interest would be purely voluntary and could be withdrawn at any time. Although two municipalities in northern Sweden permitted studies to be conducted, both asked SKB to leave when local referenda revealed strong opposition by citizens.

SKB then turned its attention to municipalities located in or near four of the existing five nuclear communities and ultimately focused on two of them—Oskarshamn and Östhammar. The company established a long-term presence in both communities, interacting with residents in what appears to have been a sincere and respectful way and, by all indications, forming solid bonds of trust. In 2010, SKB formally chose Östhammar as the repository site largely on the basis of the soundness of the granite at that location. The overwhelming majority of the residents strongly support the development of the facility.

### *United States*

In the United States, the 1982 Nuclear Waste Policy Act (NWPA) ratified four critical value trade-offs:

- Two repositories would be developed—one presumably in the west and one presumably in the east—to promote geographic equity.
- The site for a deep-mined geologic repository for high-activity radioactive waste would be chosen by comparing the *technical suitability* of at least three potential locations.
- In exchange for payment of a fee, nuclear utilities could enter into contracts that would require the

government to begin disposing of their high-activity waste by a date certain.

- State governments could veto the selection of a repository site, but the veto could be overridden by Congress.

Within four years, the trade-offs (i.e., bargains) had begun to fall apart. By 2010, the state of Nevada, whose veto of the selection of the Yucca Mountain site had been overridden by Congress eight years earlier, exercised its growing political influence to stop the waste management program in its tracks and force its fundamental reconsideration.

The NWPA required that the president submit a site recommendation for the first repository by March 31, 1987, and for the second repository three years later.[6] It further required that the Nuclear Regulatory Commission (NRC) prohibit the emplacement of more than 70,000 metric tons of heavy metal in the first repository until the second had begun operation.[7]

Notwithstanding the provisions of the law, the Reagan administration announced in May 1986 that the search for a site for the second repository would be suspended indefinitely because it would not be needed.[8] A bipartisan group of 13 key members of Congress warned the Secretary of Energy that this decision "could destroy the delicate balance and might ultimately lead to an erosion of the NWPA" (quoted in Colglazier and Langum, 1988, p. 333). How prescient that warning turned out to be!

The administration's decision to suspend the second repository program reflected growing and intense opposition, especially in the east, to the prospect of hosting a repository. In light of this political turbulence, coupled with projected increases in the cost of characterizing (investigating) sites, leaders in Congress were prompted to rethink another critical value trade-off—the technically based comparison of candidate locations. By then, the U.S. Department of Energy (DOE) had winnowed the number of potential sites from nine to five to three: a place in Deaf Smith County, Texas; the Hanford Site in Washington state; and Yucca Mountain near the Nevada Nuclear Test Site. Although DOE had ranked Yucca Mountain as technically suitable, it is clear that Nevada's (then) political weakness in Congress had been a significant contributing factor to the passage in 1987 of the Nuclear Waste Policy Amendments Act (NWPAA), which, among other things, limited site characterization to Yucca Mountain and officially terminated the second repository program.

Even though the number of sites to be evaluated had decreased dramatically, DOE routinely failed to meet the milestones in the NWPA and the agency's mission plans. By 1995, DOE acknowledged what had long been apparent: it would not be able to begin accepting waste from utilities by January 31, 1998, the deadline specified in the contract between the federal government and the nuclear utilities. In protracted litigation since then, the courts have uniformly ruled that the federal government is liable for damages incurred because of its failure to meet its contractual obligations. Although many of the nearly 80 claims filed have been settled, the federal government appears to be answerable for damages of more than $20 billion, assuming, improbably, that it begins accepting waste by 2020, and for approximately $500 million each year thereafter (BRC, 2012).

*The steady erosion of critical value trade-offs helped destabilize the U.S. repository program.*

One of the compelling technical reasons for limiting site characterization to Yucca Mountain was that the site was believed to be "dry." Water is the primary vehicle for transporting waste to the environment, and it was believed that the volcanic rocks in the Yucca Mountain site would reliably isolate and contain the deposited material for millennia. However, investigations of geologic formations often encounter surprises that force substantial adjustments in understanding. In the end, Yucca Mountain proved not to be a "dry" site, thus calling into question a central premise of the disposal concept (Metlay, 2000). In response, DOE transformed a "geologic" repository into a repository that relied heavily on engineered barriers, specifically waste packages fabricated from an esoteric corrosion-resistant alloy and drip shields fabricated from titanium, to satisfy the long-term performance requirements.

[6] Section 114(a)(2)(A).

[7] Section 114(d).

[8] A year later, the Department of Energy determined that its suspension of the second repository program was illegal without action by Congress and prepared to restart the program. But by then it was too late as events had cascaded beyond control.

Once the original disposal concept had been destabilized by this new knowledge, other technical issues came to the fore. For example, how much water flows through the rock, and how fast does it flow? Might deliquescent salts corrode the waste packages through mechanisms that were not well understood (NWTRB, 2002, 2003)?

In 2008, convinced that these uncertainties had been resolved, DOE confidently submitted an application to the Nuclear Regulatory Commission for permission to construct the repository. In the course of the hearings that followed, the state of Nevada, which, as we will see below, had never faltered in its intense opposition to the repository, advanced nearly 300 technical and legal objections to the application. From the state's perspective, DOE's repository concept was not scientifically and technically defensible because significant uncertainties about the facility's long-term performance had not been adequately resolved.[9]

*Key technical issues concern deep uncertainties about the costs and benefits of actions to reduce climate change or minimize its effects.*

Nevada's opposition to the proposed Yucca Mountain repository is undoubtedly grounded in its view of the technical weaknesses in the disposal concept, but this view cannot be separated from the state's political opposition to the process that had led to the adoption of the NWPAA in the first place. (The law is referred to locally as the "screw Nevada" bill [e.g., Kishi, 2012].)

Politically weak in 1987, the state's political position in the Senate became stronger as Harry Reid rose in the Democratic leadership. In 2001, Reid came close to defeating the congressional override of the Nevada governor's veto of the selection of the Yucca Mountain site.

By 2006, Reid had become Senate majority leader and the most powerful political figure in Nevada. He leveraged his influence to come to an understanding with the three contenders in the Democratic Party's 2008 presidential primary that, if one of them were elected, he or she would terminate the Yucca Mountain project (Fialka, 2009). Not surprisingly, the Obama administration announced in January 2010 that it considered the project "unworkable" and that it would not support any additional appropriations for it. When DOE subsequently tried to withdraw its license application,[10] the last of the four bargains in the NWPA fell apart, despite the fact that the $13 billion spent on site characterization research had probably made Yucca Mountain the most carefully studied terrain on the planet.

### Managing Climate Change

It is no secret that the world has not managed to develop a political approach to climate change, much less to the reduction of greenhouse gas emissions. Despite the enormous amount of scientific effort that has gone into characterizing the problem and the tremendous diplomatic and political capital expended to implement climate change policy at the international and national level, little progress has been made. Recent analyses of this failure have focused on the role of "merchants of doubt" in creating perceptions of uncertainty that have undermined political efforts (Oreskes and Conway, 2010). However, if we look at climate change as a messy problem, these analyses are incomplete and cannot point to a way forward.

The main technical counter-claim to opponents of action on climate change (which include some well-credentialed scientists) is that there exists a strong mainstream-scientific consensus about the reality and potential seriousness of anthropogenic climate change. We are inclined to agree that such a consensus exists, but it has little bearing on our argument.

The key technical issues that must be resolved are not about the existence of climate change per se, but about deep uncertainties related to the costs and beneficial impacts of actions to reduce climate change or minimize

[9] In 2011, a document was issued by the regulatory staff that did not include final conclusions about DOE's compliance with the environmental standards applicable to a deep-mined geologic repository. The document did, however, support virtually all of DOE's technical claims (NRC, 2011).

[10] In 2010, DOE established the Blue Ribbon Commission on America's Nuclear Future, charged with proposing a new path forward for developing a repository (BRC, 2012). In the meantime, the Nuclear Regulatory Commission's hearings were suspended without resolving the overwhelming majority of the technical objections raised by the state of Nevada. The D.C. Court of Appeals is now trying to sort out whether it should order that hearings be resumed, given the limited amount of appropriated funds available to conduct them. It is very unclear what the future holds for the waste management program in the United States.

its effects. In particular, the answers to questions about how to transform a global economy that depends on fossil fuels as its main source of energy into a non-fossil-fuel-based economy are irreducibly uncertain. Not only does the world have no experience managing complex socio-technical systems to control a single output variable (in this case, carbon emissions), but the interaction of scientific, technological, economic, and political variables is so complicated that it is unlikely a persuasive case can be made that clearly identifiable short-term costs (and their distribution) will be outweighed by uncertain future benefits.

In the following discussion, we highlight two apparently distinct aspects of this messiness. The first relates to using science to justify policy strategies. Climate change policies, like policies for nuclear waste disposal in the United States, were developed in a way that virtually guaranteed strong political opposition characterized by lack of trust in political and scientific claims about the selected policy solution—be it burying waste at Yucca Mountain or signing onto a United Nations agreement about climate change.

In the case of Yucca Mountain, scientists tried to prove that the site was safe to people living in a state in which most citizens, for various reasons, were irrevocably opposed to hosting the repository. In the case of climate change, scientists and policy advocates have tried to show that the reality of climate change demands a global policy agenda centered on top-down, United Nations–sponsored international agreements; targets and timetables for emissions reductions; and the creation of carbon markets. But in the United States, at least, significant segments of the population (especially political conservatives) typically distrust international governance regimes in general and the United Nations in particular; they strongly oppose government programs that require major transfers of wealth or overtly intervene in markets; and they are profoundly skeptical of government's ability to modify social behavior to achieve desired aims.[11]

In both cases examined here, opposition to the chosen policy regime has often been expressed in terms of uncertainty about the underlying science, which supposedly legitimates the policy regime. But behind the apparent skepticism about science is deeper political opposition.

A second aspect of the messiness of climate change seems, at least on its face, to be less about climate change politics per se than about the politics of steering technological change. To illustrate this point, one need only consider the increasingly intractable debates over the siting of solar power facilities in the United States; the apparently unexpected acceleration of fracking technologies that have radically increased recoverable U.S. natural gas reserves; and the renewal of controversies about nuclear power in the aftermath of the Fukushima disaster. In these instances we see, for example, disagreements among environmental advocates about the value implications of technical change—such as protecting undeveloped lands versus using those lands as sites for large solar farms that will generate clean energy.

Other disagreements focus on technical uncertainties about the future performance, cost, and environmental benefits of clean energy technologies. For example, the potential importance of increasing energy efficiency to reduce emissions is hotly contested. Private-sector competition for dominance over emerging markets is also involved, as those with business interests in competing technologies try to make the case for their particular sector. So politics are involved here, too, but not based on broad ideological commitments. Instead, the controversies are focused on intricate uncertainties and competing interests and values inherently involved in choices about technological pathways.

*Taking seriously the political prerogatives of local municipalities can reinforce the credibility of scientific claims about safety and risk.*

In the case of nuclear waste, Sweden has shown that taking the political prerogatives of local municipalities seriously can reinforce the credibility of scientific claims about site safety and risk. In the case of climate change, no widely accepted alternative to the broken global climate policy regime has yet emerged. Neverthe-

[11] For similar reasons, we anticipate that efforts to directly regulate carbon dioxide emissions in the United States through enforcement of the Clean Air Act will be unsuccessful. Any regulatory regime that could have a significant effect on emissions would also mobilize enormous, competing political and economic forces and, at the same time, trigger endless technical debates about efficacy, cost-benefit ratios, and so on.

less, the messy-problem perspective in general and the nuclear waste experience in particular suggest that policy approaches sensitive to particular political contexts and particular aspects of the larger climate problem will move things along much faster than increasing scientific research and development (R&D) on the causes and consequences of global climate change or offering apparently comprehensive solutions that promise to address the "whole" problem.

*A pragmatic approach disaggregates climate change into less messy problems that are amenable to solutions that can attract a variety of constituencies.*

One obvious opportunity to reduce the messiness of climate change policy is to reframe climate-energy policies to focus on both the economic and environmental opportunities of clean energy technology innovation. The creation of a new government organization for energy R&D, ARPA-E (Advanced Research Projects Agency–Energy), is one example of what appears to be a political success along these lines. Modeled after the politically popular Defense Advanced Research Projects Agency of the U.S. Department of Defense, ARPA-E is officially part of DOE but was conceived and promoted as a largely autonomous organization that would focus on high-risk, high-reward energy technology ventures, in collaboration with the private sector and universities (Bonvillian and Van Atta, 2012).

The case for the new agency was primarily based on arguments about the need to improve U.S. economic competitiveness and innovation in the energy domain. In fact, the legislation that created the organization was passed by a Republican-majority House of Representatives and signed into law by President George W. Bush. Although ARPA-E is neither justified by, nor administered with regard to, direct impacts on climate change, if it is successful in catalyzing energy technology innovation, it will undoubtedly help to open up new clean energy pathways.

Another potent avenue for eliminating some of the messiness of climate change is to develop policies that increase the capacity of societies to adapt to variations in climate regardless of what causes them. Policies might, for example, promote innovation in agriculture, water management, and the built environment.

Hurricane Katrina and the tsunami and earthquake that led to the devastation of the Fukushima nuclear power plant showed that the failure of engineered systems during extreme events can leave tens of thousands of people in jeopardy, even in the most affluent societies. But both events also showed that the strongest argument for better hazard mitigation rests on protecting society from *existing* exposure to a variety of types of familiar *known* hazards, thus side-stepping debates about the uncertain consequences of future climate change impacts. Mitigating hazards by promoting better land-use planning, stronger and better-enforced building codes, better-funded infrastructure maintenance programs, and relevant R&D not only makes political sense (independent of climate change), but also promises the sorts of concrete, near- to medium-term—and thus politically attractive—social returns on investment that climate change policies have been unable to offer (Sarewitz and Pielke, 2000, 2005).

The principles for a pragmatic, messy-problem approach to climate change were well developed more than a decade ago (see Rayner and Malone, 1999) and have more recently been articulated in the context of the clear breakdown of the United Nations process (e.g., Prins et al., 2010). A key attribute of such approaches is that they do not depend on reducing uncertainty about the long-term costs of climate change or the long-term benefits of action. Rather, they disaggregate climate change into multiple less messy problems that are amenable to solutions that can be advanced for a variety of purposes and thus can attract a variety of constituencies. Appropriate policies would provide shorter-term benefits independent of the long-term effects on reducing climate change, for example by increasing economic competitiveness and energy independence, reducing pollution and its public health effects, and improving the resilience of communities and nations to environmental stressors ranging from hurricanes to droughts to food shortages.

Unfortunately, because of the political stalemate in the United States today, and the climate debate in particular, even a pragmatic approach to problem transformation may now be greeted by climate skeptics as a

Trojan Horse that continues to advance the old climate policy agenda. However, we also note that these same kinds of pragmatic approaches to climate change have in the past been opposed by advocates of the old agenda as sops to those who really wished to do nothing at all. The point is that both sides of the debate have bought into a view of climate change that belies its fundamental and inescapable messiness.

Progress will depend on (1) agreement that climate change is, in fact, many problems (some of which are very familiar and uncontroversial), and (2) the pursuit of smaller-scale consensus on values and actions that promote focused scientific and engineering solutions to local, regional, and national problems.

## Conclusion

In the mid-20th century a number of prominent social scientists recognized that conventional notions of scientific problem solving are of little help in understanding how societies and institutions cope with multifaceted problems that involve substantial uncertainties and contested values. Thompson and Tuden (1959) provided one formulation for thinking about the challenges of taking effective action in the face of such messiness. Other contributors to this tradition include Herbert Simon (1947), whose work focused on administrative behavior and bounded rationality; Charles Lindblom (1959), who realized that real-world problem solving is often best pursued by "muddling through"; and Harold Lasswell (1935), who developed the policy sciences for understanding complex, context-dependent policy problems.

We are particularly struck by the contrast between those works, which accept the messiness of many real-world problems, and the growing expectation in modern societies that natural science and engineering research will point the way toward solving them by reducing uncertainties about the future behavior of complex natural, social, and engineered systems.

We believe that this expectation will be continually confounded, and thus we have here sought to emphasize the importance of first transforming messy problems into well-structured problems by re-imagining the relationships between politics and science and technology. For example, the selection of the site for a nuclear waste repository in Sweden succeeded because it was based on the understanding that the political conditions that influenced the choice were as important as the scientific characterization of the site. Indeed, getting the politics right made it easier to get the science right. In the case of climate change, we have argued that the intractable uncertainties and disagreements that have undermined efforts to achieve a comprehensive policy can be evaded by disaggregating the messy climate problem into smaller, more familiar problems for which agreement on goals is possible.

Well-structured problems are stable because people can see—and potentially agree upon—near- or medium-term values to be pursued and can imagine capturing some of the benefits of pursuing them. However, stability cannot be reached for messy problems when (1) the problem itself, the possible routes to a solution, and the solutions themselves are subject to multiple, competing factual descriptions and value preferences, and (2) the uncertainties about the costs and consequences of actions remain high and highly contestable.

When problems are messy, scientific knowledge and technological options become unavoidably enmeshed in political disputes in ways that we have described (Metlay, 2000; Sarewitz, 2004). However, when problems are well structured and values are aligned with an understanding of what needs to be done, the role of science and engineering also comes into better focus. Knowledge and technology are no longer expected to resolve conflicting values and eliminate deep uncertainties, but are liberated to contribute directly to the pursuit of agreed-upon goals. Democratic politics and the scientific enterprise can both benefit from efforts to transform messy problems into well-structured ones.

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