Fast, Clean, & Cheap: Cutting Global Warming's Gordian Knot

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Introduction

In the Greek legend, King Midas used a complicated knot to tie his father's ox cart to a post. An oracle prophesied that the one who untied the cart—which symbolized Apollo's father, Zeus—would rule the kingdom. For many years the knot stymied all who attempted to untie it. Then, one day, rather than trying to untie the knot, the young Alexander simply cut the rope with his sword. Alexander went on to become a brilliant military commander and, eventually, King of Macedon.

The story is traditionally interpreted to mean that one can often solve seemingly impossible problems with a single and simple bold stroke. But there are two other morals to the story. First, to find solutions, one must see old problems in a new light. Alexander saw the problem as freeing the ox cart from the post, rather than untying the knot. Alexander's new perspective—what is sometimes called a "gestalt shift"—was a prerequisite to cutting the Gordian Knot. Second, cutting the knot involved a kind of rebellion. The oracle's prophecy specified that the knot be *untied*. In *cutting* the knot Alexander had to, paradoxically and audaciously, violate the conventional meaning of the oracle's prophesy in order to realize it.

Today, there is a dilemma—a "Gordian Knot"—at the heart of any effort to deal with global warming. If policymakers limit greenhouse gases too quickly, the price of electricity and gasoline will rise abruptly, triggering a political backlash from both consumers and industry. But if policymakers limit greenhouse gases too slowly, clean energy alternatives will not become cost-competitive with fossil fuels in time to prevent catastrophic global warming.

This Essay argues that both a gestalt shift and a bold stroke are required to cut the Gordian Knot at the heart of today's energy challenge. Many

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policymakers view the problem of global warming as a pollution problem, similar to acid rain, smog, or the ozone hole. But whereas addressing the ozone hole required a simple and inexpensive chemical substitute, global warming demands a totally different way of producing energy. We were able to fight smog without replacing oil. We dealt with acid rain without dismantling our power plants. And we will continue to phase out ozone-depleting chemicals without affecting any of our energy sources.

To deal with global warming, we will need an entirely new energy infrastructure. Creating a new energy infrastructure is more comparable to the creation of the railroads, the interstate highway system, personal computers, the Internet, and the space program than it is to installing catalytic converters and scrubbers, or phasing out ozone-depleting chemicals. The latter involved mere technical fixes, not wholesale technological revolutions.

Environmentalists have been so focused on making clean energy *relatively* cheaper (by imposing regulations that make dirty energy expensive) that they overlook the possibility of making clean energy *absolutely* cheaper through major investments in technology innovation and infrastructure. The good news, however, is that the current regulation-centered approach can potentially become an investment-centered approach. For instance, the dominant proposals addressing global warming would auction mandatory pollution permits to U.S. companies.[1] Depending on how the auction is structured, the sale of pollution permits could generate between $30 and $250 billion per year for clean energy.[2] This money would come from higher energy prices, however, and in order for the American public to agree to such a project, voters must be inspired by the project's potential to free the United States from oil and to create jobs through technology innovation.

In the end, it was impossible—and unnecessary—to untie the Gordian Knot. All that was needed was to free the ox cart. In the case of global warming, we must free energy production from greenhouse gas emissions.

I. The Climate Change and Energy Challenges

A. Global Warming

Global warming threatens to trigger severe droughts, water shortages, agricultural collapses, forest fires, migration crises, and food scarcity. Ac-

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[1] *See, e.g.*, America's Climate Security Act of 2007, S. 2191, 110th Cong. §§ 3, 4 (2007). For an analysis of this Bill authored by Senators Lieberman and Warner as well as four other bills pending in the Senate, see Ray Kopp & Billy Pizer, Resources for the Future, Five Recent Senate Bills Set Mandatory Greenhouse Gas Caps: Side-by-Side Comparison and Analysis (2007), http://www.rff.org/rff/News/Features/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=27873.

[2] *See, e.g.*, S. 2191 at §§ 3, 4.

cording to scenarios commissioned by the Pentagon, climate change could lead to wars over basic resources like food and water.[3]

In the face of this crisis, there is an emerging international consensus that greenhouse gas emissions (the bulk of which are carbon dioxide) must be reduced by roughly 80% in the developed world and 50% worldwide by 2050 if we are to avoid dangerous levels of global warming.[4] Following the Industrial Revolution, total atmospheric carbon dioxide increased from roughly 280 to 430 parts per million (ppm).[5] Unless we change today's energy trajectory, total atmospheric carbon will pass 550 ppm by 2035 .[6] Scientists believe that total atmospheric carbon dioxide must be stabilized between 450 ppm and 550 ppm if we are to avoid catastrophic global warming impacts.[7]

B. The Energy Challenge

In 2007, human beings consumed roughly fifteen terawatts (trillion watts) of energy.[8] Humans will need to produce and consume roughly sixty terawatts of energy annually by 2100 if every human on earth is to reach the level of prosperity enjoyed today by the world's wealthiest one billion people.[9] Even if economies were to become 30% more efficient, the total terawatts required to bring all of humankind out of poverty would need to roughly triple by century's end.

Meanwhile, emissions continue to increase globally. The case of China demonstrates why a regulatory approach will not eliminate the problem of greenhouse gases. In 2008, China will pass the United States as the largest emitter of greenhouse gasses.[10] By 2050, estimations of the contributors of emissions in order of magnitude will be China at approximately 25%, the United States at 14%, India at 12%, and the EU at 9%.[11] The Energy Information Administration (EIA) predicts that, under a business as usual

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[3] *See* PETER SCHWARTZ & DOUG RANDALL, GLOBAL BUS. NETWORK, AN ABRUPT CLIMATE CHANGE SCENARIO AND ITS IMPLICATIONS FOR UNITED STATES NATIONAL SECURITY 2 (2003), *available at* http://www.gbn.com/ArticleDisplayServlet.srv?aid=26231; NILS GILMAN, PETER SCHWARTZ, & DOUG RANDALL, GLOBAL BUS. NETWORK, IMPACTS OF CLIMATE CHANGE: A SYSTEM VULNERABILITY APPROACH TO CONSIDER THE POTENTIAL IMPACTS TO 2050 OF A MID-UPPER GREENHOUSE GAS EMISSIONS SCENARIO (2007), *available at* http://www.gbn.com/ArticleDisplayServlet.srv?aid=39932.

[4] *See* NICHOLAS STERN, THE STERN REVIEW: THE ECONOMICS OF CLIMATE CHANGE 81, 170, 193 (2006); U.N. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE III, SUMMARY FOR POLICYMAKERS 17 (2007)[hereinafter IPCC].

[5] STERN, *supra* note 4, at 169.

[6] *Id.*

[7] *Id.* at 81, 170, 193; *See also* IPCC, *supra* note 4, at 17.

[8] Richard Smalley, *Future Global Energy Prosperity: The Terawatt Challenge*, 30 MATERIAL RES. SOC'Y BULL. 412, 414 (2005).

[9] *Id.*

[10] U.S. ENERGY INFORMATION ADMIN., DEP'T OF ENERGY, INTERNATIONAL ENERGY OUTLOOK 2007, 93 tbl.A10 (2007) [hereinafter ENERGY OUTLOOK 2007].

[11] JOHN HAKSWORTH, PRICEWATERHOUSECOOPERS, THE WORLD IN 2050: IMPLICATIONS OF GLOBAL GROWTH FOR CARBON EMISSIONS AND CLIMATE CHANGE POLICY 44 tbl.3.1 (2006).

("BAU") scenario, the rate of global emissions will grow 37%—about 1.8% every year—from 2004 until 2030. China's emissions will grow 3.4%—nearly double the global average.[12]

The EIA estimates that, between 2004 and 2012, China, India, and the United States will build over 850 coal power plants, which will put more than five times as much carbon dioxide into the atmosphere as the Kyoto Protocol aims to reduce. Over 550 of those plants will be in China.[13] Coal currently provides about 70% of China's energy,[14] and China builds roughly one new coal-fired power plant every week.[15] China's total coal-related emissions are projected to increase by 232% between 2004 and 2030.[16]

C. The Goal: Cut the Link Between Energy Production and Greenhouse Gas Emissions

Energy is the lifeblood of every society. Rising energy consumption is strongly correlated with longer life spans and higher quality of life.[17] But rising energy consumption has also resulted in rising greenhouse gas emissions and global warming. Moreover, America's dependence on fossil fuels has led to expensive and dangerous military entanglements. Given all of this, a top goal for humankind in the twenty-first century will be to increase energy consumption so the world's poorest people can climb out of poverty while also moving toward more secure, and cleaner, sources of energy.

II. The Problem with the Pollution Paradigm

A. The Regulation-Centered Approach

In 2007, the world celebrated the twentieth anniversary of the Montreal Protocol, the international treaty enacted to phase out ozone-destroying chemicals. For environmentalists, the Montreal Protocol is a model for action on global warming. In the words of David Doniger, the climate director of the Natural Resources Defense Council, "The lesson from Montreal is that curbing global warming will not be as hard as it looks."[18]

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[12] *See* Energy Outlook 2007, *supra* note 10, at 93. China's average emissions growth rate will be nearly double the global average. China will amount to 68.2% of the developing world and 42.6% of the world's total emissions from coal. *See id.* at 96 tbl.A13.

[13] Mark Clayton, *New Coal Plants Bury Kyoto*, Christian Sci. Monitor, Dec. 23, 2004, at 1.

[14] Richard Balzhiser, *The Chinese Energy Outlook*, 28 The Bridge (1998), *available at* http://www.nae.edu/nae/bridgecom.nsf/weblinks/NAEW-4NHMHU?OpenDocument.

[15] Keith Bradsher & David Barboza, *Pollution from Chinese Coal Casts a Global Shadow*, N.Y. Times, June 11, 2006, at A1.

[16] *See* Energy Outlook 2007, *supra* note 10, at 96 tbl.A13.

[17] *See* Smalley, *supra* note 8, at 414.

[18] Andy Revkin, *From Ozone Success, a Potential Climate Model*, N.Y. Times, Sept. 18, 2007, at F2.

And indeed, when one looks back at the pollution problems of old, none of them were as hard or as expensive to solve as the affected industries claimed they would be.[19] The same will be true, environmentalists say, when it comes to global warming. All the alternatives we need—efficiency, conservation, renewables, sequestration, and even nuclear energy—already exist. We just need to scale them up.[20] Sure, global warming is a bigger problem, environmentalists acknowledge, but it will be solved just like we solved acid rain.

The dominant regulation-centered policy approach to global warming is known as "cap and trade." There are a number of variations on this proposal, but each of them generally consists of two elements. First, a cap-and-trade approach would set a nationwide cap on emissions that declines gradually each year to achieve a targeted emission reduction. For our purposes, we can assume a 2% annual reduction with the objective of reducing carbon emissions by 80% between 2010 and 2050. Private firms would then purchase or receive pollution permits in order to operate. The second element is a trading mechanism that would allow firms that reduce their emissions beyond what is required by law to sell their unused emissions credits to firms that find it cheaper to purchase these credits than reduce their own emissions. This regulatory framework is called "emissions trading" in Europe and "cap and trade" in the United States.

By capping the level of emissions each year, and auctioning or giving away a limited number of emissions permits to firms, governments effectively create a price for carbon dioxide emissions and force businesses to internalize some or all of the real costs of those emissions. Advocates of this approach believe that the higher prices will create an incentive to reduce emissions and that market exchanges will, over time, create enormous value for firms that reduce their emissions, while severely punishing those that do not. As dirty energy sources like coal and oil become more expensive under the cap-and-trade system, innovative firms will invest in and adopt clean energy technology in order to capture this value. With more private firms investing in cleaner technologies, these technologies will become cost-competitive and more widely used. Advocates of this approach believe that regulation is the most efficient way to reduce our greenhouse gases by 80% by 2050.[21]

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[19] For a useful discussion, see generally GREGG EASTERBROOK, A MOMENT ON EARTH (1996).

[20] *See* AN INCONVENIENT TRUTH (Lawrence Bender Prod. 2006) (Al Gore stated: "We already know everything we need to know to effectively address this problem").

[21] The NRDC's David Hawkins, one of the most influential environmental lobbyists in Washington, wrote, "Policies that require a clear and steady reduction in emissions will move the private sector in the right direction faster than any government funded program by itself. With a schedule of declining caps on emissions as the law of the land, entrepreneurs in firms large and small will know there is a growing market for clean energy innovations. They will help the nation meet targeted emissions reduction at the lowest possible cost." Posting of David Roberts to Gristmill Blog, Passionate But Confused, http://gristmill.grist.org/story/2007/9/28/11254/2676 (Sept. 28, 2007, 11:02 EST).

This pollution regulation framework is, for many policymakers, journalists, and concerned members of the public, a reassuring one. For fifteen years it has provided a mental model for understanding how such a massive problem like climate change could be solved organically through the market, perhaps the most powerful institution ever created by human beings. There is just one problem: it will not work.

B. *The Regulation-Centered Approach Creates a Gordian Knot*

For both economic and political reasons, a regulation-centered approach to global warming cannot achieve the international consensus targets of 80% reductions in greenhouse gases in the United States, or 50% reductions globally, by 2050.

1. *Economic Constraints to the Regulation-Centered Approach*

Emissions trading will, by design, direct private investment towards the least expensive methods of emissions reduction—not towards more expensive, but equally important, clean energy technologies such as solar energy and carbon capture and storage. Pricing carbon dioxide at $7–12 per ton—whether through cap and trade or carbon taxes—can help us to get part of the way towards the 80% reduction goal. Carbon dioxide at those prices will drive investments into efficiency and conservation, and will create incentives for energy providers to build gas-fired rather than coal-fired plants. These measures could result in modest emissions reductions in the United States.

Reducing carbon emissions by 50% worldwide through regulatory limits alone, however, would require setting a much higher price for carbon dioxide. For today's clean energy alternatives to become cost-competitive with coal, gas, and oil, the price of carbon dioxide would have to be set at exorbitant levels. For example, carbon dioxide would have to be set at $37–74 per ton to make carbon-capture-and-storage technologies economically viable,[22] and it would have to be set at over $217 per ton to make photovoltaic energy cost-competitive.[23]

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[22] Robert H. Socolow & Stephen W. Pacala, *A Plan to Keep Carbon in Check*, SCI. AM., Sept. 2006, at 50.

[23] EIA data on file with author.

Table 1: Price Carbon Dioxide Must Reach to Make Clean Energy Alternatives Cost-Competitive with Coal in the United States.

Carbon Pricing Scenarios, 2010	Cents per kWh, 2010 [5]	Price above coal (cents/ kWh)	Price of CO2 necessary to compete with coal
Coal (Pulverized)	4.84	0.00	0
Solar Photovoltaic [1]	25.83	20.99	$219.97
Wind	6.67	1.23	$12.89
Solar Thermal [2]	14.22	8.78	$92.01
Fuel Cell	17.96	12.52	$131.21
Biomass [3]	5.88	0.44	$4.61
Geothermal	6.19	0.75	$7.86
Hydroelectric [4]	6.44	1.00	$10.48
Conventional Nuclear	n/a	n/a	n/a
Advanced Nuclear	n/a	n/a	n/a

[1] Central Station Generator
[2] Central Station Generator
[3] Integrated Gasification Combined Cycle
[4] Conventional
[5] EIA AEO 2007 Levelized Generation costs for 2010
[6] $100 per ton price on carbon results in price increase of $0.026 per kWh of coal electricity

Table created by authors based on 2007 EIA data.[24]

The United Nations International Panel on Climate Change (IPCC) estimates that establishing an average global carbon dioxide price of $50 per ton—a figure five times higher than the price currently being considered in legislation before U.S. Senate—would reduce global carbon emissions by 20–38% by 2030.[25] A separate, independent analysis has found that carbon dioxide would have to be priced at around $100 per ton between 2010 and 2030, and at a whopping $160–200 per ton between 2030 and 2050, to reduce greenhouse gases 90% by 2050 in the United States.[26] To gain a sense of the impact this would have on consumers, consider that carbon dioxide

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[24] It is worth noting that the costs of building coal power plants are going up, which may make clean energy sources somewhat more competitive sooner than the EIA data indicates. But there is little evidence to suggest that costs of capital for coal plants are rising fast enough to lead to dramatic moves away from coal to clean energy sources.

[25] *See* IPCC, *supra* note 4, at 17 (Category IV), 19 (Proposal 23).

[26] *See* William Nordhaus, The Challenge of Global Warming: Economic Models and Environmental Policy 26 (forthcoming 2008).

priced at $190 per ton would increase the price of coal-generated electricity in the United States by two and a half times.[27]

In order to achieve major reductions on the order of 80% in the United States, and 50% globally, we will need to replace coal and oil as energy sources almost entirely. In order to achieve the deep reductions called for by climate scientists, the per-unit cost of low-carbon energy sources and carbon-capture-and-storage technologies would need to come down dramatically. Such a price decrease will require several technology breakthroughs.

2. *Political Constraints to the Regulation-Centered Approach in the Developed World*

The price of carbon dioxide neatly illustrates the Gordian Knot created through the regulation-centered framework. If the government prices carbon dioxide high enough to make currently expensive clean energy solutions like solar and carbon capture cost competitive, then energy prices would rise dramatically and elicit a political backlash. But if the government prices carbon dioxide too low, private-sector investments will flow almost exclusively to inexpensive emissions reductions, rather than to essential technologies, such as solar and carbon capture and storage.

The regulation-centered approach depends on doing something highly unpopular with the public and the business community: raising the price of energy. New energy regulations will increase the cost of gasoline, electricity, and everything else that requires energy for its production, from food to homes to consumer products. Many industries—from building to transportation to retail to manufacturing—have genuine reason to fear and oppose price increases.

Voters, far more concerned about the immediate threat of higher energy prices than the perceived distant threat of global warming, are likely to pressure governments for low carbon dioxide prices. In an October 2006 USA Today/Gallup poll, 65% of voters said gas prices were very important to their vote for Congress, and 34% of respondents said gas prices were "extremely important."[28] Voters also oppose increasing the federal gas tax. A CBS News/New York Times poll reported in April 2007 that 58% of Americans oppose an increase in the federal gas tax.[29] In an April 2006 Gallup poll, 64% of Americans supported suspending *all* federal gas taxes.[30] Gallup even found that 70% favored government price controls on fuel prices.[31] (As

[27] *Id.*

[28] USA TODAY & THE GALLUP ORG., USA TODAY/GALLUP POLL. (Oct. 6–8, 2006), *available at* http://www.usatoday.com/news/polls/tables/live/2006-10-09-poll2.htm.

[29] CBS NEWS/N.Y. TIMES POLL, AMERICANS' VIEWS ON THE ENVIRONMENT (Apr. 20–24, 2007), *available at* http://www.cbsnews.com/htdocs/pdf/042607environment.pdf.

[30] Jeffrey Jones, *Three in Four Americans Angry about Gas Prices,* GALLUP NEWS SERVICE, May 4, 2006, http://www.gallup.com/poll/22660/Three-Four-Americans-Angry-About-Gas-Prices.aspx.

[31] *Id.*

of this writing, the price of oil had risen to over $90 a barrel, far higher than when the aforementioned polls were conducted.)

In addition to opposing higher prices for gasoline, Americans also say they do not want to pay more for electricity. When asked if the federal government should increase taxes on electricity or gasoline to encourage conservation, Americans overwhelmingly rejected the approach. A March 2006 ABC News/Washington Post Poll showed that 81% of voters oppose increasing taxes on electricity, and 68% oppose increasing taxes on gasoline, to encourage conservation. A year later, despite extensive national and local media attention about global warming, those numbers decreased only marginally.[32]

Advocates of a higher price for carbon dioxide are building their public case around the urgency of global warming. But efforts to increase the public's concern with global warming have not been particularly successful. In 1989, Gallup asked Americans how concerned they were with global warming. 63% said they worried "a great deal" or a "fair amount" about it. By 2007, that number was virtually unchanged at 65%.[33]

Public awareness reached a new high in the summer of 2006 with the publicity surrounding Al Gore's *An Inconvenient Truth*. The Pew Center for People and the Press[34] conducted a telephone survey of 1501 adults between June 14 and June 19, 2006, a period timed to coincide with the high point of the media's interest in Gore's movie. The movie did virtually nothing to increase the saliency of global warming among voters. For Republicans, the percentage of respondents rating global warming as "very important," was the lowest out of all nineteen issues presented, and, for Democrats, thirteenth lowest.[35] By January 2007, the relative importance of global warming actually declined to twenty-first out of twenty-one issues for Republicans, seventeenth out of twenty-one issues for Democrats, and nineteenth out of twenty-one issues for independents.[36]

Since voters seem to care more about the cost of energy than global warming, most policies under consideration in Congress would price carbon dioxide at around $7–12 per ton, either directly through a safety valve or indirectly through the allocation of pollution allowances. As noted above, at

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[32] ABC News & Wash. Post, The Wash. Post Poll (May 17–21, 2007), *available at* http://media.washingtonpost.com/wp-srv/politics/polls/postpoll_052407.html.

[33] Joseph Carroll, *Polluted Drinking Water is Public's Top Environmental Concern*, Gallup News Service, Apr. 20, 2007, http://www.gallup.com/poll/27274/Polluted-Drinking-Water-Publics-Top-Environmental-Concern.aspx.

[34] The Pew Center is funded by Pew Charitable Trusts, which was the largest grant maker to environmental causes in 2000, contributing $52 million to environmental concerns. *See* Douglas Jehl, *Charity Is New Force in Environmental Fight,* N.Y. Times, June 28, 2001, at A1.

[35] Pew Research Ctr. for People & the Press, Partisanship Drives Opinion: Little Consensus on Global Warming (2006), *available at* http://people-press.org/reports/display.php3?ReportID=280.

[36] Pew Research Ctr. for People & the Press, Global Warming: A Divide on Causes and Solutions: Public Views Unchanged by Unusual Weather (Jan. 24, 2007), *available at* http://pewresearch.org/pubs/282/global-warming-a-divide-on-causes-and-solutions.

that low price, private investment will mainly flow toward the least expensive options for emissions reductions and not toward the more expensive technologies.

In addition to the political obstacles posed by domestic consumers, effective carbon pricing poses free-rider and public-goods problems for domestic industries that make it difficult for policymakers to act decisively. Developed nations will likely set a low price for carbon dioxide because domestic industries, fearing disadvantage relative to competitors operating in countries that do not restrict greenhouse gas emissions, will pressure their governments for low carbon prices. Such concerns over industrial policy motivated the U.S. Senate to preemptively reject, 95-0, the Kyoto treaty on global warming in 1997.[37]

The political restraints facing American policy had a similar constraining effect in Europe. Europe's Emissions Trading System has not achieved its goal of significantly reducing the EU's emissions because European governments issued too many permits to polluters. The price of carbon dioxide peaked at € 30 per ton in April 2006, but once it became evident that countries had over-allocated permits—and that firms did not need to seriously reduce their emissions—the price fell to € 0.10 per ton in September 2007.[38] EU officials are expected to distribute fewer permits for the 2008–10 period, but governments will remain under pressure from industry to establish a low price for carbon dioxide.

3. *Political Constraints to the Regulation-Centered Approach in the Developing World*

Widespread sentiment suggests that once the United States acts, so will the developing world. "If the United States leads, other nations like India and China will follow," Senator Barbara Boxer, Chairwoman of the Senate Committee on the Environment and Public Works, told the National Press Club.[39] Indeed, Chinese firms earn billions of dollars selling emissions reductions to European firms, thus giving China a stake in the success of global emissions trading. Moreover, China has reason to be genuinely worried about global warming. But even if Beijing does eventually set a price for carbon dioxide, it will probably not be high enough to make building carbon-capture-and-storage facilities next to its coal power plants—or substituting wind, solar, and nuclear for coal—economically viable.

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[37] *See* S. Res. 98, 105th Cong. (1997) ("[T]he United States should not be a signatory to any protocol to, or other agreement regarding, the United Nations Framework Convention on Climate Change of 1992, at negotiations in Kyoto in December 1997, or thereafter, which would . . . result in serious harm to the economy of the United States . . . .").

[38] Michael Grubb & Karsten Neuhoff, *The EU Emissions Trading System: Getting it Right*, 19 Renewable Energy for Dev. 1 (2006), *available at* http://www.sei.se/red/reddec2006.pdf.

[39] Barbara Boxer, Senator, National Press Club Speech on Global Warming (Apr. 18, 2007) (transcript available at http://boxer.senate.gov/news/speeches/2007/apr18_globalwarming.cfm).

China has repeatedly maintained that it will not restrict its emissions without a strong economic reason to do so. "You cannot tell people who are struggling to earn enough to eat that they need to reduce their emissions," a Chinese government official recently explained.[40] Part of China's reluctance to reduce its emissions stems from a sense of the developed countries' historical responsibility: "[Climate] change has been caused by the long-term historic emissions of developed countries and their high per capita emissions," another government official noted.[41] Prior to the recent United Nations negotiations in Bali, China told the European Parliament that it would oppose binding emissions caps.[42]

High carbon dioxide prices would translate into dramatic increases in the price of energy and everything else that requires energy (which is to say, virtually everything). Given that increasing energy use and consumption are highly correlated with longer life spans and higher living standards in developing nations, a high carbon price would increase energy prices and thus represent a major obstacle to economic development for poor countries.

The only way to achieve a rapid transition to clean energy in the developing world is by addressing these countries' underlying concerns about security, stability, and economic growth. This is not to say that the Chinese government will never agree to emissions limits or a carbon tax. But any agreement to do so will need to be in China's short and long-term economic interests.

The most plausible scenario to induce the Chinese government to substantially reduce its country's emissions is to drive down the price of clean energy, as well as carbon capture technologies. Achieving these efficiencies may require China's manufacturing prowess. Currently, a single factory in China is estimated to produce nearly 25% of the world's solar panels.[43] The Chinese government may be more amenable to setting a price for carbon in the future if its domestic firms and workers benefited, as they would if investment dollars flowed into solar panel production.

C. The Proper Role of Regulation

Many environmental lobbyists, energy policy analysts, and policymakers conflate the two distinct challenges that regulation and investment address: increasing the cost of fossil fuels and decreasing the cost of clean energy. Writing for the *Stern Review*, Dennis Anderson noted that even many energy experts make this mistake:

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[40] Keith Bradsher, *China to Pass U.S.*, N.Y. Times, Nov. 7, 2006, at C1 (quoting Lu Xuedu, the Deputy Director General of Chinese Office of Global Environmental Affairs).

[41] Jim Yardley, *China Says Rich Countries Should Take Lead on Global Warming*," N.Y. Times, Feb. 7, 2007, at A9.

[42] Lindsay Beck, *China to Reject Binding Emissions Caps, Europe Says*, Reuters, Nov. 7, 2007, *available at* http://www.reuters.com/article/latestCrisis/idUSPEK359325.

[43] Telephone Interview with Danny Kennedy, President, Sungevity (Nov. 5, 2007).

> [Energy experts] frequently confound the aims of innovation policies with the aims of carbon pricing, which are to encourage the use of technologies that have already passed through their RD&D and commercial trial stages . . . . By facilitating invention and reducing costs, such policies complement the pricing of carbon directly, and should pave the way to lower carbon prices in the long-term.[44]

The new greenhouse regulations should instead be understood as a complement to the investments in technological innovation that will be required to address the global warming crisis. Even critics of the regulation-centered approach acknowledge that stabilizing the climate will require governments to establish a price for carbon, implement new energy regulations, and make large, long-term investments in energy-technology innovation.[45]

Gradual reductions in the allowable levels of pollution by private companies will result in greater energy efficiency gains, which are likely to have economic benefits above and beyond slowing global warming. Allowing firms to freely trade pollution permits will lead to economy-wide emissions reductions. Firms most capable of making reductions will be able to sell some of their reductions to those firms least capable of making them. And most important, if the pollution allowances are auctioned, the regulatory process can generate between $30 billion and $250 billion annually for public investment in clean energy.[46]

III. Cutting the Knot: Towards an Investment-Centered Paradigm

A. *The Case for Public Investment*

The great technological revolutions of the past did not occur via regulatory fiat. The U.S. did not invent the Internet or the personal computer by taxing or regulating typewriters. Nor did the transition to the petroleum economy occur because we taxed, regulated, or ran out of whale oil. Those revolutions happened because we invented alternatives that were vastly superior to what they replaced, and, in remarkably short order, a good deal cheaper. The transition to the clean energy economy will be no different and, like previous technological revolutions, will require substantial public investment to occur quickly and completely.

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[44] Dennis Anderson, Stern Review, Costs and Finance of Abating Carbon Emissions in the Energy Sector 41 (2006), *available at* http://www.hm-treasury.gov.uk/media/2/D/stern_review_ supporting_technical_material_dennis_anderson_231006.pdf.

[45] Michael Shellenberger et al., The Breakthrough Institute, The Investment Consensus (2007), *available at* http://www.thebreakthrough.org/blog/Investment%20Consensus.pdf.

[46] *See* America's Climate Security Act of 2007, S. 2191, 110th Cong. §§ 3, 4 (2007).

1. *Obstacles to Innovation in the Energy Sector*

Energy is arguably the least innovative sector of the economy. Coal and oil have been in widespread use for the last 200 and 100 years respectively. While alternatives to fossil fuels exist, they represent a tiny fraction of our current energy mix because they are relatively more expensive and difficult to use on a mass scale.

Several reasons account for the relative lack of innovation in the energy sector. The first is that national electricity grids are tailored for large, centralized plants. Energy companies and investors are often reluctant to expend their revenue on risky, innovative, and costly ventures without government regulation or measures designed to reduce their risks.[47]

There are additional obstacles to a transition to renewable energy sources. Solar and wind energy depend on the vagaries of the weather, and most electricity systems are not capable of taking advantage of such intermittent production. Many renewable electricity sources, such as wind, are located far from current power lines, and their integration faces regulatory and technical challenges.[48] Just as the electrical grid was created to support coal and natural gas, the transportation infrastructure is geared to oil. Alternatives like biofuels and hydrogen depend on massive public investments in public infrastructure.[49] As a result, fossil fuels remain "locked in" as energy sources.

Old energy sources are also locked in politically. As the *Stern Review* makes clear, the annual investment of $33 billion in clean energy technologies (which includes nuclear energy) is "dwarfed by the existing subsidies for fossil fuels worldwide that are estimated at $150 billion to $250 billion each year."[50]

Because consumers perceive energy as a homogenous commodity, there is little to no product differentiation for newer, cleaner, and more technologically advanced energy sources like solar and wind. Whereas pharmaceutical and high-tech companies have an incentive to invest heavily in research and development to invent new products that consumer might switch to or pay more for (such as new cell phones and personal computers), the energy sector will sell the same product—electrons—in 2100 that it sold in 1900. While there has been some very modest success selling "green power" to consumers, no serious expert believes that demand for green power will be anything more than negligible in determining future energy sources.[51]

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[47] *See* Michael Grubb, *Technology Innovation and Climate Change Policy: An Overview of Issues and Options*, 41 KEIO ECON. J. 103 (2004).
[48] *See, e.g.*, Karsten Neuhoff, *Large Scale Re-Deployment of Renewables for Electricity Generation*, 21 OXFORD REV. OF ECON. POL'Y 88 (2005).
[49] *Id.*
[50] STERN, *supra* note 4, at 367.
[51] Neuhoff, *supra* note 48, at 104.

Another obstacle to firms making large investments in technology innovation is that energy companies cannot easily capture all of the future returns on these investments. Pharmaceutical companies can invest roughly 15% of their revenue on research and development in order to develop new drugs because they can patent specific drugs and benefit from a monopoly on that patent for a certain number of years.[52] By contrast, notes one analyst, "it is far harder to define engineering patents in ways that cannot be circumvented over time."[53] Firms are often unable to capture the value of their investments because the knowledge and learning from research and development "spills over" to benefit other firms, creating a free-rider problem that discourages private firms from investing capital in research and development.[54]

Given the lack of incentives for private investment, *public* investments in energy R&D are vitally important. Yet public investment remains low and has actually declined over the last twenty years. Public investment in energy research and development in the United States dropped from an already modest $8 billion in 1980 to $3 billion in 2005 (in 2002 dollars). Private venture capital during the same period dropped from $4 billion in 1980 to a paltry $1 billion in 2005.[55] This lack of investment can be attributed to the declining cost of oil in the 1980s and 1990s, and the absence of an effective national lobby for clean energy.

2. *A High Price for Carbon Dioxide Is Not Enough*

Even if governments did set a very high price for carbon dioxide, doing so would not be enough to dramatically reduce emissions. "[T]he presence of a range of other market failures and barriers mean [sic] that carbon pricing alone is not sufficient," the *Stern Review* concluded.[56] "Technology policy, the second element of a climate change strategy, is vital to bring forward the range of low-carbon and high-efficiency technologies that will be needed to make deep emissions cuts."[57]

Technological breakthroughs are needed to boost the performance of current clean energy technologies and to decrease the cost of deploying them. Without these breakthroughs, the costs of these technologies are too high, and their performance and return on investment too low, to justify private sector investment in their widespread deployment. This will likely be

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[52] *Id.* at 98.

[53] *Id.*

[54] Gregory Nemet, Policy and Innovation in Low-Carbon Energy Technologies (May 2007) (unpublished Ph.D. dissertation, University of California, Berkeley) (on file with author).

[55] *Climate Change Technology Research: Do We Need a 'Manhattan Project' for the Environment?: Hearing Before the Committee on Government Reform*, 110th Cong. 7 (2006) (statement of Daniel Kammen, Professor, Energy Resources Group, University of California, Berkeley).

[56] STERN, *supra* note 4, at 308.

[57] *Id.*

the case even with the higher carbon prices that the many proposals currently being considered in the U.S. Congress would establish.

"Getting those new technologies on line will require more than price signals because no company on its own will invest in the necessary speculative and costly research and development concepts," wrote Stanford's David Victor and Danny Cullenward in *Scientific American*.[58] "Ultimately, the belief that prices alone will solve the climate problem is rooted in the fiction that investors in large-scale and long-lived energy infrastructures sit on a fence waiting for higher carbon prices to tip their decisions. In fact, many factors stifle the implementation of novel low-carbon policies."[59]

Relying only on a high price for carbon without also making large public investments in strategic deployment, others warn, "is likely to result in distortions in other economic sectors and to increase the total costs of climate policy to society."[60] The way to avoid these distortions and other detrimental effects to the economy is by investing in innovation. In assessing various approaches to climate policy, one influential study concluded that "investments in climate friendly technologies can reduce GDP losses to the U.S. by a factor of two or more."[61]

Finally, in order to be deployed at levels that might allow them to displace conventional energy sources on a large scale, clean energy alternatives like solar and wind will require significant improvement in the cost and performance of battery and other energy storage technologies, as well as the development of a new electricity grid. These are investments that the private sector either cannot or will not be able to make.

3. *Expert Consensus Supports a Massive Increase in Public Investment*

Over the last ten years, a consensus has emerged among energy policy experts that "disruptive" clean energy technologies that achieve "non-incremental" breakthroughs in price and performance are needed to solve the problem of global warming.[62] Although the media coverage of the Spring 2007 IPCC focused on the U.N.'s reiteration of the long-standing consensus that global warming exists and is caused by humans, the report went much further, calling not just for regulation but also for large public investments into clean energy. "Public benefits of RD&D investments are bigger than the benefits captured by the private sector," the IPCC report concluded, "justifying government support of RD&D."[63] Similarly, the *Stern Review*

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[58] David Victor & Danny Cullenward, *Making Carbon Markets Work*, Sci. Am., Sept. 24, 2007, at 8, *available at* http://www.sciam.com/search/index.cfm?q=victor+cullenward (follow "Making Carbon Markets Work (extended version)" hyperlink).

[59] *Id.*

[60] Neuhoff, *supra* note 48, at 103.

[61] Richard Richels et al., AEI-Brookings Joint Center for Regulatory Studies, Managing the Transition to Climate Stabilization 3 (2007).

[62] Nemet, *supra* note 54, at 72.

[63] IPCC, *supra* note 4, at 20.

recommends that governments boost their clean-energy investments from current global levels of $34 billion (an amount that includes nuclear) to between $68 billion and $170 billion annually.[64]

Indeed, whether it is the recommendations presented by the IPCC, the *Stern Review*, *Scientific American,* or top energy innovation experts, investment in technology is universally seen as a central element in overcoming ecological crisis. "Funding for energy research," *Scientific American* said in its lead editorial in a special issue dedicated to clean energy, "must be accorded the privileged status usually reserved for health care and defense."[65] In a 2002 article, New York University physicist Martin Hoffert and sixteen other leading energy experts argued that "although regulation can play a role, the fossil fuel greenhouse effect is an energy problem that cannot be simply regulated away."[66] It is a conclusion broadly echoed by other leading analysts.[67]

Clean energy alternatives exist, have been demonstrated in laboratory settings, and in the case of things like solar panels, have been deployed over a number of years at a relatively small scale. Other technologies, such as carbon capture and storage, are at an even earlier stage of development.

That these technologies exist, however, does not mean that the market will adopt them without further improvements:

> [I]t will require substantial effort and investment by both the public and private sectors for them to be adopted by the market . . . . Urgent action is needed to stimulate R&D, to demonstrate and deploy promising technologies, and to provide clear and predictable incentives for low carbon options and diverse energy sources.[68]

In fact, high levels of initial *public* investment can help encourage later *private* investment. MIT's John Deutsch writes, "Government support of innovation—both technology creation and technology demonstration—is desirable to encourage private investors to adopt new technology."[69]

There is a key difference between what government does well in terms of promoting technological innovation and what the private sector does well. The standard distinction is that government is the appropriate entity to fund basic research while the private sector is better and more efficient at commercializing new technologies. However, a vast chasm lies between the re-

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[64] Stern, *supra* note 4, at 347.

[65] *Cooling Our Heels*, Sci. Am., Sept. 2007, *available at* http://www.sciam.com/article.cfm?articleID=00035ED5-6113-14E3-A11383414B7F0000&sc=i100322.

[66] Martin I. Hoffert et al., *Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet*, Science, Nov. 1, 2002, at 986.

[67] *See, e.g.*, J.A. Edmonds et al., Global Energy Technology Strategy Program, Global Energy Technology Strategy: Addressing Climate Change (2007); IPCC, *supra* note 4; Stern, *supra* note 4; Grubb, *supra* note 47; Nemet, *supra* note 54; Daniel Kammen, *The Rise of Renewable Energy,* Sci. Am., Sept. 2006.

[68] Hoffert et al*., supra* note 66.

[69] John Deutsch, Center for Energy and Environmental Policy Research, What Should the Government Do to Encourage Technical Change in the Energy Sector? 1 (2005), *available at* http://mit.edu/globalchange/www/MITJPSPGC_Rpt120.pdf.

search stage and the commercialization stage where many promising energy technologies die—the so-called "technology valley of death." It represents critical early-stage production and deployment stages of commercialization. At these stages, the private energy sector has not fared well.

4. *Lack of Public Investment Is a Primary Barrier to Innovation*

Most energy experts view the lack of public investment in clean energy as the primary barrier to achieving price reductions through innovation. "Probably the most significant barrier to ETI [Energy Technology Innovation] is inadequacy of funds, especially for R&D, in relation to the challenges that are faced by [the] energy system."[70]

John Holdren, the current chairman of the American Association for the Advancement of Science, wrote:

> Around the world, the energy sector's ratio of RD&D investments to total revenues is well below that for any other high-tech sector of the economy . . . . These investments will need to be boosted at least 2–3-fold if the world is to meet the energy challenges it faces in the decades immediately ahead.[71]

Others say the level of investment should be much higher. "Using emissions scenarios from the Intergovernmental Panel on Climate Change and a previous framework for estimating the climate-related savings from energy R&D programs, we calculate that U.S. energy R&D spending of $15–30 billion per year would be sufficient to stabilize CO2 at double pre-industrial levels [550 ppm.]"[72]

B. Lessons From Past Public Investment in Technology and Infrastructure

The efficacy of this kind of public investment is well-documented. For instance, in the roughly five years that the federal government guaranteed the market for microchips in the 1960s, the price of a microchip came down from $1000 per chip to between $20 and $30 per chip.[73] According to Stern and the IPCC, "extensive and prolonged public support and private markets were both instrumental in the development of all generating technologies. Military R&D, the US space programme and learning from other markets have also been crucial to the process of innovation in the energy sector."[74] The IPCC further explains that "government support through financial con-

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[70] Kelly Sims Gallagher et al., *Energy-Technology Innovation*, 31 ANN. REV. OF ENV'T & RESOURCES 193, 221 (2006).

[71] John P. Holdren, *The Energy Innovation Imperative*, INNOVATIONS, Spring 2006, at 20, *available at* http://www.belfercenter.org/files/innovations_the_imperative_6_06.pdf.

[72] Kammen, *supra* note 67, at 4.

[73] Tom Abate, *Tech Titans' Radio Roots*, S.F. CHRON., Sept. 30, 2007, at A1 (citing PAUL E. CERUZZI, THE HISTORY OF MODERN COMPUTING (2d ed. 2003)).

[74] STERN, *supra* note 4, at 410.

tributions, tax credits, standard setting and market creation is important for effective technology development, innovation and deployment."[75]

The dramatic price and performance improvements in wind technology occurred because Denmark guaranteed its market for wind energy in the 1980s and 1990s. "Development of the Danish wind and Brazilian biofuels industries each required sustained government support over decades. The Danish subsidies totaled $1.3 billion, and Danish wind companies now earn more than that each year. At current oil prices, Brazil may soon similarly recoup its investment in biofuel technology."[76] Similarly, the Japanese government saw breakthroughs in the price of solar panels as a result of its intervention in the solar market in the 1990s.[77]

Large public investments in technology innovation and infrastructure are not new. Most of America's largest industries have benefited from strategic public investment in their development: agriculture, aerospace, transport, biotechnology, and energy. Farm land was granted to early American frontier farmers, and agriculture has been publicly subsidized since the early twentieth century. Before the Civil War, Abraham Lincoln was best known for his aggressive advocacy of publicly funded transit projects intended to modernize industry: canals, roads, and later, famously, railroads. The U.S. government created computer science, aerospace, and the modern highway system through investments that were designed to compete with the Soviets and were justified by national security concerns. And today's highly mature energy markets are the result of decades of subsidies for coal mining and oil drilling.

Government investments come in a variety of forms, from outright subsidization to various tax deductions, credits, and other mechanisms aimed at starting, financing, and otherwise supporting industries deemed important either to national wealth creation, national security, or both. The U.S. government invested directly in computer science scholarships and fellowships, prizes, research and development, and microchips. The private sector did not create, and could not have created, these high-tech markets.

Many successful new technologies cannot become commercially viable without public investment in the form of government procurement. The Defense Department's procurement of microchips facilitated the technology's market penetration and helped decrease its cost. It is not just microchip companies like Intel that benefited from these public investments. All high tech firms that depend on microchips, the Internet, and computer science exist thanks to these "tech-push" strategies.

In thinking about the history of U.S. technology policy, we need to draw conclusions about policy design, in part, from the political preconditions. The first lesson is that public investments succeed when they have strong support from both elites and the public. Cold War military leaders, for

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[75] IPCC, *supra* note 4, at 20.
[76] Grubb, *supra* note 47, at 26–27.
[77] Nemet, *supra* note 54, at 154.

instance, supported the expansion of airplane technology for security reasons, which also helped establish elite support for the space program. By the time President John F. Kennedy announced his intention to put a man on the moon and bring him safely back home, which cost over $135 billion in 2006 numbers, widespread public support for the aerospace industries already existed, with both job creation and national security driving that support.

The second lesson is that these investment-centered policies succeeded politically because they spoke to core American values, such as ingenuity, creativity, perseverance, and competition. They were also urgent: the Manhattan project was a race against the Nazis, and fear of the Soviets motivated the development of aerospace, computers, and the Internet. In the case of the Cold War space program, the United States was literally in a "space race" with the Soviets. The speed with which the United States built the railroads and the interstate highway system, invested in microchips, put a man on the moon, and built the Internet helped overcome bureaucratic obstacles to success. National security and economic development became justifications for policymakers and administrators to tunnel through various bureaucratic obstacles to success.

Today, Americans overwhelmingly view energy independence with equal urgency, and see political instability in the Middle East and the high price of oil as reasons to accelerate our transition to a clean energy future.[78] The investment-centered framework for action on energy independence and global warming should speak to both existing fear and to feelings of confidence and optimism.

The third lesson is that revolutionary new technologies generate multiple benefits. ARPANET was created primarily for communication during the Cold War, but eventually developed into the Internet. Similarly, successful public investment into clean energy has the potential to create widespread, unanticipated benefits: it can create jobs, increase national security through energy independence, reduce and stabilize energy prices by diversifying energy supplies, secure America's place in global innovation by taking part in the fast-growing clean energy technology market, and help to mitigate the effects of global warming by reducing greenhouse gas emissions.

America's national culture today remains far more supportive of a political and policy agenda grounded in accelerating the transition to a clean energy economy than one grounded in reducing pollution emissions. Poll data demonstrate strong public support for government research programs specifically. Though Americans do not support higher gasoline or electricity prices to change behavior, wide majorities also say they would be willing to pay higher gasoline and electricity prices if the money was earmarked for programs designed to achieve energy independence and develop clean en-

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[78] *See* JEFF NAVIN, AMERICAN ENVIRONICS, ENERGY ATTITUDES: RISING PUBLIC DEMAND FOR ENERGY INDEPENDENCE EVEN AS GLOBAL WARMING REMAINS A LOW PRIORITY FOR VOTERS 7 (2007), *available at* http://www.americanenvironics.com/PDF/EnergyAttitudesSummer2007.pdf.

ergy. When both the benefits and costs of the policy initiatives were listed, the support for investment far exceeded the other options in the poll.[79]

The programs would benefit industry as well. In contrast to a regulation-centered approach that seeks to impose costs on businesses, the investment-centered framework defines existing industries as potential allies rather than as likely opponents. History provides a useful guide. Private firms built the railroads, but American taxpayers paid the entire bill. Historians consider the first Transcontinental Railroad, built in the 1860s, to be the greatest American technological feat of the nineteenth century. Nearly one hundred years later, Congress passed and President Dwight D. Eisenhower signed the National Interstate and Defense Highways Act into law.[80]

Innovation in science and technology may drive as much as 90% of overall economic growth.[81] Investments in clean energy technology are particularly promising because they both drive economic growth and avoid (or reduce the cost of) the most expensive impacts of climate change. Using an economic model aimed at calculating both the economic costs of climate change and the costs of mitigation, Yale economist William Nordhaus estimates that clean energy alternatives have a net value of roughly $17 trillion in 2005 dollars.[82]

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[79] An April 2007 CBS News/*New York Times* poll showed 64% of Americans would be willing "to pay higher taxes on gasoline and other fuels if the money was used for research into renewable sources like solar and wind energy." N.Y. TIMES/CBS NEWS POLL, THE NEW YORK TIMES/CBS POLL: Apr. 20–24, 2007, at 11 (2007), *available at* http://graphics8.nytimes.com/packages/pdf/national/20070424_poll.pdf. A Gallup poll taken at the same time found that when asked a battery of questions about what the government should do to address global warming, 65% of Americans said the government should be "starting a major research effort costing up to $30 billion per year to develop new sources of energy," the highest scoring item in the battery. JOSEPH CARROLL, GALLUP, AMERICANS ASSESS WHAT THEY CAN DO TO REDUCE GLOBAL WARMING (2007), *available at* http://www.gallup.com/poll/27298/Americans-Assess-What-They-Can-Reduce-Global-Warming.aspx. An August 2006 *Los Angeles Times/Bloomberg* poll asked Americans to identify the "best way for the US to reduce reliance on foreign oil." A majority, 52%, cited "having the government invest in alternative energy sources, such as wind and solar power," the top choice by a two-to-one margin. *Anxiety About Terrorist Attacks and Conflicts in the Middle East Help to Keep Bush's Ratings Low,* L.A. TIMES, Aug. 2, 2006, at 15, *available at* http://www.latimes.com/media/acrobat/2006-08/24694273.pdf. The highest levels of support in a March 2006 Gallup poll were for spending government money on the new energy sources. The public supported proposals for "spending more government money on developing solar and wind power" by 81% in 2007, up from 77% in 2006. Gallup found that "starting a major research effort costing up to $30 billion per year to develop new sources of energy" was supported by 65% of respondents, the largest level of support of the items tested. JOSEPH CARROLL, GALLUP, MAJORITY OF AMERICANS SUPPORT USE OF NUCLEAR ENERGY (2006), *available at* http://www.gallup.com/poll/22171/Majority-Americans-Support-Use-Nuclear-Energy.aspx.

[80] Federal-Aid Highway Act of 1956, Pub. L. No. 84-627, 70 Stat. 374 (codified as amended at 23 U.S.C §§ 101–89 (2005)).

[81] Nemet, *supra* note 54, at 30.

[82] NORDHAUS, *supra* note 26, at 27.

C. Challenges to the Investment-Centered Approach

The central objection to the investment-centered approach is that only a strong regulatory framework mandating reductions on the order of 2% per year can guarantee an 80% reduction of greenhouse gas emissions by 2050. An investment-centered approach, critics say, risks distracting attention from the central importance of regulation.

Others point out that investment in technology is no guarantee of technological innovation. Some point to failed public investments in the past. Corn-based ethanol receives tens of billions of taxpayer money annually, and although ethanol promises to reduce oil dependency, it has no net impact on greenhouse gas emissions, given the need for fossil fuel inputs into agriculture. The Synfuels program started by Truman and ended by Reagan did nothing to free the United States from oil. The Clinton Administration's partnership with United States automakers on a program to accelerate the creation of hybrid gas-electric engines in the face of the Congress's repeated unwillingness to raise fuel economy standards had no technological impact.

Some have suggested that our investment-centered approach misunderstands the workings of the free market. They say that the actual price for carbon dioxide will send a symbolic "signal" to the marketplace that is far stronger than the price itself. Indeed, the public debate over new greenhouse gas regulations has spurred a huge upsurge of private investment into firms offering energy efficiency, conservation, and clean energy.

Still others have argued that our investment-centered approach differs from the dominant regulation-centered approach in degree, not kind. While it is true that our approach embraces regulation to reduce emissions, it does so primarily to generate public investment capital. The critical distinction is that we believe investment, not regulation, should be foregrounded as the main event. This argument stands in direct contrast to regulation-centered advocates who believe that a cap-and-trade system will drive necessary emissions reductions with the incidental benefit of generating additional revenue for investment in clean energy.

Massive public investment is required to bring down the price of clean energy and accelerate its deployment worldwide. This investment-centered approach does not require a massive increase in the cost of dirty energy. We can get where we need to go with a lower carbon dioxide price and still achieve the emissions reductions we need as long as pollution permits are auctioned and generate the necessary $30–80 billion annual investment. Politically speaking, such a framework is more popular, since it appeals to the American core values of economic opportunity and technological ingenuity more strongly than does the regulation-centered approach.

Critics are right to point out that public investment in technology innovation and infrastructure has failed as often as it has succeeded. But the same could be said of many past regulations as well, such as the Kyoto Protocol. The emissions of Kyoto ratifying countries went up, not down, between 2000 and 2004. Moreover, the Kyoto Protocol's failure is proof that setting regulatory limits is no guarantee of emissions reductions.

The fact that some investments in innovation fail is not an argument against public investment per se, just as the failure of Kyoto is not an argument against emissions limits per se. Indeed, in the case of technology innovation, repeated failures are widely recognized by experts and CEOs alike as preconditions to success. That some past investments and regulations failed is reason for careful examination of what has and has not worked in the past, and what needs to be done now.

IV. Specific Recommendations

We offer the following specific recommendations as a starting point for discussion. These recommendations are designed to drive home the scale of the problem and to initiate a dialogue about the best way to proceed. How much to invest, where to invest it, and how to structure the incentives for the private sector are complicated problems, and will take considerable additional thought. What is clear, however, is that a new approach to the energy challenge is imperative at this point in time.

1. *Establish a Price for Carbon Dioxide That Is Consistent With What Present Technology Can Accomplish*

Experts and stakeholders vigorously debate the level of carbon reduction Congress should mandate. The grassroots climate movement demands 80% by 2050.[83] Most legislative proposals in Congress undershoot that goal substantially. As noted above, carbon dioxide would need to be priced at around $100 per ton between 2010 and 2030, and $160–200 per ton between 2030 and 2050, to reduce greenhouse gases 90% by 2050 in the United States—prices that would increase the cost of coal-generated electricity by two and a half times.[84] For this reason, many global warming proposals under consideration in Congress include a safety valve provision that would lift the national emissions cap if the carbon dioxide price it establishes goes above a certain price, say $7–12 per ton. As long as there is a safety valve or other mechanism that would have the effect of keeping the price of carbon dioxide relatively low, the total emissions cap is largely irrelevant and what matters is the maximum carbon dioxide price that triggers the safety valve.

Expending political resources to establish emissions caps over forty years that will either prove unsustainable without technology breakthroughs, or irrelevant with them, does not make sense. We are better off establishing a modest carbon dioxide price in the shorter term, which can capture emissions reductions from efficiency and the shift to cleaner conventional energy

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[83] *See, e.g.*, 1 Sky, 1 Sky 3 Promises to do What it Takes 1 (2007), *available at* http://www.1sky.org/wp-content/uploads/pdfs/1sky_solutions.pdf.

[84] Nordhaus, *supra* note 26, at 26.

sources, while pursuing a more feasible long-term strategy of reducing the price of clean energy through politically palatable public investment.

2. *Establish a Dedicated Source of Public Funding for Clean Energy Investment That Can Rapidly Drive Down the Deployed Cost of Clean Energy Technologies*

Given this framework, the key to achieving deep reductions is to drive down the real price and improve the performance of clean energy technology as rapidly as possible. As noted above, it is our contention that targeted public investment is the most likely path to this outcome. Carbon regulation may be one source for this revenue stream. Whether through auctioning permits or taxing carbon dioxide directly, federal carbon regulation can potentially generate tens of billions of dollars annually for public clean-energy investments. These investments should include dramatic increases in funding for basic research in the energy sciences, a ten-year commitment to buy down the price of solar technology and battery and other energy storage technologies, and a commitment to build a smarter and more efficient electricity grid that can support energy generation that is both more widely distributed and, in many cases, more remote.

3. *Ramp Up: Invest $300 Billion in Research, Development, and Deployment of Clean Energy Technologies*

An emerging consensus among energy experts suggests that investment in energy research, development, and deployment should be increased to $30–80 billion in the United States, and $50–170 billion worldwide, per year.[85]

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[85] While there is a strong consensus that public investment in energy research, development and deployment should increase, the amount recommended varies from a twofold to a fourfold increase. *See* Holdren, *supra* note 71, at 20; Nemet, *supra* note 54, at 48. Nemet argues that all of these estimates are too low, pointing out that Schock's estimate of the impacts of a fourfold increase assumes "a mean climate stabilization target of between 650 and 750 ppm CO_2, and incorporates a 35% probability that no stabilization at all will be needed. This possibility of no stabilization at all is especially concerning as it would potentially involve levels exceeding 1000 ppm CO2 by the end of the century with higher levels thereafter." Nemet, *supra* note 54 at 48–49. Nemet reconfigured the Schock et al. model to reach a target of 550-ppm atmospheric level of carbon, 100 ppm below what IPCC and Stern conclude would lead to drastic and irreversible consequences, and finds that the optimal research and development investment would be between $11 and $32 billion annually in 2005 dollars, or roughly three to ten times more than current energy research and development. *Id.* at 54. That investment level would also act as "insurance" against electricity blackouts, oil price shocks, and air pollution. This would be a large increase, but Nemet points out that "[o]verall R&D in the US economy was 2.6% of GDP [between 1988 and 2003] and has been increasing. High tech industries such as pharmaceuticals, software and computers routinely invest between 5 and 15% of revenues in R&D". *Id.* at 58.

In October 2007, Gwyn Prins and Steve Rayner persuasively argued that the United States should spend $80 billion per year on clean energy. Gwyn Prins & Steve Rayner, *Time to Ditch Kyoto*, NATURE, Oct. 25, 2007, at 973, 975, *available at* http://www.nature.com/nature/journal/v449/n7165/pdf/449973a.pdf.

We are proposing a ten-year, $300 billion public investment into accelerating the transition to a clean energy economy. The goal of the program is to bring the price of clean energy down to the price of coal and natural gas as quickly as possible. Other values also should be built into the structure of the investment, such as labor, health, and other environmental standards.

This public investment will have a significant effect in generating private investment revenue.[86] This analysis is backed by various historical investment successes. Just as past public investment efforts into railroads, the highways, microchips, the Internet, computer science, and the medical biosciences triggered billions in private investment, and paid for themselves many times over, so will these new investments into energy.

This pattern of private investment following public investment remains apparent today in both biofuels and biosciences. The econometric analysis described above found that a $300 billion investment would pay for itself in ten years both through energy savings, economic growth, job creation, profit taking, and thus additional revenue for the U.S. Treasury.

4. *Insulate Federal Clean Energy Investments From Pork-Barrel Politics*

There are many models for insulating crucial policy decisions from political meddling, from the Pentagon's Defense Advanced Research Projects Agency (DARPA), to the military base closing commission, to the creation of public corporations and industry boards.

Former CIA Director John Deutsch, who also worked at the Department of Energy and now works at MIT, concludes that what is needed is both more money for commercialization *and* new institutions, such as a public Energy Technology Corporation. According to Deutsch,

> [T]he ETC would be composed of independent individuals with experience and knowledge about future market needs, industry capability, and best use of indirect financial incentives—loans, loan guarantees, production tax credits, and guaranteed purchase—in order to run a project on as commercial a basis as possible. The ETC would not be subject to federal procurement rules, and if financed with a single appropriation, would be somewhat insulated from congressional and special interest pressure.[87]

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[86] E-mail from Ray Perryman, President, The Perryman Group, to Michael Shellenberger (Nov. 16, 2007, 11:29:57 EST) (on file with author); *see also* RAY PERRYMAN, REDIFINING THE PROSPECTS FOR SUSTAINABLE PROSPERITY, EMPLOYMENT EXPANSION, AND ENVIRONMENTAL QUALITY IN THE US: AN ASSESSMENT OF THE ECONOMIC IMPACT OF THE INITIATIVES COMPRISING THE APOLLO PROJECT (2003).

[87] DEUTSCH, *supra* note 69, at 16.

5. *Buy Down the Price of Solar Technology Like We Did With Microchips*

There is no silver bullet when it comes to clean energy alternatives. For that reason, we must make investments in a wide range of low- to zero-emissions technologies, including wind, geothermal, efficiency, carbon capture and storage, nuclear, solar, and advanced energy technologies.

However, this does not mean that all clean energy sources are created equal. Solar has special potential, and merits special attention. Solar panels, like microchips, have their own kind of "Moore's Law": the price of solar comes down roughly 20% every time production capacity is doubled. Just as the Department of Defense guaranteed the nascent market for silicon microchips in the 1960s, bringing the price down from $1000 to $20 per chip in just a few years, the Pentagon should do the same with silicon solar panels. If the price of solar photovoltaic continues to decline 20% for every doubling of capacity, it would cost just $211 billion to bring the price of solar down to the price of current electricity costs in many countries.[88] It might be one of the best $200 billion investments ever made by the U.S. military.

6. *Play the Field: Make Strategic Investments in Key Energy Sectors and Technologies*

Meeting our present and future energy needs will require greater energy diversity. Experts emphasize the need for a "silver buckshot" approach that consists of investing in innovation, including deployment, of many new energy technologies.[89]

Anyone hoping to develop a new energy agenda must constantly grapple with the myriad of new technological possibilities. Delving into each specific renewable technology is beyond the scope of this essay, but targeted investments in solar, wind, geothermal, and ocean energy, as well as efficiency mechanisms, carbon capture and storage, nuclear technology, and biofuels will be important and prudent steps for the near future. Additionally, the nation desperately needs an upgraded infrastructure of batteries and transmission lines to deliver clean energy to the grid; those technologies should receive substantial public support as well.

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[88] *See* Bob Van der Zwaan & Ari Rabel, *The Learning Potential of Photovoltaics: Implications for Energy Policy*, 32 ENERGY POL'Y 1545, 1551 tbl.5 (2004) (stating the cost of breaking even).

[89] Grubb, *supra* note 47, at 33.

7. *Create a Framework for Global Carbon Regulation Tied to Living Standards*

China, despite much criticism from environmentalists, has already done more to mitigate the environmental impacts of its development than has any developing nation in history. The establishment of nascent carbon dioxide prices in the developing world should be based upon benchmarks associated with improving living standards in those countries, the attainment of real reductions in carbon emissions in the developed world, and major progress in bringing down the costs of appropriate clean energy technologies that can be deployed in developing economies. As economic development progresses, living standards improve, and the costs of clean energy technologies come down dramatically, modest carbon prices in the developing world will become both tenable and sufficient to drive the transition to low-carbon alternatives.

V. Conclusion

The energy challenge has been framed thus far as a forced choice between poverty and environmental ruin. With a choice like that, it is no surprise that the world has failed to make real strides towards a cleaner energy future. Global warming and energy independence are new challenges that require new ways of thinking. The outmoded regulation-centered approach, which seeks to curb pollution by merely imposing costs on polluters, is inadequate to deal with this new challenge.

Instead, America should take a bold step and cut this Gordian Knot by pouring public funds into new technologies. Unleashing the creativity of our brightest minds on this problem is likely to produce brilliant results not only for the environment, but for our economy, national security, and status in the world.