EYES ON A CLIMATE PRIZE:REWARDING ENERGY INNOVATION TO ACHIEVE CLIMATE STABILIZATION

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Stabilizing atmospheric concentrations of greenhouse gases at double their pre-industrial levels (or lower) will require emission reductions far in excess of what can be achieved at a politically acceptable cost with current or projected levels of technology. Substantial technological innovation is required if the nations of the world are to come anywhere close to proposed emission reduction targets. Neither traditional federal support for research and development of new technologies nor traditional command-and-control regulations are likely to spur sufficient innovation. Technology inducement prizes, on the other hand, have the potential to significantly accelerate the rate of technological innovation in the energy sector. This Article outlines the theory and history of the use of inducement prizes to encourage and direct inventive efforts and technological innovation and identifies several comparative advantages inducement prizes have over traditional grants and subsidies for encouraging the invention and development of climate-friendly technologies. While no policy measure guarantees technological innovation, greater reliance on inducement prizes would increase the likelihood of developing and deploying needed technologies in time to alter the world's climate future. Whatever their faults in other contexts, prizes are particularly well suited to the climate policy challenge.

INTRODUCTION

On February 2, 2007, eccentric billionaire Richard Branson announced the "Virgin Earth Challenge," a $25 million prize for the development of "a commercially viable design which results in the removal of anthropogenic, atmospheric greenhouse gases so as to contribute materially to the stability of Earth's climate."[1] Encouraged by the success of the Ansari X-Prize, a $10 million award for the development of a reusable, manned spacecraft, Branson sought to promote investment in technologies that could reduce the

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[1] VIRGIN EARTH CHALLENGE, http://www.virgin.com/subsites/virginearth/ (last visited Dec. 2, 2010) (on file with the Harvard Law School Library) [hereinafter VIRGIN EARTH CHALLENGE].

threat of climate change. Branson's hope is that offering a sufficiently large financial reward will spur inventors and researchers to focus their efforts on the development of climate-friendly technologies.

Branson's announcement was a media event, and with good reason. The Virgin Earth Challenge's $25 million bounty was the largest technology inducement prize in history.[2] Former Vice President Al Gore and noted ecologist James Lovelock both endorsed the effort.[3] Could it also serve as a model for serious climate change policy?

No private individual will solve the climate challenge single-handedly. While $25 million may be the largest inducement prize ever offered for a technological innovation, it is a small fraction of what the U.S. government spends annually on energy and climate-related technological research.[4] Spurring the technological innovation necessary to stabilize atmospheric concentrations of greenhouse gases will take far more. Nonetheless, inducement prizes are a promising tool for climate change policy.

Global climate change is a terribly vexing environmental problem.[5] Its scope, complexity, and potential costs are daunting. Without concerted efforts by nearly all industrialized and industrializing nations to drastically reduce net greenhouse gas ("GHG") emissions, atmospheric concentrations will likely grow to double those of pre-industrial levels before century's end.[6] President Barack Obama and congressional leaders have endorsed an ambitious target for GHG emission reductions of eighty percent by the year 2050.[7] Meeting this goal would require that the United States emit less carbon dioxide than at any point in nearly a hundred years, while simultaneously accommodating a much larger and much wealthier population.[8] This will be exceedingly difficult to do, both practically and politically. And yet,

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[2] James Owen, *Scrub CO2 From the Air, Win $25 Million — But How?*, NAT'L. GEOGRAPHIC NEWS, Feb. 16, 2007 (stating that the Virgin Earth Challenge is the "biggest science prize in history"), *available at* http://news.nationalgeographic.com/news/2007/02/070216-virgin-earth.html; VIRGIN EARTH CHALLENGE, supra note 1.

[3] VIRGIN EARTH CHALLENGE, supra note 1; *see also* Kevin Sullivan, *$25 Million Offered In Climate Challenge*, WASH. POST, Feb. 10, 2007, at A13.

[4] In 2006, the U.S. government appropriated just under $3 billion to fund research and development of technologies related to climate change policy. *See* U.S. DEP'T OF ENERGY, U.S. CLIMATE CHANGE TECHNOLOGY PROGRAM, STRATEGIC PLAN 219–20 (Sept. 2006), *available at* http://www.climatetechnology.gov/stratplan/final/index.htm [hereinafter USCCTP].

[5] Professor Richard Lazarus has dubbed climate change a "super wicked" problem. Richard J. Lazarus, *Super Wicked Problems and Climate Change: Restraining the Present to Liberate the Future*, 94 CORNELL L. REV. 1153, 1159 (2009).

[6] *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: SYNTHESIS REPORT [hereinafter IPCC, CLIMATE CHANGE 2007 SYNTHESIS REPORT]. The IPCC is an international body created by the United Nations Environmental Programme and World Meteorological Organization "to provide an authoritative international statement of scientific understanding of climate change." *History*, INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, http://www.ipcc.ch/organization/organization_history.shtml (last visited Dec. 2, 2010) (on file with the Harvard Law School Library).

[7] *See The Obama-Biden Plan, Agenda, Energy & Environment*, CHANGE.GOV http://change.gov/agenda/energy_and_environment_agenda/ (last visited Dec. 2, 2010) (on file with the Harvard Law School Library).

[8] *See infra* notes 38–39 and accompanying text.

stabilizing atmospheric concentrations of GHGs will require even greater efforts, particularly if developing countries are to be afforded an opportunity to grow.[9]

If the United States is to come anywhere close to the "80 by 50" target, let alone the reductions necessary for atmospheric stabilization, substantial innovation in energy and climate-related technologies is necessary.[10] Nothing short of a clean energy revolution will be capable of meeting this emission target while maintaining or achieving acceptable standards of living throughout the world. And yet, there is reason to doubt whether such innovation is something the dominant policy tools can deliver. Patent protection provides an insufficient incentive to develop technologies to address common pool problems like global atmospheric pollution,[11] and neither traditional federal support for research and development of new technologies[12] nor traditional command-and-control regulations are likely to spur sufficient innovation.[13] Nor is there reason to believe a proposed cap and trade system will do the trick.[14] Such tools have not shown themselves capable of affecting dramatic technological innovation. Could prizes be different?

Technology inducement prizes have a long and storied history. Throughout the eighteenth and nineteenth centuries, European governments used prizes to reward inventors and stimulate desired innovations.[15] Important advances in navigation, food preservation, and air travel were spurred by technology inducement prizes.[16] However, over time, prizes fell out of favor and were eclipsed by other innovation polices, including ex ante grants and patents.[17] Most technology inducement prizes today are funded privately; government prizes still exist, but they are relatively few and far between.[18] Instead, most federal support for technological advance comes in the form of government grants.

The dominant innovation policy tools have their merits. They also have significant limitations, particularly for inducing more than incremental technological advance. In the climate change context, grants, regulatory controls, and intellectual property are likely to be insufficient to generate desired levels of invention, innovation, and diffusion.[19] Traditional govern-

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[9] *See infra* Part I.
[10] *See id.*
[11] *See infra* notes 107–110 and accompanying text.
[12] *See infra* Part IV.
[13] *See infra* Part V.
[14] *See infra* notes 280–282 and accompanying text.
[15] *See infra* notes 111–136 and accompanying text.
[16] *See infra* notes 117–138, 148–152 and accompanying text.
[17] *See infra* notes 139–147 and accompanying text.
[18] *See infra* notes 153–192 and accompanying text.
[19] *See Joseph Alois Schumpeter*, *in* THE CONCISE ENCYCLOPEDIA OF ECONOMICS, 2d ed. (David R. Henderson ed., 2008), *available at* http://www.econlib.org/library/Enc/bios/Schumpeter.html; *see also* Adam B. Jaffe, Richard G. Newell & Robert N. Stavins, *Technological Change and the Environment*, *in* 1 HANDBOOK OF ENVIRONMENTAL ECONOMICS, 464–65 (Karl-Göran Maler & Jeffery R. Vincent eds., 2003) (distinguishing between invention, "the first development of a scientifically or technically new product or process," innovation, "when the new product or process is commercialized" or "made available on the market," and diffu-

ment research subsidies have produced relatively little in this area,[20] and it is particularly difficult to drive substantial technological advance through regulatory measures.[21] Patent awards may well provide ample incentive for innovation in other contexts, but absent other interventions, they provide insufficient incentive for the development of climate-friendly technologies.[22] There is, at present, no meaningful economic incentive to develop technologies that reduce GHG emissions or remove carbon from the atmosphere.

Meeting the climate policy challenge will require policymakers to expand their policy toolkit. Spurring technological innovation requires something more ambitious, and yet more simple, than the traditional tools deployed most often today. If the goal is to spur needed innovation of the sort that might make various greenhouse GHG targets achievable, policymakers should reconsider the use of technology inducement prizes. Prizes are particularly well-suited for the climate policy challenge because the threat of global warming cannot be reduced by any meaningful degree without dramatic technological breakthroughs that enable reductions in atmospheric concentrations of GHGs, and traditional innovation tools are inadequate. Patent protection provides ample incentive to innovate in many areas, but not where, as here, there is no direct economic benefit to be derived from relevant inventions. Specifically, because the atmosphere is, for all practical purposes, a global, open-access commons, there is no price on GHG emissions, no direct economic incentive to reduce such emissions, and consequently no meaningful market for GHG emission-reducing technologies.[23] Without such a market, there is little economic incentive to pursue patents in this area.[24] Prizes can fill the gap by providing the promise of supercompetitive returns for the development of climate-protecting innovations. Whatever their faults in other contexts, prizes are particularly well suited to the climate policy challenge.

To enhance the incentive for the development of climate-friendly technologies, the federal government should shift a substantial portion of climate-related research and development funding from grants to prizes. Instead of doling out billions to researchers in the hope that they will invent

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sion, when an innovation becomes "widely available for use in relevant applications through adoption by firms or individuals").

[20] *See infra* Part IV.

[21] *See infra* Part V.

[22] On the use of intellectual property to spur environmentally friendly technologies, *see generally* Michael A. Gollin, *Using Intellectual Property to Improve Environmental Protection*, 4 HARV. J.L. & TECH. 193 (1991).

[23] *See* NAT'L ACAD. OF SCI., LIMITING THE FUTURE MAGNITUDE OF CLIMATE CHANGE 104 (2010) (noting the lack of markets for emission-reducing technologies) [hereinafter NAT'L ACAD. OF SCI., LIMITING]; David Popp, *Innovation and Climate Policy*, 2 ANN. REV. RESOURCE ECON. 275, 277–78 (2010).

[24] Little economic incentive does not mean no economic incentive. There could be other economic benefits from technological innovations that reduce emissions, such as increased energy efficiency, and some may pursue emission-reducing technologies in the hope that such innovations will become valuable at some future date at which emission controls or prices on carbon dioxide emissions are imposed.

something that will help solve the global warming challenge, the government should offer substantial rewards to those who invent or develop technologies that solve particular climate-related problems. While no policy measure guarantees technological innovation, greater reliance on inducement prizes would increase the likelihood of developing and deploying needed technologies in time to alter the world's climate future.

Part I of this Article outlines the challenge posed by climate change and highlights the need for dramatic levels of technological innovation if atmospheric stabilization targets are to be achieved. Part II outlines the theory behind the use of inducement prizes to encourage and direct inventive efforts and technological innovation. Part III briefly surveys the use of inducement prizes beginning in the eighteenth century and discusses some of the reasons prizes went out of favor with governments and scientific societies. Accepting the need for government policies to encourage technological innovation, Part IV explains the comparative advantages of inducement prizes over traditional grants and subsidies for encouraging the invention and development of climate-friendly technologies, while Part V explains why regulatory tools, whatever their other merits, cannot be expected to produce sufficient levels of technological innovation and may even hamper such efforts. Part VI considers some of the practical questions to be considered in designing and implementing a system of prizes for climate policy, and is followed by some concluding thoughts.

I. The Climate Policy Challenge

Scientists believe that human activity is having a significant effect on the global climate system.[25] Anthropogenic emissions of carbon dioxide and other GHGs,[26] largely due to the burning of carbon-based fuels, have caused a dramatic increase in the concentration of such gases in the atmosphere.[27] This increase has contributed to a gradual increase in global mean temperatures.[28] The most recent report of the United Nations Intergovernmental Panel on Climate Change ("IPCC") concluded that it was "very likely" that such human activity was responsible for a majority of the warming observed

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[25] For a brief and accessible summary of the science of global climate change, *see* William Collins et al., *The Physical Science behind Climate Change*, Sci. Am., Aug. 2007, at 64.

[26] Other GHGs of particular concern are methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexaflouride.

[27] *See* Collins, *supra* note 25.

[28] Even many so-called "skeptics" accept the premise that human activity is contributing to a gradual warming of the atmosphere, even if they reject apocalyptic projections of the likely consequences. *See, e.g.*, Patrick J. Michaels & Robert C. Balling, Jr., Climate of Extremes: Global Warming Science They Don't Want You to Know 11–20 (2009). The case for taking action to address rising atmospheric concentrations of GHGs need not be premised upon apocalyptic climate projections. *See, e.g.*, Roger Pielke, Jr., The Climate Fix: What Scientists and Politicians Won't Tell You about Global Warming (2010); Jonathan H. Adler, *Taking Property Rights Seriously: The Case of Climate Change*, Soc. Phil. & Pol'y, July 2009, at 296–98.

during the latter part of the 20th Century.[29] The IPCC further predicted that the global mean temperature will continue to rise over the next century, as much as several degrees Celsius, as atmospheric concentrations of GHGs continue to rise.[30]

In 1992, the United States and other nations agreed to the United Nations Framework Convention on Climate Change, which established the goal of stabilizing atmospheric concentrations of GHGs at a level that avoids "dangerous anthropogenic interference with the climate system."[31] While there is no agreement as to what level of atmospheric concentration of GHGs this goal entails, most scientists believe a stabilization target of between 450 and 550 parts per million ("ppm") of carbon dioxide (or its equivalent), if not lower, will be necessary to avoid an average global temperature increase of two degrees Celsius and the most negative effects of global climate change.[32] The emission reductions necessary to achieve this goal "could require Herculean effort" on the part of both developed and developing countries.[33] By some estimates, developed country emissions will need to decline "by a factor of 10 or more on a per capita basis . . . ."[34] Yet even reductions of this scale would not leave developing nations much room to increase their emissions. Member nations of the Organisation for Economic Co-operation and Development ("OECD") could reduce their

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[29] IPCC, CLIMATE CHANGE 2007–THE PHYSICAL SCIENCE BASIS: CONTRIBUTION OF WORKING GROUP I TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 665 (2007) ("Greenhouse gas forcing has *very likely* caused most of the observed global warming over the last 50 years.").

[30] *Id.* at 749.

[31] U.N. Framework Convention on Climate Change, art. 2, *opened for signature* May 9, 1992, S. Treaty Doc. No. 102–38, 1771 U.N.T.S. 164.

[32] *See, e.g.*, S. Pacala & R. Socolow, *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies*, 305 SCI. 968, 968 (2004) ("Proposals to limit atmospheric CO_2 to a concentration that would prevent most damaging climate change have focused on a goal of 500 +/- 50 parts per million (ppm), or less than double the preindustrial concentration of 280 ppm."). Some organizations advocate a significantly lower target of 350 ppm. *See, e.g.*, 350.org, http://www.350.org (last visited Oct. 6, 2010) (on file with the Harvard Law School Library); *see also* Andrew C. Revkin, *Campaign Against Emissions Picks Number*, N.Y. TIMES, Oct. 25, 2009, at A8. To some degree, all rounded numerical stabilization targets are arbitrary. *See, e.g.*, IPCC, CLIMATE CHANGE 2007–MITIGATION. CONTRIBUTION OF WORKING GROUP III TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 42 (B. Metz et al. eds., 2007) [hereinafter IPCC, MITIGATION], ("Limited and early analytical results from integrated analyses of the costs and benefits of mitigation indicate that these are broadly comparable in magnitude, but do not as yet permit an unambiguous determination of an emissions pathway or stabilization level where benefits exceed costs."); Richard S.J. Tol, *Europe's long-term climate target: A critical evaluation*, 35 ENERGY POL'Y 424 (2007) (critiquing E.U. climate targets).

[33] Martin I. Hoffert et al., *Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet*, 298 SCI. 981, 981 (2002); *see also* NAT'L ACAD. OF SCI., LIMITING, *supra* note 23, at 67 (2010) (noting difficulty of meeting 550 ppm atmospheric stabilization target). According to Hoffert et al., simply "holding at 550 ppm is a major challenge." Hoffert et al., *supra*.

[34] Björn A. Sandén & Christian Azar, *Near-term technology policies for long-term climate targets: economy wide versus technology specific approaches*, 33 ENERGY POL'Y 1557, 1558 (2005).

GHG emissions to zero, and developing nation emissions alone would still lead to atmospheric levels above 450 ppm by mid-century.[35] In short, achieving state climate stabilization goals "requires a technological and economic revolution."[36]

The scope of the climate stabilization challenge can be illustrated by considering the "80 by 50" emission reduction goal — 80% emission reductions by the year 2050 — endorsed by the Obama Administration and some Congressional leaders.[37] "80 by 50" is far short of the emission reductions necessary for atmospheric stabilization at 450 ppm, yet would still require dramatic technological change. "80 by 50" requires capping domestic emissions at a little over one billion tons per year in 2050 — a level of emissions not seen in the United States in nearly a century. According to Department of Energy statistics, annual emissions were last at one billion tons of carbon dioxide around the year 1910, when the nation still had fewer than 100 million people and per-capita income was approximately $6,200 per year (in 2008 dollars).[38] By 2050 the U.S. population is expected to exceed 400 million.[39] Therefore, per capita emissions would need to be less than one quarter what they were a century ago to meet even this intermediary target — a goal that cannot be reached without dramatic technological change. To further illustrate this point, consider that replacing all coal burning in the United States with natural gas through 2020 would only reduce carbon dioxide emissions by 16%.[40] Wind and solar power production would have to

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[35] INT'L ENERGY AGENCY, WORLD ENERGY OUTLOOK: EXECUTIVE SUMMARY 2008 14 (2008).

[36] John Alic et al., *A new strategy for energy innovation*, 466 NATURE 316, 316 (2010) ("Limiting the concentration of carbon dioxide and other greenhouse gases in Earth's atmosphere requires a technological and economic revolution."); *see also* Scott Barrett, *The Coming Global Climate-Technology Revolution*, 23 J. ECON. PERSP. 53, 53 (2009) ("stabilizing concentrations will require a technological revolution - a 'revolution' because it will require fundamental change, achieved within a relatively short period of time."); Scott Barrett, *Kyoto and Beyond: Alternative Approaches to Global Warming*, 9 AM. ECON. REV. 22, 22 (2006); Gary E. Marchant, *Sustainable Energy Technologies: Ten Lessons from the History of Technology Regulation*, 18 WIDENER L.J. 831, 831 (2009) ("[I]t will not be possible to minimize these environmental stresses while still providing an adequate standard of living without new, cleaner technologies."); Nancy Birdsall & Arvind Subramanian, *Energy Needs and Efficiency, Not Emissions: Re-framing the Climate Change Narrative* 13–14 (Ctr. for Global Dev., Working Paper No. 187, 2009) (concluding that "any prospect of meeting the aggregate global emissions target, consistent with developing countries not sacrificing their energy needs, will require massive, revolutionary, improvements in the technology margins (production and consumption) — far greater than seen historically "); NAT'L ACAD. OF SCI., LIMITING, *supra* note 23, at ix (noting that reducing GHG emissions while accommodating economic growth will "require scientific and engineering genius"). Even those who argue that the climate challenge can be met in the near-term by "scaling up what we already know how to do" concede that "revolutionary technologies" will be necessary for atmospheric stabilization. Pacala & Socolow, *supra* note 32, at 968.

[37] *See The Obama-Biden Plan, supra* note 7.

[38] Steven F. Hayward & Kenneth P. Green, *Waxman-Markey: An Exercise in Unreality*, AEI ENERGY AND ENVTL. OUTLOOK, July 2009, at 1, 3.

[39] *Id.*

[40] *See* PIELKE, *supra* note 28, at 101.

increase twenty-five-fold to achieve equivalent emission reductions,[41] and this is still not enough to meet the "80 by 50" target, let alone stabilization. Meeting GHG emission reduction goals will require a "radical transformation of the energy system . . . ."[42]

The demands of atmospheric stabilization could be even greater than traditional analyses suggest.[43] Emission reduction scenarios are typically based upon projections developed by the IPCC. Yet the IPCC may have "seriously underestimated" the degree of technological innovation necessary to achieve climate stabilization.[44] A 2008 report in *Nature* found that the IPCC's emission projections assumed a substantial amount of "spontaneous technological change," representing "two-thirds or more of all the energy efficiency improvements and decarbonization of energy supply required to stabilize greenhouse gases," would occur independent of the adoption of any climate or energy policies.[45] These assumptions could be unduly optimistic.[46] Among other things, the IPCC predicted a greater decline in energy intensity than has been observed thus far in the 21st century[47] and assumed a

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[41] *Id.*

[42] Sandén & Azar, *supra* note 34, at 1558.

[43] *See* Robert D. Atkinson & Darrene Hackler, *Ten Myths of Addressing Global Warming and the Green Economy*, THE INFORMATION TECHNOLOGY & INNOVATION FOUNDATION (June 2010) ("[T]he magnitude of change needed is much larger than many realize[;] many conventional solutions simply won't achieve the global scale needed."), *available at* www.itif.org/files/2010-green-economy-myths.pdf.

[44] Roger Pielke Jr., Tom Wigley & Christopher Green, *Dangerous Assumptions*, 452 NATURE 531, 531 (2008).

[45] *Id*; *see also* IPCC, MITIGATION, *supra* note 32, at 218–20 (noting that the baseline scenarios already assume a significant degree of technological change and technology diffusion).

[46] *See* Pielke, Wigley, & Green, supra note 44, at 532:

> Enormous advances in energy technology will be needed to stabilize atmospheric carbon dioxide concentrations at acceptable levels. If most of these advances occur spontaneously, as suggested by the scenarios used by the IPCC, then the challenge of stabilization might be less complicated and costly. However, if most decarbonization does not occur automatically, then the challenge to stabilization could in fact be much larger than presented by the IPCC.

A widely cited paper by Pacala and Socolow asserting that existing technologies are sufficient to "solve the carbon and climate problem in the first half of this century" adopts similarly rosy assumptions. Pacala & Socolow, *supra* note 32, at 968. For example, Pacala and Socolow assume there will be only 1.5 percent annual growth in carbon emissions in their business-as-usual scenario. *Id.* Yet in the years since their study, emissions growth was double that rate. INT'L ENERGY AGENCY, CO2 EMISSIONS FROM FUEL COMBUSTION - HIGHLIGHTS, 2009 ed. 9 (2009) (global carbon dioxide emissions increased by 3 percent from 2005–2006 and 2006–2007). Further, Pacala and Socolow ignored the costs of their proposed emission reduction measures, *see* Pacala & Socolow, *supra* note 32, at 969 ("our focus is not on costs") and acknowledged that the ultimate goal of atmospheric stabilization would still require the development of "revolutionary technologies" for which "enhanced research and development would have to begin immediately." *Id.* at 968. It is also important to remember that, in actual practice new technologies are "likely" to "fall short of their technical potential." 'NAT'L ACAD. OF SCI., LIMITING, *supra* note 23, at 67.

[47] *See* Pielke, Wigley & Green, *supra* note 44, at 532.

level of emission-free power far above what current technologies can provide.[48]

Technological innovation is necessary to make climate stabilization achievable and affordable. So long as reducing GHG emissions remains costly, most nations are unlikely to act.[49] The price tag associated with limits on GHG emissions has discouraged enactment of any meaningful emission control policies in the United States. European nations have been more willing to make commitments, but, thus far, they have not been any more willing than the United States to bear meaningful economic costs in order to achieve GHG emission reductions. Several Kyoto signatories are already behind in reaching their targets.[50] Those nations that have met their Kyoto Protocol targets benefitted from exogenous factors or policy changes.[51] For the rest, emission reductions have been promised, but not yet achieved.[52] Overall, global GHG emissions have continued to climb. Emissions of carbon dioxide from fuel combustion, for example, increased 38% between 1990 and 2007, despite various pronouncements that countries were beginning to address GHG emissions.[53]

The resistance to costly controls in developing nations is even greater. In 2008, nearly 1.5 billion people around the world lacked access to electricity, including 809 million in Asia.[54] For affected nations, electrification is understandably a greater priority than emission reductions. China and India,

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[48] *See* Hoffert et al., *supra* note 33, at 981. Given current technological capabilities, and the prospective costs of meaningful climate change policies, "we are not likely to see dramatic reductions in global net emissions for some time." *Id.*

[49] Roger Pielke Jr. posits an "iron law of climate policy" such that "when policies focused on economic growth confront policies focused on emissions reductions, it is economic growth that will win out every time." PIELKE, *supra* note 28, at 46.

[50] *See Compliance under the Kyoto Protocol*, UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE, http://unfccc.int/kyoto_protocol/compliance/items/2875.php (last visited Dec. 2, 2010) (listing Greece, Canada, Bulgaria, and Croatia policies as under questions of implementation) (on file with the Harvard Law School Library); *see also* Robert W. Hahn, *Climate Policy: Separating Fact from Fantasy*, 33 HARV. ENVTL. L. REV. 557, 566 (2009) (reporting that "a few signatories are already having trouble filling their Kyoto commitments").

[51] Hahn, *supra* note 50, at 566 (noting that the choice of 1990 as the base year has made it easier for some nations to meet Kyoto targets due to exogenous factors); Thomas Heller, *The Path to EU Climate Change Policy*, *in* GLOBAL COMPETITION AND EU ENVIRONMENTAL POLICY 108, 120 (Jonathan Golub ed., 1998) (noting decline of CO_2 emissions in eastern Europe, including the former East Germany, was due to population decline and economic transition out of Soviet economic system).

[52] *See* PIELKE, *supra* note 28, at 106 (the rate of decarbonization within EU countries was the same during the nine years prior to ratification of the Kyoto Protocol as it has been since). Emission reduction obligations under the Kyoto Protocol have not stopped European nations from proceeding to build additional coal-fired power plants. *See, e.g.*, Elizabeth Rosenthal, *Europe Turns Back to Coal, Raising Climate Fears*, N.Y. TIMES, Apr. 23, 2008, at A1 (reporting that "European countries are expected to put into operation about 50 coal-fired plants over the next five years, plants that will be in use for the next five decades").

[53] *See* INT'L ENERGY AGENCY, CO_2 EMISSIONS FROM FUEL COMBUSTION – HIGHLIGHTS 44 (2010), *available at* http://www.iea.org/co2highlights/CO2highlights.pdf.

[54] *See Access to Electricity*, INT'L ENERGY AGENCY, http://www.iea.org/weo/electricity.asp (last visited Dec. 2, 2010) (on file with the Harvard Law School Library).

the first and fourth greatest emitters of GHGs respectively, are essential to any atmospheric stabilization plan and yet have made clear they will not participate in any regime which would require them to forego future economic growth.[55] China, like the United States, may have more to lose than to gain from carbon limits, as the costs of climate change may be outweighed by the costs of GHG emission controls, at least in the near to medium term.[56] Those nations that stand to lose the most from climate change, on the other hand, are not particularly large emitters.[57] Even if such nations were willing to adopt costly emission control strategies, their participation would not make a significant contribution to the ultimate goal of atmospheric stabilization.

Reducing expected compliance costs is one way to make nations more willing to impose environmental controls. The United States initially opposed international limitations on chlorofluorocarbons ("CFCs") and other substances that contributed to stratospheric ozone depletion. Yet as American manufacturers began to develop substitutes for CFCs, industry opposition declined, and the United States eventually agreed to the Montreal Protocol and a phase-out of ozone-depleting substances.[58] In this case, technological innovation helped shift the U.S. position on the desirability of an otherwise-costly international agreement to control a form of atmospheric pollution, both by reducing the costs of compliance and creating the possibility that specific companies would gain competitive advantage due to the imposition of environmental regulations.

Insofar as the United States and other developed nations can limit the cost of GHG emission reductions in developing nations — or at least make it

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[55] *See* Ravi Nessman, *India: Climate Deal Can't Sacrifice Poor Nations*, GUARDIAN (UK), Oct. 22, 2009 (citing Indian Prime Minister Manmohan Singh, who notes, "[D]eveloping countries cannot and will not compromise on development."), *available at* http://www.guardian.co.uk/world/feedarticle/8767757; Lionel Barber, *Transcript: Wen Jiabao*, FIN. TIMES (Feb. 2, 2009), http://www.ft.com/cms/s/0/795d2bca-f0fe-11dd-8790-0000779fd2ac.html ("[I]t's difficult for China to take quantified emission reduction quotas at the Copenhagen conference, because this country is still at an early stage of development.") (on file with the Harvard Law School Library); *see also* Hahn, *supra* note 50, at 564 ("[T]here is *no* simple way to get major developing countries, such as India and China, to participate in an agreement.").

[56] The research supporting this point is summarized in Cass R. Sunstein, *The World vs. the United States and China? The Complex Climate Change Incentives of the Leading Greenhouse Gas Emitters*, 55 UCLA L. REV. 1675, 1678–90 (2008). "The United States and China are the largest emitters, and on prominent projections, they also stand to lose relatively less from climate change." *Id.* at 1688.

[57] *Cf.* Robert Mendelsohn, Ariel Dinar, & Larry Williams, *The Distributional Impact of Climate Change on Rich and Poor Countries*, 11 ENVT & DEV. ECON. 159, 173 (2006) ("Overall, the poor will suffer the bulk of the damages from climate change, wheras the richest countries will likely benefit.").

[58] *Cf.* Sunstein, *supra* note 56, at 1694. It is also important to note that some chemical producers saw the phase-out as a way to obtain or maintain competitive advantage. *See id.* (citing DuPont's "ability to develop relatively inexpensive substitutes" as cultivating an "incentive to favor aggressive regulation"); *see also* Daniel F. McInnis, *Ozone Layers and Oligopoly Profits*, *in* ENVIRONMENTAL POLITICS: PUBLIC COSTS, PRIVATE REWARDS 129, 150 (Michael S. Greve & Fred L. Smith, Jr. eds., 1992).

less expensive to slow projected emission increases — developing nations may be more willing to accede to binding commitments and to pursue low-carbon development paths. At the same time, developed nations may also be more willing to fund emissions reductions, carbon remediation projects and low-carbon development in developing nations insofar as such projects are made less expensive. Again, the Montreal Protocol experience may be instructive. Developing nations were more willing to accede to an international treaty that would limit their access to low-cost refrigerants and coolants once developed nations agreed to compensate them and take other steps to reduce developing country compliance costs.[59] Whatever other policies are adopted at this time, it makes sense to adopt measures designed to increase the pace of development of climate friendly technologies, including those that reduce GHG emissions, remove carbon from the atmosphere, or enhance adaptive capacity.[60]

The level of technological innovation necessary to make atmospheric stabilization an affordable — and therefore politically viable — proposition is unlikely to happen without government intervention. The competitive pressures of a market economy provide firms with substantial incentives to improve their efficiency. These incentives often generate substantial environmental improvements. As firms learn to do more with less, they may reduce their overall environmental impact. Insofar as emissions are a consequence of incomplete combustion, increased efficiency may reduce the emission of particular pollutants. Yet such incentives are unlikely to be sufficient to produce significant GHG emission reductions. Indeed, while pollution trends for many substances have followed the inverted u-shape of the "Environmental Kuznets Curve," no such trend has been observed for carbon dioxide emissions — at least not yet.[61] To the contrary, increased economic growth has tended to correspond with increased emissions.[62] Further,

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[59] *See* Sunstein, *supra* note 56, at 1695–96.

[60] *See* Hahn, *supra* note 50, at 564 ("R&D expenditures should not only target mitigation efforts, but also increase our understanding of climate change and help identify cost-effective methods for adaptation.").

As Hoffert et al. observe: "Arguably, the most effective way to reduce CO_2 emissions with economic growth and equity is to develop revolutionary changes in the technology of energy production, distribution, storage, and conversion." Hoffert et al., *supra* note 33, at 981; *see also* Kenneth J. Arrow et al., *A Statement on the Appropriate Role for Research and Development in Climate Policy*, Economists' Voice, Feb. 2009, at 1 ("A key potential benefit of focused scientific and technological research is that it could dramatically reduce the cost of restricting greenhouse gas emissions by encouraging the development of more affordable, better performing technologies.").

[61] For a summary of the literature on whether there is an observable "Environmental Kuznets Curve" for carbon emissions, see Jody W. Lipford & Bruce Yandle, *Environmental Kuznets Curves, Carbon Emissions, and Public Choice*, 15 Env't. & Dev. Econ. 417 (2010).

[62] *Id.* at 421.

the International Energy Agency projects that energy demand will continue to increase substantially in the years ahead.[63]

Although GHG emissions, at some level, are tied to energy use, improvements in energy efficiency do not necessarily produce equivalent reductions in GHG emissions. Energy efficiency, measured in terms of energy use per unit of GDP, has steadily increased for decades. In the United States, energy consumption per unit of GDP declined by over 50 percent between 1970 and 2008.[64] Yet these improvements do not necessarily translate into equivalent GHG emission reductions. While reducing the use of carbon-based fuels should reduce the GHG emissions, increasing energy efficiency can reduce energy costs and result in an increase in energy use, and an offsetting emissions increase.[65] Alternatively, firms can reduce GHG emissions without increasing energy efficiency, through methods such as fuel switching.

In summary, climate change represents a major environmental policy challenge, likely the greatest environmental policy challenge the world has ever faced. Dramatic technological improvements will be necessary if atmospheric stabilization of GHGs is to be achieved. Such technological improvements, insofar as they lower the costs of reducing emissions or atmospheric concentrations of GHGs, could also facilitate the enactment of further climate policy measures. Technological innovation is essential to meeting the climate policy challenge. The question is how to induce it.

II. Innovation Inducing Prizes

Technology inducement prices are a promising way to enhance the degree of technological innovation necessary for climate stabilization. The idea behind technology inducement prizes is simple: Economic incentives are a powerful way to motivate human behavior toward a particular goal. If the goal is greater effort toward solving a particular problem, then one way to achieve that goal is to provide economic rewards for individuals to act accordingly. Inducement prizes provide incentives for innovative effort by offering rewards for pre-specified scientific or technological achievements, such as the solution to a mathematical problem, a device or method to per-

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[63] *See* Int'l Energy Agency, World Energy Outlook 2009 74 (2009) (presenting business-as-usual reference scenario in which energy demand in 2030 is 40 percent greater than in 2007).

[64] U.S. Energy Info. Admin., Annual Energy Review 2009 13 (2009), *available at* http://www.eia.doe.gov/aer/pdf/aer.pdf.

[65] *See* Steve Sorrell, The Rebound Effect: An Assessment of the Evidence for Economy-Wide energy Savings from Improved Energy Efficiency vi (UK Energy Research Centre 2007) (noting that energy efficiency improvements can produce a "rebound effect" that results in an increase in energy usage of ten percent or more and that such factors should be considered in policy analysis).

It is also important to keep in mind that carbon dioxide is not the only important GHG, and that other GHGs are not directly tied to the combustion of carbon-based fuels.

form a particular function within given parameters, or the completion of a particular task.[66] While some prizes — so-called "blue sky" prizes — may be awarded, ex post, for innovations for which an award had not been established ex ante, inducement prizes are targeted to achieve a specific goal.[67]

Prizes have some similarities with patents, but can also be used as a complement to patent protection. Assuming that a given innovation is valuable, both prizes and patents guarantee that a successful inventor will get an economic return greater than that which would be obtained in a competitive market.[68] With intellectual property, the increased return is provided by the monopoly right.[69] Guaranteeing an inventor an intellectual property right in her innovation enables her to charge a monopoly price and obtain monopoly rents. With prizes, the increased return comes from the financial value of the prize. In some cases, those pursuing a prize may also be motivated by ego or the potential reputational gains from being the first to solve an important or high-profile problem.

One virtue of the patent system that prizes simulate is decentralization.[70] Technological innovations, by their nature, often come from unforeseen sources and perspectives.[71] More decentralized systems are better able to draw from a wider pool of ideas and potential innovators.[72] As a McKinsey & Company report on philanthropic prizes reported: "The history of science is replete with instances of outsiders proposing novel and ultimately

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[66] *See generally* Michael Abramowicz, *Perfecting Patent Prizes*, 56 VAND. L. REV. 115 (2003); Steven Shavell & Tanguy van Ypersele, *Rewards Versus Intellectual Property Rights*, 44 J.L. & ECON. 525 (2001); Brian D. Wright, *The Economics of Invention Incentives: Patents, Prizes, and Research Contracts*, 73 AM. ECON. REV. 691 (1983).

[67] *See* SUZANNE SCOTCHMER, INNOVATION AND INCENTIVES 41–42 (2004). Scotchmer refers to ex ante prizes.

[68] *See* Kenneth w. Dam, *The Economic Underpinnings of Patent Law*, 23 J. LEGAL STUD. 247, 250 (1994) (noting that a "patent that reduces the cost of making a product will permit the patentee to enjoy economic rent. To be sure, this statement assumes that other producers are not able to use the innovation to reduce cost, but that is precisely the purpose of the power to exclude from 'manufacture, use, and sale' granted by a patent.").

[69] *See* SCOTCHMER, *supra* note 67, at 36 ("Intellectual property rights make the proprietor a monopolist.").

[70] *See* B. ZORINA KHAN, THE DEMOCRATIZATION OF INVENTION: PATENTS AND COPYRIGHTS IN AMERICAN ECONOMIC DEVELOPMENT, 1790–1920 66 (2005) (stating that in the United States, patent "statutes from the earliest years ensured that the 'progress of science and useful arts' was to be achieved through a complementary relationship between law and the market in the form of a patent system"); Peter S. Menell & Suzanne Scotchmer, *Intellectual Property Law*, *in* 2 HANDBOOK OF LAW & ECONOMICS 1473, 1477 (A. Mitchell Polinsky & Steven Shavell eds., 2007) (referring to decentralization in intellectual property systems as a "virtue" and stating "[p]robably the most important obstacle to effective public procurement is in finding the ideas for invention that are widely distributed among firms and inventors. The lure of intellectual property protection does that automatically.").

[71] *See* Thomas Kalil, *Prizes for Technological Innovation*, Hamilton Discussion Paper 2006-08, The Brookings Institution (Dec. 2006), at 7 ("Many of the most interesting discoveries in science are serendipitous.").

[72] *See* SCOTCHMER, *supra* note 67, at 38; *see also* NAT'L ACAD. OF SCI., INNOVATION INDUCEMENT PRIZES AT THE NATIONAL SCIENCE FOUNDATION 13 (2007) ("[C]ompared with grant programs, prize programs may be expected to attract more individuals, informal teams, and for-profit firms of various sizes and perhaps not as many academic institutions.").

revolutionary solutions to problems that had vexed insiders."[73] When it comes to innovation, expertise is not always an advantage. Indeed, in some cases those with less expertise may be in better position to identify solutions to difficult problems.[74]

Like traditional research and development ("R&D") grants, government supported prizes reward innovations that "are publicly valued but not privately marketable."[75] In addition, by offering an award to all comers, prizes encourage diverse research and innovation strategies, and allow for the success of outliers.[76] Indeed, a particular virtue of prizes is that they facilitate the targeting of investment without forgoing an ability to draw upon decentralized knowledge and alternative views of where innovation may lead.[77] With government research grants, on the other hand, a federal agency typically determines the goal to be achieved, the means to achieve that goal, and who will receive funding to pursue it.[78] Inducement prizes allow the government to establish a goal without being prescriptive as to how that goal should be met or who is in the best position to meet it.[79] Because technological innovation is unpredictable, can emerge from unexpected directions, and may involve a degree of serendipity, prizes have a distinct advantage insofar as they do not preclude potentially promising directions for innovation.[80] Moreover, with prizes there is no need to apply for

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[73] McKinsey & Company, "And the Winner Is . . .": Capturing the Promise of Philanthropic Prizes 23 (2009), *available at* http://www.mckinsey.com/clientservice/socialsector/And_the_winner_is.pdf.

[74] *See* Karim R. Lakhani et al., *The Value of Openness in Scientific Problem Solving*, Harvard Business School Working Paper 07-050 (October 2006), at 9, *available at* http://www.hbs.edu/research/pdf/07-050.pdf.

[75] *See* William A. Masters, *Prizes for Innovation in African Agriculture: A Framework Document*, version 2.0, 5 (Jan. 23, 2006), http://www.agecon.purdue.edu/prizes/Prizes-FrameworkDocument-RevJan2006.pdf [hereinafter Masters, *Framework*].

[76] *See* Kalil, *supra* note 71, at 5.

[77] Utilizing decentralized knowledge about economic conditions is, in fact, one of the central problems of any economic system. *See* Friedrich A. Hayek, *The Use of Knowledge in Society*, *in* Individualism and Economic Order 77, 77–78 (1948) ("The peculiar character of the problem of a rational economic order is determined precisely by the fact that the knowledge of the circumstances of which we must make use never exists in concentrated or integrated form but solely as the dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess . . . [o]r, to put it briefly, it is a problem of the utilization of knowledge which is not given to anyone in its totality.").

[78] For a fuller discussion of government research grants, see *infra* Part IV.

[79] *See* Kalil, *supra* note 71, at 5 ("[Prizes] help to blend the best of public purpose and the creativity, energy, and passion of private sector entrepreneurial teams.").

[80] According to William Baumol, "the independent innovator and the independent entrepreneur have tended to account for most of the true, fundamentally novel innovations." William J. Baumol, *Education for Innovation: Entrepreneurial Breakthroughs vs. Corporate Incremental Improvements* 5 (Nat'l Bureau of Econ. Research, Working Paper No. 10578, 2004). According to Michael Witherell, vice chancellor for research at the University of California at Santa Barbara, "[m]ost of our great breakthroughs have not been through [top-down government] funding." *See* Gautam Naik, *Energy Push Spurs Shift in U.S. Science*, Wall St. J., Nov. 25, 2009 at A1.

a government grant, comply with complex eligibility requirements, or ingratiate oneself with grant-making authorities.[81]

Some analysts have argued that prizes are actually superior to intellectual property.[82] Like patents, prizes reward innovators in proportion to their degree of innovation, but without some of the associate costs. Specifically, prizes provide a similar reward structure to patents without the offsetting welfare loss from monopoly prices.[83] If the prize is set at a level equal to the value of a patent on the innovation, then the incentive to innovate will be identical.[84] If a prize is in addition to a patent — that is, if obtaining the prize does not require giving up any intellectual property in the innovation — then the prize serves to augment the incentive to innovate already provided by intellectual property protection. Not seeking to match the prize to the value of the patent avoids the problem of trying to determine, up front, what the value of the patent might be. (Indeed, setting the prize to a level equal to the patent right with any precision may be impossible.[85])

While much of the relevant academic literature discusses prizes as a potential substitute for patent protection, the two need not be mutually exclusive.[86] To the contrary, prizes and patent protection can be complimentary. While patent protection provides a background inducement for all commercially marketable innovations, prizes augment the reward for types of innovations that have been identified, ex ante, as having particular social value.[87] Particularly in those areas in which patents alone are unlikely to generate sufficient investment in innovative endeavors, such as where free-rider or common pool problems discourage such investment, prizes can augment the power of intellectual property. In the case of climate change, there is a clear need for technological innovations that can make it less expensive to reduce GHG emissions or remove GHGs from the atmosphere, but there is as yet no real market for such technologies, making prizes a good complement for patents in this area.

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[81] *See* Scotchmer, *supra* note 67, at 38 ("The incentive operates without the inventor having to negotiate with an invention authority."); McKinsey, *supra* note 73, at 23 ("Compared with other incentive instruments, such as grants and scholarships, prizes reduce bureaucratic barriers to entry for participants and need not screen for conventional qualifications.").

[82] *See, e.g.*, Shavell & Ypersele, *supra* note 66; Wright, *supra* note 66. For one of the earliest arguments for replacing patents with government funded awards, see Michael Polanvyi, *Patent Reform*, 11 Rev. Econ. Stud. 61 (1944).

[83] *See* Wright, *supra* note 66, at 696; *see also* Scotchmer, *supra* note 67, at 39 ("The advantage of prizes over patents is that they can avoid the deadweight loss of proprietary pricing.").

[84] *See* Scotchmer, *supra* note 67, at 41.

[85] *See id.*

[86] *See* William A. Masters, *Paying for Prosperity: How and Why to Invest in Agricultural Research and Development in Africa*, 58 J. Int'l Aff. 35, 60 (2005) ("[P]rizes for technological achievements have often been used as a complement to patent rights and research contracts.") [hereinafter Masters, *Prosperity*].

[87] *See* Kalil, *supra* note 71, at 6 ("[P]rizes are especially suitable when the goal can be defined in concrete terms but the means of achieving that goal are too speculative to be reasonable for a traditional research program or procurement.").

Prizes have the capacity to stimulate increased investment in a given technological problem from a wide range of sources. Because the prize is a competition, multiple innovators may invest in trying to obtain the prize, accelerating the process of innovation.[88] As a consequence, prizes "can stimulate philanthropic and private sector investment that is greater than the value of the prize."[89] For example, the Ansari X-Prize was only $10 million, yet it stimulated over $100 million in private investment by teams seeking to win the prize,[90] in addition to substantial post-prize investments in private space travel.[91] While the Ansari X-Prize may not be typical, the experience with prizes shows that governments or other benefactors can use prizes to leverage an investment in technological innovation, inducing greater efforts than could be purchased through contracts or grants.[92] Competitors may also be motivated by more than just the financial reward.[93] Prestige and publicity can also be valuable.[94] Microsoft co-founder Paul Allen reportedly invested more than double the value of the prize itself in the team that won the Ansari X-Prize.[95]

Whether the potential for a prize to leverage the benefactor's investment is a feature or a bug depends on the extent to which one is concerned about the costs of duplicated investment. Prizes, more so than government grants, may lead to duplication of effort, as more than one individual or group seeks to obtain the prize.[96] Yet such duplication of effort is also generated by the patent system, as multiple firms or individuals seek to develop patents for useful innovations in a given field.[97] Indeed, such duplication of effort is pervasive in the private marketplace, as multiple firms seek to develop products and services that will capture market share, attract customers, and ex-

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[88] *See* John F. Duffy, *Rethinking the Prospect Theory of Patents*, 71 U. CHI. L. REV. 439 (2004) (asserting that patent races bring about innovations more quickly).

[89] *See* Kalil, *supra* note 71, at 7.

[90] MCKINSEY, *supra* note 73, at 25.

[91] *See, e.g., id.* at 21. By 2008 over 300 people had signed up for $200,000 trips on SpaceShipTwo, the successor to the vehicle that won the Ansari X-Prize.

[92] *See id.* at 25 (discussing leveraging of investment by NASA Centennial Challenge); *id.* at 29 ("One of prizes' great strengths is their ability to attract investments from competitors many times greater than the cost of delivering and awarding a prize.").

The leveraging feature of prizes is particularly important given the potential for research grants to "crowd out" other R&D efforts. As a consequence, increased R&D support in one area does not necessarily result in a net increase of overall R&D efforts. *See* David Popp & Richard G. Newell, *Where Does Energy R&D Come From? Examining Crowding Out from Environmentally Friendly R&D*, NBER Working Paper 15423 (Oct. 2009), *available at* http://www.nber.org/papers/w15423; *see also* Dominque Guellec et al., *The Effectiveness of Public Policies in R&D*, 94 REVUE D'ECONOMIE INDUSTRIELLE 49, 62 (2001) (Fr.) (discussing potential "crowding out" effect of public R&D funding on private R&D funding).

[93] MCKINSEY, *supra* note 73, at 19 ("Prizes also add additional layers of motivation beyond money, such as prestige and intellectual curiosity.").

[94] *Id.* at 26 ("[T]he recognition accompanying a prize can be very valuable in itself.").

[95] *See* Masters, *Framework*, *supra* note 75, at 11.

[96] *See* Kalil, *supra* note 71, at 7.

[97] *See* Marlynn Wei, *Should Prizes Replace Patents? A Critique of the Medical Innovation Prize Act of 2005*, 13 B.U. J. SCI. & TECH. L. 25, 25 (2007) (noting the problem of potential duplication of effort is the same under the patent system as it is under a prize system).

pand their sales. Prizes may encourage an inefficient duplication of research costs. This must be balanced against the increased likelihood of spurring the desired innovation. Such duplication may be an inevitable cost of technological progress. If, as many analysts believe, the public and private sector alike under-invest in climate and energy related R&D,[98] the risk of duplication may also not be particularly great.

One value of the patent system that prize systems do not duplicate on their own is the added incentive for commercialization of an innovation.[99] The patent holder's reward comes from turning the patent invention into a commercially saleable product. A prize winner, on the other hand, may receive the prize simply for the invention itself. In order to avoid this potential problem, prize specifications can include criteria to ensure potential marketability. This also can be addressed through prize design, such as by requiring the sale of an invented technology as a condition of winning the prize or by guaranteeing government procurement of a winning technology. Insofar as prizes draw attention to the newly possible, generate interest in new markets, or increase the prestige of participants, however, the winning of the prize itself may be enough to spur investment in commercially viable applications.[100] The lack of an independent inducement for commercialization is another reason to view prizes as complements, not substitutes, for intellectual property.

Prizes can also be particularly important to spur investment in technological innovations that would be of primary benefit to low-income consumers and people in developing nations. Few profit-seeking firms are likely to make significant investments in serving such markets. This problem has been observed in the agricultural context, where neither governments nor private firms have invested significantly in developing technologies or techniques of particular use to widely-dispersed, low-income consumers in developing nations.[101] Similarly, not many firms see massive profit opportunities in developing low-carbon energy options for developing nations. Yet the welfare benefits from improved energy efficiency and a less carbon-intensive development path in much of the world could be quite substantial.

Not all sorts of innovation can be effectively encouraged through prizes, however. In particular, the use of a prize mechanism is dependent upon the initial identification of a particular problem that needs to be solved or goal to be achieved. As a consequence, prizes may be better suited for

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[98] *See infra* notes 193–200 and accompanying text.

[99] *See generally* F. Scott Kieff, *Property Rights and Property Rules for Commercializing Inventions*, 85 MINN. L. REV. 697 (2001).

[100] *See* MCKINSEY, *supra* note 73, at 21 ("There are many examples of well-crafted prizes, backed by a relatively small amount of capital, establishing the importance of a field, catalyzing market demand, shaping public debate, and even changing the image of sponsors.").

[101] *See* Masters, *Prosperity*, *supra* note 86, at 56.

applied research than for basic scientific research.[102] In some areas, it may be difficult to identify prize terms or qualifications. In the case of climate change, however, at least some of what must be discovered and developed to facilitate atmospheric stabilization is relatively clear. While there may yet be climate-friendly innovations that emerge from left field, many characteristics of potential climate-related technologies can be identified today.

Setting the appropriate level for a prize can be difficult as well, particularly if the prize is expected to substitute for patent protection.[103] A prize that is too small will fail to stimulate sufficient investment, but a prize that is too high will waste resources.[104] Of course, if the prize is set too low, and it is insufficient to spur sufficient levels of research, the prize will not be claimed, so the fiscal cost for a sponsoring government agency is zero. In such an instance, the government may have failed to spur valuable research, but it will not have wasted taxpayer dollars on an unadvised investment. Prizes may also be the subject of controversy, particularly if the criteria for winning a prize are insufficiently clear or fail to account for possible means of satisfying the prize requirements.

A potentially significant drawback of prizes is that researchers must obtain funding for their research in order to compete. From a fiscal policy standpoint, this is a benefit, as funding prizes does not require the government to appropriate money up front.[105] Yet in fields in which research may be capital intensive, the lack of upfront funding can be inhibitive.[106] A theoretical mathematician may not have many fixed costs, but the same may not be true for a scientist researching particle physics or even nuclear power plant design. If research toward a prize requires the construction of expensive equipment, these costs may be a substantial barrier to participation. This concern may justify retaining traditional grant-based funding for basic research and for other particular types of research. It does not, however, undermine the broader case for prizes.

Whatever their drawbacks in other contexts, technology inducement prizes are particularly well-suited for climate change policy. The climate policy challenge requires the development of technologies that can help achieve particular goals, including low- or zero-carbon energy production

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[102] *Cf.* NAT'L ACAD. OF SCI., *supra* note 72, at 12–13 ("[Prizes] may be less well suited than grants and contracts to the development of basic scientific and engineering understanding underlying the achievement of goals.").

[103] *See* Abramowicz, *supra* note 66, at 121 ("[T]he devil is in the details and the devil for the prize system is the government's ability to dispense rewards accurately.").

[104] Wei, *supra* note 97, at 22 ("If the prize is too low, then the system will inadequately stimulate R&D investment. If the prize is too high, then costs such as resource duplication and the problem of favoritism will be exacerbated.").

[105] *See* Masters, *Prosperity*, *supra* note 86, at 61 ("The unique virtue of a prize program is to provide rewards *ex post*, letting other institutions provide the working capital.").

[106] *See* NAT'L ACAD. OF SCI., *supra* note 72, at 13 ("The requirement in a prize contest that would-be innovators fund the research up front may inhibit participation by entities that do not otherwise have access to discretionary funding for innovative activities.").

and the removal of carbon dioxide from the atmosphere.[107] The U.S. Climate Change Technology Program has already identified key R&D priorities for the short, medium, and long terms.[108] Further, climate change policy depends less upon additional basic research than the development and deployment of practical technological innovations, and the utility of such innovations can be readily evaluated. While there are substantial market incentives encouraging the development of environmentally friendly technologies in other contexts, the commons nature of the climate problem and lack of a price on carbon emissions discourages optimal private investment in climate-related innovation. A firm that purchases a technology to reduce its GHG emissions does not thereby reduce its operating costs. As a consequence, the financial value of the GHG reduction benefits.[109] While there are some technologies that may reduce emissions because they increase energy efficiency, the savings in such cases are a consequence of reduced energy use, and any emission reductions are incidental. This is one reason many economists endorse government support for climate-related technological innovation.[110] The question is what form that government support should take. The history of technology inducement prizes — and their successful deployment to solve pressing social problems — shows that they can be a particularly effective way to spur research and development of socially valuable innovations.

III. Prize History

Prizes for scientific and technological innovation used to be common. In the eighteenth century, research grants, the current "staple of basic research funding," were relatively rare.[111] Instead, European governments used prizes to spur technological research and scientific progress.[112] Prize competitions were not only used to reward an innovator's ability to solve a

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[107] *See supra* Part I.

[108] *See* USCCTP, *supra* note 4.

[109] *See* Adam B. Jaffe, Richard G. Newell & Robert N. Stavins, *Technological Change and the Environment*, *in* 1 Handbook of Environmental Economics 462, 473 (Karl-Göran Maler and Jeffrey R. Vincent eds., 2003) (noting that "the external social benefits of environmentally benign technology are unlikely to be fully captured by private innovators"); Marchant, *supra* note 36, at 833 (characterizing private efforts as unlikely to be "sufficient to generate the massive technology changes, fast enough, needed to meet the challenge of sustainability, and therefore, public policies are needed to stimulate induced technological change").

[110] Hahn, *supra* note 50, at 564; *see also* Kenneth J. Arrow et al., *A Statement on the Appropriate Role for Research and Development in Climate Policy*, 6 Economists' Voice 1, Feb. 2009, *available at* www.bepress.com/ev/vol6/iss1/art6/.

[111] Robin Hanson, *Patterns of Patronage: Why Grants Won Over Prizes in Science*, 2 (July 28, 1998), http://hanson.gmu.edu/whygrant.pdf (on file with the Harvard Law School Library).

[112] *See* McKinsey, *supra* note 73, at 15 ("For centuries, [prizes] were a core instrument of sovereigns, royal societies, and private benefactors alike who sought to solve pressing societal problems and idiosyncratic technical challenges.").

particular technological problem. Historically, some prize competitions rewarded the best contribution in a given area made by a set date.[113] Prizes were awarded for basic science as well as for technical advances, from topics ranging from mathematics to food preservation, alkali production to air travel. Prizes spurred James Maxwell to develop a mathematical theory of Saturn's rings and encouraged Heinrich Hertz to figure out how to detect radio waves.[114] Not all prizes included monetary rewards. In some cases, the reputational gain of solving an announced problem was sufficient.[115] Would-be prize-winning inventors needed to fund their own research, leading some to seek patronage and others to develop early venture-capital-like investment financing schemes.[116]

The most famous prize in history is likely the longitude prize financed by the British government in the early eighteenth century, and chronicled in Dava Sobel's book, *Longitude*.[117] During the sixteenth and seventeenth centuries, sea travel and trade increased dramatically. With this increase in seaborne trade came an increased demand for accurate navigational tools. A particularly perplexing problem for naval captains and merchants was how to measure longitude at sea. While determining latitude was relatively easy, determining longitude was a problem "that stumped the wisest minds of the world for the better part of human history."[118]

In response to private and military demands, and rising discontent over vessels lost at sea, the British Parliament enacted the Longitude Act in 1714, establishing a series of prizes up to £20,000 for a "[p]racticable and [u]seful" means for ship captains to determine longitude.[119] The value of the prize awarded to a given inventor would be a function of the accuracy of the measurement method.[120] Inventions and methods would be evaluated by a Board of Longitude consisting of "scientists, naval officers, and government officials," which would also have the authority to provide additional financial incentives to impoverished inventors with promising ideas.[121]

When the longitude prize was created, all assumed astronomy held the key. For centuries, scientists had looked to the stars for a solution to the longitude puzzle. The idea was intuitive and simple: if sailors knew that a particular event, such as an eclipse or the appearance of a constellation, was scheduled to occur at one time in one place, they could determine their location based upon when they saw the event. The idea worked in theory, but astronomers lacked sufficient knowledge of star positioning and sailors

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[113] Hanson, *supra* note 111, at 5.

[114] *See* SCOTCHMER, *supra* note 67, at 9–10.

[115] *See id.* at 9.

[116] *See id.* at 12–13.

[117] DAVA SOBEL, LONGITUDE (1995).

[118] *Id.* at 4.

[119] *Id.* at 8. Twenty thousand pounds sterling in 1714 would be worth "several million dollars in today's currency." *Id.*

[120] *See id.* at 53.

[121] *Id.* at 54.

could not rely upon clear nights (or clear days to set their clocks by the noon sun). Despite decades of work by various luminaries, including Galileo, the perfect algorithm to chart the stars remained elusive.[122]

The prize was eventually claimed not by an astronomer, but by a watchmaker, John Harrison — and not without a struggle. Harrison invented a clock that "could withstand storms, changes in temperature, and salt air,"[123] and provide an accurate measure of time that could be used to fix a ship's position at sea. Although Harrison's invention worked, the British Board of Longitude initially refused to recognize it.[124] The prevailing wisdom of the time was that mechanical clocks were too unreliable and cumbersome for timekeeping on an ocean voyage, let alone to position a ship at sea. The Board, which included several astronomers, wanted an astronomical solution to the problem, such as an algorithm that would enable any ship with the right charts to obtain its location. Such an approach would have been more of a "pure" public good solution to the longitude problem than the difficult-to-produce clock that Harrison invented.[125] Yet, in the end, Harrison's method was vindicated, even though he "stood alone against the vested navigational interests of the scientific establishment."[126]

That a clock, not an astronomical chart or algorithm, was the best way to determine longitude was a surprise to Harrison's contemporaries and government authorities. Had Parliament sought to solve the longitude problem with research grants for prominent astronomers, instead of a prize open to all comers, it is doubtful it would have been solved and the British Empire would not have seen the benefits of Harrison's clock. As it happened, Harrison's innovation was revolutionary, and by 1815 there were thousands of longitude clocks in use.[127]

The longitude prize is not an isolated example. Throughout the eighteenth century, the French government and Royal Academy of Sciences offered numerous prizes for scientific achievement.[128] Many of these prizes were simply honorific, conferring publicity and prestige, but not money, upon the recipient. The most prestigious of these was the *gran prix*, awarded to "the best answer to a major scientific problem selected by a group of expert members."[129] Over time, however, the Academy began offering financial awards. These prizes appear to have been quite effective, particularly those in the field of mathematics.[130] While some prizes went

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[122] *See id.* at 24–27.
[123] SCOTCHMER, *supra* note 67, at 32.
[124] *Id.* at 32–33.
[125] *See id.*
[126] *See* SOBEL, *supra* note 117, at 99.
[127] *Id.* at 163.
[128] Maurice Crosland & Antonio Gálvez, *The Emergence of Research Grants within the Prize System of the French Academy of Sciences, 1795–1914*, 19 SOC. STUD. OF SCI. 71, 71–72 (1989).
[129] *Id.* at 74.
[130] *Id.* at 75.

unclaimed, or failed to induce much practical research, others led to breakthroughs in medicine and other fields.[131] Even some of the prize awards that failed nevertheless produced success, as they sometimes encouraged research in otherwise neglected areas. The 19th century Bréant Prize offered for a cure for cholera was never claimed, but "the existence of the prize encouraged work on other infectious diseases," and led to some prize-worthy discoveries.[132]

Among the most important of French prizes offered was that for the production of alkali that could be used in glass, soap, and textiles.[133] As alkali became scarce in the late 18th century, King Louis XVI offered a 2,400 livre prize for a simple and economical method of producing alkali from sea salt.[134] Nicolas Leblanc, whose innovation laid the foundation for the inorganic chemical industry in the 19th century, claimed the prize.[135] In 1795, the French government offered a prize for improved food preservation techniques, a technology much desired by the French military.[136] The prize was awarded to Nicholas Appert in 1810.[137] Remarkably, Appert's innovation, a method of sterilizing and preserving food in bottles, is still used today.[138] And as with the longitude prize, the offer of a reward (and prestige) led to a socially desired innovation.

Despite their success in the 18th and 19th centuries, prizes gradually fell out of favor. Retrospective prizes, in which scientific societies gave unannounced ex post awards to innovators for particularly notable achievements (much like the contemporary Nobel Prize), and research grants gradually replaced innovation prizes and the sponsorship of "in-house" funding of gifted scholars and scientists.[139] It also became more acceptable to reward scientists repeatedly and give grants to those with connections to the scientific establishment.[140] Hanson reports, "As a result of these changes, the patronage of basic research came to rely more heavily on the judgment and trustworthiness of those administering the funding process."[141]

It is often assumed that the shift away from prizes toward grants and direct funding of scientific research was an advancement. Historians of sci-

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[131] *Id.* at 92.

[132] *Id.*

[133] Masters, *Framework*, *supra* note 75, at 7; *see also* David M. Kiefer, *It Was All about Alkali*, TODAY'S CHEMIST AT WORK, Jan. 2002, *available at* http://pubs.acs.org/subscribe/archive/tcaw/11/i01/html/01chemchron.html.

[134] Masters, *Framework*, *supra* note 75, at 7.

[135] *See* Lee Davis, *How Effective Are Prizes as Incentives to Innovation? Evidence from Three 20th Century Contests*, DRUID Summer Conference: Industrial Dynamics, Innovation and Development, May 7, 2004, at 4.

[136] SCOTCHMER, *supra* note 67, at 43.

[137] Wright, *supra* note 66, at 704.

[138] SCOTCHMER, *supra* note 67, at 44.

[139] *See* Hanson, *supra* note 111, at 6.

[140] *See id.* at 6 (citing Jack Sommer, *Radical Proposal for Reorganizing Research Support: Lotteries, Prizes*, THE NEW SCIENTIST (June 10, 1991), at 11 (noting the tendency to award grants based upon reputation instead of a proposal's merit)).

[141] Hanson, *supra* note 111, at 6.

ence "have mostly lauded this transition" to paying for effort instead of paying for results.[142] Increased reliance on research grants left researchers with greater control over their research efforts, and ex ante funding of research made it easier to build and maintain larger research facilities and maintain equipment. It also reinforced the gradual professionalization of scientific research.

More recent research has challenged the conventional explanation for why prizes have fallen out of favor. One reason researchers and scientific societies alike preferred grants was because direct grants made "life easier for the government bureaucrats" who oversee support for scientific research, as well as for "the scientists who received them."[143] Both grants and general retrospective awards "gave judges more discretion in choosing winners" and made it possible for scientific societies to reward "insiders."[144] This created the opportunity for patrons to reward their friends and allies and ensure that only those with the right ideas received funding.

As government became an ever-larger source of science funding, the shift away from prizes continued. Today, most prizes are privately funded, while most government-supported scientific research comes in the form of research grants.[145] Reviewing the trends, Hanson suggests that "[g]rants may have won not, as their advocates claimed, because they were a superior institution, but instead because non-local and non-autocratic governments tended to prefer them."[146] According to Hanson, "governments might prefer grant-like funding to prize-like funding because they were susceptible to distributive pressures from leaders of scientific societies, who preferred the 'pork' of increased discretion over the money that passed through their hands."[147]

Prizes did not disappear; there was just less government involvement. Privately funded prizes were essential for the development of air travel. Several million dollars worth of aviation prizes were awarded in Europe prior to World War I, and significant prizes were offered in the United States as well.[148] Gregg Maryniak of the X-Prize Foundation identified over fifty aviation prizes offered between 1900 and 1913.[149] The 1919 Orteig Prize involved a $25,000 reward for the first nonstop flight between New York

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[142] *Id.*

[143] David Leonhardt, *You Want Innovation? Offer a Prize*, N.Y. TIMES, Jan. 31, 2007, at C1.

[144] Hanson, *supra* note 111, at 9.

[145] *See* NAT'L ACAD. OF SCI., *supra* note 72, at 10 (noting that prizes "have been used only sparingly by governments").

[146] Hanson, *supra* note 111, at 17.

[147] *Id.* at 18.

[148] *See* Gregg Maryniak, *When Will We See a Golden Age of Space Flight?*, *in* SPACE: THE FREE-MARKET FRONTIER 11, 20–22 (Edward L. Hudgins ed., 2002) (identifying aviation prizes offered between 1900 and 1913); *see also* ALEX SCHROEDER, INDEPENDENCE INST., THE APPLICATION AND ADMINISTRATION OF INDUCEMENT PRIZES IN TECHNOLOGY 7, (2004) (citing estimate of $1 million in prizes offered in 1911 alone).

[149] Maryniak, *supra* note 148, at 20–22.

and Paris.[150] According to the conventional wisdom of the time, such a feat could only be accomplished by a sizable crew in a large, multi-engine plane.[151] Yet the prize was won by Charles Lindbergh, who made a solo flight in a small, single-engine plane, after several others had failed.[152] Like Harrison before him, Lindbergh claimed the prize by challenging the conventional wisdom and pursuing an independent path. As with longitude, an ex ante award of a research grant focused on the method most "experts" thought would be successful, would have failed.

The 1990s saw a "renaissance" of prize awards, largely funded by philanthropists and private companies.[153] RSA Security offered a $250,000 prize for the specification of a 2048-bit integer, which could then be used for encryption software.[154] Netflix offered a $1 million prize for improvements to the company's Cinematch algorithm that identified movies customers were likely to enjoy based upon their and other customers' reactions to other movies.[155] Specifically, Netflix said it would award the prize to a team or individual who developed an algorithm that would predict viewer ratings of movies with at least ten percent greater accuracy than Cinematch.[156] Over 55,000 entrants from 186 different countries entered the Netflix competition.[157] In September 2009, three years after the prize was proposed, Netflix awarded the prize to BellKor's Pragmatic Chaos, a team of seven programmers.[158] The company was so pleased with the results that it has announced a second prize. This time Netflix is seeking an algorithm that will make predictions based upon demographic data, and the prize will be awarded to those teams with the best algorithm at set time periods.[159]

More famously, the X-Prize Foundation created the "Ansari X-Prize," an award of $10 million for the private development of a reusable, manned spacecraft.[160] In 2004, a team bankrolled by Microsoft co-founder Paul Al-

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[150] Kalil, *supra* note 71, at 6.

[151] *Id.*

[152] *Id.*; *see* SCHROEDER, *supra* note 148, at 7–8.

[153] SCOTCHMER, *supra* note 67, at 44; *see also* MCKINSEY, *supra* note 73, at 16 (noting "prizes are booming once again" and citing an increase in prizes since 2000); Eric S. Hintz, *Creative Financing: The Rise of Cash Prizes for Innovation Is a Response to Changing Business Conditions - And a Return to Winning Strategy*, WALL ST. J., Sept. 27, 2010, at R8 (reporting on the rise of prizes for innovation). In 1972, President Richard Nixon proposed the use of prizes to "foster useful innovation." Harry Goldsmith, *An Olympiad of Science*, 177 SCI. 35, 35 (1972). Congress never acted on this proposal.

[154] SCOTCHMER, *supra* note 67, at 45.

[155] Leonhardt, *supra* note 143.

[156] *See The Netflix Prize Rules*, NETFLIX, http://www.netflixprize.com/rules (last visited Dec. 2, 2010) (on file with the Harvard Law School Library).

[157] *And the winner is . . .*, THE ECONOMIST, Aug. 5, 2010.

[158] Harrison Hoffman, *Netflix Awards $1 Million for Outdoing Cinematch*, THE WEB SERVICES REPORT (Sept. 21, 2009, 3:28 PM), http://news.cnet.com/8301-13515_3-10357807-26.html (on file with the Harvard Law School Library).

[159] *Id.*

[160] *See And the winner is . . .*, *supra* note 157; John J. Miller, *Extraordinary Feats of an X-Man*, PHILANTHROPY, July 2005, *available at* http://www.philanthropyroundtable.org/article.asp?article=750&paper=1&cat=147.

len claimed the prize for their SpaceShipOne, which managed to make two suborbital flights in less than two weeks.[161] Although only $10 million was awarded, the prize spurred over $100 million in privately funded research,[162] including over $20 million by the benefactors of the winning team.[163] The X-Prize demonstrated that spaceflight can be far less costly than the typical National Aeronautic and Space Administration ("NASA") mission would suggest.[164] It generated a far greater return per dollar spent than the federal space program and is leading to the commercialization of space flight.[165] It was recently reported that Virgin Galactic, a fledgling space tourism company, "has already collected 45 million dollars in deposits from more than 340 people who have reserved seats" aboard a spaceship that will be able to take passengers into suborbital space beginning in 2012.[166]

Due to the success of this prize, the X-Prize Foundation has announced others, including the Progressive Automotive X Prize, to encourage the development of vastly more fuel-efficient vehicles.[167] This prize includes a "units sold" metric.[168] The Progressive Automotive X Prize offered a $10 million purse for a long distance stage competition for vehicles that can exceed 100 miles per gallon.[169] The prize was awarded in September 2010 to three teams, out of over 100 competitors, one of which produced a vehicle capable of achieving the equivalent of 205 miles per gallon.[170] The X-Prize Foundation expects to announce several more multi-million dollar prizes in the coming years.[171]

The federal government has also shown a renewed interest in prizes, beginning with a 1999 National Academy of Engineering ("NAE") report encouraging government agencies to consider using technology inducement

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[161] *See* Peter Pae, *Rocket Takes 1st Prize of a New Space Race*, L.A. TIMES, Oct. 5, 2004, at A2.

[162] MCKINSEY, *supra* note 73, at 25. The 2004 Defense Advanced Research Projects Agency ("DARPA") Grand Challenge is another example, as contest entrants invested an estimated total of $55 million in pursuit of a $2 million prize. *See* Miller, *supra* note 160.

[163] Masters, *Framework*, *supra* note 75, at 11; Pae, *supra* note 161 (reporting Allen invested $25 million in SpaceShipOne).

[164] *See* David L. Chandler, *Final Frontier: Space Tourism Prize Gives Space Tourism a Boost*, BOS. GLOBE, Oct. 19, 2004, at B9.

[165] *See Virgin Spaceship to Pass New Milestone*, AGENCE FRANCE PRESSE, Oct. 22, 2010, *available at* http://news.yahoo.com/s/afp/20101022/ts_alt_afp/usaviationspacebritainvirgin_20101022091717 (reporting on maiden flight of spacecraft for commercial spaceflight).

[166] *Id.*

[167] *See And the winner is . . .*, *supra* note 157. For additional details on this prize, see PROGRESSIVE AUTOMOTIVE X PRIZE, http://progressiveautoxprize.org (last visited Dec. 2, 2010) (on file with the Harvard Law School Library).

[168] *See* Kalil, *supra* note 71, at 13.

[169] *See And the winner is . . .*, *supra* note 157.

[170] *See* Joseph B. White, *No Radio, but It Gets 100 Miles a Gallon*, WALL ST. J., Sept. 17, 2010, at A3.

[171] *See* MCKINSEY, *supra* note 73, at 30 (noting aim of launching ten prizes over 5–7 years).

prizes on an experimental basis.[172] NASA and the Defense Advanced Research Projects Agency ("DARPA") have experience with awarding prizes for technological innovation, though both agencies' programs have been designed on a rather small scale.[173] DARPA, the research agency within the Department of Defense, "has offered a $1 million prize to elicit a fortyfold improvement in robotic vehicles for rough terrain."[174] Congress recently authorized NASA to sponsor prizes out of its budget, as well as to accept private matching funds for prize rewards.[175] NASA's "Centennial Challenge" provides for several prizes to encourage more private investment in space-related technological innovation.[176] An unemployed engineer won NASA's Astronaut Glove Challenge in 2007 — yet another example of a prize stimulating innovation by an "outsider."[177]

Congress has shown some renewed interest in prizes in recent years.[178] In 2006 Congress permitted the National Science Foundation ("NSF") to begin utilizing "innovation inducement prizes" with portions of its annual appropriations.[179] In response, the NSF arranged with the National Academy of Sciences ("NAS") for a study on how the NSF could administer prizes to "achieve novel solutions to specified social or research needs or capitalize on recognized research opportunities."[180] The resulting report, published in 2007, summarizes the benefits and limitations of technology inducement prizes and makes recommendations for prize administration and topic selection.[181] Of note, the report concluded there are "many possibilities for employing innovation inducement prizes to overcome technical and scientific challenges in low-carbon energy supply, demand, and storage technologies."[182]

The Energy Policy Act of 2005 authorized the Secretary of Energy to offer cash prizes of up to $10 million for "breakthrough achievements in research, development, demonstration, and commercial application" for energy-related innovations, as well as additional "Freedom Prizes" for innovations that reduce U.S. dependence on foreign oil.[183] The Freedom Prizes will award over $4 million to "the most effective and sustainable initiatives in oil

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[172] NAT'L ACAD. OF ENG'G, CONCERNING FEDERALLY SPONSORED INDUCEMENT PRIZES IN ENGINEERING AND SCIENCE (1999); *see also* NAT'L ACAD. OF SCI., *supra* note 72, at 11 (crediting increase in prizes to NAE report).

[173] *See* Kalil, *supra* note 71, at 18; NAT'L ACAD. OF SCI., *supra* note 72, at 10.

[174] SCOTCHMER, *supra* note 67, at 2.

[175] Kalil, *supra* note 71, at 8.

[176] MCKINSEY, *supra* note 73, at 86.

[177] Id. at 23.

[178] For a summary of congressionally authorized prizes, see DEBORAH D. STINE, CONG. RESEARCH SERV., FEDERALLY FUNDED INNOVATION INDUCEMENT PRIZES (2009), *available at* http://www.fas.org/sgp/crs/misc/R40677.pdf.

[179] Science, State, Justice, Commerce, and Related Agencies Appropriations Act, Pub. L. No. 109-108, 119 Stat. 2290, 2318 (2006).

[180] NAT'L ACAD. OF SCI., *supra* note 72, at vii.

[181] *See generally id.*

[182] *Id.* at 42.

[183] Kalil, *supra* note 71, at 12.

displacement (permanent reduction in oil dependency) using existing technologies and efficiency strategies."[184] In 2006, the House of Representatives also passed the H-Prize Act to authorize $70 million in prizes for advancements in hydrogen energy.

The Obama Administration has shown interest in the use of prizes as well.[185] On April 30, 2010, the White House hosted a summit on "Promoting Innovation: Prizes, Challenges and Open Grantmaking," that featured X-Prize Foundation CEO Peter Diamandis.[186] This summit was preceded by Office of Management and Budget ("OMB") guidance to federal agencies on the use of challenges and prizes to spur technological innovation.[187] The guidance memorandum announced that it was Administration policy to "strongly encourage" federal agencies to "[u]tilize prizes and challenges as tools for advancing open government, innovation, and the agency's mission."[188] It further explained that many federal agencies have sufficient statutory authority to create technology inducement prizes with existing funds and spending authorizations. Specifically, the OMB noted that NASA and the Departments of Defense and Energy possess statutory authority to "directly administer prize competitions and use appropriated funds to provide the prize purse."[189] Existing statutes also authorize NASA and the Department of Energy ("DOE") to select third parties to administer prize competitions, and NASA and the NSF are permitted to obtain private outside funds to underwrite prize competitions.[190] Where agencies simply have authority to issue grants or enter into cooperative agreements, such authority may be sufficient to fund cash prizes for competitions, so long as such expenditures

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[184] THE FREEDOM PRIZE, http://www.freedomprize.org (last visited Dec. 2, 2010) (on file with the Harvard Law School Library).

[185] For example, prizes were briefly mentioned in a September 2009 Obama Administration white paper on spurring technological innovation. NAT'L ECON. COUNCIL, OFFICE OF SCI. & TECH. POLICY, A STRATEGY FOR AMERICAN INNOVATION: DRIVING TOWARDS SUSTAINABLE GROWTH AND QUALITY JOBS, 17 (2009), *available at* http://www.whitehouse.gov/assets/documents/SEPT_20__Innovation_Whitepaper_FINAL.pdf. During the 2008 presidential campaign, Republican candidate John McCain also proposed using prizes to spur innovation in electric car battery technology. *See* Jonathan H. Adler, *A Prize for McCain*, NATIONAL REVIEW ONLINE (June 23, 2008, 3:00 PM), http://www.nationalreview.com/articles/224850/prize-mccain/jonathan-h-adler (on file with the Harvard Law School Library).

[186] *See* Beth Noveck, Live from the White House Summit on Promoting Innovation through Prizes, Challenges, and Open Grantmaking, THE WHITE HOUSE (Apr. 30, 2010, 11:36 AM), http://www.whitehouse.gov/blog/2010/04/30/live-white-house-summit-promoting-innovation-through-prizes-challenges-and-open-gran (on file with the Harvard Law School Library).

[187] Memorandum from Jeffrey D. Zienst, Deputy Director for Management, Office of Management and Budget, to the Heads of Executive Departments and Agencies (Mar. 8, 2010) (on file with author) [hereinafter OMB Memo]; *see also Federal Agencies Encouraged to Offer Grand Challenges and Prize Contests*, SCI. CAREERS BLOG (Mar. 15, 2010), http://blogs.sciencemag.org/sciencecareers/2010/03/federal-agencie.html (on file with the Harvard Law School Library).

[188] OMB Memo, *supra* note 187, at 2.

[189] *Id.* at 5.

[190] *Id.* at 5–6.

are otherwise consistent with an agency's existing authorizations.[191] The OMB also concluded that agencies may use prizes to meet statutorily defined agency missions.[192] Taken as a whole, the OMB Memo authorizes agencies to use prizes in pursuit of their statutorily defined authorities and could lead to a significant increase in prize activity by the federal government.

IV. Prizes vs. Grants

There is broad agreement that additional funding of energy-related research and development will be necessary to spur the technological innovation necessary to reduce GHG emissions.[193] According to one estimate, the United States spends on the order of $3 billion annually on climate-related R&D.[194] Yet both public and private investment in such R&D has declined over the past few decades,[195] as has the number of patents issued for energy-related technologies.[196] While federal energy R&D spending increased significantly in 2007 and 2008, it remains well below historic levels. Energy R&D accounted for approximately 25 percent of nondefense federal R&D spending in 1980, but it was less than three percent in 2008.[197] Federal en-

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[191] *Id.* at 6.

[192] *Id.* at 6–7.

[193] *See* Hahn, *supra* note 50, at 583 ("It is fashionable to call for a large increase in R&D funding."); Gwyn Prins & Steve Rayner, *Time to ditch Kyoto*, 449 NATURE 973, 974 (2007) ("[I]nvestment in energy R&D should be placed on a wartime footing. This is a cause that embraces the political spectrum . . . ."); David Leonhardt, *A Climate Proposal Beyond Cap and Trade*, N.Y. TIMES, Oct. 12, 2010, at B1 (noting that increased funding in clean energy research has "a growing list of supporters" across the political spectrum). For an example of cross-ideological support for increased clean energy research, see STEVEN F. HAYWARD ET AL., POST-PARTISAN POWER: HOW A LIMITED AND DIRECT APPROACH TO ENERGY INNOVATION CAN DELIVER CHEAP ENERGY, ECONOMIC PRODUCTIVITY, AND NATIONAL PROSPERITY (2010), *available at* http://www.aei.org/docLib/Post-Partisan-Power-Hayward-101310.pdf, a recent report co-authored by analysts at conservative and liberal think tanks calling for increased energy R&D funding as an alternative to regulatory measures to address climate change.

[194] USCCTP, *supra* note 4, at 17. Some sources claim it is more than $4 billion. *See* Richard G. Newell, *The Energy Innovation System: A Historical Perspective*, *in* ACCELERATING ENERGY INNOVATION: INSIGHTS FROM MULTIPLE SECTORS (Rebecca Henderson & Richard Newell eds., forthcoming) (manuscript at 13), *available at* www.nber.org/chapters/c11747.pdf.

[195] Gregory F. Nemet & Daniel M. Kammen, *U.S. Energy Research and Development: Declining Investment, Increasing Need, and the Feasibility of Expansion*, 35 ENERGY POL'Y 746, 746 (2007) ("Investment in innovation in the U.S. energy sector is declining just as concerns about the environmental, geopolitical, and macroeconomic impacts of energy production and use are intensifying."). Of note, energy R&D funding has declined while overall R&D funding has increased. *Id.* at 747; *see also* A.D. Sagar & J.P. Holdren, *Assessing the Global Energy Innovation System: Some Key Issues*, 30 ENERGY POL'Y 465, 467 (2002) (noting decline in public and private energy-related R&D funding).

[196] *See* Nemet & Kammen, *supra* note 195, at 749–50; *see also* Alic et al., *supra* note 36, at 316 ("Many analysts in the United States have pointed to underinvestment in R&D by the US Department of Energy (DOE) since the 1980s as a symptom and cause of slow energy-technology development.").

[197] *See* NAT'L ACAD. OF SCI., LIMITING, *supra* note 23, at 120 (noting decline in energy R&D as percentage of non-defense federal spending from 1980 to 2008).

ergy R&D may inch higher, and the Department of Energy's Advanced Research Projects Agency-Energy ("ARPA-E") may receive a larger share of the available funds, but dramatic increases in public funding for research are unlikely.[198] The question at this point is less whether there should be more R&D funding, but the form such funding should take — and, in particular, whether the continued reliance upon traditional R&D funding mechanisms will be sufficient to meet the climate policy challenge.[199]

Traditional grant-driven funding for research and development has several limitations.[200] First, decisions about projects or efforts to fund are centralized, limiting the range of promising ventures that may receive funding and increasing the risk that research funding will not result in useful technological innovations. As the history of prizes detailed in the prior section shows, valuable technological innovations often come from surprising directions. Second, with ex ante grants, the government pays for R&D whether or not the R&D produces anything of value in return. Third, traditional grant funding is more subject to political pressure and may create negative incentives among researchers. Like traditional R&D grants, government-supported prizes reward innovations that "are publicly valued but not privately marketable."[201] Yet prizes do not suffer from these other drawbacks. Therefore, the federal government should reallocate portions of existing energy-related R&D funding from traditional research grants to the creation of technology inducement prizes.

Allocating grant money effectively requires the grant-making entity to pick "winners" and "losers," something the government has rarely done well.[202] This is particularly difficult to do when the awarding agency is not

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[198] ARPA-E was created in 2009 to spur greater technological innovation in the energy sector. Modeled on the DARPA within the Department of Defense, ARPA-E received an initial $15 million appropriation in FY 2009, and an additional $400 million in stimulus funding, but received no regular appropriations in FY 2010. *See* Katie Howell et al., *DOE: White House boosts nuclear, basic science funding*, GREENWIRE, Feb. 1, 2010.

[199] *See* Newell, *supra* note 194, at 1:

> [P]ublic resources are likely to be substantially constrained going forward given the current long-term fiscal outlook in the United States and elsewhere. This reality prompts additional questions: First, what options realistically exist for funding expanded investments in energy technology innovation? Second, what institutions are best positioned to direct and oversee publicly funded technology programs?

At the time of this writing it also appears that the Obama Administration is backing away from its pledge to "invest $150 billion over ten years in energy research and development." *See* Andrew C. Revkin, *The Case of the Missing Climate Pledge*, DOT EARTH (Aug. 19, 2010, 11:25 AM), http://dotearth.blogs.nytimes.com/2010/08/19/the-case-of-the-missing-climate-pledge/ (on file with the Harvard Law School Library).

[200] *See* Alic et al., *supra* note 36, at 316 ("[I]t is doubtful whether DOE-funded R&D alone can catalyse the type of innovation needed").

[201] *See* Masters, *Framework*, *supra* note 75, at 5.

[202] *See* JOHN A. ALIC ET AL., PEW CTR. ON GLOBAL CLIMATE CHANGE, U.S. TECHNOLOGY AND INNOVATION POLICIES: LESSONS FOR CLIMATE CHANGE 18–19 (2003), *available at* http://www.pewclimate.org/docUploads/US%20Technology%20&%20Innovation%20Policies%20(pdf).pdf ("Where government has sought to define technical attributes or design features and 'pick winners' in the marketplace, failure has been a common outcome.").

the primary "customer" of the technological solution that is to be funded.[203] Supporters of increased R&D funding often point to the successes of the Manhattan and Apollo projects as examples of successful, government-directed research.[204] Yet these are poor models for the climate technology challenge.[205] As Mowery, Nelson, and Martin note, both "were designed, funded and managed by federal agencies to achieve a specific technological solution for which the government was effectively the sole 'customer.'"[206] In the climate context, there is no single technology that will solve the problem, nor is there a single "customer" to satisfy.[207] Meeting the climate policy challenge will require the development and adoption of multiple, cost-effective technological innovations that are capable of satisfying consumers (or governments) the world over.[208]

Federal funding of science is worthwhile, particularly for basic scientific research.[209] Yet federal R&D money rarely produces commercially viable technologies or dramatic technological innovation.[210] This is particularly true for agencies that are not themselves consumers of the innovations they are trying to stimulate. The Department of Defense's procurement process may stimulate a significant degree of innovation because those defense contractors that develop technological breakthroughs may be rewarded with sizable contracts. There is competition for the contracts and innovation is rewarded. The Department of Energy, on the other hand, is not a significant consumer of the technology it funds.[211] Indeed, the Department of Defense

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[203] *See* David C. Mowery, Richard R. Nelson & Ben R. Martin, *Technology Policy and Global Warming: Why New Policy Models Are Needed (or Why Putting New Wine in Old Bottles Won't Work)*, 39 RES. POL'Y 1011, 1012 (2010).

[204] *See, e.g.*, John M. Amidon, *America's Strategic Imperative: A "Manhattan Project" for Energy*, JOINT FORCE Q., Autumn 2005 at 68; Jay Michaelson, *Geoengineering: A Climate Change Manhattan Project*, 17 STAN. ENVTL. L.J. 73, 73 (1998); Thomas L. Friedman, *Bush's Waterlogged Halo*, N.Y. TIMES, Sept. 21, 2005, at A25 (calling for a Manhattan Project for developing alternatives for energy independence); *Why Do We Call It the Apollo Alliance?*, APPOLO ALLIANCE, http://apolloalliance.org/about/why-do-we-call-it-the-apollo-alliance/ (last visited Dec. 2, 2010) (on file with the Harvard Law School Library).

[205] *See, e.g.*, Chi-Jen Yang & Michael Oppenheimer, *A "Manhattan Project" for Climate Change?*, 80 CLIMATIC CHANGE 199, 199, 203 (2007) (calling for increased R&D efforts but not under a Manhattan Project "style of governance").

[206] Mowery, Nelson & Martin, *supra* note 203, at 1012.

[207] Jaffe, Newell & Stavins, *supra* note 19, at 489 (noting that technology diffusion has been slow in a "variety of disciplines" because "potential technology adopters are heterogenous, so that a technology that is generally superior will not be equally superior for all potential users . . . .").

[208] *See* Mowery, Nelson & Martin, *supra* note 203, at 1013 (noting there was no "technology adoption" issue with either the Manhattan or Apollo projects); *see also* Newell, *supra* note 194, at 3–4 (noting need for economic incentives, including market demand, for innovation and diffusion of technology).

[209] *But see* TERENCE KEALEY, THE ECONOMIC LAWS OF SCIENTIFIC RESEARCH 344–45 (1996) (questioning value of any government support for science, including basic research).

[210] *See* Jaffe, Newell & Stavins, *supra* note 19, at 473 ("Examples of successful government technology development (as opposed to research) have been particularly few.").

[211] *See* Alic et al., *supra* note 36, at 316 ("The DOE neither buys nor sells goods or services based on energy and climate innovations. It therefore has few incentives to manage R&D in accord with marketplace needs rather than scientific norms.").

may be better positioned to encourage energy innovation through its procurement process than is the DOE with traditional R&D grants.[212] Insofar as this is so, it is because a competitive procurement process can induce innovation by offering a substantial financial reward for significant breakthroughs.

Direct federal investment R&D expenditures tend to be less productive than private sector investments. One reason for this is that federal agencies tend to develop "organizational stove pipes" that reinforce "risk-averse, parochial views" about what sorts of technologies are worth funding.[213] As a result, notes one Department of Energy official, "Government R&D dollars will tend to flow to marginal ideas."[214] Government R&D funding often goes to support relatively mature technologies rather than those projects more likely to spur needed innovation.[215]

Government grants are also subject to various regulations and reporting rules that inflate costs and may discourage the participation by some researchers.[216] Prizes, on the other hand, may "attract teams with fresh ideas who would never do business with the federal government because of procurement regulations" or other bureaucratic obstacles[217] and may be "more likely to reach innovators who happen to be good at R&D or diffusion, but are perhaps not very skilled at documenting their work."[218]

Given their limitations, it should not be all that surprising that government efforts to stimulate innovation through R&D subsidies have not borne much fruit.[219] The Synthetic Fuels Corporation is but one of many energy-related projects that failed to produce returns sufficient to justify the invest-

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[212] *See id.* at 317 ("The DOD is better placed for catalysing rapid innovation in energy technologies than the DOE because the DOD is a major customer for energy-consuming systems and equipment for its roughly 500 permanent installations, as well as for operational equipment . . . .").

[213] Benjamin K. Sovacool, *Replacing tedium with transformation: Why the U.S. Department of Energy needs to change the way it conducts long-term R&D*, 36 ENERGY POL'Y 923, 926 (2008) (quoting former DARPA director F.L. Fernandez).

[214] Jerry Taylor & Peter VanDoren, *Soft Energy Versus Hard Facts: Powering the Twenty-First Century*, *in* EARTH REPORT 2000: REVISITING THE TRUE STATE OF THE PLANET 147 (Ronald Bailey ed., 2000) (citing Department of Energy, Energy Research Advisory Board member Eric Reichl).

[215] *See, e.g.*, Michael Jefferson, *Accelerating the Transition to Sustainable Energy Systems*, 36 ENERGY POL'Y 4116, 4119 (2008) (noting subsidy support for "mature renewable energy technologies, which should be able to prosper without [it]").

[216] *See* Naik, *supra* note 80, at A1 (noting concerns about high administrative costs in federal energy R&D).

[217] *See* Kalil, *supra* note 71, at 7.

[218] Masters, *Prosperity*, *supra* note 86, at 61.

[219] *See* Newell, *supra* note 194, at 3 ("substantial public investments in alternative energy have by and large not yielded game-changing technological advances that would allow for a fundamental shift in the distribution of primary energy sources"). A 2001 NAS report examining Department of Energy research concluded that some of the Department's energy efficiency research had been worthwhile, and that the overall portfolio of DOE energy research produced a positive return, largely due to substantial benefits from a handful of projects. *See* NAT'L ACAD. OF SCI., ENERGY RESEARCH AT DOE: WAS IT WORTH IT? ENERGY EFFICIENCY AND FOSSIL ENERGY RESEARCH 1978 TO 2000 5–8 (2001).

ment, at a cost of over $4 billion.[220] Again, there may be an economic case for government support for basic scientific research, but traditional innovation-oriented fossil fuel R&D programs cannot be justified on those grounds.

While innovation requires risk taking, politically controlled agencies have a difficult time accepting failure and terminating programs.[221] Once grants have been allocated, the recipient has an interest in keeping the money flowing, even if it will not produce positive returns. As Linda Cohen and Roger Noll found, substantial political pressure to continue R&D programs remains long after it is clear they have failed.[222] At the same time, the political process has a preference for large, visible projects to the detriment of those that are less conspicuous, but more likely to produce results.[223] Encouraging needed innovation is not simply a matter of dedicating resources to those endeavors favored by scientists and technologists. Even the most educated and well-intentioned experts may focus their energies in the wrong direction. Indeed, as noted above, it is the unexpected nature of many innovations that makes them so valuable.[224]

Prizes, like patents, impose the relevant R&D costs of the invention on the inventors. Prize sponsors only pay for an inventor's work if she is ultimately successful.[225] Unsuccessful innovators, and their sponsors, are left to bear their R&D costs themselves. This has clear fiscal benefits for the government, and taxpayers.[226] If R&D is funded ex ante, there is no assurance that the investment will produce any benefits to the funder at all.[227] With prizes, on the other hand, the financial payment is conditional upon the prize conditions being fulfilled. Provided the prize is properly designed — and a would-be innovator succeeds — the funder gets its money's worth.

With any directed R&D program, there is a risk that the wrong target or goal is selected. This can be a problem with prizes or grants. Yet in the case of prizes, the financial risk is borne by each of those inventors who is seek-

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[220] *See* LINDA COHEN & ROGER NOLL, THE TECHNOLOGY PORK BARREL 365–69 (1991). Richard G. Newell, confirmed in 2009 as head of the Energy Information Administration in the Department of Energy, characterized the Synfuels Corporation as a failure. *See* Newell, *supra* note 194, at 6.

[221] *See* Michael Hart, *The Chimera of Industrial Policy: Yesterday, Today, and Tomorrow*, 19 CAN - U.S. L.J. 19, 38 (1993).

[222] *See* COHEN & NOLL, *supra* note 220, at 378; *see also* Ronald J. Sutherland & Jerry Taylor, *Time to Overhaul Federal Energy R&D*, POL'Y ANALYSIS No. 424, Cato Institute, Feb. 7, 2002, at 6.

[223] *See* Newell, *supra* note 194, at 18; COHEN & NOLL, *supra* note 220, at 370.

[224] *See supra* notes 70–81 and accompanying text.

[225] In the case of patents, on the other hand, the costs of developing successful innovations are passed through to consumers. *See* SCOTCHMER, *supra* note 67, at 34–39.

[226] As Scotchmer notes, "When innovations are funded out of general revenue, there is no guarantee that the benefits received by any individual taxpayer outweigh that taxpayer's share of the cost," if, that is, the funding generates any innovation benefits at all. *See* SCOTCHMER, *supra* note 67, at 38.

[227] Contrary to some claims, it is unclear how much government science and R&D funding directly contribute to economic growth. *See* Julia Lane, *Assessing the Impact of Science Funding*, 324 SCI. 1273, 1273 (2009).

ing the prize, and it is not borne by the funder. Moreover, the potential for there to be multiple groups seeking the same prize serves to lessen the risk for the prize funder. In effect, a prize system diversifies the risk and reduces the likelihood that the funder's resources are wasted.[228]

While even failed research projects may have value — learning what *doesn't* work is often important, and may lead to unintended discoveries — government grants on dead-end technologies may result in substantial wastes of taxpayer dollars. For example, NASA gave over $900 million to Lockheed Martin to develop the X-33, a component of the next-generation space vehicle, only to see the program canceled due to a fuel tank problem.[229] In this instance, the taxpayer was out almost $1 billion with little to show for it. The failure of a research investment to produce a viable technological innovation does not necessarily mean that the investment was wasted,[230] and discovering what doesn't work can be as important as discovering what works.[231] Nonetheless, because of fiscal limitations on government R&D funding, it is worth focusing taxpayer dollars in ways that maximize the likelihood of a positive return.

Energy policy is typically quite politicized, and energy subsidies are no exception. Government grant-making is inevitably subject to political pressures by politicians and interest groups seeking funding for their particular projects. Grants are often dispersed on political criteria, rewarding large, politically connected incumbent firms, rather than innovative upstarts.[232] In the case of the SynFuels program, fuel cell projects were "allotted to each of the 50 states, regardless of economic viability."[233] This may have bolstered political support for the program, but it did nothing to make the underlying investments worthwhile.

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[228] As Hanson notes, "Standard principal-agent theory suggests that paying for results is attractive when the principal can more easily specify the results she prefers, when the principal is more risk averse, and when agents can take more risks and have more access to capital. Paying for effort, on the other hand, is attractive when the principal can more cheaply monitor effort, when she knows better whom to hire, and when the principal can take more risks." *See* Hanson, *supra* note 111, at 4.

[229] *See* Kalil, *supra* note 71, at 7.

[230] *See* SCOTCHMER, *supra* note 67, at 55 ("ex post regret does not mean that an investment was ex ante inefficient.").

[231] *See* WILLIAM M. LANDES & RICHARD A. POSNER, THE ECONOMIC STRUCTURE OF INTELLECTUAL PROPERTY LAW 301 (2003) (stating "research expenditures of the losers of the race may not be wasted" because they "will generate information that the losers may be able to use in other projects"); *see also* Arrow et al., *supra* note 60, at 2 ("Government R&D should encourage more risk-taking and tolerate failures that could provide valuable information.").

[232] *See generally* COHEN & NOLL, *supra* note 220, at 53–71 (discussing political influence on research expenditures).

[233] NAT'L ACAD. OF SCI., THE GOVERNMENT ROLE IN CIVILIAN TECHNOLOGY: BUILDING A NEW ALLIANCE 59 (1992).

It is not uncommon for political leaders to overrule expert determinations of what types of projects should, or should not, get funded.[234] Grant programs seek to avoid this problem through the institution of various procedures, including peer-review. Yet even the most educated and well-intentioned experts may focus their energies in the wrong direction. As Cohen and Noll concluded:

> The overriding lesson from the case studies is that the goal of economic efficiency — to cure market failures in privately sponsored commercial innovation — is so severely constrained by political forces that an effective, coherent national commercial R&D program has never been put in place.[235]

Political considerations could influence prize criteria, but the risk of political interference is substantially less. A government official can see who is receiving an ex ante grant, whereas the likely recipient of an ex post prize is uncertain. It is difficult to predict, let alone ensure, that a prize for an as-yet-undeveloped innovation will go to a politically preferred recipient.

Prizes do not create the same incentives among reward seekers as government research grants may among grant seekers. Specifically, those seeking government grants may have an incentive to exaggerate the potential of their projects and, once funding is obtained, may have an incentive to divert resources and slow the rate of achievement so as to lay the groundwork for obtaining future grants.[236] Whereas prizes and patent protection are somewhat self-enforcing, because researchers will not be rewarded unless they focus their efforts on promising subjects of research, grants are not.[237]

To their detriment, the same characteristics that make innovation prizes so effective discourage their use by politicians. Grant programs empower government officials to dole out funds to favored constituencies and institutional insiders. Even where efforts are made to insulate the decision making process, grant-making officials are influenced by knowledge of who will receive grant support, and the grants go out whether or not a grant recipient delivers or a problem is solved. Prize money, on the other hand, is only paid out if someone fulfills the preset conditions and is available to all comers, irrespective of their political influence or institutional connections. Indeed,

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[234] For example, the synthetic fuels program invested in projects involving high-sulfur eastern coal for political reasons, even though low-sulfur western coal was more promising. *See* Cohen & Noll, *supra* note 220, at 368.

[235] *Id.* at 378.

[236] Michael Kremer & Rachel Glennerster, Strong Medicine: Creating Incentives for Pharmaceutical Research on Neglected Diseases 49 (2004) ("Researchers funded on the basis of an outsiders' [sic] assessment of potential rather than actual product delivery have incentives to exaggerate the prospects that their approach will succeed, and once they are funded, may even have incentives to divert resources away from the search for the desired product."); *see also* Scotchmer, *supra* note 67, at 248.

[237] *See* Scotchmer, *supra* note 67, at 247 (With grants, "the whole point is to reimburse costs before they are incurred.").

as with the longitude prize, the reward may go to an innovation disfavored by political and scientific elites.

It bears repeating, however, that prizes are not without their drawbacks. Most notably, prize systems require researchers to obtain funding for their research up front. For some types of research, particularly where expensive equipment is required, this can create a significant obstacle. Prizes are also not particularly well-suited to situations in which the funding authority cannot articulate clear criteria upon which the prize would be awarded. For this reason, prizes are not as useful for the funding of basic research. In the climate change context, however, there is a need for practical innovations that are commercially viable. This makes prizes particularly well suited for the climate policy challenge.

V. Innovation and Regulation

Thus far, this article has focused on government funding of scientific and technological research as the primary means to induce greater innovation for climate change policy. What about regulatory alternatives? Governmental regulation is the conventional approach to environmental pollution problems.[238] Historically this has meant command-and-control regulation. In recent decades, there has been increasing interest in, and occasional use of, market-oriented mechanisms such as tradable pollution allowances or "cap and trade."[239] Regulation of some sort to address the control of GHG is almost inevitable.[240] The U.S. Environmental Protection Agency has authority to regulate GHG emissions under the Clean Air Act ("CAA"),[241] and recently promulgated regulations to limit such emissions from motor vehicles and the largest stationary source emitters.[242] Legislation passed by the House of Representatives would create a cap and trade regime for GHG emissions and impose a wide range of climate-related regulations, including

[238] *See* Jonathan H. Adler, *Free & Green: A New Approach to Environmental Protection*, 24 Harv. J. L. & Pub. Pol'y 653 (2001) (discussing the conventional approach to environmental protection in contrast to an alternative paradigm).

[239] *See, e.g.*, Richard B. Stewart, *Controlling Environmental Risks through Economic Incentives*, 13 Colum. J. Envtl. L. 153 (1988) (discussing theoretical merits of market mechanisms). For an example of market mechanisms in use, see Clean Air Act §§ 401–416, 42 U.S.C. §7651 (2006) (Acid Depositions Control and Emissions Trading).

[240] *See* Jonathan H. Adler, *Warming Up to Climate Change Litigation*, 93 Va. L. Rev. In Brief 63, 75 (May 21, 2007), http://www.virginialawreview.org/inbrief/2007/05/21/adler.pdf (on file with the Harvard Law School Library).

[241] Massachusetts v. EPA, 549 U.S. 497, 533 (2007).

[242] *See* Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act, 74 Fed. Reg. 66496 (Dec. 15, 2009) (to be codified at 40 C.F.R. Ch.1); Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, 75 Fed. Reg. 25323 (May 7, 2010) (to be codified at 40 C.F.R. pts. 85, 86, and 600, 49 C.F.R. pts. 531, 533, 536–538); Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule, 75 Fed. Reg. 31513 (June 3, 2010) (to be codified at 40 C.F.R. pts 51, 52, 70, and 71).

renewable portfolio standards for utilities, appliance efficiency standards, and requirements for building codes and land-use planning.[243]

While regulation will be one of the tools used to try to address global climate change, it is doubtful that regulation alone will be sufficient.[244] Even aggressive regulatory measures are unlikely to set a path toward atmospheric stabilization.[245] Regulatory mandates can only do so much if the necessary technologies are not ready to be deployed. Whatever the other virtues of traditional and market-oriented regulatory approaches for controlling traditional (non-GHG) pollution sources, they are unlikely to stimulate the level of technological innovation necessary to achieve dramatic reductions in GHG emissions over the near- to medium-term.[246] Regulatory requirements can certainly assist with technology diffusion and accelerate the adoption and refinement of technologies that have already been discovered and developed. Yet such measures are unlikely to spur investment in technological breakthroughs. In some cases, the premature adoption of regulatory standards could even be counterproductive.

Whereas prizes have spurred dramatic technological breakthroughs, as with navigation and food preservation,[247] there is little empirical evidence that regulations are a reliable method of encouraging technological innovation, particularly revolutionary breakthroughs of the sort necessary to address climate change.[248] What evidence there is suggests that regulatory strategies are more likely to produce incremental innovations than breakthroughs, and that market-oriented instruments will be more effective than traditional command-and-control regulation.[249] Regulations are more suited to incremental technological change and the diffusion of preexisting innovations. If a given technology exists, a regulatory mandate may expand its use. Yet mandating environmental improvements produces inconsistent and unre-

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[243] *See* American Clean Energy and Security Act of 2009, H.R. 2454, 111th Cong. (as passed by H.R., June 26, 2009).

[244] *See* Arrow et al., *supra* note 60, at 3 ("Mandates and subsidies aimed at supporting the deployment of relatively mature technologies are unlikely to be cost-effective tools for eliciting the major reductions of greenhouse gas emissions that now appear to be called for."); Hoffert et al., *supra* note 33, at 986 ("[T]he fossil fuel greenhouse effect is an energy problem that cannot be simply regulated away.").

[245] *See supra* notes 36–42 and accompanying text.

[246] *See* Hahn, *supra* note 50, at 580 (observing that neither mandated standards nor subsidies are "particularly well-suited for generating cost-effective innovation addressing the problem of climate change").

[247] *See supra* Part III.

[248] *See* Adam Jaffe, Richard G. Newell & Robert N. Stavins, *Environmental Policy and Technological Change*, 22 ENVTL. & RES. ECON. 41, 55 (2002); David E. Adelman, *Climate Change, Federalism, and Promoting Technological Change*, *in* BEYOND ENVIRONMENTAL LAW: POLICY PROPOSALS FOR A BETTER ENVIRONMENTAL FUTURE 209–11 (Alyson C. Flournoy & David M. Driesen eds., 2010).

[249] *See* Jaffe, Newell & Stavins, *supra* note 248, at 55. *But see* Margaret R. Taylor, Edward S. Rubin & David A. Hounshell, *Regulation as the Mother of Invention: The Case of SO_2 Control*, 27 LAW & POL'Y 348, 370 (2005) (finding no evidence that emissions trading under the Clean Air Act of 1990 induced greater technological innovation than traditional regulation).

liable incentives for technological innovation. As former EPA Administrator Carol Browner has observed, the "traditional regulatory path" can only produce innovation that is "incremental at best" because the "current regulatory system is about going from A to B to C." But what is necessary today to address global climate change is "going from A to Z."[250]

Using traditional regulatory tools to drive technological innovation requires detailed knowledge about the desired course of technological change and what sorts of innovations are likely or foreseeable. Yet government regulators rarely have the necessary information or foresight to drive innovation in this way.[251] While government regulators "can typically assume that *some* amount of improvement over existing technology will always be feasible, it is impossible to know how much."[252] As Arrow et al. observe, "[r]egulators can find it difficult to obtain information about the status of technologies that is accurate enough to allow them to set standards that both can be achieved and will induce real innovation."[253] Even if regulators were to identify a proper target initially, the regulatory process changes so slowly that regulatory standards would be unlikely to keep up with technological change or account for new information.

It is one thing for the government to require (or subsidize) the adoption of a new technology to force its diffusion throughout an industry, but quite another to mandate production or pollution improvements that have yet to be achieved.[254] Government regulators "have a relatively poor record in picking which future technologies will best succeed in achieving a particular objective."[255] This has been as true with regulatory efforts to spur innovation along a certain path as it has been with traditional research subsidies, and for the same reasons: government officials, even those with the benefit of specialized technical knowledge, lack the foresight necessary to predict technological progress and the future path of innovation.[256]

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[250] Eric W. Orts, *Reflexive Environmental Law*, 89 Nw. U. L. Rev. 1227, 1229 (1995) (quoting Carol Browner).

[251] *See* Hahn, *supra* note 50, at 580 ("The regulator typically lacks the kind of information needed to set standards appropriately for forcing innovation."); Marchant, *supra* note 36, at 836 ("[I]t is difficult to predict the ingenious and creative innovations" that scientists and inventors might develop).

[252] Jaffe, Newell & Stavins, *supra* note 248, at 50.

[253] Arrow et al., *supra* note 60, at 3.

[254] *See* Hahn *supra* note 50, at 580 ("Standards may be effective in limited situations where the technological solution is reasonably clear, but they are unlikely to result in major breakthroughs.").

[255] Marchant, *supra* note 36, at 836.

[256] Gustavo Collantes & Daniel Sperling, *The Origin of California's Zero Emission Vehicle Mandate*, 42 Trans. Res. Part A 1302, 1307 (2008) ("Uncertainty is . . . an inherent characteristic of technology-forcing approaches, as regulators do not know how much innovation industry is capable of achieving, and industry is reluctant to provide such information (even if they knew)."); Jaffe, Newell & Stavins, *supra* note 19, at 477 ("while regulators can typically assume that *some* amount of improvement over existing technology will always be feasible, it is impossible to know how much. Standards must either be made unambitious, or else run the risk of being ultimately unachievable, leading to great political and economic disruption."); Marchant, *supra* note 36, at 836.

California's failed effort to mandate the sale of electric vehicles in the 1990s demonstrates the difficulty of trying to use regulatory mandates to force technological innovation.[257] California regulators and others believed that sufficiently stringent regulatory requirements would induce automakers to develop commercially marketable electric cars. In September 1990, the California Air Resources Board ("CARB") adopted a Low Emission Vehicle ("LEV") program that, among other things, required each automaker selling passenger vehicles within the state to ensure that those vehicles sold met a stringent average emissions standard.[258] The original mandate also required automakers to "make available for sale" vehicles that would qualify as "zero emission," such as electric cars.[259] Specifically, automakers were required to ensure that Zero Emission Vehicles ("ZEVs") accounted for at least two percent of vehicles sold in 1998-2000, and ever increasing shares in subsequent years.[260] The program was intended to be technology-forcing, but CARB believed the mandates were achievable.[261] As it turned out, however, CARB was overly optimistic about its cost estimates and the pace at which battery technology would improve.[262]

As the deadline for the ZEV mandate approached, CARB began to realize that there was no way for automakers to meet the target. Consumers were not willing to purchase a sufficient number of electric vehicles, even if sold at a loss, to satisfy the sales mandate.[263] Anticipated breakthroughs in

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[257] *See id.* at 838.

[258] *See* Collantes & Sperling, *supra* note 256, at 1304, 1309–10.

[259] For an overview of the California Zero Emissions Vehicles ("ZEV") mandate, see Collantes & Sperling, *supra* note 256. Though referred to as "Zero Emission Vehicles," electric cars are not truly emission free. The generation of electricity to charge the vehicle battery can be a substantial source of emissions. *See* Michael Moyer, *The Dirty Truth about Plug-In Hybrids*, SCI. AMER., July 2010, at 54. In some parts of the country, the use of plug-in electric vehicles will actually result in greater net emissions of carbon dioxide than traditional hybrid vehicles. *Id.* Electric vehicles are also not necessarily "zero emission" in terms of direct vehicle emissions. Due to the need to operate vehicles in colder temperatures in Northern California, in 1993 CARB issued a waiver to allow automakers to equip electric vehicles with gasoline or diesel-powered heaters without losing their "ZEV" status. *See* Oscar Suris, *Cold Weather Is Still a Problem In Electric Cars*, WALL ST. J., Mar. 8, 1994, at B1. The program also included requirements for fuel content. Insofar as the oil industry opposed the CARB policy, it opposed the fuel mandates and ignored the ZEV requirement. *See* Collantes & Sperling, *supra* note 256, at 1310.

[260] Under the original mandate, ZEVs had to account for five percent of vehicles sold in 2001 and 2002 and ten percent in 2003 and thereafter. Collantes & Sperling, *supra* note 256, at 1304.

[261] *See id.* at 1307.

[262] Among other things, CARB's estimates of the costs of operating battery-powered vehicles did not include the costs of home-recharging equipment. *Id.* CARB's cost estimates were also substantially lower than those of other economic analysts. *See* KAY H. JONES & JONATHAN H. ADLER, CATO INST., TIME TO REOPEN THE CLEAN AIR ACT 9–10 (1995). Interestingly enough, CARB may have only been following the lead of then-General Motors ("GM") CEO Roger Smith who also presented an overly optimistic view of GM's electric car prototype, the "Impact." *See* Collantes & Sperling, *supra* note 256, at 1306.

[263] GM's optimistic projections were that the Impact could account for 0.5% of its California vehicle sales, only one quarter of the CARB mandate. Collantes & Sperling, *supra* note 256, at 1308. One study, financed by two automakers, found that consumers would not

battery technology did not materialize.[264] As a consequence, CARB made repeated revisions to the ZEV mandate, delaying the date at which sales mandates would take effect.[265] In effect, CARB shifted the requirement from a specific technology mandate to a more flexible performance goal.[266] This was fortunate, as automakers ended up using a different technology to meet the LEV requirement.[267] Regulators had been wrong in their assessment of automakers' ability to produce commercially viable electric vehicles, yet they caused the diversion of substantial private and public funds in pursuit of this aim.

Regulatory measures, particularly those focused on the adoption of technologies, often have compliance periods that are too short to induce large-scale innovation or significant technological breakthroughs.[268] The regulatory environment can also generate uncertainty that further discourages investments in technological innovation.[269] Longer-term investments in innovation require credible and stable commitments, which traditional environmental regulation may undermine. Insofar as governmental commitments to future levels of regulation are of "questionable credibility," this diminishes the incentives for innovation that environmental regulations could otherwise provide.[270]

In some instances, the premature imposition of stringent regulatory requirements could actually inhibit or retard the rate of technological innova-

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purchase electric vehicles over traditional gasoline vehicles unless they were $28,000 cheaper, and yet electric vehicles were (and still are) substantially more expensive than gasoline-powered vehicles. *See* James R. Healey, *California May Soften Electric Car Mandate*, USA Today, June 2, 2000, at 3B; *see also* Stuart F. Brown, *It's the Battery, Stupid!*, Popular Sci., Feb. 1995, at 62 (arguing that batteries for electric vehicles "aren't ready for prime time"); Lawrence M. Fisher, *California is Backing Off Mandate for Electric Car*, N.Y. Times, Dec. 26, 1995, at A14 (noting the view of "some automobile experts" that "current electric cars fall short on performance, range, or both").

[264] Indeed, even in 2010 it is not clear that battery technology is sufficient to capture a significant portion of the vehicle market. The newly released Volt from GM is, by some accounts, "a vehicle that costs $41,000 but offers the performance and interior space of a $15,000 economy car." Edward Niedermeyer, *G.M.'s Electric Lemon*, N.Y. Times, July 30, 2010, at A23; *see also* Jude Anderson & Curtis D. Anderson, Electric and Hybrid Cars 161 (2005) (noting limits of battery technology); Andres Dinger et al., Boston Consultation Group, Batteries for Electric Cars: Challenges, Opportunities and the Outlook to 2020 (2010) (same), *available at* http://www.bcg.com/documents/file36615.pdf.

[265] In 1996, CARB removed the initial "ramp up" ZEV sales requirement. In 1998, it agreed to offer automakers credit toward the ZEV mandate for sales of extremely clean vehicles. In 2001 it expanded the credit for non-ZEVs further, and then made additional revisions (some in response to litigation) in 2003. *See Zero-Emission Vehicle Legal and Regulatory Activities – Background*, Cal. Air Res. Bd. (Mar. 17, 2010), http://www.arb.ca.gov/msprog/zevprog/background.htm (on file with the Harvard Law School Library).

[266] *See* Marchant, *supra* note 36, at 837–38.

[267] *See id.* at 838.

[268] *See* Arrow et al., *supra* note 60, at 3.

[269] *See* Newell, *supra* note 194, at 15–16 (noting research showing that changing regulatory conditions and uncertainty can dampen private sector investment in technological innovation).

[270] *See* Marchant, *supra* note 36, at 848.

tion.[271] By increasing the costs of modifying and enhancing existing industrial facilities, and the costs of replacing older, dirtier facilities with newer, cleaner ones, pollution-control regulations may work at cross-purposes with the goal of developing cleaner and more energy-efficient means of production. This is a well-documented problem with regulations that grandfather existing facilities. Laws that grandfather older facilities can create substantial disincentives to the development and adoption of newer, cleaner technologies.[272] Yet grandfathering is difficult to avoid politically, as the effect of regulatory measures on existing facilities is of greater political concern than the effect of regulations on facilities not yet built. As a consequence, regulations often protect incumbent firms.

Technology-based standards, in particular, can "play a key role in discouraging innovation," as they can result in the locking-in of an administratively anointed technology, thereby discouraging efforts to develop more advanced alternatives.[273] According to a 1995 report of the Office of Technology Assessment ("OTA"), "[r]egulations that are overly prescriptive can lock in existing technologies to the detriment of other technologies that might meet or exceed requirements."[274] If a regulation embraces a given technological approach to meeting a given target, there is little incentive to develop alternatives or improve upon the technology.[275] As a consequence, "technology-based standards provide the weakest incentives for both abatement technology and output technology innovation."[276] Yet even performance-based standards can discourage innovation as such standards may rest upon established reference technologies in order to facilitate implementation and enforcement. As OTA concluded, "[i]n such cases, companies and reg-

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[271] *See* Environmental Law Institute, Barriers to Environmental Technology Innovation and Use 6 (1998) (noting potential for environmental regulation to create "significant barriers to innovation") [hereinafter Barriers].

[272] U.S. Office of Tech. Assessment, Innovation and Commercialization of Emerging Technologies 87 (1995) ("Regulatory systems that grandfather existing facilities may dissuade investments in new or upgraded technologies if such changes trigger more stringent standards or lengthy permitting processes.").

[273] Barriers, *supra* note 271, at 7. This report further explains: "Emission limits or discharge standards based on a single best technology create practical barriers to innovation by limiting permissible technologies to available ones that meet the standard. This requirement precludes the normal development and refinement process most technologies need to achieve their best performance and, in many cases, can limit permissible technologies to a single one." *Id.*; *see also* Jaffe, Newell & Stavins, *supra* note 248, at 50 ("Technology standards are particularly problematic, since they tend to freeze the development of technologies that might otherwise result in greater levels of control.").

[274] U.S. Office of Tech. Assessment, Innovation and Commercialization of Emerging Technologies 87–88 (1995) [hereinafter OTA].

[275] Jaffe, Newell & Stavins, *supra* note 248, at 50; Adam B. Jaffe and Robert N. Stavins, *Dynamic Incentives of Environmental Regulations: The Effects of Alternative Policy Instruments on Technology Diffusion*, 29 J. Envtl. Econ. & Mgmt. 43, 46 (1995) ("Once a performance standard has been satisfied, there may be little benefit to developing and/or adopting even cleaner technology.").

[276] Wesley A. Magat, *The Effects of Environmental Regulation on Innovation*, 43 Law & Contemp. Problems 4, 21 (1979).

ulators are likely to prefer reference technologies they are confident will meet standards, rather than innovative approaches that are less certain."[277]

The broader effects of regulation on innovation in a given sector are also important to consider. Insofar as GHG emission regulations lead to a reduction in fossil fuel use, they may actually reduce the incentive to develop technologies to reduce emissions from such fuel sources.[278] Specifically, if emission-control policies put a price on carbon, and fossil fuel use declines, the relative incentive to make fossil fuel use more efficient will decline as well.[279]

Market-based regulatory approaches are likely to be more effective at encouraging technological innovation than command-and-control regulations, insofar as such instruments leave regulated firms substantial flexibility in meeting emission targets or other requirements.[280] Yet there is little evidence that even market-oriented instruments can produce more than incremental improvements. The CAA's acid rain program, for instance, is widely credited with achieving substantial pollution reductions at a relatively low cost, yet it does not appear to have spurred much innovation.[281] The targets imposed under that program were "well within the range of capabilities of existing technology," and thus did more to encourage diffusion than innovation.[282]

In theory, the imposition of a carbon tax or other price mechanism on GHG emissions could be sufficient to spur greater levels of technological innovation. If the tax could be set at a level equal to the social costs expected to result from climate change, then firms would have an incentive to develop cost-effective means of reducing GHG emissions.[283] Yet such a tax

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[277] OTA, *supra* note 274, at 88.

[278] *See* Joshua S. Gans, *Innovation and Climate Change Policy* 1 (Apr. 27, 2009) (unpublished manuscript), *available at* http://works.bepress.com/joshuagans/24.

[279] *See* Gans, *supra* note 278, at 2. As regulations reduce overall economic activity, they could further offset the incentive to develop emission-reducing technologies. *See id.* at 3 ("Even if socially beneficial, climate change policy reduces the size of the 'real' economy and hence, may reduce the overall rate of innovation."); *see also* Jaffe, Newell & Stavins, *supra* note 19, at 474 ("To the extent that regulation inhibits investment and/or slows productivity growth, this can be viewed as indirect evidence suggesting that induced innovation effects are either small or are outweighed by other costs of regulation.").

[280] *See* Jaffe, Newell & Stavins, *supra* note 19, at 477 (noting that market-based instruments provide greater incentives and opportunity for innovation than performance standards which provide greater incentives than technology standards). *But see* Popp, *supra* note 23, at 284 (citing research questioning whether market-based instruments induce greater innovation than command-and-control regulations).

[281] *See* David M. Driesen, *An Environmental Competition Statute*, *in* BEYOND ENVIRONMENTAL LAW: POLICY PROPSOALS FOR A BETTER ENVIRONMENTAL FUTURE 175–76 (Alyson C. Flournoy & David M. Driesen eds., 2010).

[282] Lane, *supra* note 227, at 3; *see also* Anne E. Smith, Jeremy Platt & A. Denny Ellerman, The Costs of Reducing SO2 Emissions – Not as Low as You Might Think (Ctr. for Energy and Envtl. Policy Research, Working Paper No. 98010, 1998).

[283] As Nobel laureate economist Ronald Coase noted, setting a tax at a level equal to the social costs of pollution "would require a detailed knowledge of individual preferences," and it is unclear "how the data for such a taxation system could be assembled." R.H. Coase, *The Problem of Social Cost*, 3 J.L. & ECON. 1, 41 (1960).

is unlikely. Even assuming that governments possess the level of information to set the tax at the proper Pigouvian level,[284] such a tax would not be viable politically. For the same reason that legislatures will not adopt more stringent regulatory measures, there is no possibility that a sufficiently high tax would be set. Therefore, even if such a tax would provide sufficient incentives for technological innovation, such a tax will not be adopted.

If anything, greater technological innovation is a necessary predicate to the adoption of either more stringent regulatory requirements or an optimal tax regime. Insofar as technological innovation reduces the costs of emission reductions, it will blunt the political opposition to such measures. Just as the development of CFC substitutes made adoption of the CFC phase-out a political possibility,[285] so too will the development of low-cost means to reduce GHG emissions or remove carbon from the atmosphere make more stringent climate policies a political possibility. So rather than relying upon regulation to induce technological innovation, it may be worth focusing on technological innovation as a means of facilitating greater regulation.

VI. A Prize Proposal

Richard Branson and other private individuals may continue to offer technological inducement prizes for climate-related innovations. These prize awards could be important, but they are unlikely to produce the degree of technological innovation necessary to achieve current climate policy goals in a cost-effective manner. Encouraging the desired level of innovation will require far more. Thomas Kalil believes that the federal government should offer $100-200 million annually in prize awards for innovations in zero-energy building design, reductions in urban GHG emissions, and more fuel efficient vehicles.[286] Yet even this could be insufficient. If one uses the potential social benefits of averting climate change as the benchmark, the investment in technological innovation should be far greater.

The federal government currently spends approximately $3 billion annually on R&D of climate-related technologies.[287] The U.S. Climate Change Technology Program ("USCCTP") funds research efforts into technological improvements that could potentially be achieved in the near, medium, and

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[284] Noted economist A.C. Pigou proposed the imposition of taxes equivalent to the social costs imposed by polluting or other externality-generating activities. Even assuming that governmental agencies have the necessary information to set pollution taxes at such an ideal level, Ronald Coase showed that such taxes do not necessarily enhance economic efficiency. *See* Coase, *supra* note 283, at 42 ("[E]ven if the tax is exactly adjusted to equal the damage that would be done to neighboring properties as a result of the emission of each additional puff of smoke, the tax would not necessarily bring about optimal conditions.").

[285] *See supra* notes 58–59 and accompanying text.

[286] *See* Kalil, *supra* note 71, at 9.

[287] *See* USCCTP, *supra* note 4, at 207 (noting FY 2006 funding of "nearly $3 billion").

long term.[288] Projects range from vehicle and building design to fuel cell technology, agricultural methods, and carbon sequestration technologies.[289]

Assuming current funding levels continue, the federal government will spend approximately $30 billion on climate-related technologies over the next decade. If the federal government committed one-third of USCCTP funding — either reallocating it from traditional R&D or augmenting it with a new revenue source — it would have sufficient resources to endow a series of substantial climate prizes. With $10 billion over ten years, the USCCTP, or another agency such as ARPA-E, could endow prizes across the range of technologies that the USCCTP has identified as priorities for climate change policy. This amount is significantly less than the estimated potential social welfare losses of climate change, and yet would substantially increase the incentives for needed technological innovation.

Due to the potential for prize awards to spur greater levels of private research, as occurred with the Ansari X-Prize, reallocation of USCCTP funding in this way would produce a substantial increase in overall investment into climate-friendly technologies.[290] Equally important, the announcement of prizes of this magnitude would draw additional attention to the need for climate-related research and increase the prestige of developing climate-related technologies. A high-profile government investment in prizes would underscore the importance of climate-friendly technological innovation.[291]

Developing specific prize criteria is particularly important.[292] The USCCTP's matrix of technological goals and projected time frames for development could serve as the basis for prize specifications, but would need to be refined if used for prizes instead of traditional R&D. Either the USCCTP or some other entity, such as the NAS or the NAE, could assemble an expert panel of researchers, scientists, and engineers to identify which technological goals are most suited to the use of prizes. Such a panel would also have to devote considerable time to developing prize specifications with sufficient detail to ensure that winning innovations would be worth the public investment but with enough flexibility so as not to preclude new ways of

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[288] The USCCTP defines "near-term" as less than 20 years, "mid-term" as 20–40 years, and "long-term" as more than 40 years. *Id.* at 211.

[289] *Id.*

[290] It is also possible that the creation of prizes would not require an equal offset of existing USCCTP funding, as prize awards would not be paid out unless and until the necessary innovations were developed and proven.

[291] *See* McKinsey, *supra* note 73, at 21–22 (discussing potential for prizes to change public perception and the ability of prizes to focus a community's efforts on a specific problem).

[292] X-Prize Foundation Chairman and CEO Peter Diamandis testified before Congress that "writing the rules is more than 80% of the battle." *NASA Contests and Prizes: How Can They Help Advance Space Exploration?: Hearing Before the Subcomm. on Space and Aeronautics of the H. Comm. on Sci.*, 108th Cong. 29 (2004) (statement of Dr. Peter H. Diamandis, Chairman & CEO, X-Prize Foundation).

solving existing problems.[293] It is also important that prize criteria are clear and objectively measurable.[294] The panel would also have to determine the size of prize awards and whether there would be multiple or shared awards in any given area. In some cases, structuring prizes to divide awards proportionately may increase entry rates and generate additional innovation.[295]

The recent NAS report on the NSF's prospective use of innovation inducement prizes reviewed many of the prospective implementation questions for government administered prize program.[296] Among other things, the NAS stressed the need to design prizes around objectively measurable outcomes and endorsed "first past the post" prizes with set time limits.[297] The NAS also recommended that the federal government should not seek to own, control, or influence the disposition of intellectual property resulting from a prize competition, unless the winner does not seek to commercialize resulting innovations within a reasonable time period.[298] The NAS suggested the possibility that prize awards include a stipulation requiring good faith efforts to commercialize resulting innovations or even forced licensing, but urged against requiring that such intellectual property be made available at no cost or on concessional terms.[299]

It would also be important to examine whether additional incentives would need to be created to encourage diffusion of the relevant technology. One possibility would be for prizes to include advance market commitments, through which a government commits in advance to purchase a given quantity of an innovation that meets predetermined characteristics.[300] So, for instance, the federal government could commit to purchase a given number of automobiles that meet or exceed a given fuel efficiency or emissions-per-mile standard, creating additional incentives to translate new inventions into commercially viable products.

As the OMB noted in 2010, federal agencies, including the Department of Energy, already have some ability to fund technology inducement prizes out of existing appropriations. However, it would be a mistake to leave prizes to the administrative process. The same political pressures that can distort traditional R&D funding are likely to discourage the diversion of funds from R&D grant programs to prizes. Without a direct statutory man-

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[293] *See* McKinsey, *supra* note 73, at 39–45 (discussing the goal setting process for prize competitions).

[294] *Id.* at 54 (noting "objectivity and simplicity are the biggest challenges" in drafting prize criteria).

[295] *See* Timothy N. Cason, William A. Masters & Roman M. Sheremeta, *Entry Into Winner-Take-All and Proportional Prize Contests: An Experimental Study*, 94 J. Pub. Econ. 604 (2010).

[296] *See* Nat'l Acad of Sci., *supra* note 72, at 18–39.

[297] *Id.* at 21.

[298] *Id.* at 33.

[299] *Id.*

[300] *See* Kalil, *supra* note 71, at 5.

date, agencies are more likely to talk about prize competitions than they are to implement them.[301]

Congress should mandate that specific agencies develop prizes and specify the minimum degree of funding such prizes should receive out of agency appropriations. Congress should also identify, in broad terms, the purposes for which prizes should be used, as well as to require the appointment of outside expert panels to assist in the prize development process. Directed statutory authorization of this sort could ensure that agencies pursue the potential of prizes to assist with the climate change challenge. It would also further underscore that climate-friendly technological innovation is a national priority.

CONCLUSION

Prizes are no panacea.[302] Indeed, barring some serendipitous discovery, there is no panacea for the climate policy challenge. Yet technology inducement prizes offer a relatively low-cost way to encourage greater innovation than traditional grant-based R&D funding. In order to encourage greater levels of technological innovation, it would also be desirable to reduce existing regulatory barriers to the development and deployment of alternative technologies, as well as to place a price on carbon, ideally with a simple and straightforward carbon tax. Combined with prizes, such measures could create a more favorable environment for climate-friendly innovation. Yet without prizes, or some other enhanced incentive for technological innovation, the necessary technological breakthroughs are much less likely to materialize.

Prizes have a peculiar virtue of imposing costs only to the extent they produce results, so there is room to be ambitious. Assuming the worst climate policy scenarios only strengthens the case for large climate policy prizes. Rather than funding ten who will try, the government needs to reward *only* the one who succeeds. As the patent system demonstrates, the hope of a large financial windfall is a powerful inducement for innovation. There has been substantial interest in prizes in recent years but not much action. Now it is time to up the ante for climate innovation with federally funded climate prizes.

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[301] Although the NAE recommended consideration of prizes in 1999, the NSF did not consider using prizes until required to by federal statute many years later. *See* NAT'L ACAD. OF SCI., *supra* note 72, at 11.

[302] *See* Mowery, Nelson & Martin, *supra* note 203, at 1021 (noting potential drawbacks of inducement prizes in the energy context); *see also infra* notes 102–106 and accompanying text.