Dædalus

Journal of the American Academy of Arts & Sciences

Winter 2013

The Alternative Energy Future, vol. 2




Inside front cover : Clockwise from top left : A group of men install solar panels, © moodboard/Getty Images ; a man uses a digital tablet to check energy levels in his home, © Monty Rakusen/Getty Images ; a man installs fiberglass insulation in a wall cavity, © iStockphoto .com/tinabelle ; a girl replaces an incandescent lightbulb with a compact fluorescent lightbulb, © Jeff Randall/Getty Images.

Dædalus is designed by Alvin Eisenman.

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The labyrinth designed by Daedalus for King Minos of Crete, on a silver tetradrachma from Cnossos, Crete, c. 350–300 B.C. (35 mm, Cabinet des Médailles, Bibliothèque Nationale, Paris). "Such was the work, so intricate the place, / That scarce the workman all its turns cou'd trace; / And Daedalus was puzzled how to find / The secret ways of what himself design'd." – Ovid, *Metamorphoses*, Book 8

Dædalus was founded in 1955 and established as a quarterly in 1958. The journal's namesake was renowned in ancient Greece as an inventor, scientist, and unriddler of riddles. Its emblem, a maze seen from above, symbolizes the aspiration of its founders to "lift each of us above his cell in the labyrinth of learning in order that he may see the entire structure as if from above, where each separate part loses its comfortable separateness."

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The Alternative Energy Future: The Scope of the Transition

Robert W. Fri

ROBERT W. FRI, a Fellow of the American Academy since 2010, is a Visiting Scholar and Senior Fellow Emeritus at Resources for the Future, where he previously served as President. He has also served as Director of the National Museum of Natural History and Deputy Administrator of both the Environmental Protection Agency and the Energy Research and Development Administration. He is Chair of the Academy's Alternative Energy Future project.

This issue of *Dædalus* expands a discussion that began in the journal's Spring 2012 issue. That earlier volume focused on the persistent stalemate in energy policy and on steps that might nonetheless be feasible to make progress in the relatively short term. This issue takes a longer and larger view.

Our discussion in the earlier volume began with the observation that since the time of the first OPEC oil embargo, every American president has promised to create a secure, clean, and affordable energy system. Unfortunately, every president has also come up short on his promise. The energy system is somewhat cleaner and considerably more efficient than it was in 1970, but it continues to rely heavily on fossil fuels – namely, oil, coal, and natural gas. The volume concluded that although some viable policies can usefully nudge the system away from fossil fuels, conditions do not now favor dramatic energy-policy initiatives. Developments since last spring affirm that stance and indeed seem to be providing a strong push in the opposite direction. In particular, America's vast reserves of oil and natural gas trapped in geologic shale formations are now accessible at highly competitive prices. Given this situation, it is hard to imagine that the next forty years will be much different than the last forty unless more powerful policy goals than secure, clean, and affordable energy come into play.

Actively pursuing the mitigation of global warming that results from the accumulation of carbon dioxide and other greenhouse gases can be that more compelling driving force, and in this issue, we examine the profound consequences of taking it seriously. Climate change can drive a fundamental transition in the energy system because limiting its effects means driving the emission of greenhouse gases nearly to zero over the span of a few decades. Doing so would require sharply limiting the use of fossil fuels on which more than 80 percent of today's energy system depends. And that, in turn, would set off a sweeping transition of one of the most extensive, technologically complex, and deeply embedded elements of the nation's physical infrastructure: the national energy system.

This is not news. Many careful analyses of how to manage climate change have documented the extent of the physical transition involved.[1] But the essays in this issue focus instead on an equally profound but less examined transition: that is, the far-reaching societal transition that must accompany transformation of the physical energy system. The energy system is not simply a collection of autonomous pieces of plug-and-play technology. Rather, it is an integral part of our individual lives, influencing where we live and shop, shaping how we establish social networks, and molding countless other everyday habits. Powerful industrial enterprises exist to produce, transport, and use energy; often these market incumbents wield considerable political influence. And large government bureaucracies at local, state, national, and supranational levels have evolved to monitor the system's operation and regulate its behavior. If the energy system itself changes, then all these individual and institutional links to it will have to change, too.

A useful way to gauge the magnitude of the task is to consider the budget for the quantity of greenhouse gases that can be safely emitted into the atmosphere. The budget analogy applies because carbon dioxide, the chief greenhouse gas, is very long lived; once it gets into the atmosphere, it stays there for decades, if not centuries. Several studies, including one in this volume, conclude that we have used up a good deal of the emissions budget already, and that to continue emissions at current rates would absorb the rest of it in a few decades – after which time the emission of greenhouse gases would have to be essentially zero.[2] Given the scale of the energy system, however, a few decades is not a very long time to overhaul it to the point where it emits essentially no greenhouse gases. To be sure, important scientific uncertainties exist about the pace at which temperatures would increase for any given concentration of greenhouse gases in the atmosphere. But it is difficult to come up with a high-probability scenario that does not exhaust the emissions budget by roughly 2050. For this reason, dealing with climate change means changing the energy system with a speed that has rarely been seen in the past.

The associated societal change turns out to be hard as well. The contributors to this volume discuss the role that public opinion, opposition to change by incumbent institutions, and scientific timidity all play in erecting barriers to forging a political consensus that responds appropriately to the climate challenge. The interplay of these forces is unusually complex and is likely to prove Churchill right: that America will do the right thing after it has exhausted all the alternatives. Unfortunately, we'll burn more of the carbon budget while we wait.

Once policy-makers agree to get on with it, however, they will have to deal with the dual challenge of changing the behavior of both individuals and institutions to enable change in the energy system. Persuading people to change their ways is a notoriously difficult matter, and for good reason. For example, despite compelling technical reasons to build nuclear power plants, fracture gas shale, erect windmills off Cape Cod, and spread solar panels across sacred tribal lands, there are equally good societal reasons not to do so. And even when the technology is unobtrusive, individuals have to learn to use it. Although that sounds simple enough, consider the fact that most programmable thermostats installed in homes across America are not currently programmed. The social sciences are beginning to contribute to our understanding of how to encourage individuals to accept and then adapt to a new energy system, but much remains to be done.

The institutional challenges are, if anything, more daunting. For example, the failure of the Copenhagen climate summit has demonstrated the difficulty – maybe even the impossibility – of striking a global bargain to manage greenhouse gas emissions. However, a network of less ambitious deals may suffice. The duration of the climate problem creates another institutional problem. Because the task spans several decades, climate policy has to be consistent yet flexible over that period. We have little experience in designing durable policy frameworks of this sort. Moreover, existing institutions will have to adapt to a new order. For example, climate policy will likely need to engage federal, state, and local governments in a less hierarchical way than exists today. Finally, but crucially, the energy system is closely connected to other natural systems that help sustain life on our planet, notably those involving food and water, but others as well. Maintaining the sustainability of these systems is thus a constraint on changing the energy system to meet the climate challenge.

The authors in this issue take on the individual and institutional challenges facing the societal transition that any overall energy transformation will require. We offer few definitive solutions because so many of these topics have received too little attention. And so this volume concludes by framing a social science research agenda that would demonstrate incremental progress on the climate problem in the near term while deepening our understanding of the fundamental institutional transition that must take place over the long term.

ENDNOTES

1 For example, see *America's Energy Future: Technology and Transformation* (Washington, D.C.: National Academies Press, 2009).

2 See also *Limiting the Magnitude of Future Climate Change* (Washington, D.C.: National Academies Press, 2010), which applies the budget concept to domestic U.S. emissions.

A Trillion Tons

Hal Harvey, Franklin M. Orr, Jr. & Clara Vondrich

Abstract: There is a consensus among scientists that stark dangers await in a world where the global mean temperature rises by more than about 2 degrees Celsius. That threshold corresponds to a collective human carbon emissions "budget" of around a trillion tons, of which half has been spent. This paper uses a new simulation model to look at strategies to stay within that budget, specifically assessing the impact of improvements in energy efficiency, aggressive deployment of renewables, and energy technology innovation. The simulations examine the timing of investments, turnover of capital stock, and the effect of learning on costs, among other factors. The results indicate that efficiency, renewables, and technology innovation are all required to keep humanity within the trillion-ton budget. Even so, these measures are not by themselves sufficient: changes in land use and a price on carbon emissions are also needed.

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*(*See endnotes for complete contributor biographies.)*

How much carbon can humans safely emit into the atmosphere? Climate scientists argue that a 2 degree Celsius (about 4 degree Fahrenheit) increase in global mean temperature is a threshold above which the probability of highly adverse consequences grows significantly. Such an increase would correspond to roughly a trillion tons of total human-caused carbon emissions over time.[1] If one trillion tons is humanity's carbon budget, how much have we used so far? How fast will we emit the remainder under current trends? And what can we do to make sure that we don't bust the budget?

To consider the relative contributions of different variables, ClimateWorks, a foundation that supports public policies that mitigate climate change, and its partners at Climate Interactive developed the system-dynamics computer model En-ROADS (Energy–Rapid Overview and Decision-Support simulator). En-ROADS is a global model that assesses how changes in energy supply and demand might affect emissions and, in turn, climate outcomes.[2] It is designed to rapidly assess the impact of various policy scenarios on cumulative emissions by manipulating variables as diverse as global GDP, energy efficiency, innovation, carbon price, and fuel mix.

The simulations underlying this essay emphasize the dynamics of the transition to clean energy. Changes in energy systems take time because energy production relies on large, expensive infrastructure that is slow to turn over. The oil economy, for example, entails a vast network for exploration, drilling, transport, refining, production, automobile manufacture, highway construction, and even human-settlement patterns. Each of these elements cost hundreds of billions of dollars and took decades to build. The same is true for coal production and use. To transform these systems will take decades.

The world has spent more than half of the trillion-ton carbon budget. Current trends suggest that, absent policy action, we will exhaust the remaining half by about 2050.[3] The reality of infrastructure "lock-in" and inertia in the global energy supply mix further underscores how vital it is to consider *cumulative* carbon emissions over time, rather than assessing them solely on an annual basis. For instance, Figure 1 compares a business-as-usual (BAU) trajectory with a scenario in which future emissions remain flat. The figure depicts both cumulative emissions and annual emissions.

In the BAU case, emissions increase annually and sail by the trillionth ton as early as about 2050. Conversely, one might expect that if emissions remain at current levels and do not rise, the duration before we exhaust the budget would increase significantly. Yet the flat-emissions scenario crosses the trillion-ton line just about a decade later! In other words, *even if all future demand growth from this point forward were met by zero-carbon sources, we would still grossly overshoot the budget*. This finding highlights the reality that it is not enough for us to ramp down emissions or keep them flat: we must bring them to very low levels over the next few decades.

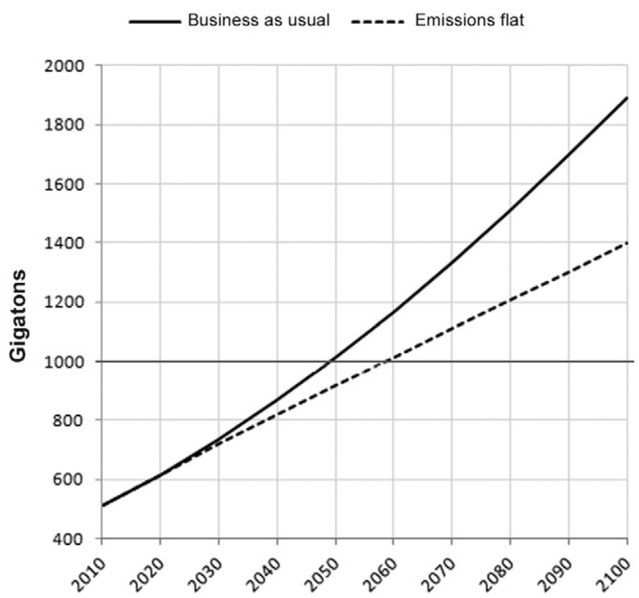
En-ROADS allows us to investigate different options for remaining below the trillionth ton and gives a sense of how long it will take for different actions, investments, and policies to reduce emissions. The model accounts for the system-wide interactions among different energy options. For example, how would the aggressive pursuit of energy efficiency affect the growth of renewable energy? How do technology learning curves change the suite of options? Underlying the model is an extensive study of factors such as construction delay times, progress ratios, price sensitivities, historic growth rates of specific energy resources, and energy-efficiency potential.

Note that En-ROADS is not a predictive model; its "results" – which, in this essay, are primarily a calculation of the year in which carbon emissions from a given test scenario cross the trillion-ton line – are approximations only, accompanied by a range of uncertainty. Instead, the model is a scenario-builder that tests assumptions about how prospective changes in the global energy supply mix might affect climate outcomes.[4]

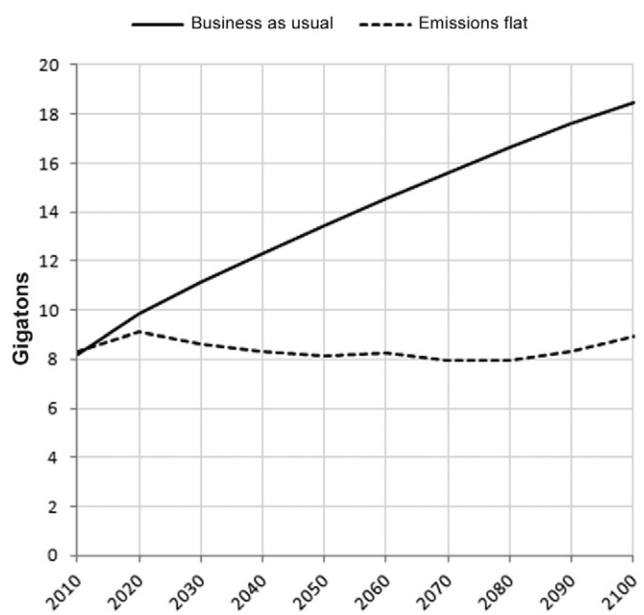
If we remain on a BAU trajectory, we will surpass the trillionth ton and the 2 degree Celsius benchmark – the threshold that scientists suggest is a dangerous one to cross – around the middle of this century. The good news is that emissions in many parts of the industrialized world have begun to flatten and even decline. The bad news is that surging carbon emissions in China, India, and other rapidly industrializing countries do not yet show signs of abating. By 2030, China's annual carbon emissions are projected to be around 5 billion tons, compared to around 2.8 billion in 2010. Left unchecked, and in light of prevailing growth rates, China's emissions alone could overwhelm the carbon budget by the end of the twenty-first century.

Figure 1
Two Carbon-Emissions Trajectories, 2010 – 2100

Cumulative Carbon Emissions



Annual Carbon Emissions



Source: All figures created by authors.

Locking in carbon-emitting infrastructure is among the more serious threats of a BAU world. Commercial and residential buildings have useful lives of several decades or more. Coal-fired power plants remain online for up to sixty years.[5] New oil and natural gas pipelines could operate for a half-century. Once these investments are made, the economic imperative is to use them. Any new zero-carbon energy source must contend with this embedded capital stock. After coal plants are built, their marginal costs of operation are relatively small, so the competitive bar for new technologies is high.

The current flood of urban migration in the developing world offers a useful case study of lock-in. China is experiencing the greatest urban population boom in human history. The United Nations estimates that Chinese cities will add 231 million people by 2025 and another 186 million by 2050[6] – numbers roughly equal to the populations of Indonesia and Brazil, respectively. To prepare for this growth, Chinese leaders plan to build at least one thousand new cities.

Well-designed cities can slash waste, reduce air and water pollution, and provide appealing spaces for people to work, shop, and socialize. Poorly designed cities sprawl across the landscape, locking in unsustainable patterns of energy use for decades. Without policy interventions, including tough building standards and regulations favoring compact development and low-carbon public transit, BAU development is likely to embed a high-consumption profile that will be virtually impossible to repair. Indeed, the International Energy Agency (IEA) has warned that without further action, by 2017 all CO_2 emissions permitted in its 450 Scenario – in which the atmospheric concentration of carbon dioxide equivalents (CO_2e) stabilizes at 450 parts per million (ppm), resulting in an average warming of 2 degrees Celsius – will be "locked in" by existing power plants, factories, buildings, and other long-lived infrastructure.[7] Today's infrastructure decisions are thus of crucial importance to long-term climate change. Society sets structural patterns for future emissions every time a highway, power plant, factory, or house is built. That capital stock lasts fifty to one hundred years or more – and every year, contributes carbon to the atmosphere. Furthermore, it is far more costly to repair or retrofit any of these investments than to get them right in the first place. The duration of those investments, in light of the unforgiving mathematics of carbon accumulation, means that the window for making business-as-usual choices is closing fast. The IEA's point is that doing this even for another half-decade locks in a future nobody wants to see.

However mundane it may seem, energy efficiency is a vital bridge to a low-carbon future. Efficiency improvements across the transportation, power, and industry sectors would slow or flatten the rise in energy demand in the coming decades, thereby making the climate problem more solvable. Aggressive pursuit of energy-efficiency solutions on the cutting edge of engineering, technology innovation, and thermodynamics would yield significant energy savings. Consider one example: If a coal plant is 33 percent efficient (the average in the United States), and an incandescent lightbulb is 5 percent efficient, then the *net conversion of energy to light* is about 1.65 percent. By contrast, a compact fluorescent lightbulb (CFL, roughly 25 percent efficient), powered by a combined-cycle natural gas turbine (about 60 percent efficient, using a lower-carbon fuel), converts 15 percent of the energy to light – almost a tenfold increase. The corresponding reduction in CO_2 emissions per hour of lighting is approximately 90 percent.

The next generation of light-emitting diode lamps (LEDs) will garner even greater energy savings.[8] Indeed, the Department of Energy estimates that replacing regular lightbulbs with LEDs could potentially save 190 terawatt-hours annually, the equivalent of lighting more than 95 million homes or roughly 5 percent of total U.S. electricity consumption in 2010.[9]

Similar opportunities exist in virtually every sector of the economy. Not surprisingly, a number of major studies have found that energy efficiency measures are a powerful tool for slashing emissions. According to a study from the National Academy of Sciences and the National Academy of Engineering, the technical abatement potential for energy efficiency in the United States is large; moreover, its cost would be low – or negative, as energy savings would outweigh the costs of new technologies over time.[10] The study found that U.S. energy use could fall below BAU projections by 17 to 20 percent in 2020, and by 25 to 31 percent in 2030, provided that "energy prices are high enough to motivate investment in energy efficiency, or if public policies are put in place that have the same effect."[11]

Globally, the prospects for energy efficiency are bright. A report published by McKinsey & Company suggests that, with reasonable investments in energy efficiency, the projected growth in global energy demand could be halved by 2020.[12] The necessary investments of roughly $170 billion annually would generate an average internal rate of return of 17 percent, with total energy savings estimated at $900 billion annually by 2020. The investment strategy would target only cost-effective opportunities, seeking efficiency improvements across systems such as lighting, cooling, and heating in particular, as well as vehicles and industrial machinery.

The authors of the report caution that their investment strategy would face a number of significant challenges. For instance, "two-thirds of the investment opportunity lies in developing countries, where consumers and businesses face a variety of competing demands for their scarce investment dollars." In many sectors, efficiency standards may have to be implemented to overcome market failures. Nevertheless, the global potential of energy efficiency to cut carbon at a low cost is tremendous.

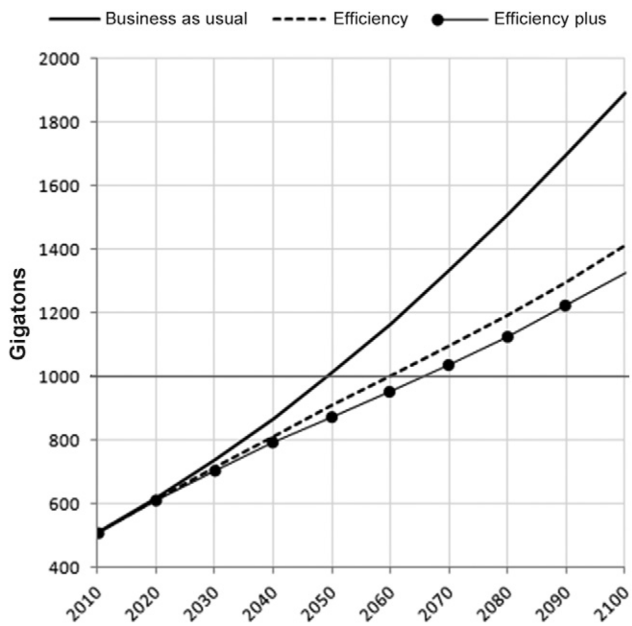
What does En-ROADS tell us about the effect of aggressively pursuing energy efficiency? With regard to the global economy, the model's BAU scenario assumes an average annual decrease in energy intensity (energy used per unit of GDP) of 1.1 percent from 2010 to 2050.[13] The globally aggregated En-ROADS model does not allow for a manipulation of efficiency improvements across individual sectors or regions. Instead, by varying the energy intensity of GDP, the model allows us to assess the impact of a highly efficient energy economy on the carbon budget.

Figure 2 compares two energy-efficiency scenarios with a BAU world: "efficiency" (EE) and "efficiency plus" (EE+). The EE scenario assumes an average annual improvement in energy intensity of roughly 2.5 percent between 2010 and 2050; EE+ assumes an average annual improvement of roughly 3 percent. Sustained 2 to 3 percent improvements are plausible given a BAU energy-intensity improvement rate of about 1.1 percent between 2010 and 2050; further, they are consistent with mitigation scenarios examined by other models.

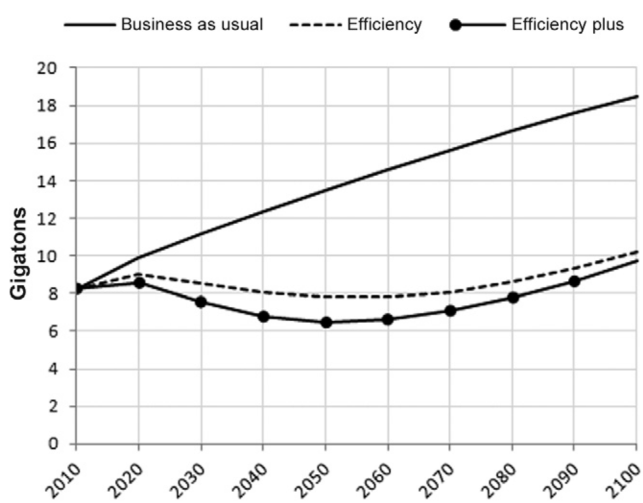
In both scenarios, cumulative carbon emissions still increase but do so more slowly relative to BAU. In the EE scenario, for example, annual emissions in 2050 are about 42 percent less than in the reference case. Although annual emissions bend downward in both test scenarios, they ultimately flatten and rise again. Why?

Figure 2
Efficiency Test Scenarios, 2010 – 2100

Cumulative Carbon Emissions



Annual Carbon Emissions



Efficiency measures provide large energy savings in the near term, but these gains are overwhelmed over time if population and GDP growth continue unabated.

The greatest reward in achieving either of the high-efficiency scenarios is that they cut the burden for new zero-carbon energy sources almost in half. Nevertheless, efficiency improvements alone are not enough to avoid exceeding the budget. The EE scenario reaches the trillionth ton in approximately 2060; EE+ crosses that line about five years later. While arguably modest, a ten- to fifteen-year grace period provides needed flexibility in the low-carbon transition and is especially significant because it can be attained at low cost.

How much can existing and near-term renewable energy sources, such as solar and wind, help? Renewable energy, excluding hydropower, is the fastest-growing source of electricity generation and is projected to account for up to a quarter of global electricity generation by 2035 (compared to less than 5 percent today).[14] The EIA predicts annual growth rates averaging 3.1 percent between now and 2035. By contrast, coal-fired electricity generation is expected to grow at an average rate of 1.9 percent per year over the same period.[15]

Recent growth rates are stunning: over the five-year period from 2005 through 2009, global renewable energy capacity grew at rates of 10 to 60 percent annually for many technologies.[16] While percentage increases of this magnitude cannot be expected to last as the base for renewables expands, the forward momentum is undeniable. In 2008, for the first time, more renewable energy than conventional power capacity was added in both the European Union and the United States.[17] In 2010, renewables represented half of all newly installed electric capacity worldwide.[18]

To further put these numbers in context, total global power-generating capacity in 2011 was estimated at 5,360 GW. By the end of 2011, total renewable power capacity worldwide exceeded 1,360 GW, up 8 percent over 2010. Renewables thus comprised more than 25 percent of total global power-generating capacity and supplied an estimated 20.3 percent of global electricity. Non-hydroelectric renewables exceeded 390 GW, a 24 percent capacity increase over 2010. Total installed capacity of non-hydroelectric renewables in 2010 was around 312 GW, just over 6 percent of the global total. Note that intermittent renewable energy resources are available only a fraction of the time, so nameplate capacity does not directly translate into energy. Energy production is equal to nameplate capacity multiplied by the capacity factor (the fraction of time plants or installations are in operation), which can vary from about 15 percent for solar photovoltaics in climates that do not receive much sunlight to up to 40 percent for offshore wind installations. Nevertheless, by 2035, renewables are expected to account for about a third of global installed capacity and to generate between 15 and 23 percent of the world's electricity.[19]

Some renewable energy technologies are close to commercially competitive, including wind. Solar photovoltaics (PV) are approaching the mark, while concentrated solar thermal power has some distance yet to go. Aggressive deployment of renewables can make a big difference relative to the carbon budget. Nevertheless, with the possible exception of onshore wind, these technologies still need to make substantial progress along the learning curve – dropping in price as their volume grows – to compete with incumbent fossil fuel sources.

Evolving technologies, including most renewable applications, have a high learning rate compared to mature technologies like coal.[20] Solar PV has traditionally exhibited an average learning rate of 20 percent, meaning that price drops by a fifth for every doubling of production.[21] If these rates persist, a few more doublings of production capacity could result in cost parity with fossil sources. Industry insiders suggest that solar PV is on track to be the cheapest energy source for many parts of the world by the end of the decade.[22] There are two caveats, however: solar learning curves may be flattening[23]; and the cost of solar cells is only half of the equation. The enclosure, glass cover, mounting racks, junction boxes, and wiring – together called the *balance of system* – are now about half the cost of solar electricity, and their price decline may be slower.[24]

Nevertheless, both wind and solar prices continue to decline. The solar industry has achieved manufacturing economies of scale, and more efficient cells are being developed. The cost of wind energy is already close to competitive with new gas and coal. According to REN21's 2011 *Global Status Report,* the cost per kilowatt-hour for onshore wind ranges from 5¢ to 9¢, for an average of 7¢/kWh.[25]

To examine the effect that an accelerated deployment of renewable technologies could have on the carbon budget, we modeled the following two scenarios:

- Renewables (REN). The cost of energy from new renewables was assumed to be 60 percent below its 2012 price, beginning in the same year. Such a dramatic decrease in price might come from an imagined technological breakthrough in R&D.[26]

- Renewables Plus (REN+). A 70 percent drop in cost was assumed beginning in 2012. We also added a 2 percent per year reduction in the barriers to electrifying the transport sector.[27]

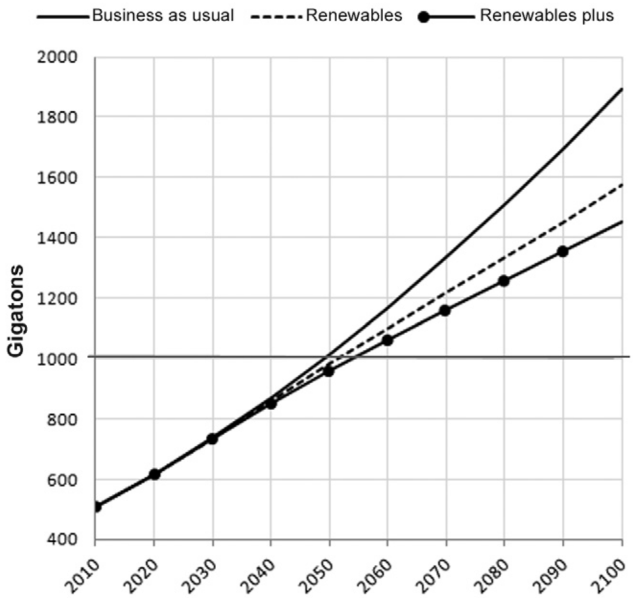
Figure 3 compares emissions in these test cases to BAU, revealing a substantial divergence – at least in annual emissions. In 2050, annual REN emissions are 20 percent below BAU emissions; REN+ emissions are 31 percent lower. The difference is less striking in the cumulative emissions view, where REN+ crosses the trillionth ton less than a decade after BAU.

This delay is slight because the displacement of fossil fuels by renewables is minimal in the near decades. Scaling renewable technologies to meet global energy needs remains a challenge even when prices become competitive. When renewables enter the market at or below the price of new coal (as they do in both test cases), demand for coal declines only marginally – a result of the embedded infrastructure of fossil-fuel generating sources. Turning over the capital stock of coal plants takes time. Moreover, cost is not the only factor determining penetration rates of a young technology. Scalability and regional differences in wind and solar resources, as well as intermittency and the corresponding firming requirements,[28] also play a role.

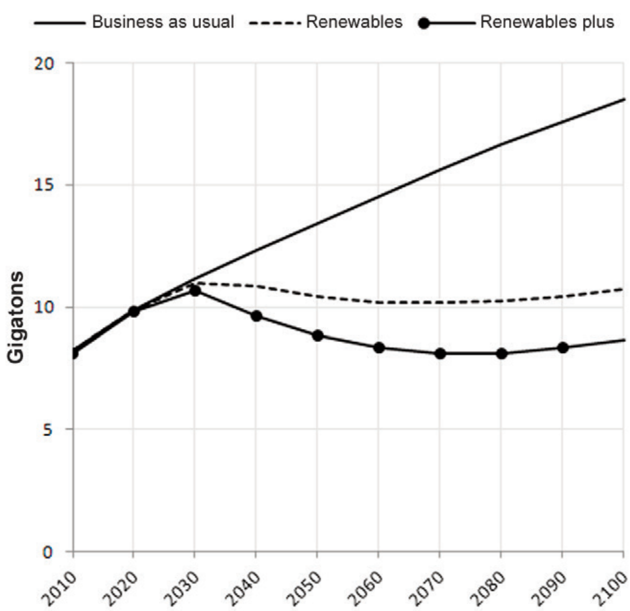
What other technology breakthroughs might play a significant role in the energy transition ahead? Carbon capture and storage (CCS) figures prominently in many mitigation scenarios as virtually a *sine qua non* of remaining on a 450 ppm pathway. However, progress has been slow in building the large-scale and capital-intensive demonstration projects needed to test the viability of the technology over its life cycle: that is, from combustion of the fossil fuel to the capture and storage of related emissions. In its 2012 report to the Clean Energy Ministerial, the IEA notes that we can expect to see about ten CCS plants operating by the middle of this decade. But we will need about 110 more by 2020, the agency argues, in order

Figure 3
Renewable Energy Scenarios, 2010 – 2100

Cumulative Carbon Emissions



Annual Carbon Emissions



to keep global temperature rise below 2 degrees Celsius.[29]

Public financing for CCS peaked in 2008 and 2009, when the technology received a boost as part of broader economic stimulus programs.[30] Nevertheless, much of the promised funding remains unallocated. As of 2012, only 60 percent of the approximately $21.4 billion available to support large-scale demonstration projects had been assigned to specific ventures.[31] Ongoing upheaval in the global market will undoubtedly continue to squeeze CCS budgets. Moreover, CCS is likely to remain underfunded in the absence of strong and reliable policy signals, such as a price on carbon.

CCS provides just one example of the potential challenges facing any new breakthrough technology. Our decades-long experience with solar PV further confirms that, even after invention and initial deployment, a technology often needs additional help to progress along its learning curve. Despite being commercialized in the 1970s, and notwithstanding its recent and striking price reductions, solar PV has yet to achieve global penetration rates of 1 percent. Certainly, a few more doublings of production capacity and concomitant price reductions could revolutionize the outlook for solar, but the sheer scale of the transition means that this will take time.

Our discussion is by no means a condemnation of renewables and other new energy-supply innovations. The above examples merely underscore the intense pressure that innovations face as they try to gain a foothold in the market. In the case of renewables, this challenge is largely attributable to the fact that cheap fossil fuels are an entrenched and ubiquitous part of our energy economy. Further complicating matters is the uneven playing field that results from the failure to price externalities associated with fossil fuels, including impacts on air quality, human health, and national security, among many other factors. Additionally, renewables are likely to have higher capital costs (but lower operating costs) than conventional resources, which cost less up front but require lifetime fuel purchase. Higher capital costs can limit financing for renewables. Financing also comprises the biggest fraction of the levelized cost of renewable energy, further undercutting competiveness with established fossil sources. Any other new zero-carbon technology will likely face similar hurdles.

But let us adopt a techno-optimist's view and assume that a new energy game-changer arrives on the scene. This path-breaking technology circumvents the problems noted above because innovations have resulted in an energy source so cheap that the new technology enters the market at half the price of coal. It is deployable at scale and available for mass penetration around the globe. What is the impact of this game-changer on the carbon budget?

Specifically, we defined our New Technology (NT) scenario by the following assumptions:

- R&D efforts produce a zero-carbon prototype in 2020;
- Global deployment takes twelve years; and
- The technology enters the market at half the price of new coal.

The NT case assumes that a new zero-carbon energy source, not yet conceived, achieves mass global penetration slightly more than twenty years from now. This ambitious scenario exceeds by a wide margin the commercialization trajectories of any large-scale energy technology existing today. For instance, in the renewables sector, wind power has only recently achieved significant rates of penetration in some countries (Denmark, Spain, and Germany) where it has received heavy public support – more than a half-century after the first grid-connected wind turbine was manufactured in 1951. Nevertheless, startling innovations are possible.

The NT scenario circumvents the most obvious hurdle to competitiveness – namely, cost – by stipulating that the new zero-carbon energy source enters the market at half the price of coal. While this strains credulity, it could be possible if a carbon price were imposed or if deployment of the new technology were declared a national or international priority. Again, our intent was to test assumptions at the outer bounds of technical or political feasibility to gauge the impact on the carbon budget. We found that the carbon emissions accumulated to date renders the budget relatively insensitive to even very aggressive assumptions on an energy game-changer.

Figure 4 shows that annual NT emissions are 11 percent below BAU emissions in 2050, but crossing the trillionth ton is delayed by less than a year (though the test case diverges more substantially from BAU as time passes beyond the trillionth ton). At first glance, the meager benefits of the NT scenario are hard to understand. The assumptions are so radical that one would expect the needle to move much more sharply. In the long run, if a new technology is cheaper, we would expect it to take over, partly because of the learning curve dynamics, which amplify any initial cost advantage (cheaper equals more sales, which leads to more learning and continued price reductions). However, this cycle is tempered by capital turnover; even if the new technology is dominant as a share of investment in new capacity, replacing existing capital and achieving dominance overall takes a long time.

For En-ROADS simulations, the fractional investment in various types of energy supply over the course of each time period is determined by the relative attractiveness of each supply type. Relative attractiveness is a function of the cost of each technology, which in turn is influenced by learning, cost of nonrenewable resources, suitability of remaining sites for renewable energy installations, and capacity for construction of new supply.[32] As a result of this structure, market shares of a new technology may not correspond in the short term with what one might expect on the basis of cost alone.

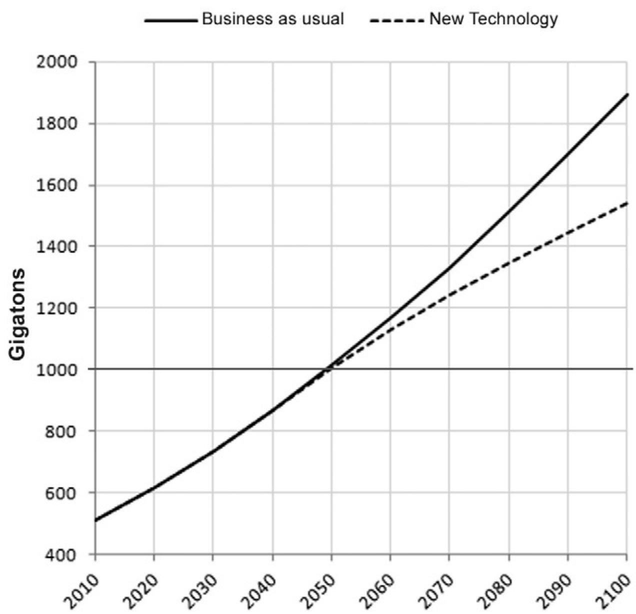
These assumptions about the energy system imply that coal, oil, and gas will continue to be burned for energy throughout the century. Even in scenarios where renewable energy or new technologies grow significantly, drop in price, and dominate the market, fossil fuel energy continues to be inexpensive (recall that there is no price on carbon) and sufficiently available to attract investment and use. Although reliance on fossil fuels is much less than in the BAU scenario, it is still enough to prolong the increase of cumulative emissions.

The En-ROADS simulations discussed in this essay indicate the value of a diversified portfolio of emissions-reducing tools. No one tool suffices. Efficiency alone, while curtailing demand, cannot stand in for a low-carbon energy source. Renewables are not powerful enough to displace coal in the near term; we need sustained investments and efficiency measures to give them time to descend the learning curve. A new technology breakthrough, though a crucial long-term solution for global energy needs, requires several decades before it can achieve sufficient market penetration to make a difference.

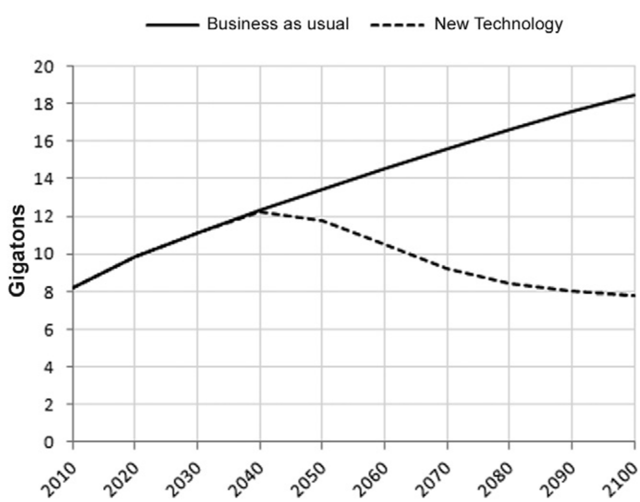
Estimated annual emissions do drop sharply in the individual scenarios. For ex-

Figure 4
New Technology Scenario, 2010 – 2100

Cumulative Carbon Emissions



Annual Carbon Emissions



ample, in 2050, EE+ emissions are 47 percent below BAU, and REN+ emissions are 31 percent below. Nevertheless, the impact on the cumulative budget is limited. The aggressive renewables test case buys only a few additional years before we cross the trillion-ton line. The NT scenario is also marginal, buying less than five years beyond BAU. The impact discrepancy between annual and cumulative emissions underscores the inadequacy of national emissions reduction schemes based on the "targets and timetables" approach. For instance, the United States has committed to 80 percent reductions relative to baseline emissions in 2050. However, unless this target is placed in the context of cumulative emissions, the numbers are fairly meaningless: "[D]espite making reference to being guided by the 'science', the [Copenhagen] Accord makes no mention of cumulative emissions as the scientifically credible framing of mitigation. [Thus] the Accord still falls short of acknowledging what the science makes absolutely clear – it is cumulative emissions that matter."[33] In other words, we cannot emit willy-nilly until 2049 and then slash emissions abruptly in 2050 and expect to be fine. Only cumulative emissions matter.

Nevertheless, we can delay emission of the trillionth ton much further by deploying a portfolio of actions. For instance, a serious ramp-up of renewables capacity coupled with an aggressive efficiency portfolio buys more than twenty years relative to BAU. Annual emissions in 2050 are 57 percent less than BAU, and the trillionth ton is not emitted until sometime around 2073. Combining the three most aggressive scenarios – EE+, REN+, and NT – is marginally better (see Figure 5).[34]

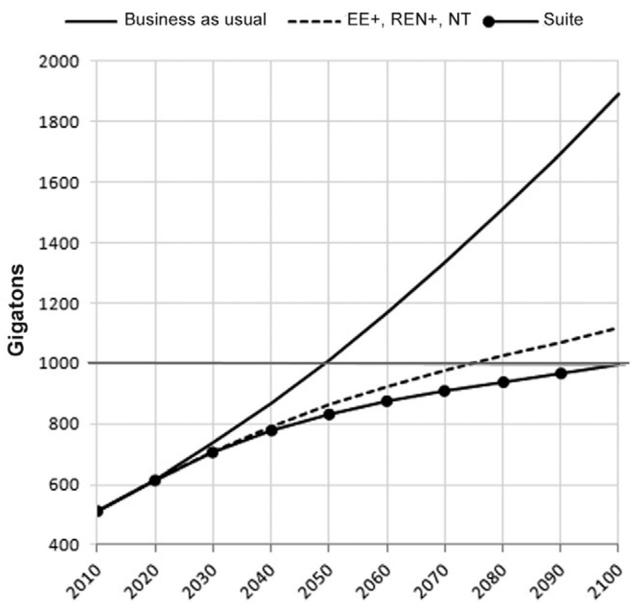
The combined scenario delays crossing the trillion-ton line by about a quarter-century – a good start, but not sufficient. Land-use changes are also an essential piece of the puzzle. Terrestrial sinks, forests, and plants have sequestered about a quarter of human-driven carbon emissions over time.[35] Thus, deforestation in the Amazon, Indonesia, and the Congo Basin is a major threat, converting a massive carbon-storage sink into a massive carbon source. The draining and burning of peat bogs is another major global source of CO_2 emissions – indeed, the third largest after burning fossil fuels and deforestation. Unsustainable farming practices are also to blame. For instance, the carbon-rich grasslands and forests in temperate zones have been replaced by crops with a much lower capacity to sequester carbon. Aggressive policies are needed to arrest these developments and further forestall the trillionth ton.

The last missing piece is the interaction of economic growth and coal. The scenarios modeled in this essay reflect this relationship in the second half of the century, when carbon emissions begin to grow after a period of steady decline. In the EE+ and REN+ scenarios, for example, annual emissions decline through the middle of the century only to rise again. Why does this happen? Quite simply, the clean energy supply is overwhelmed by growth, absent additional downward pressure on coal. If GDP continues to grow by 2 to 3 percent a year and coal remains cheap, efficiency gains and renewables will not keep pace with demand.[36] A price on carbon or an international deal on emissions reductions could alter this picture. Though policy options to achieve an ordered reduction of coal are manifold, we use the proxy of a carbon price in our final scenario below.

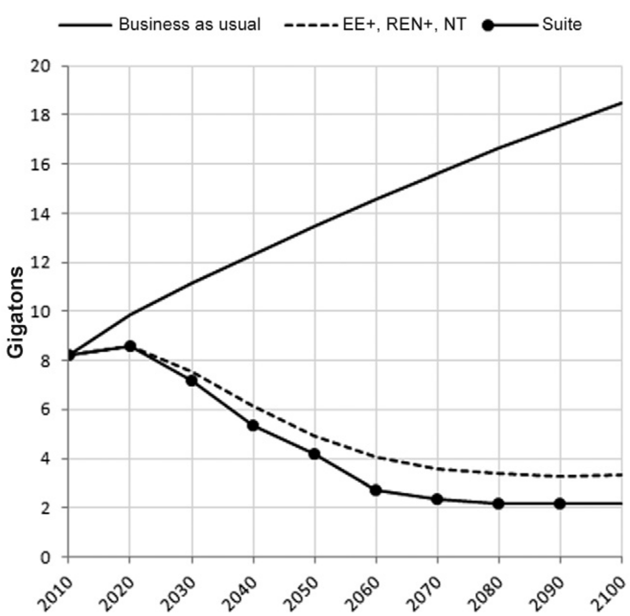
Our final scenario combines EE+, REN+, and NT with two new actions or policies: a CO_2 price of $35 per ton starting in 2025, and a 50 percent reduction in emissions from land-use sectors and other more short-lived greenhouse gases.

Figure 5
Combination Scenarios, 2010 – 2100

Cumulative Carbon Emissions



Annual Carbon Emissions



As Figure 5 shows, this scenario ("the Suite") holds cumulative emissions below the trillionth ton throughout this century. In 2050, annual emissions are 67 percent below BAU. Specific components of the Suite could be adjusted, of course. Use of nuclear power (in place of coal) could reduce emissions associated with base-load electric power generation, and recent changes in the availability of natural gas could also be explored. A more stringent land-use policy might be traded for a carbon price. This thought experiment simply highlights that there is no single solution: multiple measures are needed to keep humanity on a reasonable climate trajectory.

The En-ROADS modeling exercise shows how rapid deployment of efficiency improvements, renewables, and new technologies might impact the carbon budget over this century. Specifically, it confirms that each component is necessary and none is sufficient alone. Combined with a carbon price and effective land-use policy, these three tools offer a challenging but credible path that stays within the carbon budget. We do not have time to waste if we are to avoid dangerous, irreversible climate changes for which modern civilization is ill-suited to adapt. Indeed, the IEA warns that we have five years to get off the BAU path. After that point, the energy infrastructure we build will start to lock in emissions-generating infrastructure that will push global warming beyond 2 degrees Celsius.

Starting today, we can use existing tools to begin a steady decline in emissions at low cost. In coming years, renewable power will grow cheaper, while fossil fuel prices will adjust to future supplies and competition from other resources. A breakthrough innovation may well revolutionize the energy sector in ways we can now only dream about. Programs and policies to foster advances can be pursued on a national, state, or local level; policymakers and businesses at every level are empowered to take action now. The scenarios examined here suggest that with an aggressive and sustained effort, we can push back the timetable for expending our carbon budget and thus sharply reduce the risks of surpassing the trillionth ton.

ENDNOTES

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Acknowledgments: We would like to thank Andrew Jones and Elizabeth Sawin of Climate Interactive for their unfailing support and collaboration at all stages of producing this paper.

1 Myles Allen et al., "Warming Caused by Cumulative Carbon Emissions Towards the Trillionth Tonne," *Nature* 458 (April 30, 2009): 1163–1166. Other carbon budgets have been proposed, depending on the "acceptable risk" stipulated for crossing the 2 degree Celsius threshold. For instance, Malte Meinshausen and colleagues propose a carbon budget of roughly 830 billion tons to assure a 50 percent chance of staying under 2 degrees Celsius. See Meinshausen et al., "Greenhouse-Gas Emission Targets for Limiting Global Warming to 2° C," *Nature* 458 (April 30, 2009): 1158–1162. Despite these differences, the "need in principle for a cumulative limit near or below one trillion tonnes is generally accepted"; see Myles Allen et al., "The Case for Mandatory Sequestration," *Nature Geoscience* 2 (2009): 813–814.

2 En-ROADS was created by Climate Interactive, Ventana Systems, MIT Sloan School of Management, and the ClimateWorks Foundation global research team. It is designed to complement, not supplant, other more disaggregated models addressing similar questions, such as those in the Energy Modeling Forum's EMF-22 suite. En-ROADS relies on other models and Energy Information Administration (EIA) projections for testing and data. It is based on the Ph.D. dissertations of John Sterman, Professor in the MIT Sloan School of Management, and Tom Fiddaman of Ventana Systems. We wish to distinguish En-ROADS from the MIT Emissions Prediction and Policy Analysis model (EPPA), another simulation related to climate and energy. EPPA was developed as part of MIT's Joint Program on the Science and Policy of Global Change. En-ROADS is a system-dynamics (high-order nonlinear differential equation) simulation; a more detailed description of En-ROADS methodology and assumptions is available at http://climateinteractive.org/simulations/en-roads/en-roads.

3 Allen et al., "Warming Caused by Cumulative Carbon Emissions Towards the Trillionth Tonne." See also Catherine Brahic, "Humanity's Carbon Budget Set at One Trillion Tonnes," *New Scientist*, April 29, 2009. But compare Meinshausen et al., "Greenhouse-Gas Emission Targets for Limiting Global Warming to 2° C."

4 The En-ROADS model does not include full economic feedbacks. For example, it does not capture the effect of energy prices on the aggregate economy's growth rate, or the effect of climate impacts on economic growth. The model is not suitable, therefore, for exploring optimal trade-offs between mitigation and climate adaptation. Further, the current version of En-ROADS does not explicitly include carbon capture and storage, the dynamics of investment in and payoff from research and development, energy storage technologies, population, or labor. But it does include surrogates for each of these variables – namely, in its ability to model generic new clean-energy technologies, technology learning curves, and GDP growth.

5 Estimates of the "useful life" of a coal plant vary from thirty to sixty years. Concerns about the conventional pollutants emitted by coal-fired power plants (sulfur and nitrogen oxides, particulate matter, and mercury) have led to increasing pressure in some countries to shut down the worst offenders. Still, the large base of coal plants and the low marginal cost of operation mean that many will run for a long time.

6 United Nations Department of Economic and Social Affairs/Population Division, *World Urbanization Prospects: The 2009 Revision* (New York: United Nations, 2010), 12.

7 *World Energy Outlook 2011* (Paris: International Energy Agency, 2011).

8 At the moment, CFLs are more efficient than LEDs. Current LED efficacy is around 50 lumens per watt (60 lm/W max for some high-end Japanese products), whereas CFLs reach, at the most, 60 to 70 lm/W. CFLs will likely remain the better choice for general lighting for another five to ten years; LEDs are more likely to be used for specialty applications at first.

9 America's Energy Future Panel on Energy Efficiency Technologies, *Real Prospects for Energy Efficiency in the United States* (Washington, D.C.: National Academies Press, 2010).

10 Ibid.

11 Ibid.

12 Diana Farrell and Jaana K. Remes, "How the World Should Invest in Energy Efficiency," *McKinsey Quarterly* (July 2008).

13 The BAU scenario includes an annual improvement in primary energy intensity of 1.1 percent per year from 2010 to 2050. This estimate is somewhat lower than the reference scenarios developed by the IEA (approximately 1.8 percent per year from 2010 to 2050) and the EIA (1.7 percent per year from 2007 to 2035); but it falls in the range of EMF-22 reference scenarios (0.4 to 1.5 percent per year). See *World Energy Outlook 2011*; Energy Information Administration, *International Energy Outlook 2010* (Washington, D.C.: U.S. Department of Energy, 2010), Appendix J, "Kaya Identity Projections"; Leon Clarke et al., "International Climate Policy Architectures: Overview of the EMF 22 International Scenarios," *Energy Economics* 31 (2009): S64–S81.

14 Energy Information Administration, *International Energy Outlook 2011* (Washington, D.C.: U.S. Department of Energy, 2011), 86, Table 11. When hydropower is included, renewable sources *already* supply nearly 20 percent of global electricity generation. See REN21, *Renewables 2011: Global Status Report* (Paris: REN21 Secretariat, 2011).

15 *International Energy Outlook 2011*, 86. Note that coal-fired generation, which starts from a far higher base than renewables, still experiences cumulative growth of 67 percent during that time: from 7.7 trillion kilowatt-hours in 2008 to 12.9 trillion kWh in 2035.

16 REN21, *Renewables 2010: Global Status Report* (Paris: REN21 Secretariat, 2010), 15.

17 REN21, *Renewables Global Status Report: 2009 Update* (Paris: REN21 Secretariat, 2009), 8.

18 REN21, *Renewables 2011: Global Status Report*.

19 Compare *World Energy Outlook 2011*, 178. The IEA's report forecasts the share of generation from non-hydroelectric renewables to be 15 percent in 2035, under its "New Policies Scenario." Also compare *International Energy Outlook 2011*, 86, Table 11. The EIA's report forecasts net electricity generation of renewables to be more than 23 percent.

20 Tooraj Jamasb, "Technical Change Theory and Learning Curves: Patterns of Progress in Energy Technologies," *The Energy Journal* 28 (3) (2007): 51–71.

21 See, for example, *Technology Roadmap: Solar Photovoltaic Energy* (Paris: International Energy Agency, 2010), 18. The IEA notes that PV module costs have decreased at historical learning rates of 15 to 22 percent and, further, that balance-of-system cost reductions have kept pace. The IEA assumes a prospective learning rate of 18 percent for the whole PV system on that basis.

22 Kees van der Leun, "Solar PV Rapidly Becoming the Cheapest Option to Generate Electricity," *Grist*, October 11, 2011, http://www.grist.org/solar-power/2011-10-11-solar-pv-rapidly-becoming-cheapest-option-generate-electricity.

23 David Keith and Juan Moreno-Cruz, "Is the Solar Photovoltaic Learning Curve Flattening?" Near Zero Technical Note, June 15, 2011, http://nearzero.org.

24 The extent to which balance-of-system costs are falling is an open question, with some parties quite optimistic. For instance, the IEA maintained that balance-of-system cost reductions have kept pace with the historical solar panel learning rates of roughly 20 percent. See *Technology Roadmap: Solar Photovoltaic Energy*, 18.

25 REN21, *Renewables 2011: Global Status Report*, 33 at Table 1. ("All costs in this table are indicative economic costs, levelized, and exclusive of subsidies or policy incentives. Typical energy costs are under best conditions, including system design, siting, and resource availability.

Optimal conditions can yield lower costs, and less favorable conditions can yield substantially higher costs.")

26 A 60 percent cost reduction in renewable energy is clearly extreme. We sought to push the limits of technical feasibility for each test case to explore the ultimate impact on the carbon budget. That even extreme assumptions, individually or in partial combination, failed to prevent crossing of the trillionth ton is sobering.

27 Changes in investment and policy that would make it easier to electrify transportation were modeled by removing barriers to smarter grids, better electric vehicles, and complementary infrastructure such as fueling, parts, and maintenance.

28 Firming refers to use of a dispatchable backup resource (hydroelectric power or natural gas) to supplement an intermittent resource in order to ensure that energy supply is sufficient to meet demand.

29 *Tracking Clean Energy Progress: Energy Technology Perspectives 2012: Excerpt as IEA Input to the Clean Energy Ministerial* (Paris: International Energy Agency, 2010). The IEA scenario suggests that we need to capture about 270 million tons (Mt) CO_2 from the power and industry sectors in 2020. Meanwhile, the Global CCS Institute notes that the CO_2 storage capacity of the fourteen large-scale projects currently in operation or under construction is only about 33 Mt CO_2 per year.

30 For instance, President Obama allocated $3.4 billion to CCS research development and deployment programs as part of the American Recovery and Reinvestment Act in 2009. Meanwhile, Europe established a financing program under the Emissions Trading Scheme to support large-scale demonstration projects for CCS and other low-carbon energy technologies (the "NER 300" program, so called because it allocates 300 million allowances in the New Entrants' Reserve of the EU Emissions Trading Scheme).

31 *The Global Status of CCS: 2011* (Canberra, Australia: Global CCS Institute, 2011).

32 For details, see http://climateinteractive.org/simulations/en-roads/en-roads.

33 Kevin Anderson and Alice Bows, "Beyond 'Dangerous' Climate Change: Emissions Scenarios for a New World," *Philosophical Transactions of the Royal Society A* 369 (1934) (January 13, 2011): 20–44.

34 This result is partially explained by market competition. A driving force in the scale-up of technologies is the "learning by doing" effect, whereby prices fall and investment becomes more attractive as installed capacity increases. When new technology and renewables grow simultaneously, neither accumulates an installed total as quickly.

35 Yude Pan et al., "A Large and Persistent Carbon Sink in the World's Forests," *Science* 333 (6045) (2011): 988–993.

36 These growth rates are used in En-ROADS simulations (and those in the EMF-22 suite, for example). Whether they are realistic for the end of the century is an open question.

Does the American Public Support Legislation to Reduce Greenhouse Gas Emissions?

Jon A. Krosnick & Bo MacInnis

Abstract: Despite efforts by some congressional legislators to pass laws to limit greenhouse gas emissions and reduce the use of fossil fuels, no such laws have yet been adopted. Is this failure to pass new laws attributable to a lack of public desire for such legislation? Data from national surveys support two answers to this question. First, large majorities of Americans have endorsed a variety of policies designed to reduce greenhouse gas emissions; second, policy support has been consistent across years and across scopes and types of policies. Popular policies include fuel economy and energy-efficiency standards, mandated use of renewable sources, and limitations on emissions by utilities and by businesses more generally. Support for policies has been price sensitive, and the American public appears to have been willing to pay enough money for these purposes to cover their costs. Consistent with these policy endorsements, surveys show that large majorities of Americans believe that global warming has been happening, that it is attributable to human activity, and that future warming will be a threat if unaddressed. Not surprisingly, these beliefs appear to have been important drivers of public support for policies designed to reform energy generation and use. Thus, it seems inappropriate to attribute lack of legislation to lack of public support in these arenas.

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*(*See endnotes for complete contributor biographies.)*

Recent years have seen a number of efforts in Congress to shift American energy generation away from fossil fuels and toward cleaner and renewable energy sources. For example, in early 2009, the Obama administration and members of Congress designed and enacted the American Recovery and Reinvestment Act, earmarking nearly $80 billion in clean-energy investments. Projects included upgrading the national electricity grid to improve efficiency; assisting and encouraging the formation of clean-energy businesses through tax incentives; and investing in cleaner and more efficient forms of public transit, such as high-speed rail.

In June 2009, the House of Representatives passed the American Clean Energy and Security Act, which sought to place nationwide caps on greenhouse gas emissions. This law targeted a 17 percent reduction of greenhouse gas emissions from 2005 levels by 2020 and an 83 percent reduction by 2050. It also mandated that 20 percent of American electricity be generated from renewable sources such as solar and wind power by 2020. The Senate did not vote on the Act, so it was not adopted into law. Since then, no significant efforts have been made in Congress, and leaders either have chosen not to discuss the issue or have opposed legislative efforts to facilitate development of a new energy economy.

One possible explanation for this turn of events is lack of public support. According to many observers, reduced use of fossil fuels and adoption of new technologies would be costly for consumers and would shortcut the process of recovering investments already made in infrastructure to produce energy from conventional sources. At a time when the nation's economy is struggling, it is easy to imagine that Americans might not be willing to take such steps, so shifting legislative focus to other policy arenas might appear to reflect public will.

In this essay, we explore whether public attitudes indeed discourage immediate movement toward a new energy economy. We examine attitudes in four broad categories: two on the consumption side, and two on the supply side. The consumption policies include setting higher standards for energy efficiency and taxing electricity and gasoline use in order to reduce consumption. The supply policies address the expansion of renewable energy sources and the reduction of businesses' emissions of air pollution in general and of greenhouse gases in particular.

We explore these issues using data from national surveys that we conducted between 1997 and 2012. Each survey involved a probability sample of American adults who were representative of the nation. Interviews were done by telephone using "random digit dialing" to reach people with listed and unlisted telephone numbers. In the early years, only landline telephones were called. As the number of Americans reachable only by cellular telephone increased, we altered our approach to include both landlines and cell phones. The same question wordings were employed across the years to allow for tracking trends in opinions over time. Our survey research has been conducted collaboratively with news media organizations (for example, the Associated Press, ABC News, *The Washington Post*, *Time* magazine, and *New Scientist* magazine) and the nonpartisan think tank Resources for the Future. It has been funded by government agencies (for example, the National Science Foundation, the Environmental Protection Agency, the National Oceanic and Atmospheric Administration), a private foundation (the Electric Power Research Institute), and academic institutions (Stanford University and The Ohio State University). Data collection has been done by a variety of survey research firms, including Abt/SRBI, Ipsos Public Affairs, GfK, and TNS, and The Ohio State University's Center for Survey Research.

According to our surveys, large majorities of Americans have endorsed policies to limit the amount of air pollution in general, and greenhouse gas emissions in particular, that U.S. businesses produce. In October 1997, for example, 88 percent of respondents said the U.S. government should limit the amount of air pollution that U.S. businesses can produce; 91 percent expressed this opinion in February 1998; and in June 2010, the figure was 86 percent. Although the technical meaning of *air pollution* does not refer to greenhouse gases, we have learned over the years that Americans view this term as including greenhouse gas emissions as well. When respondents were asked in June 2010 whether the U.S. government should limit the amount of greenhouse gases thought to cause global warming that U.S. businesses can produce, 76 percent answered affirmatively. This figure was 74 percent in late 2010 and 77 percent in 2012.

When the question was phrased specifically with regard to emissions produced by utilities during electricity generation, similarly high proportions of Americans endorsed limitations. In 2006 and 2007, 86 percent and 87 percent of respondents, respectively, said the federal government should reduce utilities' emissions. This figure was slightly lower in 2009, mid-2010, late 2010, early 2012, and mid-2012: 76 percent, 80 percent, 78 percent, 70 percent, and 78 percent, respectively.

In the literature on public opinion, researchers have observed what has been dubbed a *principle-implementation gap*. Whereas many people favor policies to achieve an outcome (for example, racial integration of schools) in principle, various specific policies to achieve that outcome (such as busing children to schools in neighborhoods far from their homes) receive only low levels of support. Thus, endorsement of the goal may appear disingenuous because no actual implementation methodology would be acceptable to the public.

This is not the case for emissions-reduction policies. In fact, according to our surveys, large majorities of Americans have favored government taking steps to promote higher energy-efficiency standards in a number of arenas (see Figure 1). For example, in 2006, 84 percent of survey respondents wanted the federal government to require by law, or encourage with tax breaks, the building of cars that use less gasoline.[1] This is clearly a huge number. Similarly sizable majorities of Americans that year favored government's requiring or encouraging the building of appliances that use less electricity (82 percent) as well as building new homes and offices that use less energy to be heated and cooled (83 percent). These majorities shrank slightly between 2006 and 2010, shrank a bit more in 2011, and rebounded in 2012. None of the policies was ever opposed by a majority during this time period.

Similarly huge majorities have favored steps by the federal government to reduce the amount of greenhouse gas emissions generated when utilities produce electricity. In 2006, 86 percent of respondents favored requiring utilities, or encouraging them with tax breaks, to reduce the amount of greenhouse gases they emit (see Figure 1). Also in that year, 87 percent favored tax breaks for utilities that produce more electricity from water, wind, or sunlight (see Figure 2). These majorities were maintained between 2006 and 2010 and shrank somewhat after that.

One element of the American Clean Energy and Security Act is a government mandate that 20 percent of the nation's electricity be generated from clean, renewable sources by the year 2020. In a 2010 survey, 69 percent of American adults endorsed this notion, saying that the U.S. government should require all utilities to generate at least 20 percent of their electricity from water, wind, or solar power.

During a more limited set of years, we asked about two additional emissions-reduction policies that were endorsed by slightly smaller but nonetheless sizable majorities. The first addressed the sequestration of emissions from burning coal. Our survey question asked whether respondents favored or opposed the federal government's giving "tax breaks to companies that burn coal to make electricity if they use new methods to put the air pollution they generate into underground

Figure 1
Percent of Respondents Who Said that Government Should Require or Encourage Various Policies Designed to Reduce Greenhouse Gas Emissions, 2006 – 2012

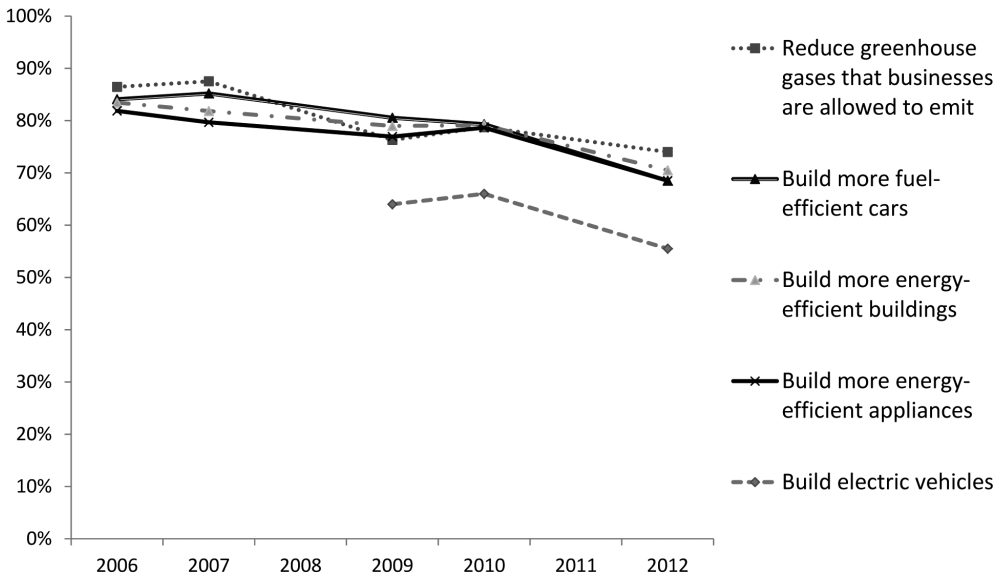
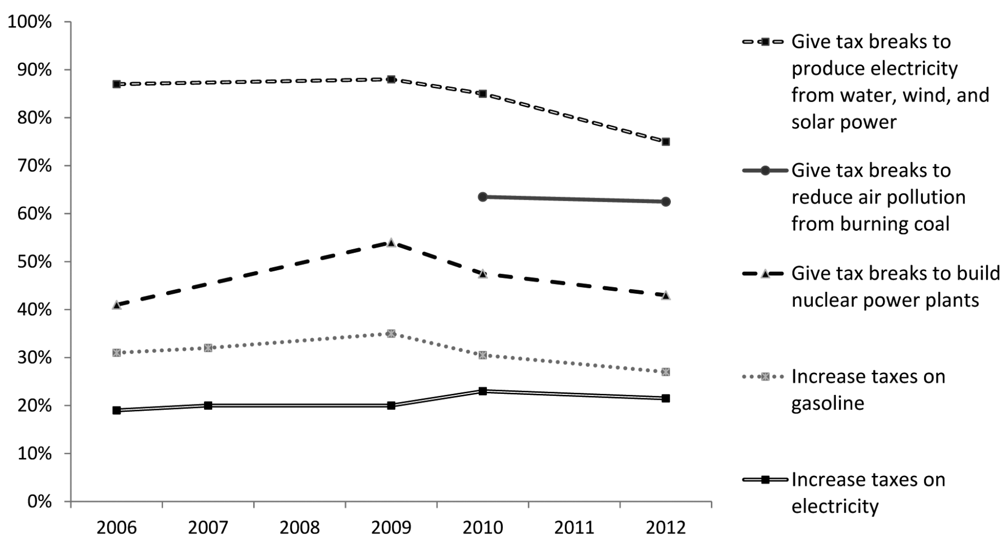


Figure 2
Percent of Respondents Endorsing Various Policies Designed to Reduce Greenhouse Gas Emissions, 2006 – 2012



Source: Figures created by authors.

storage areas instead of letting that air pollution go up the smokestacks at their factories." The proportion of respondents supporting this policy was 64 percent in 2010 and 63 percent in 2012 (see Figure 2). The other policy addressed requiring or encouraging automobile manufacturers to produce cars that run completely on electricity. When we first asked about such a policy in 2009, 64 percent of respondents endorsed it, and that figure remained fairly constant through 2012 (see Figure 1).

Other emissions-reduction policies have been notably less popular, favored by only minorities of Americans (see Figure 2). For example, in 2006 just 41 percent of respondents favored giving federal tax breaks to companies to build nuclear power plants. And even fewer people supported tax increases imposed on consumers' energy consumption simply to induce decreased consumption and without stipulating a use for the financial revenues that would be generated. Specifically, in 2006 only 19 percent of Americans favored increasing taxes on electricity to encourage people to use less of it, and only 31 percent favored increasing taxes on gasoline to do the same. Endorsement of these policies remained at about the same levels between 2006 and 2012.

A central piece of the American Clean Energy and Security Act is an economy-wide system in which the federal government sets a limit on the total amount of greenhouse gases that businesses can emit and issues tradable permits to companies restricting their individual emissions. Although Barack Obama and John McCain disagreed about many issues during the 2008 presidential election campaign, they agreed that the federal government should create such a "cap and trade" system.

During the months leading up to the 2008 presidential election, 59 percent of Americans endorsed a cap-and-trade system when it was described as follows:

> The government would issue permits limiting the amount of greenhouse gases companies can put out. Companies that did not use all their permits could sell them to other companies. The idea is that many companies would find ways to put out less greenhouse gases, because that would be cheaper than buying permits. Would you support or oppose this system?

Respondents who initially expressed opposition were then told: "A similar system has been effective in reducing emissions that cause acid rain. Knowing that it has worked in that case, would you support or oppose a cap-and-trade system for greenhouse gases?" Once this information was given, support rose to 74 percent, suggesting that some initial hesitation was based on uncertainty about whether the system would be effective.

In 2010, we asked a randomly selected half of the respondents about cap and trade, but we described the program slightly differently:

> The government would issue permits limiting the amount of greenhouse gases companies can put out. Companies that did not use all their permits could sell them to other companies. Companies that need more permits can buy them, or these companies can pay money to reduce the amount of greenhouse gases that other people or organizations put out. This will cause companies to figure out the cheapest way to reduce greenhouse gas emissions. Would you favor or oppose this system?

When asked this form of the question, 65 percent of respondents said they favored the system. For another group of respondents, the following was added to the end of the question: "This type of permit system has worked successfully in the past to reduce the air pollution that companies put out." Of these individuals, 74 percent endorsed the system. Thus, again, majority support was apparent, and initial hesitation was apparently due in part to uncertainty about program effectiveness.

This conclusion was reinforced by another, similar experiment. In March 2009, among a nationally representative sample of Americans who completed surveys online,[2] one-quarter of the respondents, chosen randomly, were asked to vote for or against a cap-and-trade program in which the permits would be sold to companies (instead of simply issued, as specified in the experiments described above). Fifty-six percent of respondents voted for the program. This proportion increased to 62 percent among another random subset of respondents who also read this additional information about the program's effectiveness:

> This kind of policy, where the government limits a certain type of air pollution and gives out permits to companies that they can buy and sell, has worked successfully in the past to reduce the amount of air pollution that companies put out. For example, in 1990, the federal government passed a law like this, called the Clean Air Act, which caused companies to put out a lot less of the air pollution that causes acid rain.[3]

One possible explanation for the slightly lower levels of popularity observed in this survey is that the permits are described as being sold rather than issued. When described as being sold, respondents might perceive the permits as generating revenue for the federal government, and presumably increasing the costs of goods and services to consumers given the pass-through of the expense to companies.

In the above study's description of the cap-and-trade program, respondents were not told what would be done with the revenue generated through the sale of permits. To explore whether disposition of revenues affects people's willingness to endorse cap and trade, we tested the appeal of a so-called cap-and-dividend program. Another randomly selected one-quarter of respondents in the March 2009 survey were told about cap and trade but were not told about past effectiveness. Instead, they were told: "All the money raised from selling permits would be returned to American taxpayers. A refund would be given on each income tax return filed with the federal government." Of these respondents, 57 percent voted for cap and trade. This number is not significantly different from the proportion who endorsed the program without this information (56 percent), meaning that the transformation from "cap and trade" to "cap and dividend" did not increase the public appeal of the policy.[4]

This conclusion was supported by results from another experiment we conducted in a 2008 Internet survey of a nonrepresentative sample of volunteers. Some of the respondents (chosen randomly) were provided a description of cap and trade and were told that the permits would be given away to companies. Another group of respondents (also chosen randomly) was instead told that the permits would be auctioned. The proportion of respondents endorsing cap and trade was not significantly different in the two conditions; therefore, federal revenue generation did not seem to increase the appeal of cap and trade.

Interestingly, public reluctance to support cap and trade is driven in part by the presence of a trading system in the policy. We observed this phenomenon in a survey conducted in April 2007 with a representative national sample of Americans who completed surveys via the Internet. Respondents were asked to evaluate two different policy approaches for reducing emissions from electricity generation and gasoline consumption by 5 percent by the year 2020. The first was a cap-and-trade system, the second a less complex system that simply capped emissions without a permit-trading system. The percent of respondents endorsing the mandated cap was considerably higher than the percent endorsing the cap-and-trade system. Thus, mandated emissions-reduction policies were the more popular option.

The survey questions measuring support for some of the emissions-reduction policies outlined above described each policy without mentioning that the goal was to reduce future global warming. Specifically, respondents were asked: "For each of the following, please tell me whether you favor or oppose the federal government doing it"; one of the named policies was to "give companies tax breaks to build nuclear power plants." Given that survey respondents may not have understood that such policies are intended to reduce future global warming, we speculated that making such a link explicit could have changed the distribution of responses.

We explored this possibility in an experiment embedded in our 2010 survey. Half of the respondents (selected randomly) were asked about five policies (ranging from very popular to very unpopular) with no mention of global warming. For the other half of the respondents, the introduction to the question sequence stated: "For each of the following, please tell me whether you favor or oppose it as a way for the federal government to try to reduce future global warming." Thus, the primary purpose of each policy was made explicit.

Linking relatively unpopular consumption taxes and the construction of nuclear power plants to global warming reduction had no impact on support for such policies. Among respondents who did not hear the added introduction, 22 percent favored taxes on electricity to reduce consumption, and 28 percent favored taxes on gasoline to do the same. Identical figures appeared among respondents who did hear the introduction. Among respondents who did not hear the introduction, 45 percent favored tax breaks to encourage nuclear power plant construction, and this figure was 51 percent among people who heard the added introduction, not a statistically significant difference ($p = 0.44$). Thus, global warming reduction did not make these unpalatable policies any more appealing.

Likewise, explicitly linking renewable power use to global warming did not alter the appeal of alternative energy. Among respondents who did not hear the added introduction, 82 percent favored giving tax breaks to utilities to produce more electricity from water, wind, and solar power. This figure rose to 87 percent among people who heard the introduction, which, again, is not a significant difference ($p = 0.17$). The same trend appeared with regard to support for carbon sequestration: among people who did not hear the added introduction, 61 percent favored it, whereas 70 percent of respondents who did hear the introduction favored it (again, not statistically significant). Thus, it appears that linking these policies more explicitly to global warming did not notably alter their popularity.

One might imagine that the very limited support for consumer taxes on gasoline and electricity is the result of public reluctance to pay for reductions in greenhouse gas emissions. And perhaps, one might speculate, public endorsement of mandates and tax incentives to alter business practices has been so high because survey respondents imagined that these policies would not cost them any money.

To explore this possibility, we conducted an experiment in our 2012 survey. A randomly selected half of the respondents were asked to evaluate four of the most popular emissions-reduction policies using question wording that made no mention of the increased consumer costs that were likely to result from the policies. The other half of the respondents were asked the same questions, but the questions were preceded by the following introduction: "Each of these changes would increase the amount of money that you pay for things you buy."

Adding this introduction had no significant impact on the distribution of responses. For example, among the respondents who did not hear the explicit reference to increased consumer costs, 74 percent endorsed federal government efforts to increase automobile fuel-efficiency standards. The figure was 70 percent among people who were told about the effect on the price of consumer goods – not a significant difference ($p = 0.69$). Similarly, when asked about U.S. government actions to lower the amount of greenhouse gas emissions that utilities release, 77 percent endorsed the policy when not told about price increases on consumer goods, and 78 percent did so when told about increases to consumer prices – again, an insignificant difference ($p = 0.61$).

Because the new question wording specified neither how much people would have to pay in order to achieve emissions reductions nor the size of those reductions, this approach to measuring respondents' willingness to incur costs raised the question of how people would respond if given specific figures. To address this concern, we conducted between-subjects experiments in which we asked questions that made both the costs and the benefits explicit. In these experiments, we observed the price sensitivity that economists would expect to see.

For example, in November 2010, after the current economic recession was well under way, we randomly assigned one-third of the respondents to be asked if they would vote for or against a law that would reduce air pollution by 85 percent by 2050 and that would cost each household an extra $75 per year on average. Sixty-six percent of respondents voted for this law. Among randomly selected respondents who were instead told that the annual cost would be $150 per household, endorsement dropped slightly, to 58 percent. And among the remaining respondents who were told that the cost would be $250 per year, support dropped to 41 percent.

This pattern of price sensitivity was also evident in surveys we conducted with representative samples of residents in Florida, Maine, and Massachusetts in July 2010. Of the total respondents from the three states, 63 percent voted for a law to reduce air pollution by 85 percent by 2050, even if it cost individual households an extra $75 per year on average. Support dropped slightly to 53 percent among respondents who were told that the annual cost would be $150. And support dropped further, to 48 percent, among people told that the cost would be $250 per year.

Similar price sensitivity was observed in an April 2007 survey. A nationally representative sample of American adults was asked about requiring electric utilities to produce low-carbon electricity to reduce greenhouse gas emissions by 5 percent by 2020. A randomly selected subset of respondents was told that the law would cost an extra $24 annually in increased electricity costs, and 75 percent endorsed the law. This number was about the same (73 percent) among respondents who were told that the price would be $120 per year, and it dropped considerably, as we expected, to 50 percent among people who were told that the annual cost would be $840.

Was public willingness to pay sufficient to cover the actual cost of the described emissions reduction? To answer this question, we can apply the Turnbull calculation method[5] to our survey data to calculate the nation's willingness to pay for an 85 percent reduction in national emissions by 2050. The Turnbull method is designed to yield a lower-bound estimate of total willingness to pay. For example, using the data we collected in 2010, we can produce estimates based on the following logic:

- Sixty-six percent of respondents voted in favor of the program at a cost of $75 per household. Because $75 was the lowest price we asked about, the Turnbull method assumes that everyone who voted against the program at this cost was willing to pay $0 (even though these respondents might have revealed some willingness to pay if we had asked them about a price between $0 and $75).
- Because 58 percent of respondents voted for the program at a cost of $150, the Turnbull method assumes that 8 percent of respondents (the difference between 66 percent and 58 percent) were willing to pay $75 (even though maximum willingness to pay among some or all of these respondents might have been between $75 and $150).
- Because 41 percent of respondents voted for the program at a cost of $250, the Turnbull method assumes that 17 percent of respondents (the difference between 58 percent and 41 percent) were willing to pay $150 (even though maximum willingness to pay among some or all of these respondents might have been between $150 and $250).
- Because $250 was the highest price we asked about, the Turnbull method assumes that the 41 percent of respondents who voted for the program at that price were willing to pay no more than that price (even though they might have revealed a willingness to pay a higher price if we had asked about that).

Having assigned each respondent a willingness to pay, we can calculate the average willingness to pay across all Americans, which turns out to be $134. We can then multiply this number by the total number of households in the nation (117 million in 2010) to yield a total willingness to pay for the country: $15.7 billion per year.

Is this figure enough to cover the costs of an 85 percent reduction in national emissions by 2050? The Environmental Protection Agency (EPA) conducted an analysis of the economic costs of the American Power Act to achieve the mitigation goals of reducing greenhouse gas emissions by 17 percent in 2020 and by 83 percent in 2050. The EPA estimated that the per-household cost would be between $79 and $146 (in 2005 dollars) if the Act were to be implemented, with a total cost between $10.8 billion and $20.2 billion per year (in 2010 dollars).[6] Using the 2010 survey data, the lower-bound estimate of total public willingness to pay ($15.7 billion) is squarely within the EPA's range of $10.8 billion to $20.2 billion. Thus, according to this measurement approach, Americans were willing to pay the price.

Some opponents of the policies outlined above have argued that, amid a national recession, this is not the time to incur such costs. This argument has often been justified by claims that reducing future global warming would hurt the nation's economy and eliminate jobs. But the high levels of support these policies have received in recent years suggest that this argument has not been convincing to Americans. Indeed, our data offer direct evidence consistent with that conclusion.

Specifically, in mid-2010, only 20 percent of respondents surveyed said that taking actions to reduce future global warming would hurt the U.S. economy, and only 18 percent said that doing so would reduce the number of jobs around the country. These numbers were nearly identical – 23 percent and 18 percent, respectively – in late 2010. In fact, in mid-2010, a majority of respondents (56 percent) said that taking actions to reduce future global warming would have a positive effect on the U.S. economy, and 50 percent said that efforts to reduce warming would create jobs and increase employment nationwide. These numbers were 53 percent and 48 percent, respectively, in late 2010.

The same beliefs have been expressed with regard to state economies. In late 2010, only 19 percent of respondents said that U.S. efforts to do something about global warming would reduce the number of jobs in their state, and only 21 percent said that doing so would hurt their state's economy. A plurality, 45 percent, said that such actions would bring jobs to the state in which they lived, and 48 percent said that these actions would help their state's economy.

The substantial public support we observed for a range of policy approaches may result from a variety of considerations. For example, support for using solar, wind, and water to generate electricity might be driven by (1) a desire to limit American dependence on foreign nations for oil; (2) a desire to use unlimited sources rather than relying on finite quantities of oil, coal, and natural gas; or (3) a desire to reduce emissions of particulate matter that result from burning organic materials. Indeed, even support for legislation explicitly intended to reduce greenhouse gas emissions might be driven by a desire to rely on alternative energy sources for reasons having nothing to do with global warming. However, it is also possible that the policy support described above is indeed a function of the desire to reduce future global warming and its perceived likely effects.

In order for the latter assertion to hold, one necessary precondition must be – and has been – met: in all the surveys we have conducted dating back to the 1990s, large majorities of Americans have said they believe that the planet has been gradually warming over the last hundred years; that if such warming has been occurring, it has been caused by human activity; and that, if unchecked, global warming will be harmful to people now and in the future and will be a serious problem for the nation and the world.

According to each of the surveys conducted between 2006 and 2012, more than three in four Americans said they believed that the world's temperature has probably been going up for the past hundred years: 85 percent in 2006 and 84 percent in 2007. The proportion dropped slightly to 80 percent in 2008, dropped a bit more the next year, later rose slightly, and then dropped slightly once more. Through all these small ups and downs, large majorities expressed belief in past warming. When asked whether future warming will occur if nothing is done to stop it, 75 percent responded affirmatively in 2010, and 72 percent did so in both 2011 and 2012. Likewise, large majorities found human activity responsible for warming: 80 percent in 2006, 83 percent in 2007, 78 percent in 2008, 69 percent in 2009, 75 percent in 2010, 72 percent in 2011, and 77 percent in 2012.

When asked whether warming of five degrees Fahrenheit over the next seventy-five years would be good, bad, or neither good nor bad, 64 percent said "bad" in 2007, followed by 61 percent in 2008, 54 percent in 2009, 59 percent in mid-2010, 56 percent in late 2010, and 53 percent in 2012. When asked how much global warming is likely to hurt future generations, 64 percent said "a great deal" or "a lot" in mid-2010, and 60 percent expressed this view in late 2010. Huge majorities said that global warming was a "very serious" or "somewhat serious" national problem: 82 percent in 2006, 85 percent in 2007, 84 percent in 2008, 73 percent in 2009, 78 percent in mid-2010, 75 percent in late 2010, and 79 percent in 2012.

To explore whether beliefs about global warming might motivate support for emissions-reduction policies, we estimated the parameters of regression equations (see Table 1). We constructed an index of respondent "greenness" on global warming using five measures: namely, belief that global warming has been happening, that it has been caused by humans, that it will be bad, that it will be a serious problem for the nation, and that it will be a serious problem for the world. This index was normalized to be a continuous variable from 0 (the least green) to 1 (the most green). Measures of endorsement of emissions-reduction policies in four categories were also constructed and normalized to be continuous scores ranging from 0 (the least endorsement) to 1 (the most endorsement). Data from the mid-2010 and late-2010 surveys were used to estimate parameters because of the completeness of the energy policy measures included in those surveys.

As we expected, global warming greenness predicted support for emissions-reduction policies in each of the four categories. For every 10 percentage-point increase in the public's global warming greenness, we observed a 1.5 percentage-point increase in endorsement of policies for fuel economy and energy-efficiency standards (see row 1, column 1 in Table 1); a 2.5 percentage-point increase in public endorsement of energy-consumption tax policies (see row 1, column 2 in Table 1); a 1 percentage-point increase in public endorsement of policies related to alternative energy sources (see row 1, column 3 in Table 1); and a 3.5 percentage-point increase in public endorsement of emissions-reduction policies (see row 1, column 4 in Table 1). When we combined all the energy policies together, for every 10 percentage-point increase in the public's global warming greenness, we observed a 1.8 percentage-point increase in public endorsement of the policies in general (see row 1, column 5 in Table 1).

Taken together, the body of evidence that we have reviewed here paints a compelling portrait of public opinion. For years, most Americans have endorsed a range of U.S. government policies designed to reduce greenhouse gas emissions and have been willing to pay for the implementation of such policies. To date, despite the national recession, most Americans have apparently been unconvinced that such policies would hurt the U.S. economy or their state's economy. Certainly, some types of policies have appealed to very few Americans, including consumer taxes designed simply to reduce consumption, with no specificity about the uses of the funds that would be raised by the federal government and no indication of what level of emissions reductions would be achieved. But policies that involve either government mandates or tax incentives to businesses have proven very popular with the public, even when the financial costs involved are made explicit. Americans are not willing to pay an unlimited amount of money for emissions reduction, and people do manifest the price sensitivity that economists would expect. But willingness to pay appears to be sufficient to fund a great deal of effort.

In light of our survey results, it seems unfair to blame the public for lack of legislative progress in limiting greenhouse gas emissions. Indeed, public support for

Table 1
Greenness in Global Warming Beliefs as a Predictor of Energy Policy Support[7]

Predictor	Support for Each Category of Energy Policies: Energy Efficiency Standards (1)	Gas Consumption Taxes (2)	Alternative Energy Sources (3)	Emissions Reduction (4)	Support for All Energy Policies (5)
Global Warming Greenness	0.15*** (0.04)	0.25*** (0.03)	0.10*** (0.04)	0.35*** (0.03)	0.18*** (0.02)
Democrat	0.04 (0.02)	0.01 (0.03)	0.05** (0.02)	0.04** (0.02)	0.03** (0.01)
Republican	0.01 (0.03)	-0.04 (0.02)	0.03 (0.03)	-0.01 (0.02)	0.00 (0.01)
Liberal	-0.03 (0.03)	0.11*** (0.03)	0.00 (0.02)	-0.03 (0.02)	-0.00 (0.01)
Conservative	0.03 (0.03)	-0.06** (0.03)	-0.01 (0.03)	-0.03 (0.02)	-0.01 (0.01)
Female	-0.03 (0.02)	-0.00 (0.02)	-0.04** (0.02)	0.05*** (0.02)	-0.02* (0.01)
Hispanic	-0.08** (0.04)	0.13*** (0.04)	0.04 (0.04)	0.01 (0.03)	0.00 (0.02)
Black	-0.09** (0.04)	0.04 (0.04)	-0.00 (0.04)	-0.02 (0.02)	-0.04** (0.02)
High school graduate	-0.01 (0.04)	0.02 (0.04)	-0.01 (0.04)	-0.00 (0.04)	0.00 (0.02)
Some college	-0.01 (0.04)	0.00 (0.04)	0.04 (0.04)	-0.01 (0.04)	0.01 (0.02)
College graduate	0.02 (0.03)	0.14*** (0.04)	0.05 (0.04)	-0.01 (0.04)	0.05* (0.02)
Age 25 – 34	0.05 (0.04)	-0.09** (0.04)	0.01 (0.04)	-0.01 (0.03)	0.01 (0.02)
Age 35 – 44	0.05 (0.04)	-0.05 (0.04)	-0.01 (0.04)	-0.04 (0.03)	-0.00 (0.02)
Age 45 – 54	0.05 (0.04)	-0.09** (0.04)	-0.04 (0.04)	-0.06* (0.03)	-0.02 (0.02)
Age 55 – 64	-0.01 (0.04)	-0.03 (0.04)	-0.01 (0.04)	-0.11*** (0.03)	-0.03* (0.02)
Age 65 or older	-0.04 (0.04)	-0.01 (0.04)	-0.05 (0.04)	-0.07*** (0.03)	-0.03* (0.02)
Midwest	0.00 (0.03)	-0.02 (0.03)	-0.02 (0.03)	-0.00 (0.02)	-0.00 (0.02)
South	-0.03 (0.03)	-0.03 (0.03)	-0.04 (0.03)	0.01 (0.02)	-0.02 (0.02)
West	0.01 (0.03)	0.01 (0.03)	-0.05* (0.03)	0.02 (0.02)	0.00 (0.02)
November 2010 survey	-0.00 (0.02)	0.04* (0.02)	-0.01 (0.02)	0.08*** (0.02)	0.02** (0.01)
N	2,001	2,001	2,001	2,001	2,001
R^2	0.051	0.170	0.041	0.223	0.149

such policies seems to be not only present but prevalent – much more so than for policies that the federal government currently implements in many other arenas. Why, then, has legislative action been so limited with regard to reduction of greenhouse gas emissions? One possibility is that legislators have thus far chosen to ignore the will of their constituents when voting on legislation in this arena. But another possibility is that legislators have been unaware of the magnitude of the public consensus on these issues. We hope that this essay helps U.S. leaders and the American public to better understand prevailing opinions on emissions reduction, and thereby to enhance the functioning of representative democracy in this country.

ENDNOTES

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1 When asked a different question in 2008, 78 percent of the public said that the federal government should make fuel-efficiency standards for cars stricter than they were at that time.

2 The data were collected via the Face-to-Face Recruited Internet Survey Platform (FFRISP). Face-to-face recruiting was done with a national area probability sample of American households that had been offered a free laptop (or its equivalent value in cash), high-speed Internet access at home (if the home did not have it already), and regular cash payments in exchange for completing monthly questionnaires for a year. The FFRISP began with one thousand panelists, who were recruited between June and October 2008. The data described here were collected during the sixth wave, initiated in March 2009.

3 One might wonder whether these findings occurred simply because the survey question offered an argument in favor of cap and trade, not because of the specific nature of that argument. We explored this possibility in an Internet survey conducted with a nonrepresentative sample of research participants in 2008. Among a randomly selected subset of the respondents who were asked about cap and trade with no argument in favor of it, 41 percent voted for the program. Among a random subset of the respondents who were also told that economists had conducted much research showing that such a policy is the least costly way to reduce greenhouse gas emissions, endorsement was not significantly different: 46 percent. Another random subset of the respondents was instead reassured that the government could accurately monitor emissions and enforce the cap; endorsement was again about the same: 45 percent. But when the final random subset of the respondents was told that cap and trade had worked effectively in the past, endorsement rose significantly, to 54 percent. Thus, adding other arguments did not increase public support for cap and trade; only the effectiveness argument did so. These findings also suggest that hesitation with regard to cap and trade was not driven by concerns about whether emissions can be monitored or whether cap and trade is truly the most desirable emissions-reduction method.

4 Among another one-quarter of respondents who were told about both the past effectiveness of cap and trade and that revenues would be returned to Americans, endorsement was 65

percent – not significantly different from the 62 percent of people who were told only about effectiveness. These results reinforce the conclusion that the "cap and dividend" framing does not enhance support.

5 Bruce Turnbull, "The Empirical Distribution Function with Arbitrarily Grouped, Censored and Truncated Data," *Journal of the Royal Statistical Society : Series B* 38 (1976) : 290 – 295.

6 To calculate this estimate, we first took the lower bound of $79 in 2005 dollars, inflated it to 2010 dollars (to match the year of the survey) using an annual consumer price index of 3.4 percent – that is, $\$79 \times 1.034^5 = \$93$ – and then multiplied $93 by 117 million households, yielding $10.8 billion for the lower bound. The upper bound of $20.2 billion is based on the per-household annual cost of $146.

7 * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Cell entries are coefficient estimates (with standard errors given in parentheses) from ordinary least square regressions predicting policy support (coded to range from 0, the least support, to 1, the most support) among respondents to the June 2010 and November 2010 Stanford Global Warming national surveys, adjusting with sampling weights. Greenness is an index of global warming beliefs, including beliefs that global warming has been happening, that it has been caused by humans, that it will be bad, that it will be a serious problem for the nation, and that it will be a serious problem for the world. All other predictors were dichotomous variables. Omitted categories were : male, independent, moderate, non-Hispanic, white, age 18 – 24, less than high school graduates, and people in the Northeast.

The Collapse of Western Civilization: A View from the Future

Naomi Oreskes & Erik M. Conway

Authors' note: Science fiction writers construct an imaginary future; historians attempt to reconstruct the past. Ultimately, both are seeking to understand the present. In this essay, we blend the two genres to imagine a future historian looking back on a past that is our present and (possible) future. The occasion is the tercentenary of the end of Western culture (1540 – 2073); the dilemma being addressed is how we – the children of the Enlightenment – failed to act on robust information about climate change and knowledge of the damaging events that were about to unfold. Our historian concludes that a second Dark Age had fallen on Western civilization, in which denial and self-deception, rooted in an ideological fixation on "free" markets, disabled the world's powerful nations in the face of tragedy. Moreover, the scientists who best understood the problem were hamstrung by their own cultural practices, which demanded an excessively stringent standard for accepting claims of any kind – even those involving imminent threats. Here, our future historian, living in the Second People's Republic of China, recounts the events of the Period of the Penumbra (1988 – 2073) that led to the Great Collapse and Mass Migration (2074).

In the prehistory of "civilization," many societies rose and fell, but few left as clear and extensive an account of what happened to them and why as the twenty-first-century nation-states that referred to themselves as *Western civilization*. Even today, two millennia after the collapse of the Roman and Mayan empires and one millennium after the end of the Byzantine and Inca empires, historians, archaeologists, and synthetic-failure paleoanalysts have been unable to agree on the primary causes of those societies' loss of population, power, stability, and identity. The case of Western civilization is different because the consequences of its actions were not only predictable, but predicted. Moreover, this technologically transitional society left extensive records both in twentieth-century-style paper and in twenty-first-century electronic formats, permitting us to reconstruct what happened in extraordinarily clear detail. While analysts differ on the details, vir-

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tually all agree that the people of Western civilization knew what was happening to them but were unable to stop it. Indeed, the most startling aspect of this story is just how much these people knew, yet how little they acted upon what they knew.

For more than one hundred years, *physical scientists*[1] in the Western world had known that carbon dioxide (CO_2) and water vapor absorbed heat in the planetary atmosphere. A three-phase Industrial Revolution led to massive release of additional CO_2, initially in the United Kingdom (1750 – 1850); then in Germany, the United States, and the rest of Europe (1850 – 1950); and finally in China, India, and Brazil (1950 – 2050). At the start of the final phase, some scientists recognized that the anthropogenic increment of CO_2 could theoretically warm the planet, but few were concerned; total emissions were still quite low, and in any case most scientists viewed the atmosphere as an essentially unlimited sink. Through the 1960s, it was often said that "the solution to pollution is dilution."

Things began to change as planetary sinks approached saturation. Some effects occurred because of the extreme power of certain chemical agents even at very low concentrations, such as organochlorine insecticides (most famously the pesticide dichlorodiphenyltrichloroethane, or DDT), and chlorinated fluorocarbons (CFCs). The former were shown in the 1960s to disrupt reproductive function in fish, birds, and mammals; scientists correctly predicted in the 1970s that the latter would deplete the stratospheric ozone layer. Other saturation effects occurred because of the huge volume of materials being released into the planetary environment. These materials included sulfates from the combustion of coal as well as CO_2 and methane (CH_4) from fossil fuels, concrete manufacture, deforestation, and then-prevalent agricultural techniques such as growing rice in paddy fields and producing cattle as a primary protein source.

In the 1970s, scientists began to recognize that human activities were changing the physical and biological functions of the planet in consequential ways – giving rise to the Anthropocene Period of Geological History.[2] None of the scientists who made these early discoveries was particularly visionary: many of the relevant studies were by-products of nuclear weapons testing and development.[3] It was the rare man (in those days, sex discrimination was still widespread) who understood that he was in fact studying the limits of planetary sinks.[4] (Along with these findings, scientists also highlighted the phenomenon of *market failure*, a discussion of which appears below.) Major research programs were launched and new institutions created to acknowledge and deal with the issue. Culturally, celebrating the planet was encouraged on an annual Earth Day (as if every day were not an Earth day!), and in the United States the establishment of the Environmental Protection Agency formalized the concept of *environmental protection*. By the late 1980s, scientists had recognized that concentrations of CO_2 and other *greenhouse gases* were having discernible effects on planetary climate, ocean chemistry, and biological systems, threatening grave consequences if not rapidly controlled. Various groups and individuals began to argue for the need to control greenhouse gas emissions and begin a transition to a non-carbon-based energy system.

Historians view 1988 as the start of the Penumbral Period. In that year, scientists created a new hybrid scientific/governmental organization, the Intergovernmental Panel on Climate Change (IPCC), to communicate relevant science and form the foundation for international governance to protect the planet and its denizens. A year later, the Montreal Protocol to Control Substances that Deplete the Ozone Layer became a model for an international framework to control greenhouse gases. In 1992, world nations signed the United Nations Framework Convention on Climate Change (UNFCCC) to prevent "dangerous anthropogenic interference" in the climate system. But there was backlash. Critics claimed that the scientific uncertainties were too great to justify the expense and inconvenience of eliminating greenhouse gas emissions, and that any attempt to solve the problem would cost more than it was worth. At first, just a handful of people made this argument, almost all of them from the United States, although in time, the arguments spread to Canada, Australia, and parts of Europe as well. In hindsight, the self-justificatory aspects of the U.S. position are obvious, but they were not apparent to many at the time. Some nations used inertia in the United States to excuse their own patterns of destructive development. Others tried but failed to force the United States into international cooperation.

By the end of the millennium, denial had spread widely. In the United States, political leaders – including the president of the United States, members of Congress, and members of state legislatures – took denialist positions. In Europe, Australia, and Canada, the message of "uncertainty" was promoted by industrialists, bankers, and some political leaders. (Meanwhile, a different version of denial emerged in non-industrialized nations, which argued that the threat of climate change was being used to prevent their development. The claims had little effect, though, because these countries produced few greenhouse gas emissions.)[5]

By the early 2000s, dangerous anthropogenic interference in the climate system was under way. Fires, floods, hurricanes, and heat waves began to intensify, but these effects were discounted. Those in what we might call *active denial* insisted that the extreme weather events reflected natural variability, despite a lack of evidence to support that claim. Those in *passive denial* continued life as they had been living it, unconvinced that a compelling justification existed for broad changes in industry and infrastructure. Scientists became entangled in arcane arguments about the "attribution" of singular events; however, the threat to civilization inhered not in any individual flood, heat wave, or hurricane, but in the overall shifting climate pattern, its impact on the cryosphere, and the increasing acidification of the world ocean.

The year 2009 is viewed as the "last best chance" the Western world had to save itself, as leaders met in Copenhagen, Denmark, to try, for the fifteenth time since the UNFCCC was written, to agree on a binding, international law to prevent disruptive climate change. Two years before, scientists involved in the IPCC had declared anthropogenic warming to be "unequivocal," and public opinion polls showed that a majority of people – even in the recalcitrant United States – believed that action was warranted. But shortly before the meeting, a massive campaign (funded primarily by fossil fuel corporations, whose annual profits at that time exceeded the GDPs of most countries[6]), was launched to discredit the scientists whose research underpinned the IPCC's conclusion.[7] Public support for action evaporated; even the president of the United States felt unable to move his nation forward.

Meanwhile, climate change was intensifying. In 2010, record-breaking summer heat and fires killed more than 50,000 people in Russia and resulted in over $15 billion (in 2009 USD) in damages. The following year, massive floods in Australia affected more than 250,000 people. In 2012, which became known in the United States as the "year without a winter," winter temperature records, including for the highest overnight lows, were shattered – something that should have been an obvious cause for concern. A summer of unprecedented heat waves and loss of livestock and agriculture followed. The "year without a winter" moniker was misleading, as the warm winter was largely restricted to the United States, but in 2021, the infamous "year of perpetual summer" lived up to its name, taking 500,000 lives worldwide and costing nearly $500 billion in losses due to fires, crop failure, and the deaths of livestock and companion animals.

The loss of pet cats and dogs garnered particular attention among wealthy Westerners, but what was anomalous in 2021 soon became the new normal. Even then, political, business, and religious leaders refused to accept that the primary cause was the burning of fossil fuels. A shadow of ignorance and denial had fallen over people who considered themselves children of the Enlightenment. For this reason, we now know this era as the Period of the Penumbra.

It is clear that in the early twenty-first century, immediate steps should have been taken to begin the Great Energy Transition. Staggeringly, the opposite occurred. At the very time that the urgent need for an energy transition became palpable, world production of greenhouse gases *increased*. This fact is so hard to understand that it calls for a closer look at what we know about this crucial juncture.

In the early Penumbral Period, scientists were accused of being "alarmist" in order to increase financial support for their enterprise, gain attention, or improve their social standing. At first, the accusations took the form of public denunciations; later they included threats, thefts, and the subpoena of private correspondence.[8] Then legislation was passed (particularly in the United States) that placed limits on what scientists could study and how they could study it, beginning with the notorious "Sea Level Rise Denial Bill," passed in 2012 by the government of what was then the U.S. state of North Carolina (now part of the Atlantic Continental Shelf)[9] and the Government Spending Accountability Act of 2012, which restricted the ability of government scientists to attend conferences to share and analyze the results of their research.[10]

Though ridiculed when first introduced, the Sea Level Rise Denial Bill would become the model for the U.S. National Stability Protection Act of 2022, which led to the conviction and imprisonment of more than three hundred scientists for "endangering the safety and well-being of the general public with unduly alarming threats."[11] By exaggerating the threat, it was argued, scientists were preventing the economic development essential for coping with climate change. When the scientists appealed, their convictions were upheld by the U.S. Supreme Court under the Clear and Present Danger doctrine, which permitted the government to limit speech deemed to represent an imminent threat.

Had scientists exaggerated the threat, inadvertently undermining the evidence that would later vindicate them? Certainly, narcissistic fulfillment played a role in the public positions that some scientists took, and in the early part of this period, funds flowed into climate research at the expense of other branches of science, not to mention other forms of intellectual and creative activity. (It is remarkable how little these extraordinarily wealthy nations spent supporting artistic production; one explanation may be that artists were among the first to truly grasp the significance of the changes that were occurring.[12]) However, by 2010 or so, it was clear that scientists had been *underestimating* the threat, as new developments outpaced early predictions of warming, sea level rise, and Arctic ice loss, among other parameters.[13]

It is difficult to understand why humans did not respond appropriately in the early Penumbral Period, when preventive measures were still possible. Many have sought an answer in the general phenomenon of *human adaptive optimism*, which later proved crucial for survivors. Even more elusive to scholars is why scientists, whose job it was to understand the threat and warn their societies – and who thought that they *did* understand the threat and that they *were* warning their societies – failed to appreciate the full magnitude of climate change. To shed light on this question, scholars have pointed to the roots of Western natural science in religious institutions.

In an almost childlike attempt to demarcate their practices from those of older explanatory traditions, scientists felt it necessary to prove to themselves and the world how strict they were in their intellectual standards. Thus, they placed the burden of proof on novel claims, including those about climate. Some scientists in the early twenty-first century, for example, had recognized that hurricanes were intensifying, but they backed down from this conclusion under pressure from their scientific colleagues. Much of the argument surrounded the concept of *statistical significance*. Given what we now know about the dominance of nonlinear systems and the distribution of stochastic processes, the then-dominant notion of a 95 percent confidence limit is hard to fathom. Yet overwhelming evidence suggests that twentieth-century scientists believed that a claim could be accepted only if, by the standards of Fisherian statistics, the possibility that an observed event could have happened by chance was less than 1 in 20. Many phenomena whose causal mechanisms were physically, chemically, or biologically linked to warmer temperatures were dismissed as "unproven" because they did not adhere to this standard of demonstration.

Historians have long argued about why this standard was accepted, given that it had no substantive mathematical basis. We have come to understand the 95 percent confidence limit as a social convention rooted in scientists' desire to demonstrate their disciplinary severity. Just as religious orders of prior centuries had demonstrated moral rigor through extreme practices of asceticism in dress, lodging, behavior, and food – in essence, practices of physical self-denial – so, too, did natural scientists of the twentieth century attempt to demonstrate their intellectual rigor through intellectual self-denial.[14] This practice led scientists to demand an excessively stringent standard for accepting claims of any kind, even those involving imminent threats.

Western scientists built an intellectual culture based on the premise that it was worse to fool oneself into believing in something that did not exist than not to believe in something that did. Scientists referred to these positions as "type I" and "type II" errors, and established protocols designed to avoid type I errors at almost all costs. One scientist wrote, "A type I error is often considered to be more serious, and therefore more important to avoid, than a type II error." Another claimed that type II errors were not errors at all, just "missed opportunities."[15] So while the pattern of weather events was clearly changing, many scientists insisted that these events could not yet be attributed with certainty to anthropogenic climate change. Even as lay citizens began to accept this link, the scientists who studied it did not.[16] More important, political leaders came to believe that they had more time to act than they really did. The irony of these beliefs need not be dwelt on; scientists missed the most important opportunity in human history, and the costs that ensued were indeed nearly "all costs."

By 2012, more than 365 billion tons of carbon had been emitted into the atmosphere since 1751. Staggeringly, more than half of these emissions occurred *after* the mid-1970s – that is, *after* scientists had built computer models demonstrating that greenhouse gases would cause warming. Emissions continued to accelerate even after the UNFCCC was established: between 1992 and 2012, total CO_2 emissions increased by 38 percent.[17] Some of this increase was understandable, as energy use grew in poor nations seeking to raise their standard of living. Less explicable is why, at the very moment when disruptive climate change was becoming apparent, wealthy nations dramatically increased their production of fossil fuels. The countries most involved in this enigma were two of the world's richest: the United States and Canada.

A key turning point was 2005, when the U.S. Energy Policy Act exempted shale gas drilling from regulatory oversight under the Safe Drinking Water Act. This statute opened the floodgates (or, more precisely, the wellheads) to massive increases in shale gas production.[18] U.S. shale gas production at that time was less than 5 trillion cubic feet (Tcf, archaic imperial units) per annum. By 2035, it had increased to 13.6 Tcf. As the United States expanded shale gas production and exported the relevant technology, other nations followed. By 2035, total gas production had exceeded 250 Tcf per annum.[19]

In the late twentieth century, Canada was considered an advanced nation with a high level of environmental sensitivity. This changed around the year 2000, when Canada's government began to push for development of huge oil sand deposits in the province of Alberta. While these deposits had been mined intermittently since the 1960s, the rising cost of conventional oil had made sustained exploitation economically feasible. The fact that 70 percent of the world's known reserves were in Canada explains the government's new denialist position on climate change: in 2011, Canada withdrew from the Kyoto Protocol to the UNFCCC.[20] Under the protocol, Canada had committed to cut its emissions by 6 percent, but its actual emissions increased more than 30 percent during this period.[21]

The massive increase in shale gas led to a collapse in the price of natural gas, driving out nascent renewable energy industries everywhere except China. Then the United States implemented laws forbidding the use of biodiesel fuels – first by the military, and then by the general public – undercutting that emerging market as well.[22] Bills were passed to restrict the development and use of other forms of renewable energy, maintaining the lock that fossil fuel companies had on energy production and use.[23]

How did these wealthy nations – rich in the resources that would have enabled an orderly transition to a zero net-carbon infrastructure – justify the deadly expansion of fossil fuel production? Certainly, they fostered the shadow of denial that obscured the link between climate change and fossil fuel production and consumption. They also entertained a second delusion: that natural gas from shale could offer a "bridge to renewables." Believing that conventional oil and gas resources were running out (which they were, but at a rate insufficient to avoid disruptive climate change), and stressing that natural gas, when combusted, produced only half as much CO_2 as coal, political and economic leaders persuaded themselves and their constituents that promoting shale gas was an environmentally and ethically sound approach.

This line of reasoning, however, neglected three crucial factors. First, *fugitive methane emissions* – CH_4 that escaped unburned into the atmosphere – greatly accelerated warming. (Again, scientists had foreseen this phenomenon, but their predictions were buried in specialized journals.) Second, the argument presupposed that net CO_2 emissions would fall, which would have required strict restrictions on coal and petroleum use.[24] Third, and most important, the sustained low prices of fossil fuels, supported by continued subsidies and a lack of external cost accounting, undercut efficiency efforts and weakened emerging markets for solar, wind, and biofuels (including crucial liquid biofuels for aviation).[25] Thus, the bridge to a zero-carbon future collapsed before the world had crossed it. The bridge to the future became a bridge to nowhere.

The net result? Fossil fuel production escalated, greenhouse gas emissions increased, and climate disruption accelerated. In 2001, the IPCC had predicted that atmospheric CO_2 would double by 2050.[26] In fact, that benchmark had been met by 2042. Scientists had expected a mean global warming of 2 to 3 degrees Celsius; the actual figure was 3.9 degrees. Though originally merely a benchmark for discussion with no particular physical meaning, the doubling of CO_2 emissions turned out to be significant: once the corresponding temperature rise reached 4 degrees, rapid changes began to ensue.

By 2040, heat waves and droughts were the norm. Control measures such as water and food rationing and Malthusian drills had been widely implemented. In wealthy countries, hurricane- and tornado-prone regions were depopulating, putting increased social pressure on areas less subject to those hazards. In poor nations, conditions were predictably worse: rural portions of Africa and Asia were already experiencing significant depopulation from out-migration, malnutrition-induced disease and infertility, and starvation. Still, sea level had risen only 9 to 15 centimeters around the globe, and coastal populations were mainly intact.

Then, in the Northern Hemisphere summer of 2041, unprecedented heat waves scorched the planet, destroying food crops around the globe. Panic ensued, with food riots in virtually every major city. Mass migration of undernourished and dehydrated individuals, coupled with explosive increases in insect populations, led to widespread outbreaks of typhus, cholera, dengue fever, yellow fever, and, strangely, AIDS (although a medical explanation for the latter has never been forthcoming). Surging insect populations also destroyed huge swaths of forests in Canada, Indonesia, and Brazil. As social order broke down, governments were overthrown, particularly in Africa, but also in many parts of Asia and Europe, further decreasing social capacity to deal with increasingly desperate populations. The U.S. government declared martial law to prevent food riots and looting, and the United States and Canada announced that the two countries would form the United States of North America in order to begin resource-sharing and northward population relocation. The European Union announced similar plans for voluntary northward relocation of eligible citizens from its southernmost regions to Scandinavia and the United Kingdom.

While governments were straining to maintain order and provide for their people, leaders in Switzerland and India – two countries that were rapidly losing substantial portions of their glacially sourced water resources – convened the First

International Emergency Summit on Climate Change, organized under the rubric of Unified Nations for Climate Protection (the former United Nations having been discredited and disbanded over the failure of the UNFCCC). Political, business, and religious leaders met in Geneva and Chandigarh to discuss emergency action. Many said that the time had come to make the Great Energy Transition. Others argued that the world could not wait the ten to fifty years required to alter the global energy infrastructure, much less the one hundred years it would take for atmospheric CO_2 to diminish. In response, participants hastily wrote and signed the Unified Nations Convention on Climate Engineering and Protection (UNCCEP), and began preparing blueprints for the International Climate Cooling Engineering Project (ICCEP).

As a first step, ICCEP launched the International Aerosol Injection Climate Engineering Project (IaICEP, pronounced ay-yi-sep) in 2042.[27] IaICEP had widespread support from wealthy nations anxious to preserve some semblance of order, poor nations desperate to see the world do something to address their plight, and frantic low-lying Pacific Island nations at risk of being submerged by rising sea levels.

IaICEP began to inject submicrometer-size sulfate particles into the stratosphere at a rate of approximately 2.0 teragrams per year, expecting to reduce mean global temperature by 0.1 degrees Celsius annually from 2042 to 2062. (In the meantime, a substantial infrastructural conversion to renewable energy could be achieved.[28]) Initial results were encouraging: during the first three years of implementation, temperature decreased as expected and the phaseout of fossil fuel production commenced. However, in the project's fourth year, an anticipated – but discounted – side effect occurred: the shutdown of the Indian Monsoon. As crop failures and famine swept across India, IaICEP's most aggressive promoter now called for its immediate cessation.

IaICEP was halted in 2047, but a fatal chain of events had already been set in motion. It began with *termination shock*: that is, the abrupt increase in global temperatures following the sudden cessation of IaICEP. Once again, this phenomenon had been predicted, but IaICEP advocates had successfully argued that, given the emergency conditions, the world had no choice but to take the risk.[29] In the following eighteen months, temperature rapidly rebounded, regaining not just the 0.4 degrees Celsius that had been reduced during the project but an additional 0.6 degrees. This rebound effect pushed the mean global temperature increase to nearly 5 degrees Celsius.

Whether it was caused by this sudden additional heating or would have happened anyway is not known, but the greenhouse effect then reached a global tipping point. By 2050, Arctic summer ice was completely gone. Scores of species perished, including the iconic polar bear, the dodo bird of the twenty-first century. While the world focused on these highly visible losses, warming had meanwhile accelerated a less visible but widespread thawing of Arctic permafrost. Scientists monitoring the phenomenon observed a sudden increase in permafrost thaw and CH_4 release. Exact figures are not available, but the estimated total carbon release from Arctic CH_4 during the next decade may have reached over 1,000 gigatons, effectively doubling the total atmospheric carbon load.[30] This massive addition of carbon led to what is known as the Sagan effect (sometimes more dramatically called the Venusian death): a strong positive feedback loop between warming and CH_4 release. Planetary temperature increased by an additional 6 degrees Celsius over the 5 degree rise that had already occurred.

The ultimate blow for Western civilization came in a development that, like so many others, had long been discussed but rarely considered as a serious threat, at least not in the twenty-first century. Technically, what happened in West Antarctica was not, in fact, a collapse. The ice sheet did not fall in on itself, and it did not happen all at once. The collapse was more of a rapid disintegration. Post hoc failure analysis shows that extreme heat in the Northern Hemisphere disrupted normal patterns of ocean circulation. This sent exceptionally warm surface waters into the southern ocean, which destabilized the ice sheet from below. As large pieces of ice shelf began to separate from the main ice sheet, removing the bulwark that had kept the sheet on the Antarctic mainland, sea level began to rise rapidly.

Social disruption hampered scientific data-gathering, but some dedicated individuals – realizing the damage could not be stopped – sought, at least, to chronicle it. Over the course of the next decade, approximately 90 percent of the ice sheet broke apart, disintegrated, and melted, driving up sea level approximately three meters across most of the globe. Meanwhile, the Greenland Ice Sheet, long thought to be less stable than the Antarctic Ice Sheet, began its own disintegration. As summer melting reached the center of the Greenland Ice Sheet, the east side began to separate from the west. Massive ice breakup ensued, adding another two meters to mean global sea level rise.[31]

Analysts had predicted that a five-meter sea level rise would dislocate 10 percent of the global population. Alas, their estimates proved low: the reality was closer to 20 percent. Although records for this period are incomplete, it is likely that 1.5 billion people were displaced around the globe, either directly from the impacts of sea level rise or indirectly from other impacts of climate change, including the secondary dislocation of inland peoples whose towns and villages were overrun by eustatic refugees. Dislocation contributed to the Second Black Death, as a new strain of the bacterium *Yersinia pestis* emerged in Europe and spread to Asia and North America. In the Middle Ages, the Black Death killed as much as half the population of Europe; this second Black Death had similar effects.[32] Disease also spread among stressed nonhuman populations. Although accurate statistics are scant because twentieth-century scientists did not have an inventory of total global species, it is not unrealistic to estimate that 60 to 70 percent of species were driven to extinction.

There is no need to rehearse the details of the human tragedy that occurred; every schoolchild knows of the terrible suffering. Survivors' accounts make clear that many thought the end of the human race was near; had the Sagan effect continued, warming would not have stopped at 11 degrees. However, when a key species of lichen evolved to use atmospheric CO_2 more efficiently,[33] this adaptation, coupled with a fortuitous shift in Earth's orbit, reversed the warming trend. Survivors in northern inland regions of Europe, Asia, and North America, as well as inland and high altitude regions of South America, were able to begin to regroup and rebuild. The human populations of Australia and Africa, of course, were wiped out.

To the historian studying this tragic period of human history, the most astounding fact is that the victims *knew what was happening and why*. Indeed, they chronicled it in detail precisely *because* they knew that fossil fuel combustion was to blame. Historical analysis also shows that Western civilization had the technological know-how and capability to effect an orderly transition to renewable energy, yet the available technologies were not implemented in time.[34] As with all great historical developments, there is no easy answer to the question of why this catastrophe occurred, but key factors stand out. The thesis of this analysis is that Western civilization became trapped in the grip of two inhibiting ideologies: namely, *positivism* and *market fundamentalism*.

Twentieth-century scientists saw themselves as the descendants of an empirical tradition often referred to as *positivism* – after the nineteenth-century French philosopher Auguste Comte, who developed the concept of "positive" knowledge (as in, "absolutely, positively true") – but the overall philosophy is more accurately known as *Baconianism*. This philosophy held that through experience, observation, and experiment, one could gather reliable knowledge about the natural world, and that this knowledge would empower its holder. Experience justified the first part of the philosophy (we have recounted how twentieth-century scientists anticipated the consequences of climate change), but the second part proved less compelling. Although billions of dollars were spent on climate research in the late twentieth and early twenty-first century, the resulting knowledge had little impact on the crucial economic and technological policies that drove the continued use of fossil fuels.

A key attribute of the period was that power did not reside in the hands of those who understood the climate system, but rather in political, economic, and social institutions that had a strong interest in maintaining the use of fossil fuels. Historians have labeled this system the *carbon-combustion complex*: a network of powerful industries comprised of primary fossil fuel producers; secondary industries that served fossil fuel companies (drilling and oil field service companies, large construction firms, and manufacturers of plastics and other petrochemicals); tertiary industries whose products relied on inexpensive fossil fuels (especially automobiles and aviation); and financial institutions that serviced their capital demands. Maintaining the carbon-combustion complex was clearly in the self-interest of these groups, so they cloaked this fact behind a network of "think tanks" that issued challenges to scientific knowledge they found threatening.[35] Newspapers often quoted think tank employees as if they were climate researchers, juxtaposing their views against those of university-based scientists. This practice gave the public the impression that the science was still uncertain, thus undermining the sense that it was time to act.[36] Meanwhile, scientists continued to do science, believing, on the one hand, that it was inappropriate for them to speak to political questions (or to speak in the emotional register required to convey urgency) and, on the other hand, that if they produced abundant and compelling scientific information (and explained it calmly and clearly), the world would take steps to avert disaster.

Scientists, to their credit, recognized some of the difficulties they were facing, and were grappling with how to communicate their knowledge effectively.[37] While they were making some headway, a large part of Western society was rejecting that knowledge in favor of an empirically inadequate yet powerful ideological system. Even at the time, some recognized this system as a quasi-religious faith, hence the label *market fundamentalism*.

Market fundamentalism – also known as free market fundamentalism, neoliberalism, laissez-faire economics, and laissez-faire capitalism – was a two-pronged ideological system. The first prong held that societal needs were served most efficiently in a free market economic system. Guided by the "invisible hand" of the marketplace, individuals would freely respond to each other's needs, establishing a net balance between solutions ("supply") and needs ("demand"). The second prong of the philosophy maintained that free markets were not merely a good or even the best manner of satisfying material wants: they were the *only* manner of doing so that did not threaten personal freedom.

The crux of this second point was the belief that marketplaces represented distributed power. Various individuals making free choices held power in their hands, preventing its undue concentration in centralized government. Conversely, centrally planned economies entailed not just the concentration of economic power, but of political power as well. Thus, to protect personal liberty – political, civic, religious, artistic – economic liberty had to be preserved. The philosophy, called *neoliberalism*, hearkened back to the liberalism of the eighteenth- and nineteenth-century Enlightenment, particularly the works of Adam Smith, David Hume, John Locke, and, later, John Stuart Mill. Reacting to the dominant form of Western governance in their time – that is, monarchy – these thinkers lionized personal liberty in contrast to control by unjust and arbitrary despots. At a time when some political leaders were imagining alternatives to despotic monarchy, many viewed the elevation of individual rights as a necessary response. In the late eighteenth century, these views influenced the architects of the American Republic and the early, "liberal" phase of the French Revolution. Even then, however, such views were more idealistic than realistic; slavery persisted in the United States, and in Europe, the French Revolution collapsed in a wave of violence and the restoration of autocratic rule under Napoleon Bonaparte.

In the nineteenth century, power became concentrated in the hands of industrialists (the "robber barons" of the United States and elsewhere), challenging liberal conceptions of the desirability of weak political governance.[38] In Europe, the German philosopher Karl Marx argued that an inherent feature of the capitalist system was the concentration of wealth and power in a ruling class that siphoned off the surplus value produced by workers. Industrialists not only employed workers under brutal and tyrannical conditions (the nineteenth-century "satanic mills"), they also corrupted democratic processes through bribery and extortion, and distorted the marketplace through a variety of practices. A powerful example is the development and expansion of American railroads. Supply of these "roads to nowhere" was heavily subsidized, and the demand for them was manufactured at the expense of the native peoples and natural environment of the American West.[39]

Marx's analysis inspired popular leaders in many nation-states then in existence – for example, Russia, China, Vietnam, Ghana, and Cuba – to turn to Communism as an alternative economic and social system. Meanwhile, the capitalist United States abolished slavery and made adjustments to remedy power imbalances and losses of liberty due to the concentration of wealth. Among other reforms, the federal government introduced *antitrust laws* to prevent monopolistic practices, established worker protections such as prohibitions on child labor, and introduced a progressive income tax. By the early twentieth century, few could argue that capitalism in its theoretical form was a functional social and economic system: the failures were too obvious. Intellectuals came to see the invisible hand, akin to the hand of God, as the quasi-religious notion that it was. The Great Depression of the 1930s – from which Europe and the United States emerged only through the centralized mobilization of World War II – led scholars and political leaders to view the idea of self-regulating markets as unworkable. After the War, most non-Communist states became "mixed" economies with a large degree of individual and corporate freedom as well as significant government involvement in markets, including extensive systems of taxes, tariffs, subsidies, and immigration control.[40]

Communism, which had spread throughout Eurasia and to some parts of Africa and Latin and South America, was revealing even worse failures than capitalism. Communist economies proved grossly inefficient at delivering goods and services; politically, early ideas of mass empowerment gave way to tyrannical and brutal dictatorship. In the Soviet Union under Joseph Stalin (1878–1953; ruled 1941–1953), tens of millions died in purges, forced collectivization of agriculture, and other forms of internal violence. Tens of millions died in China as well during the "Great Leap Forward" – the attempt by 毛泽东 (Mao Zedong, 1893–1976; ruled 1949–1976) to force rapid industrialization.[41]

Following World War II, the specter of Russian Communism's spread into Eastern (and possibly even Western) Europe – thus affecting U.S. access to markets and stoking fears that the West could sink back into economic depression – led the United States to take a strong position against Soviet expansion. Conversely, the Soviet Union's desire to control its western flanks in light of historic vulnerability led to the political occupation and control of Eastern Europe. The resulting Cold War (1945–1989) fostered a harshly polarized view of economic systems, with "communists" decrying the corruption of the capitalist system and "capitalists" condemning the tyranny and violence in Communist regimes.[42] Perhaps because of the horrible violence in the East, many Western intellectuals came to see everything associated with Communism as evil, even – and crucially for our story – modest or necessary forms of intervention in the marketplace, such as progressive taxation and environmental regulation, and humanitarian interventions, such as effective and affordable regimes of health care and birth control.

Neoliberalism was developed by a group of thinkers – most notably, Austrian Friedrich von Hayek and American Milton Friedman – who were particularly sensitive to the issue of repressive centralized government. In two key works, von Hayek's *Road to Serfdom* and Friedman's *Capitalism and Freedom*, they developed the crucial "neo-" component of neoliberalism: the idea that free market systems were the only economic systems that did not threaten individual liberty.

Neoliberalism was initially a minority view. In the 1950s and 1960s, the West experienced high overall prosperity, and individual nations developed mixed economies that suited their own national cultures and contexts. Things began to shift in the late 1970s and 1980s, when Western economies stalled and neoliberal ideas attracted world leaders searching for answers to their countries' declining economic performance, such as Margaret Thatcher in the United Kingdom and Ronald Reagan in the United States. Friedman became an advisor to President Reagan; in 1991, von Hayek received the Presidential Medal of Freedom from President George H.W. Bush.[43]

The end of the Cold War (1989–1991) was a source of celebration for citizens who had lived under the yoke of oppressive Soviet-style governance; it also ignited a slow process of overdue reforms in the First People's Republic of China. But for many observers in the West, the Soviet Union's collapse gave rise to an uncritical triumphalism, proof of the absolute superiority of the capitalist system. Some went further, arguing that if capitalism was a superior system, then the best system was capitalism in its purest form. While it is possible that some academic economists and intellectuals genuinely held this view, it was industrialists and financiers, who perceived large opportunities in less regulated marketplaces, who did the most to spread and promote it. As a result, the 1990s and 2000s featured a wave of deregulation that weakened consumer, worker, and environmental protections. A second Gilded Age reproduced concentrations of power and capital not seen since the nineteenth century, with some of the accumulated capital used to finance think tanks that further promoted neoliberal views. Most important for our purposes, neoliberal thinking led to a refusal to admit the most important limit of capitalism: market failure.

When scientists discovered the limits of planetary sinks, they also discovered market failure. The toxic effects of DDT, acid rain, the depletion of the ozone layer, and climate change were serious problems for which markets did not provide a spontaneous remedy. Rather, government intervention was required: to raise the market price of harmful products, to prohibit those products, or to finance the development of their replacements. But because neoliberals were so hostile to centralized government, they had, as Americans used to say, "painted themselves into a corner." The American people had been persuaded, in the words of President Reagan, that government was "the problem, not the solution." Thus, citizens slid into passive denial, accepting the contrarian arguments that the science was unsettled. Lacking widespread support, government leaders were unable to shift the world economy to a net carbon-neutral energy base. As the implications for market failure became indisputable, scientists came under attack, blamed for problems they had not caused but merely documented.

These physical scientists were chief among the individuals and groups who tried to warn the world of climate change, both before and as it happened. (In recognition of, and gratitude for, what they tried to achieve, millions of survivors have taken their names as middle names.)[44] In addition, social scientists introduced the concept of "late lessons from early warnings" to describe a growing tendency to neglect information. As a remedy, they promoted a *precautionary principle*, whereby early action would prevent later damage.[45] Yet the idea of managing energy use and controlling greenhouse gas emissions was anathema to the neoliberal economists whose thinking dominated at this crucial juncture. Thus, no planning was done, no precautions were taken, and no management ensued until it was disaster management.

Discerning neoliberals acknowledged that the free market was not really free; interventions were everywhere. Some advocated eliminating subsidies for fossil fuels and creating "carbon" markets.[46] Others recognized that certain interventions could be justified. Von Hayek himself was not opposed to government intervention per se; indeed, as early as 1944, he rejected the term *laissez-faire* as misleading because he recognized legitimate realms of government intervention: "The successful use of competition as the principle of social organization precludes certain types of coercive interference with economic life, but it admits of . . . and even requires [others]," he wrote. In his view, legitimate interventions included paying for signposts on roads, preventing "harmful effects of deforestation, of some methods of farming, or of the noise and smoke of factories," prohibiting the use of poisonous substances, limiting working hours, enforcing sanitary conditions in workplaces, controlling weights and measures, and preventing violent strikes.[47] Von Hayek simply (and reasonably) believed that if the government was to carry out such functions, and particularly if doing so *selectively* limited the freedom of particular groups or individuals, then the justification for intervention should be clear and compelling. Given the events recounted here, it is hard to imagine why anyone in the twentieth century would have argued against government protection of the natural environment on which human life depends. Yet such arguments were not just made, they dominated the discussion.[48]

As the devastating effects of the Great Collapse began to appear, the nation-states with democratic governments – both parliamentary and republican – were at first unwilling and then unable to deal with the unfolding crisis. As food shortages and disease outbreaks spread and sea level rose, these governments found themselves without the infrastructure and organizational ability to quarantine and relocate people.

In China, the situation was somewhat different. Like other post-socialist nations, China had taken steps toward liberalization but still retained a strong, centralized government. When sea level rise began to threaten coastal areas, China rapidly built new inland cities and villages and relocated more than 250 million people to higher, safer ground.[49] The relocation was not easy; many older citizens, as well as infants and young children, could not manage the transition. Nonetheless, survival rates exceeded 80 percent. To many survivors – in what might be viewed as a final irony of our story – China's ability to weather disastrous climate change vindicated the necessity of centralized government, leading to the establishment of the Second People's Republic of China and inspiring similar structures in other, reformulated nations. By blocking anticipatory action, neoliberals did more than expose the tragic flaws in their own system: they fostered expansion of the very system of government that they most abhorred.

Today, we remain engaged in a vigorous intellectual discussion of whether, now that the climate system has finally stabilized, decentralization and redemocratization may be considered. Many academics, in the spirit of history's great thinkers, hope that such matters may be freely debated. Others consider that outcome wishful, in light of the dreadful events of the past, and reject the reappraisal that we wish to invite here. Evidently, the Penumbra falls even today – and likely will continue to fall for years, decades, and perhaps even centuries to come.

ENDNOTES

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1 For convenience, I use the historical categories of *physical science* and *physical scientists*, recognizing the Western convention at that time of studying the physical world in isolation from social systems. I also use the nation-state terms of the era. For the reader not familiar with the physical geography of Earth prior to the Great Collapse, the remains of the United Kingdom can be found in present-day Englascotland; Germany in the Nordo-Scandinavian Union; and the United States and Canada in the United States of North America.

2 http://www.quaternary.stratigraphy.org.uk/workinggroups/anthropocene/.

3 Ronald Doel, "Constituting the Postwar Earth Sciences: The Military's Influence on the Environmental Sciences in the USA after 1945," *Social Studies of Science* 33 (2003): 535–666; Naomi Oreskes, *Science on a Mission: American Oceanography from the Cold War to Climate Change* (Chicago: University of Chicago Press, forthcoming).

4 A notable exception was the futurist Paul Ehrlich, whose book *The Population Bomb* (New York: Ballantine Books, 1968) was widely read in the late 1960s but was considered to have been discredited by the 1990s.

5 China took steps to control its population and convert its economy to non-carbon-based energy sources. These efforts were little noticed and less emulated in the West, in part because Westerners viewed Chinese population control efforts as immoral, and because, in the short run, greenhouse gas emissions were increasing dramatically in China. However, by 2020, China's emissions were falling rapidly. Had other nations followed China's lead, the history I am recounting here might have been very different. On the various forms of Chinese population control, see Susan Greenhalgh, *Just One Child: Science and Policy in Deng's China* (Berkeley: University of California Press, 2008).

6 At the time, most countries still used the archaic concept of a *gross domestic product*, a measure of consumption, rather than the Bhutanian concept of gross domestic happiness to evaluate well-being in a state.

7 http://unfccc.int/meetings/copenhagen_dec_2009/meeting/6295.php.

8 Michael Mann, *The Hockey Stick and the Climate Wars: Dispatches from the Front Lines* (New York: Columbia University Press, 2011). A less known but crucial incident was the seizing of scientific notes from scientists who had documented the damage caused by the 2011 BP Deepwater Horizon oil spill. Though leaders of the scientific community protested, scientists yielded to the demands, thus helping set the stage for further pressure on scientists from both governments and the industrial enterprises that governments subsidized and protected. See http://www.wired.com/wiredscience/2012/06/bp-scientist-emails/.

9 Seth Cline, "Sea Level Bill Would Allow North Carolina to Stick Its Head in the Sand," *U.S. News & World Report*, June 1, 2012, http://www.usnews.com/news/articles/2012/06/01/sea-level-bill-would-allow-north-carolina-to-stick-its-head-in-the-sand. One comedian at the time made a satire of the law; little did he know what impact it would later have. See Stephen Colbert, "The Word – Sink or Swim," *The Colbert Report*, June 4, 2012, http://www.colbertnation.com/the-colbert-report-videos/414796/june-04-2012/the-word---sink-or-swim.

10 Government Spending Accountability Act of 2012, 112th Cong., 2012, H.R. 4631, http://oversight.house.gov/wp-content/uploads/2012/06/WALSIL_032_xml.pdf.

11 *Hansen et al. v. United States*, 1025 U.S. 722 (2032). Hansen was deceased when the case reached the Supreme Court, nine years after the original conviction. In a speech following the ruling, co-defendant Kevin Trenberth stated, "There is nothing good to be said about this decision, except that I am relieved that James Hansen is not here to witness it"; http://www.independentscientificvoice.org.

12 The most enduring literary work of this time is a science "fiction" trilogy by an American writer; see Kim Stanley Robinson, *Forty Signs of Rain, Fifty Degrees Below,* and *Sixty Days and Counting* (New York: Spectra Publishers, 2005 – 2007). Sculptor Dario Robleto also "spoke" to the issue, particularly species loss; his material productions have been lost, but a response to his work is recorded in Naomi Oreskes, "Seeing Climate Change," in *Dario Robleto: Survival Does Not Lie in the Heavens*, ed. Gilbert Vicario (Des Moines, Iowa: Des Moines Art Center, 2011). Some environmentalists also anticipated what was to come, notably the Australians Clive Hamilton and Paul Gilding. Perhaps because Australia's population was highly educated and living on a continent at the edge of habitability, it was particularly sensitive to the changes under way. See Clive Hamilton, *Requiem for a Species: Why We Resist the Truth about Climate Change* (Sydney: Allen and Unwin, 2010), http://www.clivehamilton.net.au/cms/; and Paul Gilding, *The Great Disruption: Why the Climate Crisis Will Bring On the End of Shopping and the Birth of a New World* (New York: Bloomsbury Press, 2010).

13 For an electronic archive of predictions and data as of 2012, see http://www.columbia.edu/~mhs119/Temperature/T_moreFigs/. An interesting unpublished paper found in the translocated archives of the University of California, San Diego, addresses the issue of under-prediction; see Keynyn Brysse et al., "Climate Change Prediction: Erring on the Side of Least Drama?" paper submitted to *Global Environmental Change*, 2012. Whether this paper was ever published – or read – is unknown.

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15 Naomi Oreskes and Erik M. Conway, *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Climate Change* (New York: Bloomsbury, 2010), chap. 5, esp. 157 n.91 – 92. See also Aaron M. McCright and Riley E. Dunlap, "Challenging Global Warming as a Social Problem: An Analysis of the Conservative Movement's Counter-claims," *Social Problems* 47 (2000): 499 – 522; Aaron M. McCright and Riley E. Dunlap, "Cool Dudes: The Denial of Climate Change among Conservative White Males in the United States," *Global Environmental Change* 21 (2011): 1163 – 1172.

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[20] Emil D. Attanasi and Richard F. Meyer, "Natural Bitumen and Extra-Heavy Oil," in *Survey of Energy Resources*, 22nd ed. (London: World Energy Council, 2010), 123–140.

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[31] http://www.sciencedaily.com/releases/2012/03/120312003232.htm; http://www.pnas.org/content/105/38/14245.short.

[32] Philip Ziegler, *The Black Death* (London: The Folio Society, 1997).

33 Remarkably, this possibility was imagined by the science fiction writer Kim Stanley Robinson.

34 Amory Lovins, *Reinventing Fire: Bold Business Solutions for the New Energy Era* (White River Junction, Vt.: Chelsea Green Publishing, 2011).

35 Oreskes and Conway, *Merchants of Doubt*.

36 For an example of this characteristic, see Justin Gillis, "Rising Sea Levels Seen as Threat to Coastal U.S.," *The New York Times*, March 13, 2012, http://www.nytimes.com/2012/03/14/science/earth/study-rising-sea-levels-a-risk-to-coastal-states.html. Note how Gillis frames the evidence, first stating that "the handful of climate researchers who question the scientific consensus about global warming do not deny that the ocean is rising. But they often assert that the rise is a result of natural climate variability." He then quotes Myron Ebell, who was not a climate researcher, but an economist and paid employee of the Competitive Enterprise Institute, a think tank that was heavily funded by the carbon-combustion complex and committed to market fundamentalism. See http://cei.org/.

37 Richard Somerville, *The Forgiving Air: Understanding Environmental Change* (Washington, D.C.: American Meteorological Society, 2008); Stephen H. Schneider, *Science as a Contact Sport: Inside the Battle to Save the Earth's Climate* (Washington, D.C.: National Geographic Press, 2009); Gavin Schmidt and Joshua Wolfe, *Climate Change: Picturing the Science* (New York: W.W. Norton and Company, 2009); James Hansen, *Storms of My Grandchildren* (New York: Bloomsbury Press, 2010); Burton Richter, *Beyond Smoke and Mirrors: Climate Change and Energy in the 21st Century* (Cambridge: Cambridge University Press, 2010); Mann, *The Hockey Stick and the Climate Wars*. For an analysis of scientists' difficulties in dealing efficaciously with public communication media, see Maxwell T. Boykoff, *Who Speaks for the Climate? Making Sense of Media Reporting on Climate Change* (Cambridge: Cambridge University Press, 2011).

38 For want of space, I have omitted a discussion of slavery. Suffice it to say that this was both a contradiction to the liberal ideal of personal freedom and a violation of free markets.

39 Richard White, *Railroaded: The Transcontinentals and the Making of Modern America* (New York: W.W. Norton, 2011).

40 Scholars noted that even nineteenth-century markets were not free. See Ha-Joon Chang, *Bad Samaritans: The Myth of Free Trade and the Secret History of Capitalism* (New York: Bloomsbury, 2008); and Ha-Joon Chang, *23 Things They Don't Tell You about Capitalism* (New York: Bloomsbury, 2012).

41 Dennis Tao Yang, "China's Agricultural Crisis and Famine of 1959–1961: A Survey and Comparison to Soviet Famines," *Comparative Economic Studies* 50 (2008): 1–29.

42 Here, the terms *capitalist* and *communist* appear in quotes to acknowledge that neither system was either purely communist or purely capitalist.

43 George H.W. Bush, "Remarks on Presenting the Presidential Medal of Freedom Awards," November 18, 1991.

44 Another irony of this period is that Friedrich von Hayek had great respect and admiration for the scientific enterprise, seeing it as a companion to "free" enterprise capitalism. By fostering commerce, von Hayek suggested, science and industry were closely linked to the rise of capitalism and the growth of political freedom; this view was shared by mid-twentieth-century advocates for an expanded role of government in promoting scientific investigations (see Naomi Oreskes, "Science, Technology, and Free Enterprise," *Centaurus* 52 [2011]: 297–310; and John Krige, *American Hegemony and the Postwar Reconstruction of Science in Europe* [Cambridge, Mass.: MIT Press, 2006]). However, when environmental science showed that government action was needed to protect citizens and the natural environment from unintended harms, the carbon-combustion complex began to treat science as an enemy to be fought by whatever means necessary. The very science that had led to U.S. victory in World War II and dominance in the Cold War became the target of skepticism, scrutiny, and attack. Science, of course, was also the subject of attack in Communist nations, although for different reasons. See, for example, David Joravsky, *The Lysenko Affair* (Chicago: University of

Chicago Press, 1986); and Nils Roll-Hansen, *The Lysenko Effect* (Amherst, N.Y.: Humanity Books, 2004).

45 The *precautionary principle* was a formal instantiation of what was often thought of as common sense, reflected in the nineteenth-century European and American adages, "A stitch in time saves nine" and "An ounce of prevention is worth a pound of cure." Yet this traditional wisdom was swept away in neoliberal hostility toward planning and an overconfident belief in the power of markets to respond to social problems as they arose. One of the ironies of the Penumbral Period is that the discipline of economics – rooted in the ancient Greek concept of household management (*oikos*, or "house," and *nomos*, or "laws" or "rules") – failed to speak to the imperative of a managed transition to a new energy system. See *Late Lessons From Early Warnings: The Precautionary Principle, 1896 – 2000* (Copenhagen: European Environment Agency, 2002), http://www.eea.europa.eu/publications/environmental_issue_report_2001_22.

46 On twentieth- and twenty-first-century subsidies for fossil fuel production, see http://www.oecd.org/document/57/0,3746,en_2649_37465_45233017_1_1_1_37465,00.html; and Vidal, "World Bank: Ditch Fossil Fuel Subsidies to Address Climate Change."

47 Friedrich August von Hayek, *The Road to Serfdom, Text and Documents: The Definitive Edition*, ed. Bruce Caldwell (Chicago: University of Chicago Press, 2007), 87.

48 Yet another paradox: Classical liberalism was centered on the idea of individual liberty, and in the eighteenth century most individuals had precious little liberty – economic or otherwise. But by the mid-twentieth century this situation had changed dramatically: slavery was formally outlawed in the nineteenth century, and monarchies and other forms of empire were increasingly replaced by various forms of "liberal" democracy. In the West, individual freedoms – both formal and informal – probably peaked around the time von Hayek was writing, or shortly thereafter. By the end of the twentieth century, Western citizens still held the formal rights of voting, various forms of free thought and expression, and freedom of employment and travel. But actionable freedom was decreasing, first as economic power was increasingly concentrated in a tiny elite, who came to be known as the "1 percent," and then in a political elite propelled to power as the climate crisis forced dramatic interventions to relocate citizens displaced by sea level rise and climatic de-inhabitation, to contain contagion, and to prevent mass famine. So the development that the neoliberals most feared – centralized government and loss of personal choice – was rendered essential by the policies that they had helped put in place.

49 For estimates of populations at or near sea level at the turn of the twenty-first century, see Don Hinrichsen, "The Coastal Population Explosion," in *The Next 25 Years: Global Issues*, prepared for the National Oceanic and Atmospheric Administration Coastal Trends Workshop, 1999, http://oceanservice.noaa.gov/websites/retiredsites/natdia_pdf/3hinrichsen.pdf; and http://oceanservice.noaa.gov/websites/retiredsites/supp_natl_dialogueretired.html.

Why & How Governments Support Renewable Energy

Kelly Sims Gallagher

Abstract: Many countries have adopted comprehensive policy frameworks to support renewable energy, but the United States has not adopted any consistent and stable policies at the national level to foster the use of renewable energy. This essay explores why some nations (Germany, China, and Denmark) and certain U.S. states (Colorado, Texas, and Ohio) have developed robust policies for the deployment of renewable energy. My aim is not to evaluate the specific policy mechanisms that countries and states have chosen, but rather to shed light on the underlying societal factors that contributed to each government's decision to enact the policies in the first place. I explore four factors that could influence a government's decision to adopt favorable policies for renewable energy: (1) economic motives; (2) a high endowment of renewable resources and/or a low endowment of nonrenewable sources; (3) the political system; and (4) cultural factors and attitudes.

Many countries have adopted comprehensive policy frameworks to support renewable energy, leading to a rapid scale-up of these technologies.[1] One hundred and nine countries have enacted some form of policy regarding renewable power, and 118 countries have set targets for renewable energy.[2] In contrast, the United States has not adopted any consistent and stable set of policies at the national level to foster the use of renewable energy. There is no federal carbon tax, no nationwide cap-and-trade system for carbon, and no long-term incentive mechanism for renewable energy generation. Federal support for renewable energy has consisted mainly of R&D and production tax credits. In this essay, I explore why some nations and certain U.S. states have developed robust policies for the deployment of renewable energy while the United States as a whole has not.

The U.S. production tax credit for renewable energy, first introduced in 1992, has repeatedly expired and then been extended. It has led to a boom-and-bust cycle that inhibits long-term investments. According to Jeff Immelt, chairman and CEO of Gen-

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eral Electric, "The current energy markets don't favor cleaner technology or low carbon....No business will invest when there is no certainty....If we're serious about transforming our energy markets, we must send the right signals and create demand for the technologies that solve these problems."[3] While many technologies could contribute to an alternative energy future in the United States, including energy efficiency, nuclear energy, and carbon capture and storage, I concentrate here on renewable energy.

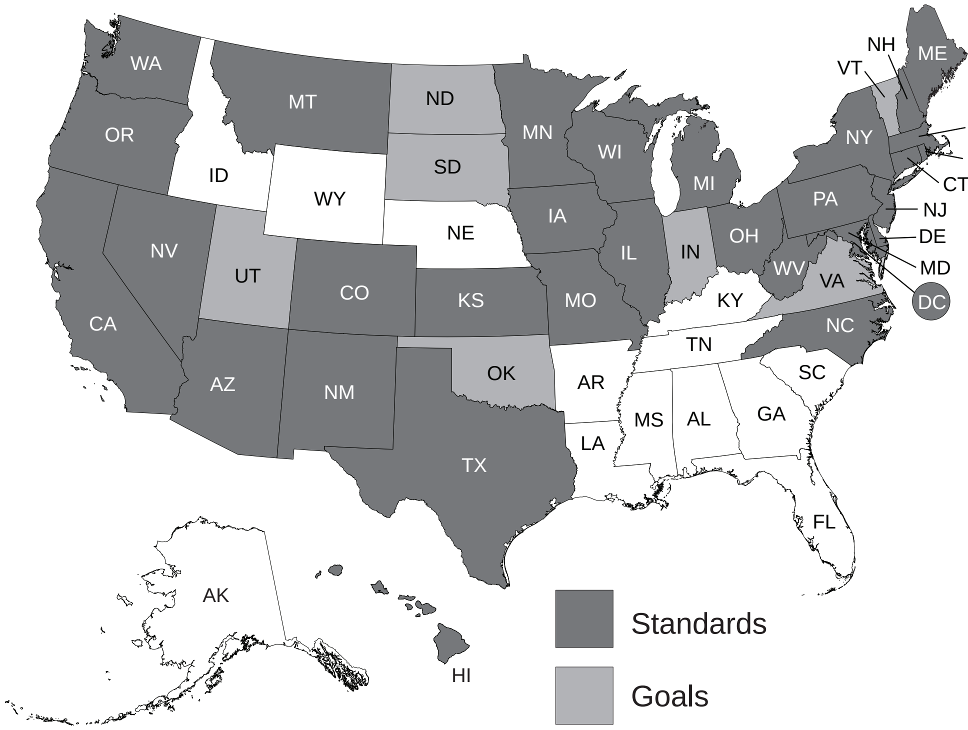
Absent a consistent national approach, thirty-nine U.S. states (including the District of Columbia and Puerto Rico) have enacted policies to foster renewable energy. The mechanism most widely used by states, the Renewable Portfolio Standard (RPS), is a set of performance requirements calling for utilities to supply a minimum amount of their electricity from renewable resources (measured in absolute or relative terms). Figure 1 shows which states have mandatory standards for renewable energy, as opposed to those with voluntary goals.

Reflecting the diversity of the nation, no two states have an identical RPS. The state-level policies differ in the percentage of renewable energy that must be achieved, in the definition of *renewable*, and in their enforcement mechanisms.[4] Some states have created a commodity called Renewable Energy Certificates (RECs) as a means to implement the portfolio standard. RECs, which usually represent 1 megawatt hour (MWh) of energy produced from renewable resources, can be sold and purchased.[5] A utility that does not produce renewable energy to comply with the applicable RPS can purchase RECs from generators of renewable electricity. Because of the differences in RPSs from state to state, there is no nationwide REC market, and RECs can be traded across states in only a few cases.

Local initiative is no doubt valuable, but it also brings disadvantages. First, the diversity of state-level approaches adds complexity for businesses that have to study individual policies and develop separate business models for each state. Such complexity increases not only transaction costs for businesses but also final electricity prices for everyone. Second, because some states have no policies to foster renewable energy, a "free rider" problem has emerged. Those states may benefit from lower sulfur dioxide and particulate emissions as a result of their neighbors' policies, without shouldering any of the effort or cost.[6] Third, the lack of a national framework increases regulatory uncertainty for investors: in many states, renewable energy incentives are created through executive orders that a newly elected governor could retract.[7] Lastly, jurisdictional inconsistencies between states inhibit the fungibility of RECs, thereby diminishing the economic efficiency of the RPS. A larger market for RECs – ideally a single national market – would allow renewable energy to be produced in locations where renewable resources are most abundant and where it is most cost-effective.[8]

Thus, there is a tension between, on the one hand, the value of local initiative and, on the other, the benefits of greater coherence that a national policy framework might provide. To probe how this tension might be resolved, I will examine both international and U.S. state-level case studies where comprehensive policies to encourage renewable energy have been adopted. My aim is not to evaluate the specific policy mechanisms that countries and states have chosen, but rather to shed light on the underlying societal factors that contributed to each government's decision to enact the policies in the first place. I explore four factors that could influence a government's decision to adopt favorable policies for renewable energy: (1) eco-

Figure 1
U.S. States with Renewable Portfolio Standards (mandatory) or Goals (voluntary)



Source: U.S. Energy Information Administration (based on the Database of State Incentives for Renewables & Efficiency, January 2012).

nomic motives; (2) a high endowment of renewable resources and/or a low endowment of nonrenewable sources; (3) the political system; and (4) cultural factors and attitudes. (I discuss only the first two factors in the case studies involving U.S. states.) To simplify matters, I focus on the electricity sector.

Germany, Denmark, and China have made tremendous efforts at the national level to catalyze and support the development and deployment of renewable energy in their countries. Similar to the United States, all three nations relied heavily on coal at one point (indeed, China still does). While Germany and China are large industrial economies, Denmark is much smaller.

In the late 1990s, a center-left coalition of the Social Democrats (SPD) and the Green Party enacted various policies to reduce carbon emissions and increase the share of renewable energy in Germany. These policies endure, in a modified form, still today. Passed into law in 2000, the Renewable Energy Sources Act (EEG) is the centerpiece of renewable energy policy in Germany. It provides for a feed-in tariff, a mechanism that guarantees generators of renewable energy the payment of fixed prices per kilowatt-hour (kWh). The tariff was scheduled to be reduced over time to account for decreasing costs, but once an installation is commissioned the price of that respective year is guaranteed for fifteen or twenty years.[9] The feed-in tariff is part of an overall policy framework that promotes renewable energy and energy efficiency in Germany, and that is embedded in EU-wide policies such as a cap-and-trade system for carbon.[10] After the 2011 nuclear accident in Fukushima, nowhere outside of Japan was the political fallout felt more keenly than in Germany. The center-right coalition of the Christian Union (CDU/CSU) and Free Democrats (FDP) agreed on a set of new policy measures to achieve the *Energiewende* (or energy transition), which includes targets to produce at least 35 percent of Germany's electricity with renewable resources by 2020 and 80 percent by 2050.[11] As of mid-2011, Germany generated 20 percent of its electricity from renewable resources.[12]

Economic Motives. A major driver for alternative energy in Germany today is the perception that renewable energies are an engine for economic growth and job creation, but this was not initially the case. As of 2011, 382,000 people in Germany worked in the renewable energy sector.[13] The scale-up of renewable energy and energy efficiency has created attractive business opportunities for smaller companies such as Enercon, a producer of wind turbines, as well as diversified industrial players such as Siemens. Siemens claims that as of 2011, it generated more than 40 percent of its entire sales revenue with its "Environmental Portfolio," which consists mainly of renewable energy and energy-efficient technologies.[14] Renewable energy technologies are now among Germany's fastest growing export segments.[15] According to Hans-Josef Fell, a member of the German Bundestag for the Green Party, "80 percent of the wind turbines produced in Germany are exported; there you can see the reward that you can get if you take a pioneering role."[16] In addition, the policies have created opportunities domestically for companies that install renewable energy technologies, ranging from large industrial players that install offshore wind turbines to small-scale installers of solar panels on rooftops. The policies have also benefited farmers using residual biomass to produce electricity as well as farmers who provide land for solar panels and wind turbines. Jürgen Trittin, former German Environmental Minister, has argued that the success of renewable energy is in part because "[e]specially in rural areas . . . people understood that renewable energies can constitute an additional source of revenue."[17] Germany's renewable energy industry has therefore reached a critical size, which in turn makes it opportune for politicians along the entire political spectrum to support it.

Resource Endowment. Germany is not blessed with optimal conditions for renewable energy. Given existing technologies and energy demand in 2010, Germany could technically cover 128 percent of its electricity consumption with renewables.[18] Overall, the renewable energy potential for electricity is around 9.7 MWh/capita/year.[19] Germany has virtually no oil reserves and only small proven natural gas reserves, but it does have considerable reserves of coal, with 4.7 percent of global proven reserves. In 2011, Germany had net imports of 76.2 billion cubic meters of natural gas, making it a major gas importer.[20] Germany's high dependence on foreign gas resources has certainly motivated policy-makers to support renewable energy for electricity. But given that coal reserves are readily available, dependence on foreign gas cannot fully explain Germany's enthusiasm for renewables.

Political System. In Germany, federal and state governments are usually formed as a coalition between different parties. The seats in the Bundestag (the directly elected legislative body) are assigned in proportion to the party vote after accounting for constituency representatives. This system has allowed the Green Party to play an important role in shaping German energy and environmental policy. Founded in 1980, the Green Party entered the Bundestag for the first time in 1983, winning 11 percent of the vote by 2009. The party's competition for votes has induced established parties, in particular the center-left SPD, to adopt environmentally friendly positions. Thus, Germany's multiparty system, with a legislature elected by means of proportional representation, has allowed "green" positions to gravitate toward the center of the political spectrum. According to Hermman Scheer, a former member of the Bundestag for the SPD and one of the architects of the EEG, "[A] decisive factor for the success of the EEG was that the SPD, a big party, could be turned around."[21]

Cultural Factors. Renewable energy enjoys widespread support among the German population. In a 2011 survey, 90 percent of Germans advocated a more rapid scale-up of renewable energy, with 73 percent in favor of renewables even if it meant increased electricity costs.[22] Renewable energy is viewed as the least bad among energy options in a country where nuclear power enjoys only tepid support. Wind energy is widely accepted, but solar photovoltaic (PV) energy is more controversial because some Germans believe that they should not subsidize a technology that is not well suited to Germany, which has poor solar insolation. Drawing a connection between support for renewable energy and German culture is difficult and runs the risk of stereotyping, but research does indicate that Germans tend to feel threatened by uncertain outcomes and thus have created beliefs and institutions to avoid unknowns.[23] In the context of environmental or security threats, Germans may be willing to act in a precautionary manner without knowing the exact consequences that environmental threats would have on their lives.[24] Furthermore, compared to the United States, Germany is a less individualistic society.[25] This lower degree of individualism might create a higher tolerance for policy measures that lead to higher levels of government intervention, such as taxes on energy and subsidies for renewable energies. These factors suggest that German culture may indeed have had a strengthening influence on the development of renewable energy policies in that country.

Denmark began to promote a transition to renewable energy in the mid-1970s as part of a strategy to shift away from its heavy reliance on coal. Early support mechanisms included a national certification program for wind turbines, investment subsidies, and mandatory grid connections for decentralized energy generation. Renewable energy was scaled up rapidly in the 1990s, driven by financial incentives including a feed-in tariff established in 1992 and policies that enabled communities to benefit directly from wind energy development.[26] In the late 1990s, the growth of renewable energy in Denmark slowed significantly. In 1999, the Danish government expected that the EU would ban feed-in tariffs and therefore switched from the feed-in model to a system for trading green certificates. This transition largely failed because complicated transition rules took years to implement and led to significant uncertainty for investors.[27] In 2001, a newly elected conservative government abolished many support mechanisms for renewable energy, leading to stagnation in wind development until 2007.[28]

Since then, two important cross-party "energy agreements" between the government and opposition parties have created consistent support for renewable energy. In 2008, an agreement was reached that fixed the goal of 20 percent share of renewables in total gross energy consumption by 2011, guaranteed prices for renewable energy, and established a compensation scheme and participation model for local populations.[29] In March 2012, a new target was established by the Danish Parliament: to achieve 100 percent of total energy consumption (that is, electricity, heating, and transport) with renewable energy by 2050.[30] No other energy agreement in Denmark has received broader parliamentary support (171 out of 179 seats).[31] The goal is for wind to supply 50 percent of Denmark's electricity by 2020. (Wind currently provides 25 percent of total electricity.)[32] The agreement covers a comprehensive range of measures to achieve these goals, including a commitment to build 1 gigawatt (GW) of offshore wind capacity and financial support for the development of new energy technologies (for example, wave energy).[33]

Economic Motives. Support for renewable energy in Denmark has been closely tied to industrial policy. With the announcement of the 2012 energy agreement, Martin Lidegaard, Minister for Climate, Energy, and Building, said, "Denmark will once again be the global leader in the transition to green energy. This will prepare us for a future with increasing prices for oil and coal. Moreover it will create some of the jobs that we need so desperately, now and in the coming years."[34] According to the central government, the Danish cleantech sector already accounts for 100,000 jobs, a significant number for a population of only 5.6 million.[35] Renewable energy technology has become a major export for Denmark, with energy equipment (mostly wind technology) accounting for 11 percent of total exports.[36] The continuous support for wind power has resulted in internationally renowned success stories, most notably Vestas, the world market leader in wind turbines. Vestas entered the wind turbine industry in 1979 and now has a global market share of 12.7 percent.[37] The Danish state has a 79.96 percent ownership stake in Dong Energy, the nation's largest energy company.

A remarkable feature of the Danish example is the direct economic participation of individuals in the development of wind power. Cooperatives were a critical form of ownership, particularly from the 1970s to the early 2000s. They were enabled by legislation that restricted the ownership of turbines to people who resided in close proximity to the wind turbine sites.[38] In 2001, 175,000 households and farmers owned 80 percent of all wind turbines in Denmark, but as of 2008, co-op ownership had fallen to 20 percent due to increasing turbine sizes that necessitate much higher levels of investment and new legislation that no longer requires shareholders to reside in the vicinity of the turbine.[39] Because local ownership has been an important factor in garnering support for wind energy, the Danish government created new policy measures in the 2008 energy agreement to revive local participation. The measures include the possibility to purchase turbine shares, a guarantee fund for local cooperatives, and a compensation scheme for local residents.[40]

Resource Endowment. Another factor that can explain the motivation for Danish policy-makers to foster renewable energy is the excellent potential for renewable energy in the country. Denmark has a renewable energy potential for electricity of up to 28.6 MWh/capita/year, with the great majority coming from wind resources.[41] In principle, wind power could cover current levels of electricity consumption many times over.[42] At the same time, Denmark has only a moderate endowment of oil and natural gas.[43] In 1973, when the first oil crisis occurred, Denmark was 90 percent dependent on foreign oil, and its economy was badly damaged as a result. Through aggressive measures since then to improve energy efficiency and boost domestic offshore production, Denmark is now a net exporter of oil and gas.[44]

Political System. With the exception of the unfavorable regulatory environment in the early 2000s, there has been consistent support for renewable energy in Denmark. The political system is characterized by a multiparty structure, whereby many parties are represented in the parliament at any one time. Parties need only 2 percent of the vote to obtain a seat in the Danish parliament, the Folketing. Several of the current parties are known for their commitment to environmental protection. Because of the large number of parties in the Folketing, Danish governments are often formed as coalition administrations. For more than a century, no single party has ever held a majority.[45] Danish politics therefore requires formulation of consensus across parties. These attributes of the political system have contributed to relatively stable support for renewables.

Cultural Factors. Attitudes in Denmark have long been supportive of renewable energy development. As early as the 1890s, the Danish scientist Poul la Cour played a pioneering role in the development of wind turbines; today, wind energy in Denmark is part of the social landscape.[46] Energy generation is decentralized and close to the end user, even in the capital city of Copenhagen. Wind turbines, which have been around the country for centuries, are visible everywhere and are perceived as a natural part of the landscape. Another factor that might explain the success of renewable energy in Denmark is an embedded long-term orientation in Danish society that is more pronounced than in the United States or Germany.[47]

China is full of energy contradictions. It is the largest coal producer, the largest emitter of carbon dioxide, and also one of the largest clean energy investors in the world. In 2010, China invested $51 billion (USD) in clean energy.[48] Most of China's environmental policies are implemented to achieve targets set by the central government in its five-year plans. In the 12th Five Year Plan, for the period 2011 to 2015, the government set ambitious targets for renewables, for "nonfossil" fuels, for carbon intensity, and for energy intensity.[49] To reduce the resource intensity of China's economy, the central government enacts some national-level policies and then assigns partial responsibility to provinces and municipalities to achieve the targets.[50] China's support for renewable energy was greatly enhanced in 2005 with passage of "The Renewable Energy Law of the People's Republic of China."[51] The law created four mechanisms to promote renewable energy: (1) a national renewable energy target; (2) a mandatory connection and purchase policy; (3) a feed-in tariff system; and (4) a cost-sharing mechanism, including a fund for renewable energy development.[52]

Apart from large hydropower, solar PV and wind energy play the biggest role in China. The growth of the wind energy industry was amazingly swift: in 2010, China became the largest wind power market in terms of annual capacity increase and total cumulative installed capacity.[53] In the case of solar PV, only a small fraction of the Chinese PV module production has been installed domestically, with most products going to Germany, the United States, and Spain. But China has created the Golden Sun demonstration project and, in 2011, announced a feed-in tariff to encourage domestic installation of solar PV.[54] Despite its dependence on coal, China is taking significant steps to foster alternative forms of energy.

Economic Motives. In an April 2012 speech, China's Premier Wen Jiabao said, "Greening of the economy is not a burden on growth; rather, it is an engine that drives growth and an effective means to achieve sustainable development."[55] As of 2011, four of the ten largest manufacturers of wind turbines were Chinese companies.[56] Similarly, five of the top ten manufacturers of solar PV cells were headquartered in China.[57] China's wind power industry (power generation and turbine manufacturing) generated an average of 40,000 direct jobs annually between 2006 and 2010 and is expected to generate 34,000 jobs annually between 2011 and 2020.[58] China's renewable energy industry has reached a scale large enough to contribute directly to global price reductions, further incentivizing domestic deployment of renewable energy.

Resource Endowment. China has a moderate endowment of renewable energy resources, mostly in wind energy and large hydropower.[59] Its renewable electricity potential is up to 6.1 MWh/capita/year,[60] significantly lower than the Danish potential. Including biomass, solar thermal, and geothermal energy, China could possibly meet its entire domestic energy demand with renewables.[61] In terms of nonrenewable resources, China's main endowment is coal, with 13.3 percent of global reserves; yet China's reserve-to-production ratio is only thirty-three years, indicating that China either needs to find alternatives to coal or bear the energy-security risks of becoming a massive coal importer. China has poor remaining endowments of oil and gas, quickly becoming a major importer of both.[62] China is now the second largest oil importer in the world after the United States.

Political System. China's single-party system, its "socialist market" economy, and its long traditions of planning and industrial policy have facilitated the rapid buildup of its solar PV and wind energy industries. The one-party system requires extensive internal consensus-building among elite Communist Party leaders but suffers from few external challenges. Party leaders are rotated around China to govern provinces and cities, so there is less regional political strength than in most countries. The key challenge in Chinese energy policy has not been in the *passing* of laws and regulations but rather in their *implementation*. Indeed, the central government has often issued progressive targets, regulations, and rules, only to find it difficult to persuade and incentivize local governments to implement them. China's population size, local competitive pressures, and limited enforcement capacities conspire to make policy implementation a huge challenge.[63] Still, the government has successfully used incentives to spur the development and deployment of renewables in China.

Cultural Factors. As with other countries, it is difficult to generalize about Chinese culture, but one factor that might help explain China's large investment in renewable energies is a pervasive long-term orientation in Chinese culture.[64] The Chinese people have a strong awareness of their country's long history, and they also appear to have unusual patience about the future – manifest in their willingness to invest in long-term outcomes. The Chinese have an extremely high savings rate, for example, which is equal to approximately 50 percent of GDP. This cultural predilection coupled with the Communist Party's tradition of planning could partially explain the Chinese government's ability to develop a long-term renewable energy plan and to make relatively large and steady investments in renewable energy.

Since the late 1990s, Colorado, Texas, and Ohio have each adopted strategies to manufacture and/or deploy renewable energy. Politically, these states range from independent to conservative, yet they have embraced renewable energy.

In 2004, Colorado became the first U.S. state to adopt an RPS by ballot initiative.

The RPS was subsequently extended in 2007 and 2010. The current RPS requires investor-owned utilities to provide 30 percent of their retail electricity from renewable resources, while cooperatives and municipal utilities must provide 10 percent of their electricity from renewable resources by 2020.[65] In February 2012, Colorado generated 15.4 percent of its electricity from renewable resources.[66]

Economic Motives. In a national radio address, former Colorado Governor Bill Ritter remarked, "At a time when concern about our economy is growing and American families are struggling with high energy costs, [we] have proposed policies that will take advantage of renewable energy resources. . . . In Colorado, we call this the New Energy Economy. By creating a 21st century energy policy, we are creating jobs, revitalizing the economy, protecting the environment and helping secure our nation's energy future."[67] This strong-willed push for renewable energy has indeed attracted U.S. and foreign renewable energy companies to Colorado. Vestas, the Danish wind company, operates four manufacturing plants in Colorado. It employs around 1,700 people and has invested $1 billion in the state. Other companies that supply Vestas, including Hexel and Bach Composites, have followed.[68] Therefore, support for renewable energy is viewed as interconnected with economic development.

Resource Endowment. Colorado has significant renewable and fossil fuel energy resources. The state is particularly rich in natural gas, holding 8.5 percent of total U.S. reserves.[69] The state also contains vast coal reserves and produces more than it needs for its own electricity generation. In addition, Colorado is rich in renewable resources, providing excellent opportunities for energy generation from both fossil fuels and renewables.

Texas first adopted an RPS in 1999, when George W. Bush was governor. The standard required an additional 2,000 MW of renewable energy capacity to be installed by 2009. The current standard requires 5,880 MW of renewable energy capacity by 2015 and 10,000 MW by 2025, although the 2025 standard had already been reached as of 2009. The RPS is binding for all investor-owned utilities and voluntary for all municipal and cooperative utilities.[70] As of February 2012, Texas had the highest wind energy capacity installed in the United States. Texas is a particularly interesting case because policies in support of renewable energy were not enacted to counter climate change. In fact, Texas policymakers avoided framing support for wind energy as an environmental effort.[71] Texas Governor Rick Perry, who describes himself as a climate change skeptic and rejects federal carbon regulations, had other motivations to support renewable energy development.

Economic Motives. Governor Perry has made diversification of the energy industry in Texas one of his top priorities. In a 2010 talk, he asked: "Is it wind? solar? biomass? clean coal? next generation nuclear? My answer is four simple words: all of the above. That's exactly the strategy we're pursuing in Texas, and it's working which shouldn't surprise anyone because Texas knows energy."[72] President Obama later adopted Governor Perry's popular "all of the above" rhetoric. The Texas economy relies heavily on the energy sector, and renewable energy is simply seen as one new building block within the energy industry. In the course of the rapid scale-up of wind capacity, various wind energy companies, including GE, have established manufacturing facilities in the state.[73] Wind energy has also garnered support in rural Western Texas, where most of the wind parks have been built. In rural areas, wind energy provides struggling farmers with an additional source of income, creates jobs, and raises local tax revenues. Landowners, provisioning their land for the wind turbines, usually receive a signing payment as well as royalties based on the amount of electricity produced.[74] Thus, renewable energy – wind, in particular – has evolved into a considerable source of jobs and revenues in Texas.

Resource Endowment. Texas has the largest wind energy potential in the United States. Despite its position as a national leader in terms of oil and gas reserves, Texas has historically imported coal from Wyoming to supply its coal-fueled power plants.[75]

Ohio enacted an RPS in 2008, requiring investor-owned utilities to provide 25 percent of their electricity from alternative energy resources by 2025. In this case, "alternative energy" includes not only renewable energy technologies but also clean coal and advanced nuclear power. Of this 25 percent, at least 12.5 percent must come from renewable resources and at least 0.5 percent from solar energy.[76] Ohio is far from reaching this target: as of February 2012, only 1.7 percent of total electricity in the state came from renewable resources.[77]

Economic Motives. Ohio has repositioned itself as a manufacturer of renewable energy technologies in an effort to transform the Rust Belt into a Green Belt. Ohio-based companies are successfully leveraging their traditional competencies and infrastructure to develop and produce world-class solar PV technologies, for example. Building on existing expertise in glass and plastic film manufacturing to support the automotive industry, Ohio today hosts important solar companies. The city of Toledo is now a hotspot for solar technology R&D and commercialization in part because the University of Toledo decided to support research in the field of alternative energy.[78] First Solar, one of the largest vertically integrated solar companies in the world, has its U.S. manufacturing facilities and its major R&D activities in Ohio. In the wind energy sector, Ohio-based companies have become leading component suppliers for turbine manufacturers. Businesses have retooled their facilities and trained their workforces to produce components like bearings, gears, or composites for the wind energy industry.[79] Interestingly, actual deployment of wind and solar technologies in Ohio has lagged other states. Only very recently, after the enactment of Ohio's RPS, has Ohio begun to catch up, growing its wind capacity by an amazing 950 percent in 2011 (admittedly from a very low base). With a current capacity of around 100 MW, Ohio has 300 MW capacity of wind energy under construction and 3,683 MW in queue.[80] These developments are creating opportunities for companies to plan, build, and maintain wind parks.

Resource Endowment. Ohio has a low endowment of oil and gas but relatively large coal reserves. Despite its coal endowment, Ohio imports about two-thirds of its coal demand from other states. In terms of renewables, Ohio possesses vast resources of onshore and offshore resources. Wind speeds offshore over Lake Erie achieve the highest energy-potential classification.[81] Ohio also has onshore wind resources that alone could generate 13.2 MWh/capita/year of electricity.[82]

All these examples reveal that economic motives played an important role everywhere. The resource endowment had a strong influence on policy decisions in some cases (for example, Texas) but cannot explain the extent of motivation in other cases (Germany, for instance). The degree of dependence on foreign sources of energy, coupled with domestic resource endowments, better explains the motivation to aggressively pursue renewable energy. The structure of the political systems in Germany, Denmark, and China facilitated the enactment of renewable energy policies, but in different ways. The parliamentary systems in Germany and Denmark allow for the direct participation of "green" parties, although in neither case have these parties ever gained majorities. Instead, they have developed compromises with other parties that led to policies favorable to renewables. China and Denmark both have strong state-owned energy companies. This ownership structure forces these firms to comply with the will of the government, but the firms may have special political influence during policy formation that could limit the shift to renewables. In Denmark's case, Dong Energy has become enthusiastic about renewable energy even though the majority of its current production is based on fossil fuels. In China, the enterprises owned by the central government are predominantly based on fossil fuels, with most of the renewable energy firms either privately owned or owned by the local government. Culture and attitudes appear to play an important role in Germany and Denmark especially, but also in China.

In the U.S. states considered here, it appears that Colorado's and Texas's historical experience with energy industries may have contributed to an understanding of the opportunities and a readiness to diversify the industry. Also, these two Western states have a cultural tradition of self-reliance and independence, so renewable energy may be attractive in these respects. Figure 2 summarizes the importance of the factors in supporting the adoption of renewable energy policies in each country or state. By analyzing surveys of Americans conducted between 2002 and 2010, Stephen Ansolabehere and David Konisky have examined why Americans support renewable energy. They find that 75 percent of Americans want to increase the amount of solar and wind in the American energy portfolio mainly because these technologies are perceived to reduce environmental harm at the local level and because they are perceived to be relatively affordable. They write, "Attitudes about global warming have weak or no correlation with attitudes about which fuels we use to generate electricity in the United States."[83] Their findings illuminate the cases of Colorado, Texas, and Ohio, where factors other than climate change motivated action.

The case studies provide insight into the underlying societal drivers that motivate policy-makers to adopt comprehensive policies in support of renewable energy. Approaches by other countries or individual states cannot serve as a blueprint for the United States: the policies emerged in the specific economic, social, and political contexts of each case. Comparing the United States to examples of what has worked elsewhere can, however, serve two purposes. First, one can identify which motivating factors are lacking at the national level in the United States. Second, learning from the experience of other governments, including at the state-level in the United States, could inform the design of a U.S. national policy framework. With these two purposes in mind, I conclude by examining each of the four factors in the U.S. context.

Economic Motives. One striking similarity across all the case studies is the importance of economic interests in motivating country and state governments to support renewable energy policies. Why, then, has the United States at the federal level not realized sufficient economic interest to enact legislation, even though thirty-nine U.S. states have implemented an RPS and/or goals? The most striking contrast between the United States at the national level and all the cases is that beyond wish-

Figure 2
Level of Supportive Influence of Selected Factors on Renewable Energy Policy

Country/State	Economic Motives	Resource Endowment	Political System	Cultural Factors
Germany	● Renewable energy is pillar of German (export) industry	◔ Moderate potential for renewables; high coal endowment	◑ System allowed green party to exert influence	● Uncertainty avoidance fosters renewable energy
Denmark	● Renewable energy is pillar of Danish (export) industry	◕ Very high potential for wind; moderate fossil fuel resources	◑ Consensus politics provides stable policies	● Wind energy is part of "social landscape"
China	◕ Renewable energy industry is of strategic importance	◔ Moderate wind and solar resources; high coal endowment	◑ Centralized system allows fast enactment of policies	◑ Long-term orientation fosters renewable energy
Colorado	◕ Colorado strives to excel in the "new energy economy"	◑ Colorado is rich in fossil fuel and renewable resources	n.a.	n.a.
Texas	◕ Interest in diversification and rural development	● Best wind resources in United States; net importer of coal	n.a.	n.a.
Ohio	◕ Home to many PV producers and wind component suppliers	◑ Good wind and solar resources; high coal endowment	n.a.	n.a.

● Very high ◕ High ◑ Medium ◔ Low ○ Very low

Source: Qualitative analysis by author.

ful thinking about creating "green jobs," little effort has been made to determine the direct economic benefits of renewable energy for ordinary Americans. Also, one cannot help but notice that the renewable energy industry is very small compared to the fossil fuel industry in the United States, so the political strength of the renewable energy industry is tiny by comparison. It is worth noting that this was also the case at the beginning of the transition from coal to wind in Denmark, and it is still the case in China. The recent surge of unconventional natural gas production in the United States has also overshadowed (or competed with) growth in renewable energy.

Opponents portray government regulations that support renewable energy as harmful to the economy. A common argument in the United States is that you can *either* mitigate climate change *or* grow the economy. Such debate is by no means unprecedented, even in Germany and Denmark. And a certain degree of skepticism about the promise of the "green economy" is appropriate. Not every policy that supports renewable energy will directly stimulate economic growth, especially if the government cannot stay the course; and even if it does, the jobs, economic spillover, and revenue benefits remain uncertain.

Often the number of jobs in the renewable energy industry is cited to prove its positive impact on the economy. While these employment figures might serve as a crude indicator, they are insufficient to describe the impact that support for renewable energy has on economic development, especially because these industries are subsidized by tax- or ratepayers and there is always an opportunity cost for investment. In Europe, the net economic impact is calculated as a function of the price difference between renewables and fossil fuel generation (which changes over time due to learning and economies of scale), the extent to which technologies are produced domestically and exported, and spillover effects to other economic sectors. For Europe, this net economic impact has been estimated to be slightly positive.[84] Thus, even without accounting for society's health and environmental benefits, economic welfare appears to be better off with public support for renewable energy than without.

There is also evidence in Germany, Denmark, and China that domestic incentive mechanisms for renewable energy deployment increase national companies' likelihood to export products and compete globally. The emergent industrial cluster in each country appears to promote interfirm learning and positive spillovers for the economy. This outcome is consistent with earlier findings that local rivalry and demand conditions can foster innovation and productivity in an industry.[85] But support for certain industries (that is, industrial policy) is not the norm in the United States. From the case studies, one can observe a positive feedback cycle between economic motives and renewable energy policies. Renewable energy deployment incentives are initially necessary to correct for market failures and create the demand needed for the renewable energy industry to prosper. Once such industries have grown, this market support can be ratcheted down and business interests will emerge to reinforce the support for renewable energy. Hence, the first lesson for the United States is that a predictable and stable incentive mechanism for domestic electricity generation would be helpful. The repeated expiration and renewal of production tax credits has fallen short of providing the market consistency needed to foster a strong U.S. renewable energy industry.

A second lesson from the case studies is that the economic participation of local populations appears to be critical to garner widespread and sustained popular support. The examples from Denmark, Germany, and Texas have shown that the decentralized nature of renewable energies has the potential to stimulate local economies, especially in rural areas. The extent to which local communities can participate in renewable energy development depends on the ability of local communities to participate in the construction, operation, and ownership of renewable energy projects. Projects that involve local ownership are currently very rare, constituting, for example, only 2 percent of the wind capacity installed in the United States.[86] Development of U.S.-specific models for local ownership or participation in the market might generate broader support for renewable energy in the United States. Mechanisms that have been applied successfully in Denmark, such as issuing shares in wind parks, could serve as a starting point for policies that are suitable in the U.S. context. State ownership of energy firms is almost unimaginable in the United States, but there is a robust tradition of rural electricity cooperatives that could be used to build local support.

Resource Endowment. America's resource endowment helps explain the lack of a national move toward renewable energy for electricity generation. The United States has the largest coal reserves worldwide, with 27 percent of global reserves.[87] With the unconventional natural gas resources that have become economically feasible to recover, the United States is estimated to have 482 trillion cubic feet of "new" gas resources, much larger than its remaining conventional resources of 273 trillion cubic feet.[88] The United States could therefore be completely independent in electricity generation based on fossil fuels if it chose to do so. On the other hand, the United States also has abundant renewable energy resources. Several studies have shown that wind resources alone exceed the total projected demand for electricity in the United States.[89] Especially in the Southwest, there are also excellent conditions for solar energy.

With its exceptional renewable resources, the United States has a natural potential to become a leader in renewable energy despite its large fossil resources. Other countries with less favorable conditions for renewable energy deployment, such as Germany or China, have enacted far more ambitious policies. The only practical policy implication that can be derived from my analysis is that those technologies that are most suitable to the local conditions should be pursued, rather than fighting against comparative advantage. A national policy framework would support renewable energy in regions that are most appropriate for the respective technology, and therefore would be more economically attractive.

Political System. Some have argued that the U.S. political system is less conducive to the formation of effective renewable energy policies at the national level. According to one argument, there is often one party controlling one house of Congress and another controlling the presidency and/or the other house of Congress, leading to stalemate.[90] Another argument is that the incumbent fossil fuel firms in the United States are so strong politically that they can prevent any major changes to current policies. While both of these issues may reinforce difficulties in achieving a national framework and may slow the process, they fall short as an explanation for inactivity at the national level over such a long period of time, especially given that there have been periods when one party has controlled all three institutions. Recall also that thirty-nine U.S. states have managed to enact renewable energy policies. One could even argue that the U.S. political system, requiring strong majorities, should promote compromises that are more stable than in parliamentary system, whereby one party in control of the executive branch and legislature pushes through a policy on its own.

In the United States, because two Senators are elected per state, those states with smaller populations have a larger voice in the Senate than they do in the House. During past congressional debates about energy and climate change, the Senate proved to be the greater obstacle to passage of major legislation because coal, oil, or gas states could exercise their influence to a greater degree than they could in the House. Moreover, the United States has only two main political parties, which have become increasingly polarized. As in the United States, Germany and Denmark elect representatives to parliament on a constituent basis, but the key difference is that there is a second vote for the party, which determines the representation of the different parties in the parliament. Where more parties exist, there seems to be greater policy compromise on energy topics. China is a one-party state, so it does not have to compromise with other political parties; but it does have to achieve consensus within the party elite. A key difference is that this consensus-building is not done publicly.

Cultural Factors. In countries like Germany or Denmark, cultural factors appear to have aided the enactment of renewable energy policies. By comparing the United States to such countries, one notices three cultural factors that may have held back national policy formation in the United States. First, U.S. society has a more pronounced belief in the "free market," leading to greater resistance to government intervention in the market. Second, there is a deeply ingrained expectation in the United States that abundant and cheap energy should be available just as it has always been. Third, there is much less environmental concern about climate change in the United States than in most other countries. Only a thin majority in the United States believes that climate change is already happening, and U.S. public opinion on climate change has become more polarized along conservative/liberal lines and by party affiliation.[91] Yet Americans are very supportive of clean energy on other environmental and public health grounds.

In summary, the lessons from these cases suggest that it is possible to develop a national policy framework to spur clean energy in the United States. Barriers to developing renewable energy markets should be removed because the current patchwork of state-level approaches creates complexity, instills uncertainty, and inhibits opportunities to optimize resource allocation. A national framework would have to recognize the value of local forces in creating renewable energy supply through utilization of local renewable resources, as well as the need for local communities to benefit through ownership opportunities and improved local environmental conditions. Such a policy would be a significant departure from the preemptive nature of many prior federal regulations. A national policy framework would need to be designed to provide stability and predictability, but this does not mean that renewable energy would need to be subsidized forever. Supportive deployment policies could be scheduled to rise and fall over time. The main selling points for a national policy should be improved economic growth, jobs, and competitiveness, as well as reduced local air pollution, improved public health, and enhanced energy security.

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Reducing Carbon-Based Energy Consumption through Changes in Household Behavior

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Abstract: Actions by individuals and households to reduce carbon-based energy consumption have the potential to change the picture of U.S. energy consumption and carbon dioxide emissions in the near term. To tap this potential, however, energy policies and programs need to replace outmoded assumptions about what drives human behavior; they must integrate insights from the behavioral and social sciences with those from engineering and economics. This integrated approach has thus far only occasionally been implemented. This essay summarizes knowledge from the social sciences and from highly successful energy programs to show what the potential is and how it can be achieved.

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Individuals and households make many decisions that are critical in shaping our energy future. As citizens, people favor some policies and oppose others, support some candidates for elective office and not others, write op-eds, comment on blogs, and otherwise engage in political action. They attempt to influence decisions that help determine which kind of local, state, federal, and international policies are adopted, and such policies in turn shape the energy system of the future. People sometimes engage in more direct politics by organizing to support or oppose proposed technological changes, especially the siting of new facilities. For example, the use of nuclear power in the United States stopped expanding in the 1980s largely as a result of massive public opposition to new nuclear power plants.[1] Current proposals for developing wind power facilities often face serious local opposition, as do efforts to develop unconventional shale gas deposits and to implement smart electrical grids and smart home metering.[2]

Such political actions are critically important to the energy futures of democracies. We focus here, however, on the decisions made when individuals and households act as consumers. These consequential decisions are diverse: selecting a car and deciding when to use it, how to maintain it, and how to drive it; buying and using appliances; and modifying and using the basic space and water heating and cooling systems of dwellings. In some cases, these are "non-decisions," in that actions are taken without much conscious reflection. Often when reflection does occur, it takes no account of energy use per se or is based on poor understanding of the energy consumption and related (for example, climate) consequences of choices and actions. We limit our discussion to decisions that directly affect energy use. Many other consumer decisions, such as food choices or residential location, also have immense consequences for the energy system, although these are harder to analyze. The energy consequences of a dietary choice, for instance, depend on not only the food chosen but how and where it was produced and processed. Some quantitative estimates of the carbon emissions impacts of consumer food choices are beginning to appear; they suggest that at least in Europe, these emissions approach the magnitude of those from direct energy use.[3] In this review, we stick to simpler cases, where the actions taken have direct and easily identifiable impacts on energy use.

The important role of individual and household decisions in the trajectory of our energy future is sometimes overlooked in discussions of energy policy. Analyses of energy use based on the economic sectors where use occurs (for example, in electricity generation, agriculture, or transportation) typically suggest that residential sector uses constitute only about 5 percent of U.S. CO_2 emissions. Such small numbers have probably led many researchers and policy-makers to ignore household choices. But for policy purposes, it makes sense to subdivide energy use according to who makes the choices about energy use, because policies are intended first of all to influence decision-makers. If we classify energy use in this way, household decisions that directly affect energy consumption – choices about personal transportation, appliance purchase and use, or home heating and cooling, for instance – are very consequential. A conservative estimate suggests that these decisions account for more than 30 percent of U.S. CO_2 emissions and a comparable amount of overall energy use.[4]

In policy circles, prices are believed to dominate household energy decisions. This assumption follows from the standard economic model of consumer decisions. If price drives decisions, then changing energy prices is a logical energy-policy strategy; higher prices driven by an energy tax or a cap-and-trade policy would drive consumption down in a predictable way for all decision-makers. But a substantial body of research shows that this "prices only" model is not sufficient to explain real world choices by either households or companies. Economists who consider energy consumption have acknowledged this problem and label it the *energy efficiency gap*.[5] Households and businesses do not make investments in energy efficiency that would yield highly competitive rates of return. For that matter, they often fail to take actions – reducing unnecessarily hot water temperatures, for example – that would cut their energy expenditures at no cost whatsoever. Clearly, energy consumers do not always behave as simple versions of economic theory would predict. The result is a gap between the behavior that would make economic sense to energy consumers and the behavior that is actually observed. The size of the gap is particularly large with investments that would reduce household energy use and CO_2 emissions. Thus, policies that only increase energy prices will not be sufficient to steer the energy future toward more efficiency; indeed, they will not even come close to being sufficient.

The effects of financial incentives to encourage home energy efficiency vary by at least a factor of ten, depending on how those incentives are structured and implemented.[6] A similarly large variation occurs when incentives are provided for the purchase of hybrid cars and vans.[7] State sales-tax exemptions increased purchases seven times as much per dollar of incentive than did the federal income-tax credit. This difference shows that it is not just the potential costs and savings that matter, but also how they appear to decision-makers. We do not always notice opportunities, we do not take the time to evaluate our options carefully, and our mental calculations do not always match the best practices of accounting. To close the energy efficiency gap, we have to design programs for the ways real people make choices, not for the formally rational decision-makers of economic theory. The design and implementation of policy interventions must account for the full range of human motivation and the ways people process information about options, costs, and benefits. Policy design needs to consider that people use cognitive shortcuts, for example, and that they use different mental accounts for different kinds of costs and benefits.[8]

What drives household decision-making about energy consumption and choice of energy-using technologies? How are costs and benefits interpreted and balanced, and what other factors matter? How can we deploy what we know about the influences on household decisions to help shape a more sustainable energy future? To answer these questions, we draw from social science research, especially efforts to understand the effects of policies and programs on household decision-making. By learning lessons from the most successful behavioral-change programs of the past, it is possible to design new programs that can be highly effective in making household energy use more efficient.

A starting point for any energy policy is to focus on decisions that can have substantial impact. The overall impact of a potential decision is the product of three factors. One is the amount of change in energy consumption that will take place with more efficient practices: that is, the technical potential of energy savings for the household that adopts the new technology or practice. A second factor is the number of households that could make the change. Some homes are already well weatherized, some drivers already carpool or operate highly efficient vehicles, and many water heaters are set at an optimal temperature. These two factors – the technical potential and the size of the target population – set an upper bound on what a policy or program might achieve, not a realistic goal.

A third factor, much neglected in energy policy analysis, is the likelihood that a household will make the change that a policy or program encourages. The proportion of households that will change in response to a well-designed policy has been called the *plasticity* of the behavior.[9] For example, shifting household trips from individual drivers to carpooling has substantial technical potential (energy savings per trip shifted from individual cars to a shared trip) and could possibly be adopted by a large number of households. But we know that this is a very difficult behavior to change. Home weatherization also has large technical potential and could benefit many homes, but unlike carpooling, change in this behavior has been achieved in large proportions of households by well-designed programs. Plasticity is not an inherent attribute of particular human choices; rather, it depends on context. A useful estimate of plasticity for a choice in a particular technical, economic, and regulatory context can be provided by the most effective non-coercive policies or programs for influencing that choice. Only by assessing the product of technical potential, number of eligible households, and behavioral plasticity can we determine if a behavior is a reasonable target for policies intended to reduce energy consumption or greenhouse gas emissions.[10]

Thomas Dietz and colleagues were able to estimate the plasticity as well as the technical potential and size of the target populations for seventeen household energy-efficiency actions.[11] The list included such items as home weatherization, line-drying of clothes, carpooling, and trip chaining. By multiplying the technical potential of each household change, the number of households eligible to take the action, and the proportion of households that have made the change under well-designed policies or programs, Dietz and his team estimated the Reasonably Achievable Emissions Reductions (RAER).[12] Generally, the actions with the highest RAER values, and thus the most promising targets for policies intended to shape a more sustainable energy future, are those that involve the *adoption* of more efficient equipment rather than those that involve the *use* of equipment. This may reflect the fact that we know more about how to encourage the one-time adoption of new equipment than we do about how to change behaviors that must be repeated regularly to achieve savings. It certainly reflects the fact that once more efficient equipment is adopted, the savings are usually locked in; in a sense, policies directed at adoption have to work only once, while policies directed at use have to work continuously. Intermediate categories of behavior, such as getting home heating and cooling systems tuned or checking tire pressure, need to be repeated periodically but infrequently, and tend to have relatively low RAER values.

The most attractive targets for household behavioral change involve adoption of household technologies that reduce fossil energy consumption, including building weatherization, motor vehicles, heating and cooling systems, and major appliances. These are not the choices that most households think of first when they consider ways to save energy.[13] Instead, most people tend to think of behaviors that are easy to recall, and these tend to be frequently repeated behaviors. They also overemphasize the potential of these behaviors to save energy, relative to actions that are harder to recall and especially to actions that involve invisible factors in energy use: for example, upgrading wall insulation, replacing water heaters hidden in basements, or perhaps tuning up cars and furnaces.[14] The behaviors that first come to mind – the daily use of energy-consuming household equipment – can be changed by well-designed interventions, but the impact achieved by these interventions has never approached what has been achieved by well-designed, integrated programs directed at upgrading household technologies.

Efforts to encourage increased household energy efficiency should begin with a careful analysis of reasonably achievable reductions. Analysis of technical potential for reductions is necessary, but it is by no means sufficient. Behavioral plasticity must be examined as well, raising a number of questions about household decision-making:

- Do households have a reasonable understanding of the energy use and energy savings associated with various activities and technologies? Studies show that people typically make substantial errors in estimating energy use and potential energy savings in the household.[15] They tend to overestimate the effect of actions that have little impact – commonly repeated actions, in particular – and underestimate the effect of behaviors that have great impact.
- Is the behavior that needs to change a one-time fix, as in buying a new appliance or setting the temperature of a water heater? Or does it require daily action, such as air-drying clothes or carpooling? If the latter, how conscious are the decision-makers of the actions they are taking?
- Do choices involve a bundle of characteristics that matter to consumers as much or more than energy use? Carpooling is different from driving alone in many ways, while the only notable differences between a high- and a low-efficiency water heater are the differences in initial cost and energy consumption.
- Do those who take the actions benefit from them? In rental housing, for example, if the renter pays the utility bills, little benefit accrues to the landlord from spending extra money on weatherization or high-efficiency appliances.
- Do changes require breaking old habits or undertaking actions that are unfamiliar? Setting back a thermostat is a simple action that nearly everyone knows how to do. Furnace tune-ups may be unfamiliar to those who do not do them regularly.
- Are substantial up-front investments of time, money, and effort required? Weatherizing a home requires an initial investment even if the economic rate of return is favorable, and finding a trusted and skilled contractor is challenging. Adjusting tire pressure is awkward and dirty, and requires finding a filling station with a working air pump. Resetting the thermostat on a home space conditioning system or a water heater takes little time and effort, and has no financial cost.

Of course, the purpose of policies to reduce fossil energy use is to overcome these difficulties. The key question is, how much change can effective policies and programs bring about? Experience, summarized by the RAER estimates, indicates that some kinds of behavior have proven much more difficult to change on a large scale than others. In addition, programs to reduce household energy use have varied greatly in effectiveness, both across types of actions and across programs with the same behavioral goals. Estimates of plasticity across seventeen household actions range from 90 percent for home weatherization to 15 percent for carpooling and trip chaining.[16] Substantial variation also arises across types of programs for a single behavior. In the case of home weatherization, while the most effective programs were able to secure a 90 percent participation rate, programs that were not well designed achieved less than 10 percent uptake, even with the same financial incentives.[17]

The most effective interventions implement five design principles in addition to targeting actions that will have the greatest impact.[18] First, for many actions with high RAER, financial incentives are essential, even though they are not sufficient by themselves. Steps like home weatherization and equipment upgrades, whatever their long-term benefits, can have up-front costs that are daunting to many households. A substantial financial incentive can get households to pay attention to a choice that it had not previously considered feasible and may also help signal the desirability of the action if the incentive is offered by a trusted source. The size of the incentive may be less important than the fact that it is large enough to open up consideration.

Second, the program has to be smartly communicated. Providing information effectively may not mean depending on mass advertising. We should consider when the information will be useful for making decisions. We are bombarded with information and ignore most of it. But a reminder about the value of car tune-ups at the gas pump is likely to have more impact than a public service announcement on evening television. Word of mouth through people's informal social networks was critical to the outstanding success of the Hood River, Oregon, energy-efficiency program of the early 1980s, as discussed below.[19]

Third, information must be accurate and come from credible sources. Admonishments about the value of smoke detectors come from fire departments, a credible source in most communities. But we are likely to be skeptical of flyers from home improvement contractors telling us how much energy we can save if we hire their services. It is much easier to provide accurate and credible information about the energy attributes of mass-produced items such as motor vehicles and appliances than about individualized products and services like home weatherization. For this reason, a record of results from independent energy audits can be an important element of credibility for weatherization programs.

Fourth, simple processes lead to adoption, complex processes often do not. The Cash for Clunkers rebate for trading in an old car was not exemplary for the amount of enhanced fuel efficiency it achieved.[20] But it was a very well-designed program in terms of how easy it was for a consumer to use it; the car retailer completed the paperwork, and consumers collected the incentive with no extra effort when they traded in their old vehicles. In contrast, tax rebates on home energy-efficiency improvements involve multiple steps: picking a qualifying improvement that makes economic sense, finding a contractor, making sure the work is done properly, keeping track of the paperwork to document the improvement, filing extra forms on a tax return, and so on.

Fifth, quality assurance is essential. The United States and many other countries have good systems for quality assurance for mass-produced consumer goods like motor vehicles and appliances. There are government mandated recalls of faulty products at manufacturers' expense, which assures consumers that product defects will be rare, and there are independent consumer organizations that publicize their assessments of the products. For home improvements, the system is not so good, largely because the products and services are individualized. Some solar energy companies have tried to provide quality assurance as part of their business plans, as we discuss below.

Each of these design features is important individually, but their combined effect is critical. For example, a financial incentive may take the form of a sales-tax subsidy on the purchase of a hybrid vehicle, or a rebate on income tax. Even if the dollar amounts are the same, the sales-tax rebate is likely to have far greater impact for several reasons. First, it results in a change to the "bottom line" that the purchaser sees immediately, rather than a change in some future tax bill or refund. This makes it more desirable to consumers who tend to discount future rewards very substantially.[21] Second, the income-tax rebate requires additional paperwork and the effort of remembering to do the paperwork in the future, while the sales-tax refund paperwork is processed by the car dealer during the sale. In addition, because sales taxes are regressive, reducing them provides a larger incentive to those who are most likely to be influenced by financial costs.

The potential for combining these design features is illustrated by the Cash for Clunkers program, which combined a sizable financial incentive – about 30 percent of the price of a low-end new vehicle – with strong marketing by manufacturers and with features that reduced the level of effort involved in capturing the incentive. And the program involved a product whose quality is easy for consumers to evaluate. Potential can also be seen in the business plans of some private companies that offer power purchase agreements for residential solar energy installations. These companies install solar collectors on a home and provide quality assurance by insuring the homeowner against damage from the installation and guaranteeing under contract to provide a predetermined amount of power per year for many years at a preset price. The company simplifies the process by doing the considerable paperwork required to take advantage of available federal, state, local, and utility incentives and to provide connectivity to the utility grid. The financial benefit to the homeowner, which may be considerable, is easily calculated and guaranteed by contract.

There are many ways these general principles manifest themselves in the design of policies and programs. In the following paragraphs, we offer some examples and describe the social science underlying them. The discussion gives a sense of how substantial changes in the energy system could be brought about at low to moderate cost through effective program design.

The communication element of program design can be enhanced by engaging social norms, which can be powerful for encouraging certain kinds of behavioral change.[22] For example, Opower is a company that helps utilities reduce household energy use with strategies based on social science understanding of household decision-making, including the influence of norms. It provides detailed feedback to households, including comparisons of their energy consumption to that of their neighbors. This information induces individuals to compare themselves to others; those who are above the community average tend to reduce consumption.[23] To discourage those who are below average from adjusting up, Opower uses other feedback, such as a smiley face icon, to encourage continued low consumption.[24] More research is needed to know whether these effects will persist over time, but there is some evidence that invoking norms does produce persistent changes.[25] In addition, the experience of the Hood River project suggests that social norms can help influence people to make expensive investments to reduce fossil energy consumption, but this requires more extensive social interaction and discussion. The municipal utility in Hood River employed a team of sociologists to design a communication element of the program that relied on existing neighborhood and community organizations to spread the word. This effort, together with a sizable incentive and other program features, led to major energy-efficiency retrofits in almost 90 percent of the homes in the city. To our knowledge, the Hood River approach has not been replicated elsewhere to influence investments in residential efficiency or renewable energy.

Research in both laboratory and field settings shows that people tend to maintain current behavior. While this stability could be an obstacle in getting people to start conserving energy, it also may mean that behaviors that promote efficiency will endure once they are started. The fact that consumers make many decisions habitually, and thus relatively automatically, helps explain the weak short-term response to price signals alone; but it also argues for the importance of instilling good energy-use habits early on, and thus for targeting educational initiatives to the young.[26] Desirable current behavior can also be signaled in ways that do not reduce choice options, for example in programs that establish efficiency as a default, such as those that allow utility customers to choose energy sources and make the more expensive green (rather than the current brown) providers of electricity the source if no choice is made.[27] Such use of default choices has been shown to be effective because, like a habit, it achieves a desired goal without requiring much information-processing.[28]

Technologies that reduce fossil energy use are not adopted simply because of their technical advantages or their economic benefits. Many other factors influence decision-making, and in many cases, energy consumption never rises to the level of consideration in making a decision. This is particularly the case for many home improvements that have major impacts on energy consumption but that are undertaken with the intent of providing amenities, often out of emotional motivation.[29] The hidden market for energy improvements as amenities (for example, solar collectors, in some communities) provides opportunities for using emotional motives to affect high-impact energy choices.

There is debate about how single energy actions might affect overall household impacts on fossil fuel use. The economist William Stanley Jevons once observed that increased efficiencies in the useful work produced by coal technologies led to increased uses of coal as more applications were found.[30] Some have expressed concern that households undertaking a few actions to reduce energy consumption will become more profligate in other forms of energy consumption. Others have argued that household and individual actions to cut fossil energy use might reduce effort expended on political and policy changes.[31] This concern is consistent with the idea that people have a finite pool of worry: increased concern about one issue reduces concern about other issues.[32] The single-action bias – that is, the propensity to take only a single action to alleviate a concern, even in situations where a broader set of remedies might be called for – also points to such a tendency.[33] However, the exact opposite is also plausible: that those who start down a path of reduced energy use with small initial steps become committed to further steps, and that those who are making personal changes to protect the environment will demand the same of government and other organizations. At present, we lack strong evidence about which of these effects is dominant for the kinds of energy-efficiency actions that will have the most impact in U.S. households.[34]

The potential for household choices to reduce fossil energy consumption is substantial. The estimate we have used – 7 percent reduction in U.S. greenhouse gas emissions – is conservative in two regards. First, it is based on estimates of plasticity from the best programs that have been examined in the literature. But almost no program has drawn on our full understanding of effective program design. Future programs could produce much higher adoption rates than have been observed in the past. Second, the 7 percent estimate is based only on existing, "on the shelf" technology and does not include emerging energy-efficiency technologies (for example, heat pump heating and cooling or LED lighting), residential renewable energy technologies, or technologies that will emerge in the near future. In addition to advances in the engineering of energy-efficiency technology, we will need to take advantage of existing and future advances in the social science of policy design and delivery. New insights from social science will help create environments that support both active and passive decisions: for example, using environmentally and financially desirable no-choice default options, priming longer time horizons and long-term goals, or describing and framing choice options to match household concerns. In turn, we will minimize choices that do not optimize either individual or collective welfare.[35]

As noted above, one of the biggest obstacles comes from programs that are overly complex and require substantial paperwork. We suspect that these problems arise from demands for detailed accountability. For example, in the 1980s, three financial grant programs for energy-efficient home improvements in the United States offered a median subsidy of 77 percent and achieved participation of 4 percent of eligible households per year. In Canada and Europe, five similar programs offered a median subsidy of 50 percent and achieved a participation rate of 8 percent per year. The most likely explanation for this difference is that all the U.S. programs and none of the others required a home energy audit as a precondition for receiving the grant.[36] The audit arguably reduced fraud, but also reduced participation. Program designers would do well to compare relative risks and benefits. If onerous procedures are required to prevent fraud, then the costs in time and the tepid response to programs should be weighed against the savings from fraud prevention.

Given the importance of increasing equipment efficiency, more attention should be paid to policies that engage when equipment turns over – that is, to timely evocation of goals related to energy savings or amenity production – for financial, environmental, or other reasons. The city of Davis, California, for example, has had rules that include energy-efficiency standards as part of building sale requirements for more than thirty years.[37] When a house is bought or sold, the costs of upgrading energy-efficiency features is usually a small fraction of the price, and thus is not burdensome. The costs in such a program could be included in the mortgage, with a lower financing rate than for typical home improvements. Further, home buying is a transaction that already involves a substantial amount of paperwork that is usually handled by a professional realtor or attorney paid to do so, and professional home inspections are nearly always required. So the certification of energy standards does not add much complexity to the transaction. To give another example, most people replace home water heaters when the previous heater fails. Consumer choice is often limited to what the plumber has on the truck. So an incentives program might be designed to encourage the plumber to supply high-efficiency units. Standards may be the simplest way to do that, although standards have their own complex dynamics.[38] Undoubtedly, there are other potential points of intervention that can be identified by thinking carefully about when and how households make decisions and about their motives for choice.

Although the potential for reducing fossil energy consumption through household decisions is immense, it can be realized only through effective programs. Such programs need to build on understanding of household choice processes, and this understanding must be rooted in behavioral and social science that goes far beyond current assumptions about rational and deliberative information use. Much of this understanding exists. Our current challenge is to put existing theory and methods to use for more effective design and implementation of policies targeting fossil energy use.

ENDNOTES

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The Public Acceptance of New Energy Technologies

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Abstract: In the wake of ominous results about the impending path of climate change, and with gasoline prices hovering around four dollars per gallon, the 2012 presidential and congressional campaigns are full of claims and counterclaims about the transformation of the U.S. energy system. Although much discussion has centered on the need for new energy technologies, this debate as yet has been narrow and limited. Meaningful deployment of any technology will raise questions of public acceptance. Little is known about how diverse publics in the United States will respond to the advent of new energy sources, whether they involve a "second renaissance" for nuclear power, a dash to embrace hydraulic fracking for oil and natural gas, or emerging prospects for renewable energies like wind and solar power. Yet public acceptance will determine the outlook. Adding further complication is the growing debate about traditional energy sources and the extent to which a fossil fuel–based energy system should continue to be central to the American economy. This essay explores the issues involved in public acceptance of stability and change in the U.S. energy system. We conclude with several recommendations for gaining a greater understanding of the public acceptance quandary.

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In the United States, new technology promising to solve the nation's sundry problems seems to be everywhere, and nowhere more than in the energy sector. Amid an economic downturn and rampant unemployment, the vision of new technologies beckons. The nuclear dream appears in the new guise of a "second nuclear renaissance," which offers a safer and more acceptable technology as well as the prospect of decentralized nuclear reactors operating at a community or neighborhood scale. In the search for a bridge to an energy system without fossil fuels, shale gas has burst into the energy arena as a salvation with nearly unlimited supply and the potential to reduce greenhouse gas emissions relative to coal. Meanwhile, renewable energy sources – especially wind and solar power – are touted as long-term solutions for achieving low-carbon and, eventually, low-cost energy options for the future. Accordingly, the race is on to ensure that the needed technology will be there. Some observers have even espoused technological solutions through geoengineering to deal with past and accumulating carbon emissions in the atmosphere.

Not all of these are new technologies, however; some are new applications of existing or old technologies. Windmills have abounded for several centuries, but their scale and size have shifted dramatically. Currently, offshore wind technologies are in the early stages of deployment.[1] Fracking involves new processes for liberating natural gas from shale formations, but established technologies have largely been the instruments used to capture this energy source. Even the exploration of decentralized nuclear plants has drawn largely from existing technology, with new deployment oriented at a different scale.

Issues surrounding public acceptance are not simply about the adoption of new and unfamiliar technology; they also arise in response to new applications of familiar technology. This is not surprising, as technological processes do not always proceed along a smooth curve. Uncertainty plays a major role in how technology adopters and various policies respond to what are likely unfamiliar risks. Therefore, uncertainty also plays a major role in public response. Lack of experience inevitably contributes to large and multiple uncertainties when new technologies and novel applications appear. Given that few new deployments have occurred, data are often scarce. While modeling is intrinsic to the characterization of emerging benefits and risks, the models are often early in development and have parameters that are still rudimentary and incomplete. What may be termed "deep uncertainty," or limited knowledge of the basic phenomena, may be a more major problem. Rapid and effective diffusion of a new socio-technical approach will not be determined by a unidimensional focus on developing the needed technology or application; rather, the primary consideration will be whether the social dimensions of what is at heart a social-technical system are in place.

The socio-technical system involves multiple social issues. To begin, public attitudes toward technology have shifted in the United States. As Ann Carlson and Robert Fri note in their essay for this issue, past energy transformations created an economic value that was captured by the market – a key condition for overcoming the difficulty of changing a socio-technical system. But in the twenty-first century, public values for energy security and low-carbon portfolios are externalities not captured by the market.[2] In previous decades and during the past century, public sentiment favored technology, which was seen as part of the American prospect. But in recent years, perhaps as American society has become more wealthy (if increasingly unequal and security conscious), sentiment has shifted against new technology and novel technological applications. Publics are increasingly suspicious and hypercritical. And where experience is meager and few deployments have occurred, supporting institutions have yet to emerge and regulatory systems are often embryonic. Even professional organizations may still be quite limited.

However, no problem is more stark or troublesome – yet extremely important – than that of public acceptance. We know from past risk studies that there is often a marked divergence between expert scientific assessment and public perceptions. At one time, it was largely believed that publics are ignorant, and that the gap could best be narrowed by more education – still a favorite solution of many experts. Yet subsequent studies have revealed conclusively that publics are not irrational; indeed, they can rank risks in an orderly and consistent manner.[3] But it is also clear that the general population assesses technologies and applications differently than experts do. Individuals consider, for example, ethical issues that may be involved, the trustworthiness of managers, and the adequacy with which they have been consulted and decisions made.

Complicating the risk issues are the uncertainty and complexity of new energy technologies. Thus, nothing is more central than public acceptance. Where the rubber meets the road in the deployment of new facilities, energy or otherwise, is in the siting process. We have discovered that general attitudes toward renewable energy facilities – such as wind, solar, geothermal, and biomass facilities – may be benign and supportive. Once a location is chosen, however, it is not unusual for new concerns to surface. In simplistic and frequently misleading terms, this effect is often referred to as the NIMBY ("Not in My Backyard") syndrome: that is, the idea that people ostensibly object to any risk when it is in their backyard and not someone else's. This pretext is, in fact, a well-honed means of blaming the victim, whereby deficiencies in the risk-communication or public-participation processes are blamed not on the manager or the process but on concerned local residents. This phenomenon is part of a larger, self-serving indictment of so-called uneducated publics that do not automatically accept the technical assessments and assurances of the managers, whatever the deficiencies in the process. On the other hand, there are challenges presented by vocal minorities opposing certain sites and new technologies that would otherwise provide benefits to the larger community.

Stakeholder involvement is being advocated as a means to improve public acceptance and developmental decisions, particularly those involving complex technology, uncertain risks, and contending values. Various reports from the U.S. National Research Council (NRC) have highlighted stakeholder participation as a central element in a well-orchestrated policy of seeking public acceptance for new policy or technology solutions. For example, in its influential report *Understanding Risk*, the NRC emphasized deliberative processes as central in "developing the understanding required to inform decisions."[4] Recent reports on public participation, including the NRC's *Science and Decisions*, have reaffirmed and expanded these views.[5]

Internationally, major assessments of global environmental risks, such as those conducted by the Intergovernmental Panel on Climate Change and the Millennium Ecosystem Assessment, have recognized widespread stakeholder participation as essential to addressing environmental threats, new and old. Even in remote villages in China, India, and sub-Saharan Africa, studies have called for greater local involvement in decisions made at higher levels of government that affect residents' lives and security. Many experts believe that broad stakeholder participation will increase public acceptance, leading to ongoing decisions that are better informed and more sensitive to local conditions, that limit the power of elite interests, and that assure greater implementation of needed projects and development.

The stakeholder-involvement imperative abounds with allusions to democratic ideals and the positive outcomes expected to result from such exercises. Implicit throughout is the notion that broad public involvement is the principal route to improved decision-making, especially when the risks are controversial and disputed. Expected outcomes, it is claimed, include increased trust in experts and decision-makers, greater consensus among publics and between science and politics, reductions in conflict and controversy, greater public acceptance of preferred solutions, and increased ease of implementation. From this perspective, it is not surprising that public involvement is becoming routinized as a standard component of risk deliberations. At the same time, a host of consulting institutions have emerged to exploit a new, lucrative opportunity: providing the analytic support that environmental and energy managers need to include the public in energy decisions.

But the impediments to deploying new energy technologies are formidable, pervasive, often underestimated, and well beyond issues of stakeholder involvement. Perhaps it is only natural to expect the ready acceptance of new energy technologies. After all, observers increasingly point to the historical embrace of coal technologies, which led to the casual removal of mountaintops, health-threatening air pollution, and widespread environmental damage to lakes and streams in Europe and the United States. But it is now well known that publics often respond to risks in different ways than technical experts. And given changing attitudes toward technology in the United States, there appear to be historical differences as well.[6] New risks often involve perceptions of dread and severity among publics, reflecting a basic tendency of laypeople to assess risks using a different, often broader framework than experts use. As a result, new risks in the mix of energy options can generate concerns that are not likely to be assuaged by information and assurances from experts and managers.

Making matters worse is the long-term decline in social trust in the United States. Social trust provides the essential lubricant, especially the base of supporting public values, needed to usher in a concert of changes. With social trust currently in short supply, this vital resource may not be anywhere near the levels needed to support major changes in the energy system, which would necessarily involve changes to institutional norms, individual behavior, cost and pricing, and social values.

Social trust is a complex, multidimensional concept. Competence, predictability, and caring are all part of the picture, sometimes in consonance and at other times in conflict.[7] On the one hand, for example, early release of risk information demonstrates that a manager is open and caring. On the other hand, if the information is found in subsequent studies to be flawed and/or misleading, then questions of competence are likely to emerge, resulting in distrust rather than trust.[8] Those at risk must believe in the high scientific quality of the analyses that managers provide. Thus, managers' interactions with stakeholders, particularly risk-bearers, are always fraught with potential social trust concerns. It is not easy to be open, to communicate information in a timely manner, and to show high competence at the same time.

Where does social trust come from? This issue adds to the complex world of energy management and decision-making. It is often assumed, for example, that if a manager behaves in a trustworthy fashion, greater social trust will result. But this may not be the case.[9] While personal experience with particular institutions or managers can lead to greater social trust or distrust, the long-term erosion of social trust in the United States implies that such confidence is built and lost systemically. Evidence suggests that deployment of new technology in the U.S. electric power industry will need to proceed under conditions of high distrust. Indeed, trust in corporations, particularly the coal, nuclear, oil, and gas industries, is at an all-time low (as the BP oil spill in the Gulf of Mexico and the Fukushima Daiichi disaster make clear). Levels of trust with regard to several other key actors, such as Congress and the mass media, are also at historic lows.[10] There is little reason to believe that substantially greater social trust will soon appear, whatever the urgency of energy security and global climate change.

Complicating this paucity of social trust is a broad set of value-based and ethical concerns that arise in the dissemination and adoption of new energy technologies, including issues of environmental protection, democratic values and processes, and poverty reduction. Energy technologies are not value neutral; all entail varying combinations of distributional and generational equity issues – specifically, who reaps the benefits and who bears the risks and burdens? For example, the proposed Keystone XL pipeline would pose risks along its transit route from Alberta, Canada, to the Gulf of Mexico for the benefit of energy consumers throughout the United States. Geothermal energy carries localized risks but benefits broader regions. Fracking has similar distributional issues and may entail generational problems as well. To the extent that solar and wind technologies contribute to reducing climate change, the benefits are global as well as national. These issues are often largely implicit rather than openly discussed. Yet questions of equity need to be explicitly raised and addressed, and the public processes used to do so will significantly influence stakeholder response.

The importance of risk communication highlights the problem of determining "acceptable" or "tolerable" risk. Technology managers frequently assume that judging whether the risks are too great and thus must be reduced is only a matter of biophysical science. This is not the case: experience and comparative analyses have established that evaluating risk necessarily involves public values and political interests. In addition, the acceptability of risk varies according to the magnitude of perceived benefits and whether the risks are voluntary or involuntary.[11] The assessment of public values is a critical task that requires a sustained commitment from energy managers, extending far beyond scientific assessment.

To win greater public acceptance, and to draw social-science thinking into that process, calls for major efforts in capacity-building. Precious little social-science expertise exists to address risk assessment and public-acceptance processes at the federal, state, or local level. Earning public acceptance is seen primarily as a job for advertisers and public relations officials. With the relevant government agencies largely staffed by engineers, biophysical scientists, and lawyers, and with a hiring process that tends to reproduce existing expertise, social scientists are unlikely to be recruited anytime soon. This gap in expertise only compounds the challenges to understanding how individuals and social institutions behave in a social-technical system. Indeed, the most difficult problems in the deployment of new solutions and technologies are rooted in social issues and public perceptions that are difficult to change.

One of the more immediate challenges is the outmoded U.S. energy grid. Tripartite in structure, the national grid varies in regional performance and cost characteristics. Future utility-scale energy facilities, such as wind and solar, may be sited far from the energy grid and prospective markets, raising public acceptance and equity problems. Modernization and expansion of this grid, whether for existing fossil fuels or renewable energy sources, will be vital to a robust public acceptance strategy.

Transforming the U.S. energy system will require widespread adoption of an alternative vision of how energy should be generated, delivered, and consumed. Therefore, the goal of public acceptance requires as much attention as developing the needed technology. In order to achieve a low-carbon technology transformation and a flow of new applications, several major issues must be addressed:

- Early efforts, through surveys and interviews, must be undertaken to define a baseline of public concerns, values, and perceptions of risks.
- A national commitment to an alternative energy future must be established, with supporting justification in terms of climate change and energy security.[12]
- Collaborative approaches to assessment and decision-making are essential, particularly in a context of meager social trust. Low levels of social trust will require empowerment of those who host the facility and bear the risks.
- Public acceptance of new energy facilities at particular sites will require a consent-based approach rather than the imposition of risk by outside decision-makers.
- Active public involvement can provide a means to monitor facility performance and impacts on the community and local ecology. If risks are underestimated and facility performance does not meet regulatory standards, provisions should be in place to allow local officials to petition for or effect closure of the facility.
- Evaluation, jointly arranged by the developer and the host community, should be ongoing throughout the stages of development – namely, planning, construction, operation, and decommissioning. This assessment should involve rigorous peer review – designed by experts, regulators, and state and local officials – at each stage. Evaluation should be seen as a key element in mid-course corrections and adaptive management.

Building greater social-science capability in risk-management assessment is a pressing need that requires extraordinary measures. Long-term initiatives should be established to develop the social-science capacity now lacking in government and private agencies at all levels. Efforts should include the establishment of specific hiring and training processes, special research programs, and analyses of pressing needs.

While there is no assured process for achieving public acceptance of new energy technologies and applications, and although greater stakeholder participation does not always lead to better decision-making, working toward these objectives is crucial. Meeting the existing regulatory requirements of the National Environmental Protection Act, among others, does not guarantee the adoption of new energy technologies and applications. Probabilities for success improve greatly with serious attention to, and investment in, achieving public acceptance. This issue cannot be left to the end of the process and whatever budget scraps remain.[13]

ENDNOTES

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The Transnational Politics of Energy

Robert O. Keohane & David G. Victor

Abstract: Creating effective energy policy is hard, in part because it often requires effective international coordination. For most salient energy-related issues – such as control of the emissions that cause global climate change or the building of stockpiles to make oil supplies more secure – international coordination is inherently difficult. Solutions lie in making these problems more manageable by working in small groups of relevant countries; successful cooperation also hinges on finding incentive-compatible commitments that align, to the extent feasible, with national interests and are focused on areas where cooperation will yield tangible joint gains. The outcomes of such cooperation efforts are likely to be decentralized complexes of networked institutions rather than integrated, hierarchical treaties that govern a coherently defined issue-area.

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For countries to deal successfully with energy issues, they must engage in international cooperation. This requires being strategic in selecting issues to address. Although domestic politics undoubtedly takes center stage in formulating energy policy, energy markets and environmental problems have both become global. As a result, any nation's actions to reduce greenhouse gas emissions meaningfully, to secure reliable energy supplies, or to stabilize energy prices will be affected by the actions of many other countries. International considerations raise hurdles in the formulation of effective national policies, but they can also create opportunities. In this essay, we explore when such opportunities can arise, how some hurdles to effective international coordination can be cleared, and how analysts and policy-makers should think about the design and impact of international regulatory frameworks. We argue that the structure of international cooperation on some energy problems, such as climate change, is prone to deadlock. But by recrafting these problems – usually by making them "smaller" and focusing on the areas where national interests are better aligned for international cooperation – participating countries can avoid an impasse.

In the first volume of this two-volume special issue of *Dædalus*, editors Robert Fri and Stephen Ansolabehere ask, "Why is creating energy policy so hard?"[1] Focusing on the United States, they identify a number of reasons, three of which could be summarized as follows:

1. Most important, the U.S. public does not want to pay more for energy even though full social-cost pricing is key to a coherent energy policy.
2. In particular, the U.S. public does not put significant weight on global warming as a driving force for policy regarding choice of fuels and energy technologies.
3. Finally, the competitive and intensely polarized state of U.S. politics means that no policy elite can develop and impose a coherent energy policy without facing the impossible task of appealing to extreme positions while also retaining enough centrist support to achieve policy passage.

The problems are *not* principally about a lack of scientific knowledge, and they cannot be rectified with research. Instead, the problems are political and, as the first volume makes clear, apparently intractable. Action can be taken at the margin. For example, the Obama administration recently imposed new regulations that make the construction of new coal-fired plants in the United States very unlikely while also creating strong incentives to shut down a large fraction of the existing (mainly older) coal-fired plants. Overall, however, as volume 1 suggests, the political forces needed for major changes in U.S. energy policy are not in place. This second volume, which also focuses primarily on the United States, devotes much attention to the underlying behavioral and institutional forces that drive decision-making and choice. While there are some causes for optimism, this volume echoes the pessimistic message of volume 1.

It would be gratifying to report that the situation in other countries looks more promising, and there are indeed some glimmers of hope. The European Union is in principle committed to reducing emissions by 80 percent by 2050; there is more support in most of the European Union for vigorous action on climate change – and, therefore, on energy – than elsewhere in the world.[2] But Europe is declining as an economic force, accounting now for only about one-fifth of the world's commercial energy consumption.[3] China and India are rising forces in energy (and most other matters of international importance). Together, these two countries account for at least half of the likely growth in energy consumption and global warming emissions over the next three decades. If the advanced, industrialized countries continue to struggle with economic stagnation as well as meeting limits on emissions, the share of growth in emissions from these and other emerging economies will be even greater.[4] Both India and China (especially China) have aggressive national programs to address some aspects of energy use, such as the need to cut local pollution and raise energy efficiency; nonetheless, independent national action is unlikely to add up to an effective global response on any of the major energy issues requiring international coordination. Neither China nor India integrates its oil stockpiles with the International Energy Agency (IEA) system, and both have signaled wariness about entering into binding international agreements on climate change.

International cooperation is essential for an effective global response to energy and climate change issues, but true international coordination is inherently difficult to organize. Because there is no world government, effective collaboration must involve states, multilateral institutions, and those firms and non-state actors that play important roles in an issue-area. Such cooperation does occur, most notably in trade through the World Trade Organization (WTO), in development through the World Bank, and on monetary issues – at least when crisis concentrates the minds of elites and publics – through the International Monetary Fund and Group of 20 (G-20). But with respect to energy and climate change, cooperation has been halting at best.

Under favorable conditions, cooperation emerges because there are tangible joint gains to be reached, such as benefits from international trade. In economic terms, as long as the status quo lies below the Pareto frontier, arrangements can be made that benefit all parties – provided that agreements are reliably crafted and enforced. In such situations, cooperation emerges not out of harmony but from the discord that has hitherto prevented parties from capturing these potential joint gains. Discord in such situations adversely affects the interests of all participants, generating mutual desire for policy coordination that all crucial players find preferable to what would otherwise ensue.[5] Our task in this essay is to apply the logic of international cooperation to energy questions. In many respects, there is little that is "new" about energy. The fundamental challenges to and opportunities of political action within and among countries are familiar.

Conditions for cooperation at the global level vary by the nature of the problem. Problems that are close to pure coordination problems – with minimal conflicts of interest – are relatively easy to solve. For example, establishing common rules that all aircraft will follow as they fly through different national airspaces involves complex transnational coordination on topics such as radio frequencies, language, and the design of navigational equipment, but these rules raise few difficult political issues because interests usually converge around a focal point that provides the basis for a solution. Often these focal points simply reflect the path blazed by early, large adopters. When distributional issues loom large, however, problems become more difficult: wrangles over "who pays" are familiar.

Also important is whether the benefits in question accrue to those who take action. Participants are more likely to invest in cooperation when its benefits accrue only to them than when nonparticipants also benefit. When benefits can be appropriated, actors can employ reciprocity to generate cooperation because one party's cooperative actions are contingent on reciprocal moves by others. If the sequence of moves extends indefinitely into the future, and if the prospective benefits to each party are substantial, the reputations for credibility that develop can lead to sustainable cooperation.[6] Leadership is also more likely to be forthcoming when potential leaders see that they can appropriate benefits from their actions.

By focusing on these two dimensions of cooperation problems – that is, the degree of conflict of interest and whether benefits accrue to cooperating states or are more widely diffused – we can generate expectations about the relative difficulty of solving different energy-related problems at the international level. Table 1 provides a useful stylization of the various cooperation problems. When there are few distributional issues and private goods are involved, we expect relatively easy cooperation on a voluntary, decentralized basis between parties that will benefit (upper left-hand quadrant). In contrast, when severe distributional issues and public goods are in play, as in the lower-right

Table 1
Four Basic Problem Structures: Prospects and Strategies for Cooperation

	Cooperation Focuses on *Private* Goods	**Cooperation Focuses on *Public* Goods**
***Low* Conflict over Distribution of Gains and Losses**	**Harmony:** Least severe challenges for cooperation; soluble when parties know their interests	**Hegemonic cooperation:** Soluble when a large country obtains a large enough share of the benefits that it is willing to invest in cooperation that benefits all
***High* Conflict over Distribution of Gains and Losses**	**Iteration:** Soluble with repeated play	**Entrenched discord:** Most severe challenges; difficult to solve unless problem is broken down into smaller units where harmony, iteration, or hegemonic cooperation strategies are available

Source: Table created by authors.

quadrant of Table 1, cooperation is very difficult. No single actor or small set of actors has incentive to bear the costs and risks of cooperation; potential leaders do not step in because they fear having to pay disproportionately for revealing their preferences for action.

The off-diagonal boxes in Table 1 represent intermediate situations, in which cooperation is conditional on some other variable. If the goods are public but relatively inexpensive to provide – keeping distributional issues relatively minor – a single participant or small group may find it worthwhile to bear the expense of providing the public good (Table 1, upper-right quadrant). In this scenario, the hegemonic actor or small group benefits, on balance, even after paying the costs; others get a free ride. Finally, if goods are private but distributional issues are pronounced, devising institutions that promote repeated play, in which no actor makes huge unconditional commitments and confidence is slowly built up over time, can promote cooperation (Table 1, lower-left quadrant).

Table 1 shows that the prospects for cooperation (and the appropriate institutional design) depend on the "problem structure." The two dimensions shown in Table 1 are not the only possibilities; problems vary in many other ways, such as whether costs and benefits are proximate or far into the future. However, this simple framework is a useful first step in analysis. Applied to international energy problems, the framework in Table 1 reveals why some problems have garnered cooperation while others fester. Table 2 applies that framework to some major energy-related issues that have inspired efforts at international coordination. In the following sections, we illustrate how the problem structure affects the degree of cooperation on each set of issues, and then draw some implications for policy.

Cooperation is easiest in areas marked by *harmony* because countries already have an

Table 2
Energy Issues by Problem Structure

	Cooperation Focuses on *Private* Goods	Cooperation Focuses on *Public* Goods
Low Conflict over Distribution of Gains and Losses	**Harmony:** Example: phaseout of fossil fuel subsidies agreed by the G-20; agreements to "transfer" technology	**Hegemonic cooperation:** Example: coordinated management of international oil market, including strategic oil stockpiles, through the IEA
High Conflict over Distribution of Gains and Losses	**Iteration:** Example: investment in deploying new energy technologies through U.S.-China bilateral energy partnership	**Entrenched discord:** Example: constructing an effective global regime for climate change or energy

Source: Table created by authors.

incentive to make needed changes in policy. Nonetheless, many of these cases look like instances of international cooperation, in which agendas are set for international talks, diplomats and political leaders meet and wrangle over texts, and agreements are forged. But underlying those overt efforts at cooperation is a problem structure that almost guarantees success.

Consider the G-20's 2009 agreement to phase out fossil fuel subsidies.[7] Many countries were already far along in the process of removing subsidies for conventional fossil fuel technologies and redirecting those subsidies toward new energy technologies – notably, renewables. A large amount of research had documented the harmful fiscal and environmental effects of these subsidies and had shown that where subsidies promoted consumption of imported fuels, they also degraded national energy security. By the time the G-20 took up the matter, the various national policy efforts were far from complete. In India, for example, large subsidies for kerosene and electric power, which had originally been justified on grounds that they helped promote welfare in rural, poor populations, had become politically entrenched. But even in these cases, governments were mobilized and making progress in changing policy.[8] In the large energy-producer members of the G-20 – notably in Russia, and to some degree Saudi Arabia – substantial market-oriented (and subsidy-reducing) energy-reform efforts were under way. (The world's biggest users of fossil fuel subsidies – Iran and Venezuela – were conveniently not members of the G-20, and their subsidizing behavior remains unswayed by the G-20's proclamations.) The politics for significant (if not complete) subsidy reform were aligned within nearly all the major G-20 nations.[9] Conversely, if the G-20's subsidy reform agenda had included other topics on which the countries did not already agree – such as realigning subsidies for renewable energy or nuclear power – the prospects for bold international agreements would have been dim.

Even in these cases of harmony, international cooperation is not automatic;

active efforts at cooperation are often needed. For example, international agreements such as the 2009 G-20 deal can generate common knowledge of commitments and help lock collective gains into place, preventing backsliding.[10] They can reduce the costs of transactions – for instance, by creating a focal point for future cooperation. Work on fossil fuel subsidies could beget reforms on other types of subsidies. (As governments, besieged by fiscal austerity, start reforming renewable power subsidies on their own, the prospects for international cooperation on these subsidy reforms will rise as well.[11]) Visible success in an important area of policy can signal to countries that are not members of the cooperative effort – in the case of fossil fuel subsidies, that includes most major energy exporters – that reforms are both needed and feasible.

Problems that seem intractable, whether because they have severe distributional implications, involve public goods, or both, often become much easier to manage as a result of exogenous changes in policy, technology, or other circumstances. For example, consider the issue of *technology transfer*: that is, the overt (by gift or with concessional funding) transfer of hardware and intellectual property from rich industrialized countries to developing countries. Ever since the New International Economic Order of the 1970s, most international talks on energy and environmental issues that include developing countries have also involved contentious diplomacy on technology transfer. Every major international environmental treaty crafted from the 1980s to the present has included different obligations for industrialized and developing countries; in many cases, such as in the ozone layer accords, special funds have helped countries on both sides of the rift find common ground and engage in collective action.[12]

Meanwhile, an array of changes in national policy and economic growth is making technology transfer easier. Since the late 1980s, barriers to trade in products with high intellectual property content have plummeted because states have viewed it as advantageous to open trade, within or outside the WTO. For example, a sweeping set of reforms in India in the early 1990s reduced or removed barriers to importing foreign energy technologies. As a result, Indian manufacturers of these technologies have been forced to become more competitive, foreign suppliers now have new markets in India, and new power plants in India are significantly more efficient than the older vintages.[13] (Higher efficiency means lower emissions as well as lower use of fuel, reducing the danger of national shortages of coal and dependence on large coal imports.[14]) The sharp uptick in economic growth in all the major developing economies, at least until recently, has also boosted demand for trade in technology and focused governments on the national policies needed to keep energy use in check.

All these changes have made technology transfer much easier. This progress has not erased the regular theatrical discussion of technology transfer in global environmental talks, but it has led markets to transfer much more technology. A problem with the characteristics of discord was transformed into one that much more closely approximates harmony.

Turning to the off-diagonal boxes in Tables 1 and 2, we now consider the two kinds of cooperation known as *hegemonic cooperation* and *iteration*. The most visible historical example of multilateral cooperation on energy – the IEA's efforts to coordinate large oil consumers and manage oil markets – arose largely as a result of hegemonic leadership by the United States. In the wake of the first oil shock, the large oil consumers saw a compelling need to join forces. Given that oil is a fungible commodity, unilateral action by one consumer (for example, hoarding) can be harmful to other major consumers, while concerted action (for example, the coordinated filling and release of oil stockpiles) can improve the welfare of the collective. Cooperation of this type aims to provide public goods but does not face severe distributional barriers. At the time, all the large oil importers were already cooperating on other economic issues through the Organisation for Economic Co-operation and Development (OECD). Thus, they assigned the task to a new agency created within the OECD: the IEA.[15]

The second oil shock (in 1979) revealed that the mechanisms the oil importers had created did not work well in a crisis, compelling the IEA to tighten its procedures and strengthen its systems for intergovernmental cooperation. Since then, no oil shocks of that severity have occurred – in part because large changes in the oil markets and the elimination of most price controls and quota systems have made market signals more effective in encouraging the private sector to stockpile and adjust behavior in line with fundamentals. The few tests of the system, such as in the aftermath of Hurricanes Katrina and Rita in the United States (which knocked out a large fraction of U.S. oil-refining capacity), suggest that the system is truly cooperative and reasonably effective.

Hegemonic leadership took a problem marked by strong incentives for countries to defect and made cooperation more likely. While all consuming countries stood to gain from coordination, the largest consumer (the United States) was positioned to reap the largest benefits. Thus, the United States had a strong incentive to incur most of the costs and risks associated with establishing the IEA.[16] Once created, the institution has endured even as U.S. economic power (in relative terms) has waned. Whether the IEA can endure the rise of new economic powers remains to be seen. Both China and India are large oil importers, and thus both gain from effective coordination of stockpiles and management of the oil market; but both also have strong incentives to accept a free ride. China, in particular, faces strong internal pressures to seek security through unilateral actions – namely, special deals that "lock up" supplies for China, import quotas, and a national system of oil stockpiles that is large yet whose purpose and operation are shrouded in secrecy.

Looking at the lower-left box in Tables 1 and 2, iteration can help yield cooperation in areas where the parties might disagree about the allocation of benefits and costs but are able to internalize the gains from cooperation. In such settings, countries will cooperate if they are confident that the other side will not defect. While there are many ways to boost confidence, one of the most reliable is through iteration. Past cooperation becomes a reliable signal that more cooperation is possible, and the prospect of future interaction focuses minds on long-term gains rather than short-term opportunities to defect. Joint investment agreements are an example. Solving most energy problems requires new technologies, and most energy technologies are capital-intensive and fixed to the ground. Most intellectual property also requires high up-front costs and a long time horizon for profitability. As a result, a large fraction of international investment disputes concern energy technologies such as power plants. Yet cooperation produces huge gains because it raises overall levels of investment (which generally leads to more secure and less polluting energy systems). Moreover, a larger international market gives innovators more installations on which they can test new ideas that, through learning, yield technological change. Iteration is one of the logics behind bilateral investment treaties (BITs), and it is also the logic that inspires the U.S.-China bilateral innovation and investment talks.

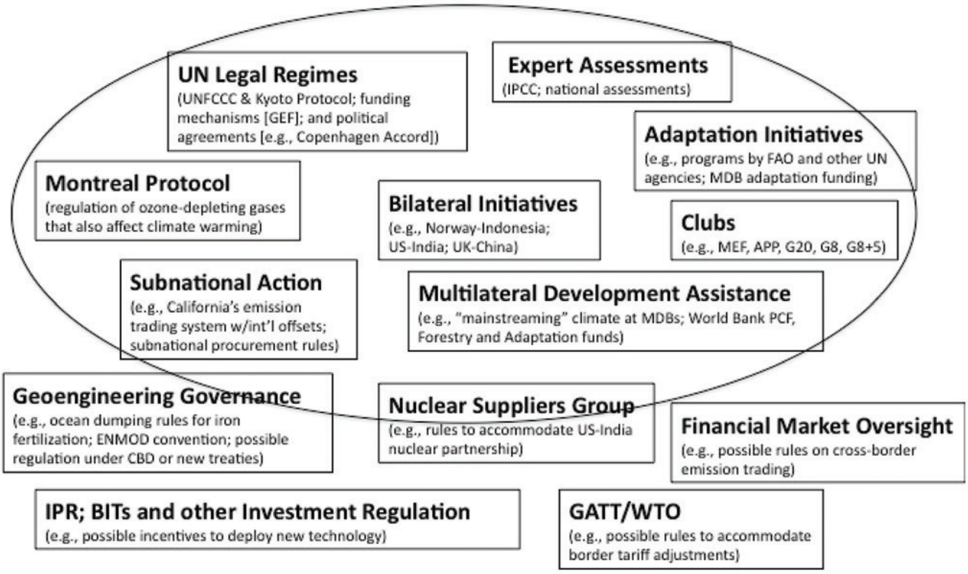
"Energy" intersects with many other issue-areas, including climate change; thus, there are often calls for coherent international arrangements to manage these problems. In light of the framework presented in this essay, it is not surprising that a coherent international regime does not exist for either energy or climate change, let alone both of them together. In a word, these issue-areas fall into the lower-right box of Tables 1 and 2: *discord*. Understanding why there is no such regime for climate change helps explain the absence of an energy regime as well.

International regimes – institutions with legally binding rules – are formally constructed by elites who represent state interests as they conceive them. A coherent climate change regime on the model of the Kyoto Protocol would impose large sovereignty costs on states by committing them to carbon emissions targets far into the future. Adhering to these targets would be very expensive in economic terms, and leaders who took action would capture almost none of the material benefits. Limiting climate change is a public good because CO_2 emissions affect Earth's climate – a public good that is available to (and potentially tarnished by) all peoples. Making matters worse, *future generations* would be the major beneficiaries, but present generations would pay the cost. It is difficult to imagine either democratic or authoritarian leaders paying significant costs during their terms of office for the sake mostly of people yet to be born in other countries, unless the prospect of climate change becomes so severe and palpable that ordinary people begin to worry intensely about it.

With respect to energy, the distributional problems are even more serious. A rise in the price of oil, while good for producers, is bad for consumers. The situation is not zero-sum because both sides have an interest in relative stability. That stability might, in fact, arise through iteration – such as current efforts by oil suppliers and users to improve the quality of data about the oil market – were the conflicts over distribution not so large and the economic consequences of energy supply so highly diffused. But interests diverge sharply. The interests of oil producers, reflected in the Organization of Petroleum Exporting Countries (OPEC), and those of consumers, reflected in the IEA, are often at odds with one another. Consumers want security of supply, price stability, and relatively low prices. The producers are divided between price hawks and relative moderates, such as Saudi Arabia, which value stability more highly; but their joint preference, certainly, is for higher prices than consumers prefer. And some producers want to retain the "oil weapon" to put pressure on consuming countries with respect to other issues, such as political relationships in the Middle East.

As a result of these centrifugal political forces, efforts in the contemporary world to construct integrated regimes that limit the extent of climate change and assure the supply of energy have failed. Instead, there is in each issue-area a *regime complex*: a loosely coupled set of specific regimes, as depicted for climate change in Figure 1. The most important reason for the emergence of a regime complex rather than a coherent regime lies in the nature of state interests as described above: that is, due to intense distributional conflict and high uncertainty, incentives for states to make commitments are low. Yet both broad issue-areas present opportunities for

Figure 1
The Regime Complex for Managing Climate Change



Boxes show the main institutional elements and initiatives that make up the climate change regime complex. Elements inside the oval represent forums where substantial efforts at rule-making have occurred, focused on one or more of the tasks needed to manage the diversity of cooperation problems that arise with climate change; elements outside are areas where climate rule-making requires additional, supporting rules. Guide to acronyms used in the figure: Asia-Pacific Partnership on Clean Development and Climate (APP); bilateral investment treaty (BIT); Convention on Biological Diversity (CBD); Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD); Food and Agricultural Organization of the United Nations (FAO); General Agreement on Tariffs and Trade (GATT); Global Environment Fund (GEF); Intergovernmental Panel on Climate Change (IPCC); intellectual property rights (IPR); multilateral development bank (MDB); Major Economies Forum (MEF); Post Conflict Fund (PCF); United Nations Framework Convention on Climate Change (UNFCCC); World Trade Organization (WTO). Source: Reprinted from Robert O. Keohane and David G. Victor, "The Regime Complex for Climate Change," *Perspective on Politics* 9 (1) (March 2011): 10.

greater convergence on particular issues, or for smaller "clubs" to act. Remarkably, for example, the European Union has made significant commitments to take deep action.[17] The result is a regime complex rather than a coherent regime or the absence of agreement altogether.

In other words, discord helps explain why there is no coherent, integrated regime for climate or energy and why, instead, "complexes" of institutions have emerged in both areas. Progress is being made on issues that pose few conflicts of interest, are dominated by one or a few states, and in which iteration over time enables cooperation to emerge and sustain itself: that is, issues that fall into the upper half and lower-left cell of Table 2.

The emergence of a regime complex rather than an integrated, comprehensive regime on issues such as energy and climate change should not lead us to despair. On the contrary, policy-makers who seek more effective limitation on the magnitude of climate change can use regime complexes to their advantage. And the availability of a regime-complex policy strategy suggests that countries most committed to doing something about energy issues should reflect on how to take advantage of the flexibility and adaptability of regime complexes, insofar as the more coherent approach of an international regime remains unavailable.

One potential advantage of regime complexes lies in the faults of integrated regulatory systems that are already apparent in the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. It is difficult to design effective regulatory systems in the context of a multiplicity of cooperation problems, a broad and shifting distribution of interests, extreme uncertainty about which measures governments are willing and able to implement, and ambiguity about how to craft viable linkages. When regimes are constructed, therefore, they are likely to be unwieldy – a product of political compromise. But the difficulty of renegotiation will lead participants to cling to existing institutions, which take on monopoly characteristics. For example, the broad coalition of developing countries – the Group of 77 and China – lambasted attempts led by rich countries to work in small groups and outside the UNFCCC process during the run-up to the Copenhagen conference, despite mounting evidence that the formal sessions were making little progress.

The dysfunctions of the UNFCCC monopoly are especially evident in the Kyoto Protocol's Clean Development Mechanism (CDM), a system for encouraging low-emission investments in developing countries. Over the long term, engagement with developing countries is essential; it is mathematically impossible to reach deep cuts in world emissions of warming gases without these countries' participation. The main compensation mechanism for enticing developing countries to participate has been linkage to emission credit markets through the CDM. Yet studies suggest that, due to poor administration, perhaps two-thirds or more of CDM credits issued do not represent bona fide reductions in emissions. Despite this realization, it is proving very difficult to fix the CDM. The complex and highly politicized nature of decision-making within its UN-based administrative system as well as the UNFCCC and the Kyoto Protocol have precluded meaningful reform.

While institutional monopolies have dysfunctions, a regime complex can be too fragmented. Components may conflict with one another in ways that yield gridlock rather than innovation; the lack of hierarchy among specific regimes can create critical veto points; and forum-shopping can lead to a "race to the bottom." Various crises in the energy regime complex over the years – notably the oil price surges associated with the 1973 to 1974 Arab state oil embargo and the Iran-Iraq war, particularly from 1979 to 1980 – disrupted consumer markets.[18] We are not arguing that regime complexes are necessarily better than other institutional forms. Instead, we view them as likely outcomes in areas such as energy and climate, where grand issue-wide efforts at international cooperation are likely to yield discord. In the linked issue-areas of energy and climate change, an integrated regime might be attractive as the most legitimate institutional form, but efforts to craft such a regime face enormous political and organizational barriers. The result of efforts to construct such systems in these issue-areas will be gridlock and only weak substantive commitments. A more loosely coupled system is inevitable.

If governments and non-state actors seeking more effective management of climate change and energy issues behave strategically, they can use fragmented institutions to their advantage. A broad topic such as "climate change" or "energy" consists of many detailed areas for international cooperation, including the reform and eventual elimination of most fossil fuel subsidies; the creation of incentives for private investment in new low-emission technologies, such as renewables, nuclear, and natural gas; and reforms to existing institutions such as the CDM. Decentralized institutions can be more inviting for leader countries that wish to take action on one or more of these topics yet find the full agenda daunting. For such reasons, elsewhere we have argued that regime complexes, if managed well, offer at least two distinct advantages over efforts to create single, integrated regimes: flexibility across issues and adaptability over time.[19]

Dispersed institutions also have disadvantages, including multiple opportunities for manipulation, a proliferation of veto points, and gridlock as well as the fact that it is time-consuming and costly not to have a single set of rules. Therefore, proposals for specific elements, such as new clubs, that would further fragment climate institutions should be carefully assessed relative to whether they would enhance the overall performance of the regime complex. Whether the proliferation of different forums working on these issues is an asset or liability depends on how these dispersed efforts are coupled.[20]

Yet thinking about regime complexes rather than simply focusing on the Kyoto climate change regime can open up interesting possibilities for policy action. For example, it may be possible to address non-CO_2 contributors to climate change, such as black carbon, methane, lower atmospheric ozone, and industrial gases such as chlorofluorocarbons (CFCs) and hydrofluorocarbons.[21] Thus, while taking care to ensure that the regime complex does not become dysfunctional, climate policymakers should look for additional actions that are feasible within the framework outlined in Tables 1 and 2 and seize opportunities to design programs consciously built on hegemonic power and iteration.

Domestic policy choices with respect to energy and its externalities depend heavily on the potential for successful international cooperation. Without ambitious global agreements and processes for detailed policy coordination, many potential actions (such as raising the price of carbon) are likely to be politically infeasible within individual countries because they will create competitive disadvantages. Even innovative countries – such as the EU nations acting on climate change – will be wary of adopting national measures that impose costs much greater than what can be justified through international cooperation. Wise energy and climate change policy hinges on what sorts of international agreements are viable.

We have argued that the feasibility of potential international agreements depends on problem structure as indicated in Tables 1 and 2, which emphasize concerns over access to public goods and the severity of distributional issues. Directly tackling issues that involve both public goods and severe distributional issues – which, unfortunately, include core issues of energy and climate change – is likely to be futile. But this conclusion is not a recipe for inaction. Instead, it suggests the need to identify elements within those broad topics where the problem type is more amenable to cooperation, where basic harmony of interests or hegemonic power and iteration can be brought to bear.

For countries to deal meaningfully with energy issues over the next decade, they must engage in international cooperation. To do so successfully, they will need to be strategic in choosing the issues they will address.

ENDNOTES

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2 *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A Roadmap for Moving to a Competitive Low Carbon Economy in 2050* (Brussels: European Commission, August 3, 2011).

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14 David G. Victor and Richard K. Morse, "Living with Coal: Climate Policy's Most Inconvenient Truth," *Boston Review* (September/October 2009).

[15] Wilfrid L. Kohl, "Consumer Country Energy Cooperation: The International Energy Agency and the Global Energy Order," in *Global Energy Governance: The New Rules of the Game*, ed. Andreas Goldthau and Jan Martin Witte (Washington, D.C.: Brookings Institution, 2010), 195–220.

[16] Robert O. Keohane, "The International Energy Agency: State Influence and Transgovernmental Politics," *International Organization* 32 (4) (Fall 1978): 929–951.

[17] The nature of the problem structure makes us skeptical about the sustainability of these proposed cuts, absent reciprocal action by other major emitters.

[18] OPEC revenues quadrupled between 1972 and 1974 and increased by more than 50 percent between 1978 and 1980. See Jeffrey Colgan, Robert O. Keohane, and Thjis van der Graaf, "Punctuated Equilibrium in the Energy Regime Complex," *Review of International Organizations* 7 (2012): 117–143, Table 4.

[19] For this argument, see Robert O. Keohane and David G. Victor, "The Regime Complex for Climate Change," *Perspective on Politics* 9 (1) (March 2011): 14–16.

[20] In the climate change issue-area, such forums are indicated in Figure 1 and include the G-20 Major Economies Forum (MEF), various technology and investment partnerships, and private sector and nongovernmental initiatives. In the energy area they include, in addition to OPEC and the IEA, organizations such as the International Energy Forum and the International Renewable Energy Agency. See Keohane and Victor, "The Regime Complex for Climate Change"; and Colgan, Keohane, and van der Graaf, "Punctuated Equilibrium in the Energy Regime Complex."

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The Institutional Blind Spot in Environmental Economics

Dallas Burtraw

Abstract: Economic approaches are expected to achieve environmental goals at less cost than traditional regulations, but they have yet to find widespread application. One reason is the way these tools interact with existing institutions. The federalist nature of governmental authority assigns to subnational governments much of the implementation of environmental policy and primary authority for planning the infrastructure that affects environmental outcomes. The federalist structure also interacts with the choice of economic instruments; a national emissions cap erodes the additionality of actions by subnational governments. Even the flagship application of sulfur dioxide emissions trading has been outperformed by the venerable Clean Air Act, and greenhouse gas emissions in the United States are on course to be less than they would have been if Congress had frozen emissions with a cap in 2009. The widespread application of economic tools requires a stronger political theory of how they interact with governing institutions.

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At least among economists, one often-heard lament is that those who develop and implement environmental policy rarely follow economic advice.[1] Economics also has something to say about the efficient stringency of environmental policy, but most economists readily appreciate that efficiency, such as it is measured, is just one among many criteria to be considered. However, after a policy goal is established, economists typically feel confident that economic approaches to environmental policy can help achieve the goal at less cost, which should be good for everyone.

Why then are economic methods not the central tools for implementation of environmental policy? One reason may be that these tools have been developed in an intellectual laboratory that, for the most part, is free from consideration of institutions that influence how they will be used. These institutions include the agencies that implement regulations, the broader legal structure of business and government, and existing regulations. Economic authors sometimes argue that sweeping away existing prescriptive standards in favor of economic tools would yield more cost-effective results, which is possible. Many other interested parties believe that confidence in this outcome requires full consideration of the broader institutional setting. Economic methods may not work exactly as anticipated, in part perhaps because institutional influences are not addressed in most economic writing. To resolve this issue, economic discourse must incorporate a more sophisticated understanding of institutions (broadly defined) than is usually achieved.

In this essay, I consider three institutional relationships that strongly influence how economic tools can be used in environmental policy. One such institution is the federalist nature of governmental authority, especially with respect to issues central to the management of the environment and natural resources. Arguably, economic instruments may not provide adequate incentives for behavioral responses by subnational authorities that are responsible for infrastructure planning. A second issue is how this federalist structure interacts with the economic alternatives of cap and trade versus emissions fees; an emissions cap eliminates the additionality of subnational efforts, which could have an important effect on local initiatives. Third, another core institution is the venerable Clean Air Act. I conclude by comparing the effectiveness of economic instruments versus regulation under the Act in the context of mitigating emissions of sulfur dioxide and greenhouse gases. Even compared to the flagship example of sulfur dioxide trading, regulation under the Act has done more to achieve emissions reductions since 1990, and greenhouse gas emissions in the United States are on course to be less than they would have been if Congress had enacted cap and trade in 2009. Economic tools offer the promise of substantial cost savings, but the advantages are not likely to be embraced until there exists a stronger political theory of how they interact with institutions on national and subnational levels.

The straightforward axiom that incentives affect behavior leads economists to emphasize how various policy designs might provide incentives with intended as well as unintended consequences. Consider, for example, the introduction of a standard that mandates efficient technology for new capital purchases. Such standards are prevalent, ranging from fuel efficiency standards for new vehicles to performance standards for new power plants, and their motivation is clear: it is typically less expensive to adopt efficient (nonpolluting) technology at the time something is first built than to try to improve its performance in the future. If capital has a long lifetime, the consequence of a technology choice may have long-term environmental consequences. Unfortunately, such a policy is likely to raise the initial cost of new investment, providing an incentive to delay investment and extend the life of existing capital. This result is perverse because new investment, even if it lacks state-of-the-art technology, is likely to be more efficient than existing capital. Consequently, the emissions standard might actually cause emissions to increase, at least in the short run.

The dilemma for regulators in this case is how to promote the adoption of state-of-the-art technology without providing incentives for deviant or unintended responses. Economists have an answer: use prices to provide incentives for investors to align their actions with social interests. In principle, a set of prices that accurately reflects the damage from various investment choices, including the continued operation of an existing facility, will accomplish just that. But honestly, after providing a recommendation like that, economists like me often feel our work is done. We offer guidance that is logical and compelling. Why does it not just happen?

One obvious answer is that the status quo has its own constituency. In any context, a change in the rules will create losers who will act to obstruct such a change. More deeply, though, existing rules and institutions strongly affect our ability to implement new ideas. Although sometimes institutions can be painfully recalcitrant, it might be useful to think of them as the watchtowers that protect the precedents and values of previous social decisions.

A relevant core institution is the federal structure of governance in the United States. Most economic analysis focuses on national policy within a uniform model of governance and implicitly assumes the harmonization of climate policies at the subnational level. However, harmonization is not guaranteed; the design and implementation of policy in a federal union will diverge in important ways from policy in a unitary government. Economic advice built on the assumption of a unitary model of governance may not achieve the expected outcome in a federal system because of interactions with policy choices made at the subnational level, and because choices at the subnational level are so important to the success of the policy. Most economic analysis suffers from a lack of understanding of how price incentives are transmitted to markets through levels of government. For instance, the way in which environmental prices would propagate through and provide incentives for the consumers and producers of electricity varies importantly among states that have regulated cost-of-service versus competitive electricity markets.

We have even less understanding of how price signals under a national policy directly affect other layers of government. There is evidence that mobile resources such as labor and new capital investment move to jurisdictions that are less expensive and/or provide better services, which provides an economic incentive for efficient government. Similarly, when facing a national emissions price, a locality has the incentive to choose a cost-effective response. But the myriad layers of institutional authority mean that the response of individual bureaus may not be efficient or timely. Local officials will face a tradeoff between price signals and the local preferences of incumbent consumers and businesses. Generally, local regulatory institutions are organized to modify the influence of price signals, not to transmit or amplify them. For instance, in land-use planning, private parties are expected to respond assertively to the profit motive, and local regulators are expected to moderate and channel that motive to the benefit of the entire community, including incumbent residents in particular.

To understand this issue, especially in the context of climate policy, requires consideration of what state and local governments do. Local governments conduct a variety of functions with substantial environmental consequences that federal authorities could not possibly provide based on the information available to them.[2] For example, local authorities decide the alignment of streets and building footprints and implement building standards that affect heating and cooling needs; they determine land use and transportation systems that influence where people live in relation to their work. The sum of these subnational activities pervasively shapes the long-lived infrastructure that will constrain our options to address issues such as climate change for decades into the future. The influence on the global climate, in the aggregate, is profound.

Some of the models of economic approaches to climate policy consider the role for subnational economic policies, such as cap and trade or emissions fees at the state level, but virtually all ignore the planning function at the subnational level.[3] The implicit assumption is that in the face of mobile capital and households, the price signal will efficiently influence economic behavior throughout the economy. However, local planners and policy-makers may respond slowly or only partially to the direct incentives of price signals stemming from the national emissions-quantity constraint. The primary concern of their constituents is likely the preservation of the status quo and protection of values associated with existing land use. Perhaps surprisingly, in the local planning process it is typically developers and builders who take the role of innovator, and they often encounter substantial friction at the local planning department. Indeed, an individual homeowner who wants to introduce innovative architecture or align a house differently to maximize solar gain is likely to encounter stiff resistance if that design detracts from the neighborhood norm.

Compound layers of agency exist between national-level policy, fuel markets, and local decision-makers. Information asymmetries between multiple layers of government imply that a cost-effective outcome is dependent on decentralized policies and behavior such as could occur on a subnational level. Hence, state and local governments are uniquely positioned to implement many aspects of an overall climate strategy. The institutional question is whether a price signal would provide incentive for these governmental actors to do so.

Unfortunately, we do not know much about how responsive local authorities will be to a modest market signal associated with the introduction of pollution prices; modest changes in fuel prices have not prompted much response in most jurisdictions. Is it surprising, then, that many people discount the likely effectiveness of economic prescriptions such as prices? Instead, polling shows that the public holds a general preference for regulatory approaches in constructing climate policy.[4]

One can anticipate that economic forces will ultimately influence local tastes in planning functions. The difficulty is that one may have to wait for prices to rise high enough and persist long enough to evoke changes in infrastructure investment, and then wait decades longer for new infrastructure to take shape broadly. If one's concern is climate change, the process may feel like too long of a wait because, in the meantime, local decisions using conventional planning tools continue to lay the foundation that constrains society's options for decades to come. Legal scholar Holly Doremus and economist Michael Hanemann have argued that a price signal created by a national cap-and-trade policy is not salient enough to induce all the behavioral changes necessary to achieve the desired emissions reductions in an efficient and timely manner.[5] They explicitly invoke a federalist model calling for price-based policies at the national level to be joined to regulatory policy that would be developed by subnational authorities.

Leaving aside whether subnational levels of government are responsive to price signals in the market in a timely way, there are other aspects of the economic prescription for national environmental policy that typically do not anticipate how those signals are transmitted and received or what incentives they provide. A persistent parlor question in economic thinking is the relative advantage of cap and trade versus an emissions tax. For the most part, economic advice considers the two approaches fairly equivalent, with nuanced issues favoring one or the other policy in the face of uncertainty about benefits or costs.[6] The answer to this question almost never addresses the influence of each instrument within a federalist system of governance. However, the two approaches are dramatically opposed when it comes to transmitting incentives to affect behavior by subnational levels of government.

Under an emissions cap, because maximum emissions are fixed at the national level, the actions of subnational government cannot affect the overall level of emissions. Although described as an emissions cap, such a policy is also effectively an *emissions floor* because any effort to reduce emissions by one entity, including state and local governments or private parties, does not affect the overall level of emissions.[7] With an emissions cap, efforts to reduce emissions by one party make possible additional emissions by another party. The emissions floor undermines the incentive for state and local governments to adopt measures unilaterally that may contribute to local emissions reductions because leakage of emissions to other jurisdictions would be 100 percent. In effect, a cap-and-trade program at the national level preempts efforts to achieve additional emissions reductions at the local level.

In contrast, the same issues do not arise under a national emissions fee. A jurisdiction with a greater willingness to pay for emissions reductions could adopt ancillary measures that would result in additional reductions. Unlike under a quantity constraint, net reductions in emissions can be achieved.

Economic advice typically has not considered the interaction of policy design at the national level with the incentive or need for subnational action. If one believes prices to be perfectly salient and that the national government can set the optimal policy, there is no role for subnational action; one effectively embraces a unitary model of government. After a goal is established at the national level, the actions of subnational units of government are determined by the change in prices. However, if prices are not perfectly salient, then the ability of policy to provide incentives to subnational levels of government is important. A tax instrument at the national level would have strong advantages over cap and trade in this regard.

This example illustrates that new ideas are usually not born fully formed and can have their own unanticipated outcomes. Few advocates of a cap-and-trade program have anticipated that this approach is likely to diminish greatly the incentives for local innovation in climate policy. Whether this characteristic is a disadvantage or not depends on one's point of view, but the fact that it is generally unappreciated in economic discourse could legitimately cause many advocates to favor more traditional approaches over new and untested ones.

Traditional approaches to regulation under the Clean Air Act are disparaged by many economists for their inefficiencies. But for environmental advocates, a remarkable attribute of the Act is that it provides a safety ratchet promoting incremental environmental progress without backsliding. Perhaps surprisingly, this is evident even where economic approaches have ostensibly had their greatest influence – the innovation of emissions allowance trading for sulfur dioxide. Indeed, the sulfur dioxide trading program is trumpeted for providing a cost-effective implementation of substantial reductions in emissions and is the leading example of the use of economic instruments in environmental policy.[8]

The trading program was statutorily created in the Clean Air Act Amendments of 1990 and led to cost reductions of roughly 40 percent compared to traditional approaches under the Clean Air Act.[9] However, the program had what literally became a fatal flaw: namely, an inability to adjust to new scientific or economic information. Though information current in 1990 suggested that benefits of the program would be nearly equal to costs,[10] by 1995 there was strong evidence that benefits were an order of magnitude greater than costs.[11] Today the Environmental Protection Agency would argue that benefits are more than thirty times the costs.[12] Unfortunately, to change the stringency of the program requires an act of Congress, at least according to the D.C. Circuit Court.[13] The Act locked in the emissions cap, and despite several legislative initiatives to change the stringency of the trading program, none have been successful.[14]

The failure to amend the statute is emblematic of the limitation of legislative actors to finely manage scientific information, a role that is usually left to expert agencies. If the nation's fate with respect to sulfur dioxide emissions were left to Congress, tens of billions of dollars in additional environmental and public health costs would have been incurred in the last few years and into the future. Fortunately, the inability of Congress to act was backstopped by the regulatory ratchet of the Clean Air Act that triggers a procession of regulatory initiatives based on scientific findings that have been effective in shaping investment and environmental behavior in the electricity sector.

The sulfur dioxide cap-and-trade program was intended to reduce sulfur dioxide emissions from power plants from anticipated levels of 16 million tons per year to 8.95 million tons per year by 2010. However, evidence based on integrated assessment suggests an efficient level would be just over 1 million tons per year.[15] In the absence of legislative action, regulatory initiatives have taken effect and driven emissions from power plants to 5.157 million tons, as measured in 2010. By 2015, the Clean Air Interstate Rule and the Mercury and Air Toxics Standard will further reduce emissions to 2.3 million tons per year. (The Cross State Air Pollution Rule would have lowered them to 2.1 million tons per year, but that rule was overturned by the D.C. Circuit Court of Appeals.) With these changes, the emissions constraint under the 1990 Clean Air Act amendment has become irrelevant, and the price of those tradable emissions allowances has fallen from several hundred dollars a ton to near zero.

The sulfur dioxide cap-and-trade program is the flagship example of the use of economic instruments in environmental policy. However, since its adoption in 1990, although the sulfur dioxide trading program gets most of the credit in textbooks, more than half of the emissions reductions that have and will occur are due to regulation. Without the Clean Air Act in place, the flagship program in emissions trading would have left unrealized substantial benefits to public health and the environment.

The sulfur dioxide experience highlights a central controversy in contemporary proposals to use price-based approaches (cap and trade or an emissions fee) to mitigate greenhouse gas emissions in the United States: that is, the possible preemption of the Clean Air Act. In general, there are redundant mechanisms and overlapping regulations under the Act, a structure sometimes referred to as "belts and suspenders." If one mechanism fails, another mechanism can fill in. With adoption of the sulfur dioxide trading program, many economists (including me) clamored initially that other regulations under the Act were unnecessary, inefficient, and raised costs; but ultimately they delivered substantial public health and economic benefits. What would be the fate of the Act under national climate policy?

The most prominent proposal, H.R. 2454 (also known as the Waxman-Markey Bill), was introduced in the 111th Congress, passing in the House but not in the Senate in 2009. It not only would have instigated a system with 100 percent leakage for subnational efforts to reduce emissions, effectively preempting those efforts (as discussed above); it would have preempted specific aspects of the Clean Air Act as well. Representatives Waxman and Markey have recently proposed an alternative price-based policy in the form of an emissions fee to address climate concerns; other commentators have suggested that such a proposal might be more likely if it included preemption of greenhouse gas regulation under the Clean Air Act.[16]

The possibility raises several questions. Would a national price on greenhouse gas emissions make the Clean Air Act's authority to regulate greenhouse gases irrelevant? How do the two approaches compare with respect to climate goals? Could the slow ratchet of the Clean Air Act regime achieve emissions reductions as great as could be achieved under a price-based policy? In fact, it appears it might.

The Energy Information Administration's (EIA) modeling of H.R. 2454 projects U.S. emissions in 2020 to be about 10.2 percent below 2005 emissions levels. (The year 2005 was the benchmark year for emissions covered under H.R. 2454.) About 40 percent of these reductions would contribute to the emissions bank under cap and trade and would reappear in later years as actual emissions, leaving permanent emissions reductions within the United States of about 6 percent below the benchmark. The contribution of offsets, from both within and outside the United States, would have made up the difference between emissions reductions in the United States and President Obama's Copenhagen commitment to make reductions in the neighborhood of 17 percent.

Reductions in the electricity sector arising from greater use of natural gas would have occurred with H.R. 2454 also, but because *the emissions cap is an emissions floor*, they would not directly result in equivalent emissions reductions. Instead, the price of emissions allowances would fall. Indirectly, there may have been a smaller purchase of international offsets and the realization of more emissions reductions onshore, but to an important extent the emissions reductions would be crowded out by lower allowance prices, making it less costly to emit elsewhere in the economy. Additional policies to reduce greenhouse gas emissions that may still have occurred under H.R. 2454, such as increased fuel economy standards and California's emissions reduction goal, would similarly be crowded out by lower allowance prices under a greenhouse gas cap-and-trade program.

What will happen given the legislative defeat of H.R. 2454? The Clean Air Act regime remains in place, and three factors contribute to emissions reductions under this regime. First, substantial impacts have come from subnational policies that would have effectively been preempted by 100 percent leakage under a national emissions cap. California's goal embedded in state law requires emissions reductions of 80 million metric tons annually in 2020, equivalent to 1.3 percent of benchmark emissions at the national level. Reductions in other states, including the emissions cap for the nine-state Regional Greenhouse Gas Initiative, would be additional. Second, in its technical documents, the Environmental Protection Agency has identified opportunities at existing stationary sources to be pursued under the Clean Air Act totaling approximately 7.2 percent of benchmark emissions.[17] It is uncertain whether these reductions will be fully realized, but the legal and institutional dominoes are in place for this to occur. Further, in the transportation sector, the 2007 vehicle standards were included in the EIA's baseline projections for H.R. 2454, but the 2011 standards, which take effect in 2017, will achieve additional reductions of approximately 200 million metric tons by 2020, or 4.3 percent of benchmark emissions. H.R. 2454 did not preempt the portion of the Clean Air Act addressing mobile source standards or the ability of California to set its own emissions reduction goal, so these policies might have emerged even if H.R. 2454 had become law. However, much of these emissions reductions would have been crowded out by emissions increases elsewhere, resulting in little change in domestic emissions given the overall national cap.

Finally, there is the influence of secular trends in the economy, including not only the recession but, more important, the reduction in natural gas prices that has resulted in a shift away from coal for electricity generation and the increasing influence of energy efficiency investments in reduced demand. These developments have led to additional reductions of 3.3 percent, compared to 2005 levels. Total reductions by 2020 – accounting for changes due to subnational policy, regulatory actions under the Clean Air Act, and advantageous secular trends – are on track to yield emissions reductions of 16.3 percent relative to 2005 levels.

The anticipated emissions reductions under the Clean Air Act regime exceed those reductions within the United States that would have occurred under cap and trade. It is noteworthy, to be sure, that the comparison ignores the contribution of emissions reductions abroad through the purchase of international offsets. Global emissions may have been lower with passage of H.R. 2454, but, surprisingly, in the domestic economy they likely would have been more than will occur under the Clean Air Act regime.[18]

Perhaps with the exception of economists, the enthusiasm of advocates for H.R. 2454 was not an endorsement of emissions pricing per se; rather, it was support for an overall limit on emissions and the legislative certainty of emissions reductions. The pathway under the Clean Air Act remains uncertain, and is not likely to be as efficient as would a national price on carbon, but it remains effective. The comparison invites a more circumspect consideration of the trade-offs in the potential creation of a new price-based institution for regulating greenhouse gases and addressing other environmental challenges.

Economic advice for the design of environmental policy emphasizes cost effectiveness, a criterion that is centrally important in facing the most challenging environmental issue of our time, climate change. A virtue of economic approaches is that they are typically simple and, in principle, cost effective. However, for economic advice to reach its full influence requires consideration of the role of institutions and their complexity that determines how economic policies will ultimately function. The success of economic prescriptions for environmental policy depends on a new round of sophisticated thinking about institutions and how they interact with the policy tools at our disposal.

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Designing a Durable Energy Policy

Ann E. Carlson & Robert W. Fri

Abstract: Although the U.S. energy system seems to resist the changes necessary to meet today's challenges related to energy security and climate change, the system has gone through massive change several times since 1850. A major driver in each of these earlier transitions was an economic value, such as mobility, that markets could capture. Because environmental and security values are public goods, changing today's energy system will require a policy that creates a market signal reflecting these values. However, it is also necessary to craft a policy framework that is both durable over a long time period and able to adapt to new information as it becomes available. This essay examines some of the possible attributes of a durable and adaptable policy. The discussion is necessarily preliminary because relatively little formal research exists on this topic. However, even a preliminary examination suggests that considerations of policy durability could affect the choice between a carbon tax and a cap-and-trade system.

Since the early 1970s, U.S. policy has sought to create an energy system – both for transportation and for electricity – that is cleaner and more secure than the one we have without significantly raising energy prices. We have made some progress, especially in reducing by about half the energy intensity of the economy (that is, the amount of energy needed to produce a unit of GDP) and in reducing emissions of conventional pollutants.[1] Even so, the National Research Council recently estimated that available technology could reduce energy consumption by a third.[2] Moreover, despite the emergence of electric vehicles and biofuels, our transportation system still depends on petroleum for over 95 percent of its fuel. This dependence exposes our economy to variations in world oil prices over which we have little control. More than 83 percent of our overall energy system still uses fossil fuel; this is better than the 93 percent dependence on fossil fuel in 1973, although the emergence of nuclear power accounts for most of the improvement.[3] Fossil fuels not only create greenhouse gas emissions, but also impose significant health costs on the economy through the emission of conventional pollutants, despite consid-

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erable improvements resulting from the federal Clean Air Act.[4]

We have a long way to go until we have the energy system that we say we want. Fundamentally changing the energy system is no simple task because this system is more than a collection of easily replaced hardware. Rather, it is deeply embedded in both the physical and social infrastructure of the nation.[5] The petroleum, transportation, and electric systems are not only technological but also social; their operation requires behaviors on which modern life has become utterly dependent. One might also suggest that the energy system is deeply embedded in the nation's political infrastructure.

Despite these difficulties, the energy system has at various stages in our history undergone fundamental change. Thus, in 1850, wood produced 90 percent of the energy in the United States. By 1910, coal ran 90 percent of the energy system. And by 1950, oil and natural gas were the fuels of choice for two-thirds of U.S. energy production. It is worth noting that each of these major transitions evolved over about six decades.[6]

But these transitions involved more than simply fuel substitution. In each case, a crucial condition was that a transition in fuel was accompanied by new technology, and together these two elements created new economic value.[7] Thus, the steam engine using coal as a fuel made industrialization and steam transportation possible. Oil coupled with the internal combustion engine created not just automobiles but a mobile society. And electricity generated by a variety of fuels produces clean and convenient light, comfort, and communication. Electricity has also been responsible for an extended surge in total factor productivity in the U.S. economy.[8]

This brief history provides an important insight into the inability of policy to effect dramatic change in the energy system over the last forty years. Each of the past system transformations created an economic value that the market readily captured. If we wanted to ride the rails or cross the ocean using steam power, we could buy a ticket. When we wanted to live in the quiet suburbs while still working in town, we bought a car. Heating, cooling, and light were ours by merely paying the utility bill. But today's goals of energy security, cleanliness, and affordability are different. The first two are public goods that certainly have value, but it is a value external to the market. Affordability – that is, a lower energy bill – is captured in the market (and through government policies to keep prices low), but its effect is to drive the energy system toward reducing cost rather than introducing new technologies that are cleaner and more secure.

Creating the technological change needed to transform the energy system is a complicated process. However, the absence of change-induced economic value is a crucial problem, for history suggests that such value has been a necessary if not sufficient condition to promote change. Indeed, its presence works in two ways: first by sustaining change during a long period of system transformation, and second by driving the development of technology that makes the transformation affordable. With regard to the first effect, economist Robert Heilbroner characterizes economics as the "force field" that enables the steady progression of technology on many fronts.[9] In his view, technology can alter the material condition of human existence. If the change has value and can be priced in the market, the economic system effectively transmits the price signals necessary to sustain the incremental technological improvements that, over time, lead to a life that is in some sense "better."

Joseph Bower and Clayton Christensen, both scholars of business administration, explore the second effect of economic value: the emergence of new technology.[10] Disruptive technological change has been the goal of huge government investments in new energy technology over the past four decades. More often than not, however, disruptive technological change results from unexpected value creation rather than technological breakthrough. Bower and Christensen argue that technology that appears to be disruptive usually enters an existing market as an incremental improvement to an existing product. But once established in this routine application, it becomes apparent that the new technology also makes possible new applications or markets. Thus, magnetic disk storage for mainframe computers became smaller in incremental steps, but at some point became small enough to make personal computers possible. Past transitions in the energy system appear to have followed a similar path. For example, electricity was originally introduced as a substitute for gas lighting using direct current from Edison's Pearl Street Station in New York City. But then alternating current emerged as a preferred technology for transmitting electricity over long distances. Next, alternating current made possible the electric motor, which created new values throughout the economy.

What should we make of this history as we struggle to develop a policy that delivers clean, secure, and affordable energy? One lesson is that because our goals are public goods, we should find a way to create a market price for them; this would encourage the most efficient allocation of resources for producing those goods. Accordingly, we agree with the overwhelming majority of economists who argue that internalizing the cost of energy insecurity and environmental harm is a crucial policy goal.[11] But our understanding of the role of economic value in creating technological change suggests that successful policy must have two other attributes beyond efficiency and environmental effectiveness. First, it must sustain change over a long time period – decades, in the case of the energy system. Thus, any policy to promote the transition of our energy economy must be durable. Second, it must be structured in a way that drives the incremental changes that create technological disruption, taking into account future economic, environmental, and technological shifts that we can only begin to imagine. Thus, long-term policy must also build in flexibility to allow our regulatory structure to adapt to new information.

In focusing on durability and flexibility as important components of transformational energy policy, we do not mean to suggest that these criteria are more important than environmental outcomes and cost-effectiveness. We mean simply to focus on criteria that have received less attention in the debate over which policy instruments would help us transition to a cleaner energy system. So how do we design policy that is both durable and flexible?

We have never embarked on a policy specifically intended to transition our entire energy system to new fuel sources or fundamentally new ways of operating. Yet such a transition is required in order to reduce greenhouse gas emissions to near zero by mid-century, the level necessary to stabilize the climate. We do, however, have at least some models that have produced dramatic shifts in the internalization of pollution externalities through the Clean Air Act (CAA), which contains both traditional "command and control" mechanisms as well as market-based schemes for reducing pollutants. From the forty-year experience of the CAA as well as other programs and policy areas, we can draw lessons about how to craft policy that is adaptable yet long-lasting and about the pitfalls to avoid.

One measure of durability is whether a program not only remains on the books but continues to have real effect long after its passage. By this definition, much of the CAA is durable. It passed in 1970 and was amended in both 1977 and 1990, but its principal provisions – regulating pollutants from automobiles and establishing and implementing National Ambient Air Quality Standards through a system of cooperative federalism – remain in effect. Moreover, the most innovative part of the 1990 amendments, the creation of a cap-and-trade program to regulate the pollutants that cause acid rain, not only remains in effect but has been strengthened and expanded.

Though this measure of durability – that is, merely remaining in effect – may seem modest, other expansive programs adopted with great fanfare have done less well by this measure. For instance, Congress eviscerated almost all the provisions of the sweeping Tax Reform Act of 1986, which repealed many exemptions and loopholes while lowering tax rates, by reopening the loopholes.[12] And the Freedom to Farm Act of 1996, which was designed to phase out farm subsidies, has met a similar fate.[13]

According to public policy scholar Eric Patashnik, one important predictor for whether a policy will remain durable is the degree to which the policy creates a political constituency for its continuation. With respect to taxes, there is little pressure to resist opening up new loopholes while a great deal of pressure – from industry benefiting from the breaks – exists to repeal their closure. The same is true for the cutting and subsequent reinstatement of farm subsidies. This experience should signal caution in putting a market price on carbon externalities generated through the burning of fossil fuels, because a tax on carbon may likewise be subject to erosion over time.

By contrast, policies that create a political constituency seem to fare better over the long run. The success of the Acid Rain Trading Program (adopted as part of the 1990 amendments to the CAA), for example, may have something to do with the fact that emitters of sulfur dioxide (which leads to the formation of acid rain) were awarded valuable allowances that they could use to meet their compliance obligations or could sell or bank to use or trade in future years.[14] Those allowances became valuable currency, and to repeal the program would eliminate their value.

Of course, creating a value by implementing an allowance-based program presumes that the political will existed to create the program in the first place. But once created, the program's value may help resist attack on the underlying policy. For example, California's Global Warming Solutions Act, which seeks to roll back greenhouse gas emissions to 1990 levels by 2020, survived an initiative to halt its implementation largely because the campaign against the initiative was funded by the green technology industry that has emerged in California partially in response to the legislation. Experience with the CAA's trading program suggests that coal-burning utilities might become supporters of an allowance-based program once their opposition to the mere existence of the program has been overcome. And producers of renewable energy and other innovative technologies to reduce emissions may also favor the continuation and even the strengthening of programs that make carbon emissions more expensive (and hence increase demand for their products).

That is not to say that the development of a political constituency in favor of government policy is the only important variable in determining whether the policy will be durable. It is simply to note that the lack of such a constituency may lead to a policy's demise while the presence of a constituency may help ensure its success. And again, in thinking about how to construct a policy that prices the greenhouse gas externalities created by burning fossil fuel, past experience suggests that a cap-and-trade program may prove more durable over time than a tax on carbon emissions.

More traditional environmental regulatory approaches have also proved durable at the federal level. Despite significant congressional opposition since the mid-1990s to various provisions of the CAA, for example, no part of the statute has been repealed. It is unclear exactly why the CAA has remained so durable, but one reason may be its success in producing measurable improvements in clean air across the country. Another reason may be that various presidential administrations have used their administrative discretion to ease in stringent new regulatory requirements rather than imposing them with no notice. A third reason may be that an environmental constituency has developed, providing resistance to repeal efforts.

However, it is worth noting the obvious: simply because a statute remains in effect does not mean that the statute is environmentally effective. Several provisions of the Clean Water Act, for example, saw little to no implementation effort for decades, and observers have documented numerous and sometimes egregious violations of the Act across the country that have gone unenforced.[15] The hazardous air pollutant provisions of the CAA resulted in virtually no pollutants being regulated until Congress stepped in and altered the statutory scheme. These examples reveal that in order for a policy to be both durable and effective, the agency responsible for its implementation needs sufficient staffing to do its job. One suggestion, put forth by law professor Richard Lazarus, is for agencies to be provided with self-financing so that they can build and maintain sufficient staffing levels and insulate themselves from annual budget debates.[16]

In short, for a policy to remain durable across many decades it may need an organized political constituency to ensure that it remains in effect. Cap and trade as well as traditional regulation may fare better on this score than taxes. Additionally, the agency responsible for programmatic implementation needs sufficient staffing to succeed.

Though durability is important, it is by no means sufficient to stimulate the long-term transformation we seek in the energy system. Indeed, policies may sometimes be durable simply because they are weak or ineffectual and thus generate little opposition. Durability over time may be especially likely for policies that remain in place with little change. To produce innovative transformation in our energy system, then, durability needs to be accompanied by processes of evaluation that allow regulators and/or policy-makers to impose changes to the regulatory system in the face of new information. With respect to climate change in particular, although there is near consensus on the fact that human-induced warming is occurring, there is significant uncertainty about a number of dimensions of the problem, including how much warming will occur by when; how fast the global economy will grow over the course of the next several decades; and what innovations in clean energy will develop and at what cost. As more information becomes available about each of these issues, regulatory mechanisms that provide flexibility can incorporate the new information in order to achieve environmental, reliability, or economic goals.

Policy mechanisms to promote flexibility can take a number of forms. They can be triggered automatically once certain events occur. They can require mandatory review by an implementing agency on a regular basis. They can be built directly into a statute. And of course, a legislative body can always amend enabling legislation to respond to new information.

One clear concern about the long-term transformation of our energy system is cost uncertainty. On the one hand, policymakers may fear that a shift to cleaner energy sources will cost more than original estimates due to higher-than-expected compliance costs for greenhouse gas emitters. On the other hand, initial compliance costs may actually be too low to spur the technological innovation necessary to reduce emissions to near zero over the course of the century. Designing flexible policy mechanisms to respond to financial uncertainty in either direction can help avoid these extremes.

The European Union, members of the Regional Greenhouse Gas Initiative, and the state of California have all adopted variations of cap and trade, and even China is considering implementing city-level cap-and-trade programs. Given the dominance of cap and trade as a policy choice for reducing greenhouse gases, we focus here on ways that cap and trade can incorporate mechanisms to protect against financial uncertainty in both directions. If, for example, exogenous events create large upward pressure on allowance prices, thereby increasing the overall cost of compliance with greenhouse gas emissions reduction, a number of mechanisms could help alleviate that pressure. Creating a large enough market for allowances would provide one such means; others include allowing for the banking of allowances, holding some allowances in reserve, allowing for a multiyear compliance period, and promoting transparency and consistency in implementation.[17] By permitting the banking of allowances for use in future years, for example, emitters can purchase allowances at a time when prices are relatively low in order to use them in future compliance periods when allowances might otherwise be more expensive. Systems can also establish allowance price reserves, whereby regulators set aside a portion of allowances that they can make available only if allowance prices reach a predetermined level.[18] The new California cap-and-trade program establishes such a reserve.[19] A more controversial mechanism includes establishing a safety valve that permits the government to issue more allowances in the event that allowance prices reach a certain level; the downside of such a mechanism is that overall emissions rise if new allowances are released, unless emissions in future years are cut more dramatically.[20]

But financial uncertainty can create problems in the other direction as well if one of the goals of a cap-and-trade system is to spur innovation. When allowance prices fall too low, incentives to innovate disappear. Indeed, the problem of too-low allowance prices has plagued the two operational greenhouse gas cap-and-trade programs, the European Union's European Trading System (ETS) and the Regional Greenhouse Gas Initiative. The latter is a relatively modest program requiring only minimal emissions reductions and involving a relatively small portion of the U.S. electricity sector; so the expectations that it would spur technological innovation were never large. But the European Union's ETS has seen prices in the allowance market fall rather dramatically, prompting many critics to complain that the system is failing. The state of Bavaria, in Germany, has just announced that it will no longer trade allowances through the system given the glut of allowances on the market and the consequent lack of trading.[21] Prices have plunged 60 percent in the last year due to both slow economic activity and an accumulation of allowances as a result of declining energy use.[22] Prices peaked at around $30 per allowance prior to the recession and are now hovering around $9.[23] If the cap-and-trade system had been designed to account for the possibility of a massive economic slowdown, the low-end price volatility could have been mitigated.

Before suggesting possible means to mitigate low allowance prices, it is worth noting that the ETS has in fact accomplished its environmental goal of cutting greenhouse gas emissions to the level of the cap. The ETS has met the cap not only through the reduced demand for energy caused by the recession but also through real emissions cuts.[24] Yet as economist Robert Stavins has pointed out, the ETS system has failed in the ancillary goal of stimulating technological innovation. One could view the ETS, then, as successful to date in achieving its environmental objectives but unsuccessful in stimulating the technological change necessary to transition to a much cleaner energy system over the next thirty to fifty years. And given the oversupply of allowances on the market combined with provisions that permit the banking of allowances for use in future compliance periods, the potential for innovation going forward is low absent any changes to the ETS.

Cap and trade could, however, be designed to include flexible mechanisms to anticipate dramatic drops in allowance prices. There are at least two possible approaches. One is essentially the opposite of the allowance mechanism described above, under which allowances are held in reserve and released only if allowance prices escalate to a certain level. Instead, if allowance prices drop below a predetermined level, the regulator would automatically remove allowances from the market. Such a floor would have the effect of not only keeping prices from falling too low to stimulate innovation but also achieving additional environmental benefits through lower emissions. Researchers at Resources for the Future have suggested that imposing what they term a "soft price collar" – with both an allowance reserve and a price floor – "could provide considerable assurance about cost while preventing the possibility that emissions could spiral out of control."[25] Interestingly, though, the current cap-and-trade schemes, including that of California, include only the allowance reserve, not the price floor.

If a principal concern about cap-and-trade programs to reduce greenhouse gas emissions is allowance price volatility in both directions, a major concern of a carbon tax is instead whether it will achieve its environmental objectives. One advantage of a carbon tax over cap and trade is that policy-makers can set the "price" of compliance by choosing the tax rate and base. Thus, concerns about large fluctuations in the cost of compliance inherent in cap and trade do not exist with a carbon tax. A disadvantage of a carbon tax, however, is that it can be difficult to predict what environmental outcome will occur based on the tax rate and base chosen. By contrast, a cap-and-trade system chooses the desired level of emissions reductions and then lets the trading system determine the cost of compliance.

In theory, a tax and a cap-and-trade system work in the same way: by pricing environmental externalities into the cost of producing energy. With a tax, though, policy-makers must choose what cost of compliance (the tax) they believe will achieve a desired level of environmental compliance. If they are wrong because they underpredict the cost of compliance by setting the tax rate too low, emissions will be higher than desired because emitters will choose to pay more in taxes rather than pay to reduce emissions. If, instead, they underpredict the cost of compliance by setting the tax rate too high, they will achieve greater emissions reductions because emitters would likely choose to reduce emissions rather than pay the tax. Given the politics of tax debates, it seems safe to predict that policy-makers would be more apt to set taxes too low – resulting in lower emissions reductions than desired – than they would be to set taxes too high.

Therefore, if taxes are adopted to achieve long-term emissions reductions, just as cap and trade needs to include mechanisms to constrain price volatility, a tax system should incorporate mechanisms to constrain environmental volatility. These mechanisms could include, for example, automatic triggers that increase the carbon tax rate in the event that the tax is not sufficiently high to achieve an emissions target, or that decrease the tax rate if emissions decline by an amount greater than predicted. Or a tax scheme could provide authority to an agency to evaluate environmental outcomes and adjust the tax rate in the event that those outcomes are not being met. These suggestions, though, are politically controversial and highlight why a cap-and-trade system may retain political support more easily than a carbon tax.

Finally, under either a cap-and-trade system or a carbon tax, we may gain new information about the level of emissions reductions necessary to slow climate change or about whether we are regulating the appropriate pollutants. If our initial assumptions prove to be wrong, we will want a means to incorporate new information into whichever system we have chosen for regulating the price of carbon. One approach that forces regulators to take into account new information about environmental progress is modeled on a mechanism included in the CAA. The CAA requires the Environmental Protection Agency to review its National Ambient Air Quality Standards – set for major pollutants – every five years and revise them if necessary to protect public health and welfare. Although it has not always met this statutory deadline, the agency has nevertheless revised the standards on a number of occasions. A carbon tax – or any regulatory policy to reduce greenhouse gas emissions – could include such a regulation-forcing mechanism that requires the regulator to revise the cap periodically based on new information about cost, environmental progress, and/or technological advances.

We have attempted to provide examples of past efforts to incorporate both flexibility and durability into regulatory schemes and have suggested means to do so in a cap-and-trade or tax system to regulate greenhouse gases. But our efforts are only preliminary. Scholarship and policy-making to achieve a long-term transition to a clean energy economy have frequently focused on environmental outcomes and cost-effectiveness with less attention paid to the need for adaptable, yet long-lasting, policies. There is a robust debate, for example, about whether a carbon tax or cap and trade is the superior instrument to achieve our desired environmental outcomes and to do so cost-effectively. In our view, however, less attention has been paid to whether a tax or a cap-and-trade system is more likely to be durable or flexible. We think that cap and trade may be superior on both fronts, but our conclusions are very preliminary. Our broader aim is to focus attention on, and stimulate conversation about, the importance of durability and flexibility in transitioning our energy system – a dramatic transformation that will be achieved without the endogenous market changes that accompanied our earlier energy history.

ENDNOTES

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Rethinking the Scale, Structure & Scope of U.S. Energy Institutions

Michael H. Dworkin, Roman V. Sidortsov & Benjamin K. Sovacool

Abstract: This essay notes some of the key institutions created in the twentieth century for the purpose of delivering energy in North America. Those institutions are being challenged by a combination of stresses in three interconnected areas: reliability, economics, and environmental sustainability. The essay argues that these three stresses create an "energy trilemma" requiring institutional reform. We suggest that new and modified institutions can best be understood if we evaluate them along three dimensions: institutional scale, structure, and scope. We consider real-world examples of recent institutions in light of each of these dimensions and note both successes and concerns that those factors illuminate. We conclude by noting that some institutional changes will be organic and unplanned; but many others, including responses to climate change, will benefit from conscious attention to scale, structure, and scope by those engaged in designing and building the energy institutions needed in the twenty-first century.

> "Men work together," I told him from the heart,
> "Whether they work together or apart."
>
> – Robert Frost, "The Tuft of Flowers,"
> *A Boy's Will* (1913)

People act in many ways. Occasionally we act alone. More often, we act together, because, as Aristotle said, humans are indeed social animals.[1] Some group actions – and most individual ones – have short-lived effects. Other mutual actions are organized, enduring, and extraordinarily effective. These cases usually involve organizations, called *institutions*, that coordinate and maximize the effectiveness of individual actions. Over time, however, institutions often take on their own lives, beyond those of the people acting within them. Eventually, the institutions may be so rooted in past crises that they no longer fit emerging needs. We can see this phenomenon now, in the institutions that our grandparents developed to deal with our nation's – indeed, our entire continent's – energy needs.

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In the United States, those institutions were characterized by:

- an energy system with two broad wings, one based on lightly regulated delivery of energy for transportation through liquid fuels, and the other based on closely regulated delivery of even larger amounts of energy in the form of electricity;
- an energy supply for transportation that came to rely on petroleum purchased through international markets – with easy transport on a global scale and an assumption of stable patterns of users and suppliers – supported by major governmental subsidies and preferences, but with price regulation only in the rarest of circumstances;
- an energy supply for light, heat, cooling, and power that is dependent on electric grids combining large, centralized electric power plants with bottleneck transmission systems;
- control systems that coordinated generation and transmission through a pyramidal architecture for the operational control, dispatch, and delivery of power with a primary emphasis on reliability;
- the financing of central-station power plants through long-term bonds, as valued by Wall Street ratings analysts;
- a primary reliance on investor-owned utilities that attracted private investors who expected decades of technological stability to yield long-term, low-risk revenues; and
- a regulatory structure that limited both excessive returns and easy entry of new retail competitors, and that recognized both local and national concerns through state and federal regulatory agencies.

Those functions, and the institutions providing them, worked well (at least for America) in the postwar world of the 1950s and 1960s. They met the fundamental test of "fitness" by matching the scale, scope, and structure of institutions to those of the problems they addressed.[2]

However, in the decades since then, energy institutions have come under increasingly difficult strains in at least three strategic areas. The first of these is *reliability*, as measured against both accidental and deliberate security challenges. The second is *financial*, with a long-term trend of increasing burdens on gross national product and individual households. And the third is *environmental*, with rising concerns about toxic substances (such as mercury) and the role of energy production as the prime source of the greenhouse gases that are driving global climate change.

Major institutional change will be required to meet the closely interrelated challenges of this "energy trilemma."[3] Some of those changes will arise unexpectedly, without planning and through organic processes that may be painful for us all; others may come more readily if we can think in organized ways about the institutional transformations we expect and desire. In that effort, it is useful to organize our thoughts in terms of the *scale*, *structure*, and *scope* of the ways in which institutions behave.

This will be a decades-long process of "continual improvement" extending far beyond what can be discussed within the bounds of this essay; but to help begin the process, we offer here some examples of both theoretical concepts and practical steps that may be useful. Our suggestions are aimed at the low-hanging fruit: that is, the relationships that already exist and the approaches that have already been adopted in different sectors. In calling them *examples*, we mean to focus on them as illustrating emergent trends in each area, not as assertions about the many changes that will actually be needed. One example is spatial, dealing with scale; a second is structural, blending public and private enterprises; and the third is jurisdictional, arguing that energy institutions must have the scope to address climate change.

Currently, our energy systems are usually conceived of as multiple entities, each nested within a tidy jurisdictional hierarchy. This is in many ways similar to the "pyramidal structure" of the telecommunications system managed by AT&T from the 1920s until its breakup in the 1970s. The breakup of that system-network architecture was the result of antitrust litigation and consent decrees, but its underlying cause was technological innovation.[4] When that physical architecture became outmoded, so did the monopolistic control structure. As Peter Huber stated in a 1987 report on the telephone industry:

> The old pyramid, with all its mass in the center, is being transformed into a geodesic dome, with a profusion of nodes and links unknown in the older architecture, connected around the outside. AT&T undoubtedly recognized this clearly when it agreed to surrender the heart of its old network for permission to participate fully in building the new one.[5]

The energy sector would benefit from a similarly networked structure, as the slowly emerging architecture of a "distributed network" suggests. As that happens, traditional institutions of control will need radical change or replacements.

Before we delve into the details of how U.S. energy institutions ought to be reformed, we should clarify what we mean by the terms *governance* and *polycentrism*. Governance, broadly considered, refers to how humans make decisions and form institutions that craft rules shaping behavior. At its most elemental level, governance is about deciding who can do what, who will monitor it, and how rules are modified and changed over time.[6] The term refers to "any of the myriad processes through which a group of people set and enforce the rules needed to enable that group to achieve desired outcomes."[7] Both public and private bodies have created institutions to carry out governance functions. Traditionally these have been nested vertically, with neighborhoods operating below cities, which operate below states/provinces, which operate below national institutions.[8] Within its scope, and at its scale, each provides a variety of services (such as education, national defense, and administration of a currency).[9]

Although much research and dialogue continues to emphasize what these government actors do, in recent decades scholars have begun to address governance that occurs outside of traditional structures at scales ranging from families and firms to nations and intergovernmental organizations. *Polycentrism* is a term with many meanings. In the context of institutions of governance relating to energy, it describes the concepts identified by the late Nobel laureate Elinor Ostrom. She uses *polycentric* to refer to the self-organization of citizens into multiple authorities at many scales simultaneously.[10] The notion of polycentric governance evolved out of discussions of governance related to public goods, common-pool resources, and collective action problems.

Polycentrism emphasizes that sharing of power among numerous scales of governance must be seamlessly managed, resulting in a "polycentricity" or "nestedness" that involves multiple authorities and overlapping jurisdictions. It can also stipulate that different energy institutions be harmonized to the geographic scale of the particular energy problem at hand. This criterion is similar to the "matching principle" in environmental law, which states that governance structures need to be "matched" to the specific type of threat: for instance, pollution of a river would require a governance regime encompassing all states and communities along that river basin; local groundwater threats would by contract need only a governance regime at the city or municipal level.[11]

When applied to the debate over U.S. energy policy, relying on a polycentric lens has helpful implications regarding the appropriate scale of institutions and their responsibilities. For a problem like collecting data on energy-related pollution from mercury, particulate matter, nitrogen oxide, sulfur dioxide, and carbon dioxide, a national system is far preferable to a local one. It makes little sense to have every state, city, or town measure carbon dioxide emissions, track the carbon intensity of fuels, determine their health effects, identify a safe level of emissions, and design cost-effective policy responses. Such a system is inefficient, and having many pairs of eyes spread across the country is more likely to result in anomalies than if regulation is concentrated in just one location.[12]

However, issues at the scale of electric utilities (which span individual states) and transmission operators should be treated as regional concerns. The best examples here are existing regional transmission operators (RTOs) and independent system operators (ISOs). The Energy Policy Act of 1992 greatly enhanced U.S. electricity *restructuring*, a term that generally refers to the introduction of retail competition and the unbundling of electricity assets into distinct generation, transmission, and distribution entities. Worried about reliability issues, groups of electric utilities pooled together to form RTOs and ISOs to ensure equal access to the power grid and operate wholesale electricity networks.[13] Federal Energy Regulatory Commission (FERC) orders 888 and 889 also encouraged the creation of operators such as the Midwest Independent Transmission System Operator and PJM Interconnection. These operators coordinate electricity supply and high-voltage transmission across wide geographic regions to maximize delivery; ensure sufficient reserves and backup power; and enable firms to buy, sell, and trade electricity on spot markets. In an important sense, they provide the vital governance functions for electricity issues that we call "too large for states and too small for a nation."

Energy issues that correspond to worldwide problems are best treated at the scale of global firms and institutions. Subsidies for fossil fuels are one example, particularly in the transportation sector. Total subsidies are difficult to pin down, but one independent review estimated that in 1999, energy subsidies existed in more than one hundred countries and amounted to a whopping 21.1 percent of all energy prices, in essence subsidizing more than one-fifth of global energy consumption. The reviewers calculated that subsidies for fossil fuels and energy exceeded $331 billion in 2000 and that subsidies for road transportation amounted to $1,180 billion – a total of $1.5 trillion in 2000, or $1.9 trillion in today's dollars.[14] At the level of individual states or countries, subsidy reform would be ineffective because the market effects of subsidies from other countries would continue to hide true global energy costs. Climate change presents a similar problem. Individual countries have little incentive to cut emissions without reductions from other countries because those acting first may suffer higher energy costs and may risk losing economic activity to countries without emissions caps.

Another complex energy issue requires forms of polycentric governance that address international maritime regions. For example, Barents 2020 is a joint Norwegian-Russian health, safety, and environmental standards-setting project involving government agencies, oil and gas firms, scientific and research institutions, and nongovernmental organizations (NGOs) across the geographic scope of the Barents Sea. These actors collaborate to harmonize "common acceptable standards for safeguarding people, environment and asset values in the oil and gas industry."[15] The founders of the project concluded that the optimal way to mitigate the risks and overcome the challenges that are unique to the Barents Sea marine area was to develop standards tailored specifically to the region. They formed an international body that matched in scale the regional problem shared by two nations, and they created rules of conduct for every player – public or private – that operates in the region, regardless of nationality.

At the other end of the scale, polycentric analysis can identify places where local and decentralized action is best. For example, the Renewable Energy and Energy Efficiency Partnership (REEEP) funnels investment into clean-energy projects in the developing world – but only at the local level. Established in 2002 by a collection of regulators, businesses, banks, and NGOs, REEEP works to reduce emissions, improve access to reliable and clean energy in developing countries, and promote energy efficiency. REEEP funds energy-efficiency and renewable-energy projects that have the potential to be widely replicated in many different regulatory frameworks and in a variety of countries and energy markets. The organization receives its funding from governments and a collection of banks, other NGOs, and businesses, primarily through donations and voluntary contributions.

In the 2008 program year, REEEP partnered with 44 governments, 180 private organizations (such as banks, businesses, and other NGOs), and six multilateral organizations (such as the United Nations). The organization managed a €6.1 million ($7.8 million) annual operating budget distributed among 145 projects representing a total cumulative investment of €65 million ($83.4 million), most of which was leveraged from REEEP partners through equity financing. Thirty-seven additional projects were in the works by late 2008 and early 2009. These new projects included the promotion of solar water heaters in Uganda, energy-efficient lighting in India, rural biomass development in China, renewable-energy financing in Mexico, and assessment of the regulatory framework for renewable energy in Argentina.[16]

In short, polycentrism suggests that some energy problems are best addressed by neighborhood, city, and state institutions; others by state, regional, and federal institutions. But again, at each scale a multitude of actors must be involved to ensure institutional diversity.

A look at the structure of institutional relationships can help us search for improvements. In recent years, confrontational tones have dominated media coverage of interactions between U.S. energy institutions and the industry. However, that portrayal does not reflect reality. The government has cooperated with the energy industry in a number of ways. In this section, we argue that U.S. energy institutions should do more to recognize, strengthen, and expand the public-private partnership elements of their structures.

Judging by the headlines, the U.S. government seems to be engaged in pervasive conflict with large electrical utilities and the fossil fuel industries. Consider the following statement by the President and CEO of the American Petroleum Institute, Jack Gerard:

> [The administration] has been restricting oil and natural gas development, leasing less often, shortening lease terms, and going slow on permit approvals – actions which have undermined public support for the administration on energy. It is also increasing or threatening to increase industry's development costs through higher taxes, higher royalty rates, and higher minimum lease bids.[17]

Similarly, American Electric Power (AEP), an Ohio-based megautility, dedicated a portion of the "Corporate Citizenship" section of its website to criticism of the Obama administration, particularly the Environmental Protection Agency (EPA).[18] A subsection entitled "What Others Are Saying" contained twenty-two news articles criticizing rules that have been and are being promulgated by the EPA under the Clean Air Act and Clean Water Act.[19] Interestingly, these "others" unanimously agree that the results of the EPA's recent rule-making will significantly hurt the U.S. economy and lead to the loss of as many as 1.4 million jobs. With sharply worded titles like "Go green, kill jobs" and "The EPA's War on Jobs," many of the articles use a militarized tone in expressing support for AEP's position.

Unsurprisingly, the government sometimes responds in a similar manner. For example, when the oil and gas industries criticized changes in how permits are issued following the BP Deepwater Horizon oil spill, former Director of the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) Michael Bromwich called the industry's accusations "politically motivated" and "erroneous."[20] EPA Administrator Lisa P. Jackson, who became the primary target of the large utilities that rely on coal-fired power generation, reacted to mounting criticism of upcoming rules under the Clean Air Act with a strike of her own. "I do very much believe that it's time for us to get past this tired dance, where folks inside this Beltway get paid a lot of money to say things that aren't true about public health initiatives that this agency is charged by law with undertaking," said Jackson in response to pressure from industry lobbying groups.[21]

The point of these examples is not to assess the merits of arguments presented by either side, but rather to highlight the common assertions that government and industry are in conflict with each other.[22] However, underlying the appearance of discord is a deeper truth: namely, that public and private energy institutions have a long history of working together. One entire energy sector, the nuclear industry, was conceived, born, and taught to walk in government labs, mines, and naval vessels. The transportation fuels sector relies on the U.S. military presence around the world to ensure reliable transport of oil and gas. Both sectors, like other energy industries, rely heavily on supportive tax policies and governmental grants. Moreover, regulated companies commonly play a major part in shaping the regulations under which they operate.[23]

Public-private cooperation on energy issues exists for several reasons. Perhaps the most compelling is that many energy-related technologies have grown so complex that regulators simply cannot keep up with technological advances. Offshore oil and gas exploration and extraction are good examples of such technological advancement. Members of the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling stated in their 2011 report to the president that drilling the Macondo well was "a complex, even dazzling, enterprise." The authors also noted: "The remarkable advances that have propelled the move to deepwater drilling merit comparison with exploring outer space." Unsurprisingly, the commission recommended arming "those in charge of regulatory oversight" with necessary technical expertise.[24] Failure to raise a red flag is not the only problem created by a lack of technical know-how. An overly cautious regulator may shut down a promising new technology because she simply does not understand it. For both reasons, the need for technological expertise often presses parties to blur the line between public and private governance of energy projects.

Government and industry cooperate in other ways. Research and development support, government procurement, and energy pilot programs all offer significant benefits to private enterprises. According to the Congressional Budget Office, federal support for developing and producing energy technologies totaled approximately $24 billion in 2011.[25] Federal, state, and municipal governments have large vehicle fleets and real estate inventories, both requiring vast amounts of energy. Governments also have unique needs that at times can be met only with the technologies that have not penetrated the commercial market. For example, many municipalities have switched to natural gas–powered buses. Thus, government procurement and trial programs can accomplish perhaps the hardest task: bringing a shiny prototype through to a commercially scalable product.

Although sharply worded headlines and remarks give the impression that both sides would have to build a relationship from scratch, a legal and regulatory framework for such cooperation already exists. The Administrative Procedure Act (APA) of 1946 sets forth the process for federal agency rule-making, allowing the public – including energy providers – to use notice-and-comment procedures to influence the regulations to which they might be subject.[26]

The National Technology Transfer and Advancement Act (NTTAA) of 1995 lays out, among other things, a system of research and development cooperation between the energy industry and the government.[27] It also directs federal agencies to use technical standards developed by voluntary consensus standards bodies, except where "inconsistent with applicable law or otherwise impractical."[28] Thus, the NTTAA gives congressional endorsement to the practice of "recruiting" outside authority in developing standards and regulations.[29] The Office of Management and Budget (OMB) Circular No. A-119, "Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities," which clarifies section 12 of the NTTAA, represents yet another endorsement of this cooperative regulatory approach.[30] In a 2010 report on voluntary consensus standards and conformity assessment, Mary F. Donaldson of the National Institute of Standards and Technology emphasized the following benefits of private-public partnership in setting standards:

> Federal investment in voluntary standards development helps to provide sound technological underpinning to standards, speeds the standards development process, and enables the adoption of VCSs [voluntary consensus standards] to support agency missions. Furthermore, adoption of VCSs for Federal agency use provides cost savings to Federal agencies, the Nation's businesses, and the taxpayer through reduced injuries and deaths, increased transactional efficiencies, reduced administrative burdens, and lower costs of products and services.[31]

More recently, the Federal Energy Regulatory Commission (FERC) recruited industry expertise to address concerns raised by the widespread electricity blackout that occurred in 2003. After the Energy Policy Act of 2005 granted FERC explicit authority to require mandatory standards for reliability in the electric sector, the commission authorized a new institution, the National Electric Reliability Corporation (NERC), to coordinate industry expertise and develop specific reliability standards and sanctions.

In spite of these examples, some may view the possibility of closer cooperation between U.S. energy institutions and the energy industry with skepticism. It is true that when regulators and the regulated are close in every facet of their relationship, the lines between the two begin to blur. Therefore, it is critical for energy institutions to determine whether industry cooperation is appropriate with respect to specific instances, areas, and functions. A case in point is the failure of the Minerals Management Service (MMS) to prevent the BP Deepwater Horizon accident.

The MMS was what the members of the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling called in their Report to the President a "cross-purposes regulator." This means it was responsible for three distinct and conflicting functions: resource management; revenue collection; and health, safety, and environmental oversight. The authors of the report eloquently captured the biggest structural flaw of the MMS: "From birth, MMS had a built-in incentive to promote offshore drilling in sharp tension with its mandate to ensure safe drilling and environmental protection." As a result, the agency developed a very close "cooperative" relationship with the industry, the kind that led to one of the worst environmental and economic disasters in the nation's history. Cooperation relative to safety, however, was virtually nonexistent. "It was like pulling teeth," stated a senior MMS employee: "We never got positive cooperation from either industry or the Office of Management and Budget."[32]

The existing legal framework allows government agencies, including energy institutions, to be creative in placing safeguards to prevent the cross-purposes regulator problem. For example, agencies do not always have to follow "the somewhat rudimentary rulemaking provisions of the APA."[33] Separation of functions among and within U.S. energy institutions and their structural units allows private-public cooperation where it is appropriate and beneficial for both sides. This approach can also block the industry from infiltrating governmental oversight, permitting, and licensing functions and allows agencies, departments, and civil servants to fulfill their missions.

In this section, we have discussed research and development cooperation, commercialization of new technologies, participation in rule-making, and use of industry standards as possible avenues of cooperation between energy institutions and the industry. We also see a place in this kind of cooperation for creative ideas – such as William Pedersen's "regulatory reform contracts" – provided that governmental institutions can always be distinguished from regulated entities.[34] In fact, the energy sector is not the only field in which players can be both governmental and regulated entities at the same time. Consider, for example, the Port Authority of the States of New York and New Jersey or the role of any telecommunications utility exercising eminent domain over the land of others. In the 1982 case *Loretto v. Teleprompter Manahttan CATV Corporation*, the U.S. Supreme Court declared that apartment owners had to be compensated if the state of New York required them to allow cable companies to run wires to their residential apartments. A year later, on remand, the Court of Appeals held that the economic value of that compensation could be set at a level too low to be worth collecting, typically a token $1 per building.[35]

The Barents 2020 project (discussed above) is also instructive. After providing the initial funding, the Norwegian government connected its standardization agencies with the project. It then helped facilitate a coalition consisting of the domestic and international oil and gas industries, research institutions, and NGOs. Finally, the Norwegian government and other Barents 2020 partners persuaded the Russian government, research institutions, and the oil and gas industry to join as well.[36] As a result, Norwegian and Russian governments were kept in the loop during the technically challenging standards-setting process. The industry benefited from the scientific expertise of participating research institutions, as well as from the trust it gained from government authorities and NGOs, none of which were separated from the process by closed boardroom doors.

The successes of some public-private cooperation and the potential for new creative ideas are difficult to disregard.[37] U.S. energy institutions and the energy industry should continue on the same path, giving increased consideration to the need for transparency and public understanding of each party's complex role.

A third factor, the jurisdictional scope of an institution, is also helpful to consider. A prime example is the historic view of climate change as merely an environmental issue. This outlook has contributed to the failure of decision-makers to recognize and mitigate the phenomenon's economic risks. Such risks are foreseeable and, to some degree, manageable, especially if considered in the context of an institution's goals and responsibilities. Therefore, it is mandatory that U.S. energy institutions incorporate climate change risks into the scope of their decision-making, fundamentally altering how they weigh economic costs and benefits.

Climate change has been a topic of global public discussion for more than thirty years. However, in the United States, it has gained serious governmental consideration only in the last decade.[38] Exxon Mobil, a longtime climate change skeptic, softened its public position in 2007.[39] The Regional Greenhouse Gas Initiative (RGGI), the first market-based program designed to decrease greenhouse gas emissions in the United States, held its first auction on September 25, 2008.[40] There was much public excitement surrounding the Fifteenth Conference of the Parties (COP 15) that took place in Copenhagen in December 2009. There, the U.S. delegation, led by President Obama, played an active role in negotiating the Copenhagen Accord, a political agreement that served as a first step to the post-Kyoto regime.[41] With the Waxman-Markey climate bill pending in Congress, it seemed that the United States was on the verge of significant domestic policy changes.[42]

Yet those changes never materialized. The climate legislation died in the Senate, and the 2010 midterm elections ended all near-term prospects for its revival in the House of Representatives.[43] COP 16 in Cancun, Mexico, and COP 17 in Durban, South Africa, garnered only a fraction of the media coverage that the Copenhagen meeting received. The level of public awareness and concern about climate change dropped as well. Americans now seem less certain than they were a decade ago about the accuracy of global warming news coverage, about humankind's role in causing global warming, and about the scientific consensus on the issue.[44]

On the other hand, RGGI appears to be weathering the climate change policy "chill" of the early 2010s. It held its sixteenth auction on June 6, 2012.[45] In terms of our three factors of scale, structure, and scope, RGGI may be a good example of a new institution that is larger than a state but smaller than a nation, is structured by government to channel private investment, and has a scope that includes both environmental and economic considerations.

The fact that climate change is no longer a front-page issue does not mean that the problem itself has ceased to exist. Moreover, the failure to address climate change amplifies potentially grave risks for the struggling U.S. economy. Unfortunately, most Americans do not view climate change as an economic issue. In fact, Gallup poll analysis of the "Most Important Problem" facing the nation does not list climate change as an economic issue.[46] The historic perception of climate change as a predominately environmental issue has slowed the response to the problem.[47] The framing of climate change as an environmental, rather than an energy, priority is also tied to the fact that it was meteorologists, climatologists, and environmental scientists who first sounded the alarm.[48] In addition, calls for climate change mitigation, or even mere acknowledgment of the problem, are often labeled "radical environmentalism" by conservative politicians.[49]

Early attempts to reclassify climate change as something more than an environmental issue were made in the early 2000s. In the 2003 Pentagon report "An Abrupt Climate Change Scenario and Its Implications for United States National Security," authors Peter Schwartz and Doug Randall described the national security threats posed by rapid climate change.[50] British economist Nicholas Stern released the most comprehensive analysis of the economic impacts of climate change, the *Stern Review on the Economics of Climate Change*, in October 2006.[51] The Stern Review noted that the economic cost of inaction can range from 5 percent to 20 percent of global GDP per year.[52] By contrast, the cost of reducing greenhouse gas emissions and avoiding related economic damage is estimated to be around 1 percent of global GDP.[53] According to the report, the risks of catastrophic damage can be significantly decreased if atmospheric greenhouse gas levels are stabilized between 450 and 550 ppm of CO_2 equivalent.[54]

Unfortunately, the Stern Review's recommendations have not been taken seriously in most sectors of the U.S. economy, including the energy sector. Because the energy sector is the economy's driving force, failure to take into account the economic implications of climate change may lead to dire consequences, not only for the sector itself, but for the entire economy.

Expanding the scope of institutional concerns turns a debate over sea-level rise into a conversation about the economic risk of allowing the construction of large power plants near the coastline. This shift in perspective converts the high costs and uncertain benefits of mitigating climate change into the manageable costs of mitigating climate change risks and the palpable benefits of avoiding foreseeable economic, social, and environmental damage. Therefore, by bringing the economic risks of climate change into the scope of factors that an energy institution should consider, the scale of the problem can be adjusted to fit the scale of the institution. This shift in perspective also has the potential to humanize the impacts of climate change, making them more visible and visceral. The previously abstract notion of "populations occupying low-lying coastlines" becomes indigenous communities struggling with the intrusion of saltwater in their wells; similarly, "percentage of GDP lost" becomes minority shop owners in New Jersey and New York repairing hurricane-damaged boardwalks, and "displaced populations" becomes tribal refugees in the Maldives relocating their homes to higher ground.

It may be an interesting and intellectually challenging exercise for economists to dissect the aggressive assumptions made by the authors of the Stern Review.[55] After all, environmental economists William Nordhaus and Robert O. Mendelsohn somewhat infamously critiqued certain aspects of its methods concerning discounting,[56] demographics, extreme weather, and equity.[57] However, it is simply imprudent for U.S. energy institutions to ignore the economic risks noted in the report in relation to the energy subsector, even if those risks cannot be precisely known or forecasted by economic models.

Treating climate change from the standpoint of risk assessment has been embraced by the U.S. Navy and the insurance industry, entities that cannot be described as "radically environmental," even by conservative pundits. In May 2010, the Department of the Navy released the "U.S. Navy Climate Change Roadmap."[58] In the opening paragraph of their report, the members of Task Force Climate Change unambiguously stated the rationale for preparing the roadmap:

> Climate change is a national security challenge with strategic implications for the Navy. Climate change will lead to increased tensions in nations with weak economies and political institutions. While climate change alone is not likely to lead to future conflict, it may be a contributing factor. Climate change is affecting, and will continue to affect, U.S. military installations and access to natural resources worldwide. It will affect the type, scope, and location of future Navy missions.[59]

The roadmap identifies the following focus areas for incorporating climate change considerations: 1) strategy, policy, and plans; 2) operations and training; 3) investments in capability and infrastructure; 4) strategic communications and outreach; and 5) environmental assessment and prediction. The final focus area is especially noteworthy, as it lays out the basis for incorporating climate change considerations into the scope of the U.S. Navy's decision-making process. The goal of the roadmap is "[t]o provide Navy leadership and decision makers a science-based, comprehensive understanding of the timing, severity, and impact of current and predicted global environmental change on tactical, operational, and strategic (climatic) scales."[60]

For their part, insurance companies assess risk for a living. They, too, believe that the scope of climate change is larger than an environmental concern. Among the first private enterprises to place serious emphasis on the economic risks posed by climate change, many insurance companies no longer rely on individual efforts to grapple with climate change risks; they have joined the industry-wide movement ClimateWise.[61] Established in 2007 by the Prince of Wales, ClimateWise now has more than forty members, including insurance giants such as Allianz, Aviva, Lloyd's, Swiss Re, and Zurich.[62] Chairman John Coomber, a member of the Swiss Re's board, captured the essence of the ClimateWise mission in the following statement:

> Insurers everywhere should be using our industry's core expertise to better understand and communicate the risks climate change poses to our economic and social systems and to forge and promote solutions to bring those risks down to an acceptable level. This independent review demonstrates that insurers across the

world are indeed actively playing this role in a variety of ways.[63]

By joining ClimateWise, members commit to the following principles. They must 1) lead in risk analysis, 2) inform public policy-making, 3) support climate awareness among customers, 4) incorporate climate change into investment strategies, 5) reduce the environmental impact of their own businesses, and 6) report and be accountable.[64] The participating insurers may act individually or collectively to "reduce the economy's and society's long-term risk from climate change, within the confines of a competitive market."[65]

Despite the obvious differences in each entity's reasons for incorporating climate change risks into their decision-making processes, U.S. energy institutions have much in common with the U.S. Navy and the insurance industry. Large coal-fired and nuclear power plants, oil pipelines, and unexplored offshore oil and gas fields are capital-intensive investments. They are economically attractive only if construction costs can be spread over time and reduced to competitive levels through the use of long-term financings such as thirty-year bonds; to appreciate this issue, imagine the rate effect of recovering the full cost of a $5 billion power plant in ten years of 10 percent annual depreciation, rather than with thirty-plus years of 3 percent annual depreciation. However, spreading cost recovery over a thirty-year period is rational only if one is sure that neither fundamental climate, nor basic fuels, nor regulatory requirements, nor access to huge quantities of water will become problematic during those decades. Utilities may be willing to gamble on those expectations, but their investors are unlikely to do so.

Therefore, just as the U.S. Navy believes that climate change implications will compromise its ability to protect national security, U.S. energy institutions should view climate change as a threat to their mission of ensuring a reliable energy supply. Similarly, as the insurance industry works to protect investments that can be susceptible to the economic risks posed by climate change, U.S. energy institutions should work to protect their customers – and American society at large – from investing in energy projects and technologies that will become obsolete in the face of a changing climate.

It is encouraging to see more calls for incorporating climate change risk into the scope of energy decision-making. In the last two years, Ceres, a promoter of sustainable business practices, has issued a series of reports targeting climate change risks in connection with the energy sector.[66] One recent report, "Practicing Risk-Aware Electricity Regulation: What Every State Regulator Needs to Know," is particularly noteworthy. It provides an overview of risks associated with investment in energy infrastructure, discusses the regulatory challenges of managing such risks, and outlines seven critical strategies for making risk-aware regulatory decisions. The report captures the message of this essay: U.S. energy institutions need to include climate change risks in the scope of their decision-making process; and moreover, this must be done now in order to avoid economic losses in the near future.[67]

We began by noting some of the key institutions created in the twentieth century for the purpose of delivering energy throughout North America. We observed that these institutions are being challenged by a combination of stresses in three areas: reliability, economics, and environmental sustainability. As we have suggested, the institutional reforms needed to address this energy trilemma can best be understood in terms of the scale, structure, and scope of new and modified institutions. In considering real-world examples of recently formed institutions, we have noted both successes and concerns that these three factors illustrate.

In particular, issues of scale will increasingly call for polycentric organizations that interlace multiple interests rather than operate in simple hierarchies. Thus, polycentrism offers a way forward, a way to connect the different levels, and a way to use the level of the household and the local community to find solutions to regional and international challenges. Issues of structure will require cooperation between public and private sectors, signaling an increasing need to clarify the distinctions between those sectors. Issues of scope help explain both the failure of the energy sector's responses to climate change and the need to face that challenge.

The social science research cited above can help explain and improve the delivery of energy services; indeed, there is real value in further research on these topics. For a century or more, societies like ours have treated social and technical issues as fundamentally different. The costs of doing so have been profound, as C. P. Snow illustrates in *The Two Cultures and a Second Look* (1959).[68] Conversely, the benefits of bridging the gap between Lord Snow's two cultures may be vital. In pragmatic terms, key energy institutions are hiring behavioral analysts to predict and identify the factors that drive such things as energy demand, public responses to siting proposals, and climate change denial.[69] Similarly, the conceptual work of Carnegie Mellon University's program on Engineering and Public Policy is starting to produce helpful insights into behavioral responses to new energy policies.

Some institutional changes will be organic and unplanned, but many others will benefit from conscious attention to scale, structure, and scope by those engaged in designing and building the energy institutions that the twenty-first century needs. Those who are "present at the creation"[70] of energy institutions for a new energy world will do well to use those concepts consciously as they face the age-old tasks of "fitting" institutions to technological realities and of looking to the social sciences for guidance.

ENDNOTES

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1 Aristotle, *Politics*, I.

2 For a seminal use of the concept of *fitness*, see Stephen Breyer, *Regulation and its Reform* (Cambridge, Mass.: Harvard University Press, 1982). In that book, Breyer, then a professor of law and now a Justice of the U.S. Supreme Court, argues that regulation itself is inherently neither good nor bad, but that its merits turn on "regulatory fit": that is, a match between social problems and the response of regulatory institutions.

3 Use of the term *energy trilemma* is increasing. The earliest public use of which we are aware was in a 2005 series of lectures by Michael Dworkin. The term first appeared in a published article three years later; see John A. Sautter, James Landis, and Michael H. Dworkin, "The Energy Trilemma in the Green Mountain State: An Analysis of Vermont's Energy Challenges and Policy Options," *Vermont Journal of Environmental Law* 10 (2008 – 2009): 477.

4 For an overview of recent patterns of institutional change caused by technological change, see Debora L. Spar, *Ruling the Waves : Cycles of Discovery, Chaos, and Wealth from the Compass to the Internet* (New York: Harcourt, 2001).

5 Peter Huber, *The Geodesic Network: 1987 Report on Competition in the Telephone Industry* (Washington, D.C.: U.S. Department of Justice, January 1987).

6 Elinor Ostrom, "Polycentric Systems for Coping with Collective Action and Global Environmental Change," *Global Environmental Change* 20 (2010): 550 – 557.

7 Ann E. Florini and Benjamin K. Sovacool, "Who Governs Energy? The Challenges Facing Global Energy Governance," *Energy Policy* 37 (12) (December 2009): 5239 – 5248. See also Ann E. Florini and Benjamin K. Sovacool, "Bridging the Gaps in Global Energy Governance," *Global Governance* 17 (1) (January–March 2011): 57 – 74.

8 In theory, international entities can be seen as one hierarchical rank up from nation-states. In practice, however, no body larger than a nation-state – neither the Papacy, nor the Comintern, nor the United Nations – has imposed its will on those beneath in ways that match the sustained and detailed impact that nation-states have had since their seventeenth-century origins in the Westphalian system (which invoked the concept of nation-states to end Europe's Wars of Religion).

9 Benjamin K. Sovacool, "An International Comparison of Four Polycentric Approaches to Climate and Energy Governance," *Energy Policy* 39 (6) (2011): 3832 – 3844.

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11 Timothy Doyle and Brian Doherty, "Green Public Spheres and the Green Governance State: The Politics of Emancipation and Ecological Conditionality," *Environmental Politics* 15 (5) (November 2006): 881 – 892.

12 Daniel C. Esty, "Revitalizing Environmental Federalism," *Michigan Law Review* 95 (December 1996): 560.

13 The body of literature discussing RTOs and ISOs is large, complex, and often contradictory. For a discussion focused on governance issues, see Michael H. Dworkin and Rachel Aslin

Goldwasser, "Ensuring Consideration of the Public Interest in the Governance and Accountability of Regional Transmission Organizations," *Energy Law Journal* 28 (November 1998): 543.

14 Norman Myers and Jennifer Kent, *Perverse Subsidies: How Tax Dollars Can Undercut the Environment and the Economy* (Washington, D.C.: Island Press, 2001).

15 *Barents 2020: Assessment of International Standards for Safe Exploration, Production and Transportation of Oil and Gas in the Barents Sea*, Final Report no. 2009-1626 (2009), 11.

16 Florini and Sovacool, "Who Governs Energy?"

17 http://www.pennenergy.com/index/petroleum/display/6705820362/articles/pennenergy/petroleum/exploration/2012/may/api-says_administration.html?cmpid=EnlDailyPetroMay172012&cmpid=EnlWeeklyPetroMay182012.

18 See http://www.aep.com/environmental/NewEPARules/. The EPA statutes criticized by AEP include the Cross-State Air Pollutants Rule (CSAPR), the Regional Haze Program, the Hazardous Air Pollutants (HAPs) Rule, the Coal Combustion Residuals (CCR) Rule, and Section 316(b) of the Clean Water Act.

19 The section "What Others Are Saying," which appeared on AEP's website (http://www.aep.com) as of July 4, 2012, has since been removed.

20 BOEMRE served as an "interim" agency in the process of reorganizing the former Minerals Management Service (MMS). After the Deepwater disaster, the MMS was broken into two separate agencies, the Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE). As the titles of the newly formed agencies suggest, the BOEM is charged with offshore resource management, whereas the BSEE is responsible for health, safety, and environmental oversight. Bromwich was appointed in June 2010 to orchestrate the reorganization. See "BOEMRE Director Delivers Final Speech Before Agency Reorganization," press release (Washington, D.C.: Bureau of Ocean Energy Management, Regulation and Enforcement, September 13, 2011), sec. 1 and 3.

21 Darren Samuelson, "The Environmental Protection Agency's Lisa Jackson Swings Back at Critics," Politico, October 6, 2010, http://www.politico.com/news/stories/1010/43168.html.

22 Bromwich made a convincing case in support of his response using data and real-life examples. See "BOEMRE Director Delivers Final Speech Before Agency Reorganization," sec. 3 and 4. For an assessment of the recent EPA regulations, see also James E. McCarthy and Claudia Copeland, *EPA Regulations: Too Much, Too Little, or On Track?* (Washington, D.C.: Congressional Research Service, April 25, 2012), http://www.fas.org/sgp/crs/misc/R41561.pdf.

23 Jody Freeman, "The Private Role in Public Governance," *New York University Law Review* 75 (2000): 543, 639.

24 National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, *Deep Water: The Gulf Oil Disaster and the Future of Offshore Drilling – Report to the President* (Washington, D.C.: Government Printing Office, 2011), vii–viii.

25 Note that approximately $20.5 billion came in the form of tax subsidies and the remaining $3.5 billion in the form of direct spending. See Congressional Budget Office, http://www.cbo.gov/publication/43040.

26 Public Law 79-404.

27 Public Law 104-113, sec. 2.

28 Ibid., sec. 12(d).

29 Freeman, "The Private Role in Public Governance," 640. Government agencies use industry standards in a number of ways. For example, an agency may adopt a standard as part of a rule, use it as a basis for rule-making, or show strong deference to a standard. See http://standards.gov/regulations.cfm.

30 As of this writing, OMB Circular No. A-119 is being revised to conform the Circular's terminology to the NTTAA and to increase its clarity and effectiveness. See http://www.whitehouse.gov/omb/fedreg_a119rev.

31 Mary F. Donaldson, *Thirteenth Annual Report on Federal Agency Use of Voluntary Consensus Standards and Conformity Assessment* (Washington, D.C.: National Institute of Standards and Technology, U.S. Department of Congress, August 2010), http://standards.gov/nttaa/resources/nttaa_ar_2009.pdf.

32 National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, *Deep Water*, 55–57, 72, 76–78.

33 William F. Pedersen, Jr., "The Decline of Separation of Functions in Regulatory Agencies," *Virginia Law Review* 64 (1978): 991, 1016. Note that courts, practitioners, and legal scholars have grappled with the interpretation of Section 5(c) of the APA on the "Separation of Functions" since the act was passed in 1946. See generally Kenneth Culp Davis, "Separation of Functions in Administrative Agencies," part 2, *Harvard Law Review* 61 (1948): 612.

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36 *Barents* 2020, 11, 12.

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47 Ibid.

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66 http://www.ceres.org/resources/reports.

67 See Ronald J. Binz et al., "Practicing Risk-Aware Electricity Regulation: What Every State Regulator Needs to Know" (Boston: Ceres, April 2012), 1, 5, 31.

68 C. P. Snow, *The Two Cultures and a Second Look* (Cambridge: Cambridge University Press, 1959).

69 This observation is based on Michael Dworkin's personal experience as a member of the Boards of Directors of the American Council for an Energy-Efficient Economy and of the Electric Power Research Institute.

70 The phrase is borrowed from former U.S. Secretary of State Dean Acheson, who used it to describe the conscious creation of institutions (such as the United Nations, NATO, the International Monetary Fund, the World Trade Organization, and the World Bank) that aided U.S. policy for a half-century following World War II. See Dean Acheson, *Present at the Creation: My Years in the State Department* (New York: Norton, 1969). Acheson received the 1970 Pulitzer Prize in History for his book.

Energy in the Context of Sustainability

Rosina M. Bierbaum & Pamela A. Matson

Abstract: Today and in the coming decades, the world faces the challenge of meeting the needs of a still-growing human population, and of doing it sustainably – that is, without affecting the ability of future generations to meet their needs. Energy plays a pivotal role in this challenge, both because of its importance to economic development and because of the myriad interactions and influences it has on other critical sustainability issues. In this essay, we explore some of the direct interactions between energy and other things people need, such as food, water, fuel, and clean air, and also some of its indirect interactions with climate, ecosystems, and the habitability of the planet. We discuss some of the challenges and potential unintended consequences that are associated with a transition to clean, affordable energy as well as opportunities that make sense for energy and other sustainability goals. Pursuing such opportunities is critical not just to meeting the energy needs of nine billion people, but also to meeting their other critical needs and to maintaining a planet that supports human life in the near and long term.

The term *sustainability* – widely used today in corporate, academic, government, nongovernmental, and community settings – is defined in multiple ways. In the corporate sector, sustainability typically refers to the triple bottom line, or "three-legged stool," that incorporates concern for the economy, the environment, and social equity into industrial or economic activities. In development circles, the term often describes a pattern of development that "meets the needs of the present without compromising the ability of future generations to meet their own needs,"[1] or that promotes human well-being while protecting and conserving the life support systems of the planet.[2] Most biodiversity-conservation organizations embrace the strategy that the International Union for Conservation of Nature outlined in 1980 to integrate conservation and development objectives.[3] Despite differences in these and other definitions, all share a common concern: to maintain the planetary resources needed to meet today's needs as well as those of future generations.

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No resource is more fundamental to human development and well-being than energy. Energy is a key ingredient of almost all aspects of human existence, from producing food, to accessing and purifying water, to heating and lighting homes, to transporting materials and people, to creating the goods and technologies that humanity has come to rely on. Therefore, human well-being depends on sustainable, reliable, and enduring forms of energy. Yet for many, access to affordable energy remains an aspiration: there are still billions of people worldwide who do not have access to electricity and modern forms of energy, and as a result, energy is among the most frequently cited sustainability challenges.[4] As population growth combines with increased consumption patterns, demand for energy services will rise sharply.[5] Moreover, access to reliable sources of energy – even in areas that have had access in the recent past – is a growing concern. Significant technical, economic, and national security issues affect the availability of fossil fuels – namely, coal, oil, and natural gas – that currently supply 82 percent of global energy and 85 percent of U.S. energy.[6] The use of fossil fuels also has significant environmental impacts, including the production of pollutants that affect the health of people and ecosystems from local to global scales.

As a result of these burgeoning concerns, efforts are under way around the world to transform energy systems into something cleaner, more reliable, and affordable for all.[7] This transformation is urgently needed, as global demand for energy will likely triple over this century.[8] How that energy is supplied and distributed – and in what form – will determine whether the next generation inherits a sustainable planet.

This essay explores energy in the context of sustainability, focusing on some of the critical inter-linkages between energy use and other key issues, such as food, water, health, national security, and preservation of ecosystem services. It also examines what may be energy's largest long-term challenge to sustainability: namely, its impact on climate change. The rapidly evolving sustainability challenges on the planet – driven by the speed of change in population, consumption, infrastructure development, and climate change, among other factors – threaten to outpace the capacity of human and natural systems to adapt. Thus, transformation of global energy systems must be quick, and it must commence immediately. This essay discusses these factors and calls for enhanced public and private support of technology development worldwide, as well as for a workforce trained to solve interdisciplinary problems, in order to achieve revolutionary – not evolutionary – advances in energy and progress toward sustainability goals.

Among the many interconnections between energy and other resources, the nexus of energy and water is perhaps the most well studied and clearly documented.[9] Energy is used to collect and pump surface and groundwater; to transport and distribute water for multiple uses; to desalinate seawater; to transport and treat wastewater; and to heat and cool water for industrial, commercial, and residential end use.[10] Nearly one billion people do not have access to clean water, and nearly two billion do not have access to sanitation, so the demands for energy to help provide these essential services will only increase.[11]

Water is also essential to many elements of energy production. Among other uses, it is used to extract fuels and manage other aspects of mining and geologic production; for cooling in thermal electricity generation (using coal, gas, nuclear, and other fuel sources); for producing geothermal and hydrothermal energy; for scrubbing pollutants in coal-fired plants; and in the steam turbines of power plants. In turn, contamination of surface water and shallow groundwater from the production of energy resources is one of the most critical sources of water pollution.[12] Acid mine drainage from coal mines has a long history of environmental and health concerns, but newer technologies also raise concerns. Indeed, one of the most worrisome consequences of hydraulic fracturing of shale for natural gas production, which has recently skyrocketed in the United States and elsewhere, is related to the large amounts of water needed to carry out the fracturing process, as well as inadvertent contamination of surface water and shallow aquifer resources that can take place under poor drilling practices.[13]

The cautious good news is that efficiency of water use in traditional energy production has been on the rise and is expected to continue. In the United States, for example, the average amount of water withdrawn per kilowatt-hour of electricity production has decreased over the past several decades. But because absolute energy consumption has risen, the total amount of water consumed has also increased.[14] Some alternative energy sources, such as solar photovoltaics and wind, use relatively low amounts of water. Thus, diversifying the energy supply with these alternatives will help reduce the water demand for energy production.[15] Some bioenergy sources, on the other hand, use substantial amounts of water in the growth, conversion, maintenance, and harvesting of crops to produce fuels such as ethanol,[16] raising concerns about water shortages and the sustainability of biofuel energy production.[17]

Given that more than one billion people live in river basin areas where water use currently exceeds recharge levels, and because global water consumption doubled between 1960 and 2000 and continues to grow rapidly, the energy/water nexus will require more integrated and innovative planning to manage these systems in the coming decades.[18]

Energy and food production are likewise connected. Energy is critical to every step of the food supply chain,[19] and food-related energy use across the cycle – from production to use and disposal – is a major and growing fraction of national energy budgets. At the agricultural end of this chain, energy is used to produce and apply fertilizers; to pump and distribute irrigation water; to produce and apply pesticides; and to till the soil, harvest crops, and carry out other on-site management practices. Among these, irrigation is often the most significant consumer of energy. For example, a 2005 study estimated that pumping groundwater for agriculture represents one-third of annual energy use in India; as a result, high-energy costs can limit the use of irrigation pumping to maintain and expand agriculture.[20] Energy use per "unit" output is much higher for livestock systems than for cropping systems because there are inefficiencies at several steps in the process. In 2008, ecologist David Pimentel and colleagues calculated that the fossil energy required to produce animal products consumed in the American diet accounts for 50 percent of the nation's total food-related energy demand.[21]

Energy is used along the remainder of the food supply chain as well – from transportation, processing, and packaging to household food-related activities such as travel for purchasing food, refrigeration, freezer storage, and food preparation. Not surprisingly, given the close connection between energy and food, rising energy costs lead to higher average food costs, and spikes in oil prices are related to spikes in food prices.[22] Many opportunities exist for improving the efficiency of energy use (and other resource use) in food production, but as is the case with water, increases in efficiency can easily be offset by population growth and shifts to less-efficient consumption patterns. To meet the estimated 70 to 100 percent increase in food needed by 2050 to feed the growing global population, many analysts suggest that we must radically change the way food is produced, processed, stored, and distributed. In addition, methods for eliminating waste must be found; 30 to 40 percent of food is lost to waste in both developing and developed countries.[23] Such goals can have significant consequences for energy as well as food and water.[24]

Despite the clear influence of energy on the production, distribution, and cost of food, until recently the food/energy connection was not well understood. Modern biofuels have been heralded for their contributions to energy security and for reductions in environmental costs from fossil fuels; but many analysts suggest that, at least for first-generation biofuels like corn ethanol, the return on investment may not yield significant net energy benefits or greenhouse gas reductions. At the same time, the manufacture of corn ethanol competes for valuable land with activities such as food production and biodiversity conservation.[25] Moreover, some studies have found that food prices may rise as a result of increased competition for land between food and biofuels.[26]

There is a long litany of health impacts associated with energy use. More than five million premature deaths annually are attributable to air pollution and other energy-related effects.[27] In most developed countries, exposure to particulates – predominantly sulfates and soot from fossil fuel combustion – can reduce life expectancy. Air pollutants, especially volatile carbon and nitrogen oxides from stationary and mobile sources, drive tropospheric ozone pollution, with impacts on lung function as well as agricultural systems.[28] Although exposure to air pollution damages the health of everyone, numerous studies have shown that certain groups – for example, the elderly, children, and those with underlying disease – are at greater risk of being affected by air pollutants.[29]

About 40 percent of the global population – often the poorest – relies on dung, agricultural wastes, and wood fuels for cooking and heating.[30] Exposure to emissions from these fuels in the home extracts huge health care consequences.[31] Beyond the direct health concerns, the fact that poorer individuals expend proportionally more of their income on energy, despite using far less energy than the rich, leads to insecurity in critical areas such as health care, education, and food.[32] Moreover, because higher energy prices inflate the prices of almost all other goods and services (and can account for up to 15 percent of total prices of food, textiles, lumber, paper, and other necessities), the poor suffer not just in access to energy under rising prices, but in access to other essential needs.[33]

Energy also plays a significant role in national security. All the issues discussed thus far (energy and water, energy and food, and energy and health), in addition to issues such as population migration, energy acquisition, and energy diversification, are key determinants of both national and global security.[34] The energy transition can either reduce or enhance the potential for conflict. In particular, the diversification of energy supplies and the transition to alternative sources of energy is critical – as suggested by the staggering official estimates that the Pentagon has paid $40 to $400 per gallon of fuel (including the cost to transport the fuel) to power a combat vehicle or aircraft in Afghanistan.[35] Ensuring that energy is readily available, sustainable, and resilient will continue to be a key component of national and global security concerns.[36]

The preceding sections illustrate some of the most direct ways that energy choices affect our ability to meet other critical human needs. Our energy choices also have an impact on the life support capacity of the planet, including on our atmosphere and ecosystems (and the services they provide), and, perhaps most important, on climate – specifically, through the emissions of greenhouse gases, principally carbon dioxide, methane, nitrous oxide and particulates from combusting carbon-based fossil fuels. Climate change in turn affects all components of human and natural systems, adding both complexity and urgency to the search for sustainable energy solutions. A substantial body of evidence, accumulated through several decades of multidisciplinary research, indicates that Earth's global climate has already warmed 1.4 degrees Fahrenheit. Most of the warming can be attributed to greenhouse gas emissions from the burning of fossil fuels for energy as well as, to a lesser extent, emissions from land use and agriculture.[37] The pace and magnitude of current changes are challenging the historic tolerances of species and infrastructure; planning based on the climate of the past is no longer an option.

Climate change is associated with a broad spectrum of other changes, including increases in extreme precipitation events, more frequent hot spells, rising sea levels, and shifts in ranges of crops, forests, and pests. The future severity of these and other impacts will depend on how much the climate changes, and that will depend on what humanity does both to reduce greenhouse gas emissions and to increase resilience to climate impacts. Climate change poses great risks for a wide range of resources and environmental systems, including freshwater resources, agriculture and fisheries, coastal environments, and ocean and land ecosystems.[38] For example, as the climate changes, dry places on the planet are expected to become drier and subject to more severe drought, while wet places may experience increasing intensity of rainfall and associated damages. Agricultural systems will face higher temperatures, which could push certain crops out of historical production zones; increased demand for water; and new disease vectors that could disrupt production. Most models suggest dramatic increases in the frequency of very hot temperatures,[39] which could lead to greater public health impacts from heat stress, increased demand for energy to cool built environments, and greater risks of food shortages.[40]

The impact of climate change on the frequency and intensity of extreme weather events is of particular concern.[41] During the past several decades, the United States has been subjected to a greater frequency of extreme weather.[42] We have too often seen how floods and droughts can affect global production of goods and services, thereby disrupting energy, water, and food systems as well as global trade. Hurricanes Katrina and Rita, for example, shut down or suspended three-quarters of the more than four thousand offshore oil and gas platforms overseen by the U.S. Department of the Interior.[43] Moreover, recent droughts and floods in Pakistan and Thailand have killed thousands, displaced millions, and disrupted supply chains for commodities as diverse as clothing, food, and computer hard disks.[44]

While strategies for achieving the sustainable production and supply of energy must seek to reduce greenhouse gas emissions and climate change, they will also need to consider the energy system's resilience to climate-related impacts. Such efforts will be critically important across temporal and spatial scales; indeed, extreme events as well as slow-onset events, such as sea level rise, can pose serious challenges to the ability to meet global energy demand.

International, national, and regional institutions are, in many ways, ill-prepared to cope with current weather-related disasters, let alone potential problems such as a growing number of refugees fleeing environmental damages spawned by climate change.[45] Concomitant with an energy transition, society must improve natural resource management and preparedness/response strategies to deal with future climatic conditions that will be fundamentally different from those experienced in the last hundred years.

Pursuing the energy transition in the context of sustainable development raises special challenges and opportunities. Among these, equity among the more and less developed countries of the world and trends in urbanization deserve special attention. Energy access across the planet is deeply uneven; the poorest on the planet use about 5 percent of the energy consumed by the average U.S. citizen. According to the World Bank's Data Catalog, the United States used 7,000 kg of oil equivalent per capita in 2009. By comparison, India, China, South Africa, Ethiopia, and Bangladesh used 560, 1,700, 3,000, 400, and 200 kg of oil equivalent per capita, respectively.[46] However, many of the easiest and cheapest opportunities to reduce energy use, produce clean energy, and reduce climate and other environmental changes can be found in developing countries, where infrastructure has yet to be built, where there is potential to greatly improve efficiency of energy use, and where land-use practices can decrease greenhouse gas emissions. A clean-energy transformation can go hand in hand with other forms of sustainable development in developing countries.[47]

Whether developing countries embark on a more sustainable development path will be heavily influenced by transition costs; higher-income countries must provide financial and technical support. Global cooperation will require more than financial contributions, however. Developing countries harbor the concern that integrating climate concerns with development decisions could erode existing development assistance or shift responsibility for mitigation onto the developing world. Enshrining a principle of equity in regional or global deals would do much to dispel such concerns and generate trust.[48] Moreover, high-income countries must bring their own indefensible energy footprints down to sustainable levels.

A major concern of developing countries is technology access. Innovation in energy-related technologies remains concentrated in high-income countries, although developing countries are increasing their presence. (For example, China is seventh in overall renewable energy patents, and an Indian firm is now the leader in on-road electric cars.) In addition, developing countries – at least the smaller or poorer ones – may need assistance to produce new technology or tailor it to their unique local circumstances. International transfers of clean technologies have so far been modest. They have occurred in, at best, one-third of the projects funded through the Clean Development Mechanism, the main channel for financing investments in low-carbon technologies in developing countries.[49]

Meeting clean-energy objectives without detracting from other sustainability goals will require careful processes, tools, and approaches for selecting among options and recognizing competing demands for land, water, energy, and a variety of ecosystem services in the face of a growing population.[50] Over the course of the last few decades, progressive degradation of the environment by human activities has been increasingly well documented. Loss of biodiversity and overuse of natural resources have already reduced or rendered less reliable some ecosystem services, with significant adverse impacts on society.[51] The energy sources that we choose, where those sources are located, and the amount of water and land consumed to access the sources will affect sustainability goals.

Certain types of biomass (ethanol, for example) currently compete with traditional agriculture for access to limited land and water.[52] This competition is projected to intensify as global demand for biofuels rises; looking ahead, a fourfold increase in biofuel production, primarily in North America and Europe, is expected by 2030.[53] Pressure to expand land for biofuels could lead to a massive conversion of managed and unmanaged forests and preserved areas, further jeopardizing indigenous cultures and biodiversity. Placing a value on the carbon held in forests and soils could lessen this impact significantly.[54]

Large wind and solar developments also pose challenges.[55] They consume large tracks of land, raise potential noise concerns associated with energy generation, and rely on a manufacturing process that could produce toxic waste if new generation techniques are not created.[56] Additionally, wind and solar both face pressure from NIMBY ("Not In My Backyard") syndrome, whereby local residents want to have access to these technologies but, for aesthetic reasons, do not want new developments in their communities. Carbon capture and storage and nuclear energy can also affect local landscapes and carry risks associated with accidents and storage of waste material.[57]

We must also carefully consider how future energy choices affect our ability both to mitigate and adapt to climate change. As noted above, the range of clean-energy choices could reduce or mitigate climate change but could also negatively affect the preservation of biodiversity, natural resources, and ecosystem services. At the same time, the effects of climate change on food and water resources and ecosystem services could impede the use of these resources in the development of clean-energy alternatives. Moreover, efforts to meet human needs through adaptation to climate change – for example, greater use of electricity for air conditioning or water and energy resources for irrigation – could have unintended impacts on energy use, increasing greenhouse gas emissions. A sensible strategy should, on the one hand, seek to rapidly mitigate the pace and ultimate magnitude of climate change and other environmental degradation and, on the other hand, adapt to unavoidable climate changes already under way as well as those that are yet to come.[58]

Growing urbanization poses both opportunities and challenges for the energy transition as well as for broader climate and sustainable development goals. Cities are major consumers of resources; they are also centers for job creation and economic growth. Cities are responsible for two-thirds of global energy consumption, and this proportion will continue to grow.[59] By 2050, eight billion of the nine billion people in the world will live in cities (with five billion in the developing world). Today, one million people are added to the urban population each week. Such rapid urbanization is compatible with sustainability goals only if green infrastructure becomes a criterion for new buildings and retrofits, and if negative consequences on food access and human health are avoided.[60]

Given the need to transform energy in the near term in order to reduce the most critical challenges of climate change, inertia in the built environment poses a particular challenge. Infrastructure investments are long-lived; existing factories, power plants, roads, and power distribution networks will remain in place for decades. Decisions made today concerning land use and urban form (the structure and density of cities) will have impacts lasting more than a century. And long-lived infrastructure triggers investments in associated capital (such as cars for low-density municipalities, or gas-fired heat and power generation capacity where there are gas pipelines), locking economies into lifestyles and energy consumption patterns.

Because of their density, efficiency, and ability to incorporate innovations and new technologies (in addition to the infrastructural opportunities noted above), cities are ideal environments for enhancing quality of life, using land and water more efficiently, and reducing greenhouse gas emissions. Particularly for underserved communities, there are many opportunities in cities to modernize delivery of energy services while also prioritizing more efficient infrastructure and protecting and restoring green spaces. Coordination of place-based policies can simultaneously enhance transportation choices, improve air and water quality, reduce waste, maintain a reliable water and energy supply, advance public health and awareness, enhance disaster preparedness and response, increase climate resilience, use public resources more efficiently, help mobilize private investment, and strengthen local decision-making. Cities also offer opportunities for capturing cross-cutting efficiencies (for example, across water and energy systems) through joint strategies for resource management and public/private finance.

Change in global energy systems that is concordant with sustainable development will require policy and regulatory actions, as well as other incentives, to be aligned. For new technologies to be accepted in the market, they must be attractive – in terms of performance, convenience, and cost – to investors, purchasers, and users. Regulations and standards that target performance characteristics can help spur technological development and improve market attractiveness.[61]

Many of the alternative energy options needed to address the sustainability challenge are available today. In the United States, existing energy-efficiency technologies could more than offset the projected increase in energy consumption between now and 2030, thereby substantially reducing health impacts, greenhouse gas emissions, and expenditures.[62] Globally, one dollar spent on energy efficiency saves two dollars through investments in new supply, with the savings being even greater in developing countries.[63] In addition, solar, wind, and geothermal technologies are rapidly becoming more efficient and affordable, increasing their viability.[64] These three technologies use little water and can be scaled in size and tailored to local contexts; thus, they can help promote energy security while also reducing greenhouse gas emissions from fossil fuels.[65] Although still only a small percentage of installed energy supply, investments in clean energy grew by 5 percent in 2011, to a record $260 billion, with a total of $30 billion in new solar and $30 billion in new wind investments put into place.[66]

The near-term transition to the cleanest energy choices available requires policy tools to enable and encourage sustainable energy development. Incentives must be tailored to the maturity and costs of technologies as well as to national context. For example, most energy-efficiency measures are financially viable for investors at their current prices, but other barriers must be overcome: the upfront capital necessary to install efficiency devices, lack of financing, market failures, and high transaction costs.[67] Regulatory reform, such as updated standards and codes, and financial incentives, such as fuel surcharges and consumer rebates, are crucial to alleviate these pressures.[68] Many available renewable energy technologies are economically viable but not financially viable; that is, with the exception of hydroelectric power, they are not yet cost competitive with fossil fuels. Global subsidies for fossil fuel production and consumption, estimated to total $400 billion per year, make it difficult for new technologies to compete.[69] Therefore, policies that subsidize renewables or that reduce subsidies to fossil fuels can help level the playing field.

In theory, developing countries could leapfrog to available clean-energy technologies. However, low-income countries face significant market barriers to technology absorption. Meeting development goals and providing access to clean energy requires significantly stepping up international efforts to diffuse existing technologies and to develop and deploy new ones. Public and private investment must be ramped up significantly to several hundreds of billions of dollars annually. "Technology push" policies that increase public investments in R&D will not alone be sufficient; they must be matched with "market pull" policies that create public- and private-sector incentives for entrepreneurship, for collaboration, and for finding innovative solutions in unlikely places. Diffusion of climate-smart technology requires much more than shipping ready-to-use equipment to developing countries: it entails building absorptive capacity and enhancing the ability of the public and private sectors to identify, adopt, adapt, improve, and employ the most appropriate technologies.[70] To establish these conditions, governments must implement enabling policies and build regulatory frameworks – targeting public resources carefully – to leverage private capital, reduce the risk associated with investing capital, stimulate innovation, and create competitive and viable markets for electricity and energy.[71]

In addition to rapid transitions in current energy systems, addressing today's complex, interconnected sustainability challenges will require developing and deploying the next generation of technologies and implementing the tools and approaches needed to make good choices. A successful energy transformation calls for greatly enhanced efforts to support R&D, to finance incremental costs of new technologies and approaches, and to facilitate technology transfer. Nothing short of a paradigm shift is needed to promote a "green growth" economy that can meet burgeoning energy demands, especially for the world's poorest, while also enhancing sustainable development. Poverty reduction remains urgent but growth and equity can be pursued without relying on policies and practices that foul the air, water, and land and that degrade ecosystem services.[72]

Technological innovation and its associated institutional adjustments are key to developing sustainable energy at a reasonable cost. Strengthening national innovation and technology capacity can provide a powerful catalyst for development. High-income economies – the world's major emitters – can replace their stock of high-carbon technologies with climate-smart alternatives and invest in tomorrow's breakthrough innovations. Middle-income countries can invest in low-carbon growth and ensure that their firms take advantage of existing technologies to compete globally. Low-income countries can enhance the technological capacity to meet sustainability goals and adapt to climate change by identifying, assessing, adopting, and improving available technologies with local knowledge and know-how.

Reaping the benefits of low-carbon technologies will require significant changes in individual and organizational behavior, as well as a host of innovative approaches and policies to improve human well-being, reduce human vulnerability, and manage natural resources.[73] Current public expenditures on basic energy R&D amount to about $13 billion – roughly what Americans spend on pet food each year. Despite a recent upsurge in private spending on energy R&D, to about $60 billion per year, the total hovers around 0.5 percent of revenue. That remains an order of magnitude smaller than the 8 percent of revenue invested in R&D in the electronics industry and the 15 percent that goes into the pharmaceuticals sector.[74] For more than a decade, many reports have called for increasing money directed toward basic energy research by anywhere in the range of twofold to tenfold.[75] We will not be able to meet energy needs while sustaining human and ecosystem well-being without a substantially increased and sustained investment in new clean-energy technologies by both the public and private sectors.

Certainly, knowledge institutions such as universities and research centers are engaged in research to help develop such technologies and approaches, but they can also help inform decision-making, including the development of context-specific energy policies. Increasingly, universities must strive to share knowledge, solutions, and experiences with planners, managers, and policy-makers in a two-way dialogue that improves both research and decision-making. There is a tremendous opportunity to share "best practices" with other nations, regions, and localities. Communities and organizations faced with energy-sustainability decisions would benefit from regional sustainability hubs, or "clearinghouses," that could integrate research and practice, share processes and approaches, and make available success stories and options from around the world.[76]

Investments in new kinds of education and training will also be needed.[77] Managing the interconnected issues that affect sustainability will require interdisciplinary perspectives and "systems" thinking. Integrative perspectives will be vital in developing new technologies that can provide affordable, accessible clean energy while they conserve water, ensure reliable food production, and preserve ecosystems and their services. The full suite of social and natural sciences and engineering must be galvanized to develop solutions that are technologically feasible, socially desirable, inclusive, and politically and economically possible.

Fortunately, today's college and graduate students appear to be increasingly interested in, and capable of, tackling these complex interdisciplinary problems. One-third of the graduate students in the School of Natural Resources and Environment at the University of Michigan have chosen to pursue dual master's degrees in such disparate areas as natural resources, engineering, business, economics, public policy, public health, and urban planning. Likewise, at Stanford University, approximately one-third of undergraduates obtain degrees in interdisciplinary programs, and many graduate students select joint, dual, or interdisciplinary programs. The undergraduate Earth Systems Program and the graduate Emmett Interdisciplinary Program in Environment and Resources, both at Stanford, and the Program in the Environment at the University of Michigan help prepare students to address complex global challenges related to energy, food, water, and environmental change. There is great promise in these future problem-solvers working creatively toward a more sustainable world.

Today's choices about energy production and generation will influence, both directly and indirectly, the trajectory of water consumption, food production, public health, national security, ecosystem services, and greenhouse gas emissions for years to come.[78] These issues are linked to one another. Efforts to address the energy challenge – or any other sustainability challenge – will be best served by a systematic and integrative approach, one that seeks to understand costs, trade-offs, and co-benefits across the range of critical concerns. Our choices about current and future energy sources need to be made in the context of the multiple goals of sustainable development. Indeed, the future of humankind and the planet depend on it.

ENDNOTES

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Social Sciences & the Alternative Energy Future

Stephen Ansolabehere & Robert W. Fri

Three decades ago the United States, Japan, and the European nations entered into a treaty to limit the use of chlorofluorocarbons (CFCs) and other ozone-depleting chemicals. Scientists at that time concluded that industrial and residential use of CFCs and similar chemicals had caused significant loss of ozone high in the atmosphere, especially over the polar regions. There was further consensus that the thinning of the stratospheric ozone layer would increase human exposure to ultraviolet rays, which can cause skin cancers and other adverse health effects, and would degrade the environment in other ways. The Montreal Protocol on Substances that Deplete the Ozone Layer was signed and put into effect in 1989, and it is expected that the damage to the ozone layer will be largely repaired by 2050.[1]

Worldwide cooperation can solve global environmental crises.[2] The Montreal Protocol stands as a clear example of such concerted action. Yet there are notable differences between the global action required to respond to climate change and what was necessary in the case of CFCs. Looking back on the experience with CFCs and the Montreal Protocol, Nobel Prize-winning chemist Mario Molina noted that the global warming challenge is as much a matter of public policy and social science as engineering, physics, and chemistry. In fact, the science behind carbon emissions and climate change is far more certain now than the science behind CFCs and ozone depletion was in 1989.[3] The vastly different political

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responses to these two environmental challenges can be explained by their particular root causes. On the one hand, the technologies accounting for most of the ozone-depleting chemicals were highly concentrated in a few industries, and close substitutes for CFCs existed. CFCs could thus be isolated and addressed through relatively straightforward regulatory regimes.

On the other hand, greenhouse gas emissions from human activities come primarily from burning fossil fuels for electricity and transportation. Those activities are not isolated to a few industries: electricity and transportation are integral to nearly every aspect of modern economies and societies. To curb global carbon emissions we must fundamentally alter the ways that we consume and produce energy. And unlike CFCs, fossil fuels do not currently have inexpensive alternatives that would deliver the same amount of energy for economic activities at a global scale. For these reasons, the path forward on climate change will be very different from the story of CFCs.

Two issues of *Dædalus* have examined the Alternative Energy Future. The essays in this volume and its earlier companion (Spring 2012) offer various perspectives on what that future might be and how economic, social, and political decisions made today will shape energy use and the environment over the next fifty to one hundred years. The central theme of these issues echoes Mario Molina's insight: the problems are as much social, political, and economic as they are technological. As a result, the expertise of social scientists, historians, business leaders, legal scholars, and policy-makers will be essential to understanding what an alternative energy future might be and how it might be achieved. Our purpose in this concluding essay is to explore how best to link energy policy and the social sciences.

To understand the nature of this linkage more clearly, we have supplemented the views of social scientists represented in this volume with those of respected thinkers in the energy and climate fields. We conducted an informal poll of thought leaders in the current policy debates, especially Steven Koonin, Director of New York University's Center for Urban Science and Progress and former Under Secretary for Science at the Department of Energy; environmental economist at MIT and the Brookings Institution Michael Greenstone; and Rebecca Henderson, business economist and Codirector of the Business and Environment Initiative at Harvard University. We also reviewed highly regarded reports from the National Academy of Sciences, the American Association for the Advancement of Science, and the President's Council of Advisors on Science and Technology. We wanted to identify the specific questions that are prominent in the energy and climate policy communities. To summarize our findings, we have outlined six key areas of crucial policy questions.

First: Understanding the Consequences and Risks of Inaction. Current climate policy in the United States, China, and other countries amounts to addressing future events that may happen as a result of changes in the climate as they become evident. In short, we are taking our chances on adaptation.

This policy might make sense if the associated risks of inaction are tolerable. If not, the policy could be very costly. Thus, a research priority should be to pin down the potential consequences of a changed climate and, crucially, its impact on human activities. What concrete changes can we expect in key factors such as the amount and location of arable land and potable water, the frequency of catastrophic storms, and so forth? What are the costs and benefits associated with these changes? For example, rising global temperatures will likely reduce the amount of arable land in Mexico and the Central United States, but the amount of arable land in Canada might increase. What are the projected effects on nations' GDPs? What migration patterns might we expect as a result? How might changes in water supplies and arable land affect international relations and the probability of wars or civil wars? In addition to comprehensive assessments of longer-term consequences, there is a need for understanding how such projections can be used to make decisions today. What sorts of risks are insurable, and which are not? Which are likely to occur and be highly damaging when they do, and how might they be addressed?

In short, social scientists working with policy-makers can develop appropriate modeling tools for decision-making. Such tools would assess the outcomes and scenarios that people living in particular parts of the nation will likely face, and then would identify possible ways to mitigate the risks. For example, rising sea levels over the next fifty years will begin to inundate low-lying areas of coastal cities such as New Orleans, Miami, Boston, and New York. That prospect ought to guide urban planning, zoning, and development decisions in these cities so as to avoid even greater problems in a few decades.

Different approaches to solving this problem also have consequences – economic, environmental, and social. The Stern Review, for example, projected that 2 percent lower economic growth over a century would avoid some of the worst climatic outcomes.[4] That would amount to a long-term economic recession in many countries, which would adversely affect the health and well-being of people living in those countries. Expansion of certain technologies, such as some forms of nuclear power, might bring other risks. We need continued modeling of the possible consequences of the business-as-usual approach as compared with alternative energy futures.

Second: Behavior. Here, *behavior* refers to how people decide to use energy. There has been a significant push to study energy use by individuals, households, and companies. Of particular interest is the use of behavioral psychology to influence people's energy consumption, such as providing people with feedback about their monthly electricity bill or their energy use compared to their neighbors. Information can be extremely powerful, reminding us of what is important or showing us something about our behavior that we hadn't noticed. There are many different mechanisms for providing information to energy consumers (be they firms, households, or governments), whether it is given at the point of use or summarized later in energy bills; is expressed in terms of utilization, emissions, and costs; or emphasizes improvements, targets, or data about other consumers. Many studies find that incremental changes in behavior are possible when people are given information or simple nudges; however, it is not yet clear how long-lived those effects may be. There needs to be a systematic evaluation of what works and why.

The thorniest issue is how to get people to care. In their 1994 article "The Energy Efficiency Gap," economists Adam Jaffe and Robert Stavins describe the "energy paradox": that is, the apparent disconnect between availability and use of technologies that improve energy efficiency. Technologies such as energy-efficient appliances, insulation, smart thermostats, and motion sensor lights ostensibly could save households and businesses considerable amounts on their annual energy expenses, but households and businesses underinvest in such items.[5] If the economic gains from efficiency are real, then why can't we capture them? One important behavioral problem lies in the nature of energy costs. Energy costs are a very small fraction of the cost of renting and operating most businesses, purchasing and operating a car, or owning and maintaining a house. As a result, energy is often not as salient as other factors, such as households' monthly mortgage payments and rent or businesses' labor costs. The Energy Information Administration estimates that the monthly energy cost per square foot in commercial real estate is approximately $1.25. The square-foot cost to rent a commercial space nationwide is $25 per month.[6] Reducing energy costs may thus have a modest effect on the net operating income for a business, but that is a secondary or tertiary concern to the bottom line. A natural contribution from behavioral research would be to find ways to repackage energy costs so that consumers can realize the returns from investment in more efficient energy use.

Aggregating individual decisions at the national level also reveals results that are not well understood. For example, we do not know why countries vary in their energy efficiency. A common metric for measuring energy intensity is energy use (or carbon emissions) per unit of GDP per person. Energy intensity decreases with economic development. The countries with the highest GDP per capita tend to have much lower energy use per unit of GDP per person. While this insight is helpful, it also shows that different countries appear to be on different energy-efficiency curves. In Russia and China, for example, energy use per unit of GDP is much higher than in India.[7] Why are some countries more efficient in their energy use per unit of GDP than others? Understanding this phenomenon might reveal how developing countries can shift to a more efficient energy-growth trajectory. But because a transition from one curve to another likely depends on the availability of technology, a successful transition will require the willingness of developed countries to make advanced energy technologies available worldwide, perhaps including nuclear energy technologies. Such transfers are fraught with strains on international relations.

Third: Price. Global warming, pollution, and security are all external consequences or costs of the production and distribution of energy. The central thrust of social science research on global warming has focused rightly on how to adjust prices to make the market reflect the true external costs of carbon emissions. In this regard, there are four broad policy options that can help internalize the cost of carbon: namely, carbon taxes, tradable carbon emissions permits (or cap and trade), renewable portfolio standards, and minimum installed capacity requirements. Each of these approaches attempts to force the market to realize the social costs of carbon emissions, either by altering prices directly (as with a tax) or making producers and consumers of electricity and transportation fuel change their mix of inputs (as with renewable portfolio standards).

Since the late 1980s, pricing carbon has been – and ought to continue to be – the central thrust of social science research on this subject. Most technology studies of the incorporation of solar, wind, or other alternatives assume some level of carbon price,[8] and most policy studies make a suitable carbon price the centerpiece of any road map to the future or comprehensive policy proposal.[9] Creating such a pricing mechanism is, of course, a difficult matter. Markets do not emerge magically, especially markets for externalities. Their viability depends on the development of social and legal institutions, such as property rights. In the area of pollution, for example, regulations have successfully incorporated the social costs into the price of goods by imposing financial penalties on firms. Regulations also create scarcity, thereby increasing incentives to distribute the social costs more efficiently. There has been much work on how to structure such markets but relatively little research into their political feasibility, especially at the subnational level, or on how to entice businesses to participate in such markets.

Fourth: Finance. New energy projects require funding. And nearly all policy studies that lay down a road map for new energy development call for some form of targeted government investment to make up for the apparent lack of capital in a given industry. In some areas of energy, the capital costs of building a new project – such as a nuclear reactor or an integrated gasification combined cycle power plant – are too great for investors given the time to completion as well as the complexity and uncertainties associated with those technologies. In other areas, such as energy use in buildings, the energy costs are such a small fraction of the value of the economic activity that the payback to even modest capital investment is not sufficiently attractive to investors. In still other areas, such as the national power grid, it is unclear how to make money in the management of the infrastructure because of regulatory and technical uncertainty.

An essential area for innovation in the energy sector is the development of new investment instruments and financial models. Some of these instruments will take the form of guarantees against risk for projects that offer the upside of reduced carbon emissions. For example, a 2003 MIT study on the future of nuclear power argued for government-backed loans to support new power plant construction. The study contended that guarantees were necessary to draw finance back into the nuclear industry because the capital costs of constructing large, complex facilities such as nuclear power plants created huge barriers to the expansion of this power source.[10] Very little research has examined how such financial incentives are most efficiently structured, how large they must be, or how effective existing loan guarantees have been.

Another class of financial instruments consists of small or midsize funds designed to capture inefficient energy use in organizations. Many institutional users, such as hospitals, universities, and firms, set up funds that divisions within their organization can use for facility or operational improvements that have high returns in energy costs. Because the divisions themselves do not necessarily control their capital budgets or pay their energy costs, they may have little incentive to eliminate inefficiencies on their own.

The need for new funding models raises an important question: why is there insufficient capital in energy innovation? The problem may be institutional, as firms, government agencies, and other institutions may be organized in ways that eliminate incentives for people to use energy efficiently. Or the barriers may be purely economic – that is, the return on investment is too small. If the obstacles are institutional, then the challenge is identifying ways to overcome those structural impediments. If the obstacles are purely economic, then government regulations or subsidies might encourage greater investment in energy efficiency.

The prospect of government intervention raises a second key question: how effective are government subsidies, loan guarantees, and other incentives? Do government-supported financial mechanisms induce firms and consumers to make long-term investments in more efficient energy use? There is a long history of such programs in the United States and in other countries, but we know of no systematic study of their effectiveness.

Fifth: Monitoring. Any effort to regulate emissions of carbon or other greenhouse gases requires protocols for monitoring and accounting for such emissions. For the Environmental Protection Agency to enforce any carbon emissions regulations in the United States, a monitoring system at the level of individual power plants or vehicles would certainly be required. The United States has put in place such mechanisms for nitrogen oxides, sulfur oxides, particulate matter, and other airborne pollutants. Research is needed to determine both how to extend the existing monitoring system to include carbon emissions and how to design effective monitoring and accounting systems for carbon emissions regulations and taxes. Some of these issues are technical (developing sensors, for example), but others are behavioral, such as constructing a system that is trusted and that ensures compliance.

Beyond the immediate regulatory design issues lies an even bigger monitoring and enforcement challenge. A global system of emissions caps or tradable emissions permits would require a monitoring and accounting system that is transparent and that all nations trust. Such systems have been constructed for nuclear technologies and other dangerous materials. What are the lessons from those domains? Without a trusted and effective monitoring mechanism, implementing policy ideas such as cap and trade may be impossible.

Sixth: Political Will. Many of the societal changes needed to alter the ways that the United States and other countries produce and use energy will come from changes in consumer behavior, technology innovations, and corporate finance – in short, from the private sector. To tackle the climate problem, however, governments must also act. Many of the visions for an alternative energy future laid out in this volume and elsewhere assume that a carbon price will be imposed through a tax or tradable permits. There is a growing expectation that this price will be set by governments – either directly, through energy taxes, or indirectly, through regulations. There is an equally strong sense that this expectation is well ahead of public opinion on climate change.

Price offers a convenient way to see the gap between public attitudes today and the policies required to change the U.S. energy portfolio. Since the 1990s, public opinion polling in the United States and other advanced industrial economies has shown that majorities of people are "concerned" about climate change. That concern is superficial. Large majorities also express little or no willingness to pay higher electricity bills in order to reduce carbon emissions. The MIT Energy Surveys show that throughout the past decade, a majority of Americans were not willing to pay more than an additional 10 to 15 percent on their monthly electricity bill to "solve global warming."[11] Because the price of wind or nuclear power is at least 50 percent higher than the cost of coal or natural gas, we must overcome the gap in public attitudes in order to move forward. Shifting our energy mix would require a tax or carbon price that doubled the price of electricity. Such a price increase far exceeds what typical Americans today say they would support. Could such a price increase be structured so that it would enjoy the support of a majority of Americans? Would a powerful public backlash ensue regardless of which politicians championed the policy? Or do people care enough about this issue to endorse comprehensive change in energy policy?

Short of a magic-bullet technology breakthrough, a low-carbon energy portfolio will require a change in public attitudes toward energy provision in general and individual technologies in particular. Our colleagues in engineering often stress that if the public only knew the implications of current energy use, it would support aggressive policies to reduce the carbon-intensity of our economy. That is not clear to us. It is assumed that by educating people, we would raise the importance of climate in their thinking sufficiently to make them willing to pay higher energy prices. However, education might change people in other ways. As the research in the first *Dædalus* volume has showed, people underestimate the true cost of electricity from solar and wind power. Thus, public education might make alternative energies less – rather than more – popular. The effect of public education on this matter is still not understood. Would a complete and thorough education campaign alter how people think? Would such a campaign rehabilitate nuclear power as an alternative energy source? How would local attitudes about energy development affect the ability to bring on-line new energy technologies?

Beyond domestic political considerations, questions about public will in the global context loom large. In order for the level of carbon in the atmosphere to stay below 550 parts per million (ppm), the world, especially developing and emerging economies, will have to forgo a great deal of economic growth. Given China's current growth curve and its energy intensity, that nation would have to give up approximately $50 trillion in economic growth over the course of the coming century in order to keep atmospheric carbon below 550 ppm.[12] How can the advanced industrial economies ask the developing economies not to grow as quickly? Where is the political will to make a global deal that will stabilize Earth's climate?

Resolving the specific questions already on the research agenda in these six broad categories of policy activity will not be easy. Even a cursory glance at these problems confirms that unless social scientists play a central role in attacking them, successful policy development will be unlikely. However, as the articles in these two *Dædalus* volumes show, the social science disciplines that should be driving energy policy discussions are in many cases not well developed. In view of this shortcoming, how might the social science research community most effectively cut into these problems?

To address this question, we frame the agenda for social science research and public policy along two dimensions: the scope and scale of the problems being addressed. *Scope* refers to the extent of the economy implicated, with the most limited scope focusing on a specific technology (for example, a nuclear power plant); a broader scope taking into account an energy sector (at the most rudimentary level, electricity versus transportation); and the widest possible scope encompassing the entire economy. Technologies that break the barriers between sectors, such as efficient electricity or energy storage, can have economy-wide implications.

We define *scale* as the level of aggregation at which an energy problem is analyzed or addressed. The smallest scale is usually the household, firm, or power plant. A broader scale, which might include an entire city or industry, presents new opportunities for examining energy production and utilization. Households and cities both engage in monitoring and planning their activities in ways that affect energy use, but with a qualitative difference: a city's development decisions can have substantial and very long-lived consequences for large numbers of people over many decades. Even higher levels of scale are nations, with the entire globe being the highest level.

The climate challenge differs from earlier issues such as CFCs because it is of the highest scale and the widest scope. Successfully dealing with climate change requires changing the energy portfolio of the entire globe and throughout the economy. This is not to say that the challenge cannot be met. Climate change is at once more difficult and easier to address than CFCs and similar problems. It is more difficult because the scope and scale are massive. It is easier because anything accomplished in any sector can make a difference. Accordingly, we conclude that social science research should follow two paths: research designed to understand the fundamental individual and institutional changes that must ultimately take place in the transition to a new energy system; and applied research designed to make tangible progress at the local level.

Our conclusion relies on one of the great insights of the late Elinor Ostrom – that cooperation and production of collective goods, like clean water and sewer systems, can be accomplished effectively at a very local level. Those local changes can become the basis for wholesale changes on a broader scale if they can be replicated. Many of the essays in this issue point to localized (or at least relatively small-scale) changes as ways to foster the creation of less carbon-intensive energy use and production. These local efforts, if they are consistent with each other and can be linked, may produce cumulative changes in energy use or may cause energy technologies to evolve more rapidly.

Activity at this manageable scope and scale is already under way. Social scientists have begun to engage with the energy problem in new ways. Increasingly, as engineers and scientists tackle the problem of technology development at sufficient scope and scale, social scientists are working with them to study energy at the level of large cities and states. Projects in Tokyo, London, Toronto, and New York are mapping and monitoring energy use at the scale of large cities. New York University's Center for Urban Science and Progress (CUSP), working with the Office of the Mayor, is developing a massive "living lab" in Brooklyn to measure how people use energy in their daily lives, to experiment with ways of altering behavior, and to examine how to implement new technologies that can significantly lessen the energy intensity of economic activity.

At the state level, California is implementing Assembly Bill 32, which would cut the state's greenhouse gas emissions to 1990 levels by 2020, and the state (among others) has long had a Renewable Portfolio Standard. The New England states created an emissions trading system, called the Regional Greenhouse Gas Initiative, that is designed to reduce CO_2 emissions in the power sectors by 10 percent in Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont by 2018. The California and New England experiments are in their nascence, but these initial attempts to create markets for carbon are instructive about how to create effective trading markets for carbon as well as how to assess the effectiveness of such markets compared with taxes, renewable portfolio standards, and other ways of reducing greenhouse gas emissions.

Perhaps the most telling feature of all these attempts to alter energy use is their scale. These are not experiments conducted in small labs in a university setting. Rather, they are efforts to use entire cities and states as test beds in which to solve the problems of modifying behavior; monitoring energy use; changing public attitudes; financing energy innovations; and understanding in concrete terms the consequences, costs, and risks of our actions. Doing that requires stepping out of the traditional lab setting and observing society on a relatively large scale.

Each of these cases provides examples of collaborative efforts between technologists and social scientists to address the energy challenge head-on and with concrete research. What is needed today is evidence of what works and what does not; which technologies can be brought to scale and which cannot; and which institutional arrangements work in a given legal, political, or cultural context and which do not.

At the same time, research is needed to understand the fundamental societal changes required for solving the climate problem. A good example is research into pricing greenhouse gas emissions. While it is unlikely that a global pricing scheme will come into being anytime soon, the important research on structuring national and international markets for pricing and regulating carbon must continue as a central activity of the social science research agenda. Ultimately, some form of greenhouse gas pricing will likely be needed; thus, understanding how to design a workable system is essential.

But the design of pricing mechanisms and markets will address only some of the issues involved in transitioning from a heavily coal-based electricity sector and oil-based transportation sector to a less-carbon-intensive energy portfolio. This volume has identified other issues that, like a pricing mechanism, need research now to ensure the development of tools that future policy issues will require. These issues include the design of international agreements, the creation of durable yet adaptable policies, the shaping of public opinion, and the institutional changes that will inevitably accompany a new energy system.

In short, the social science research agenda requires a combination of real-world experiments designed to take positive steps at modest scale and scope along with more fundamental research into the institutional and political changes that will ultimately allow climate and energy policy to operate economy-wide and at a global scale.

ENDNOTES

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Inside back cover: Clockwise from top left: High-tension power lines in Oregon, © David A. Barmes/Getty Images; a nuclear reactor, © C. Borland/PhotoLink/Getty Images; wind generators on agricultural lands, © Grant Faint/Getty Images; solar panels in Mt. Laguna, California, © Digital Vision/Getty Images.

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