POST-PARTISAN POWER

HOW A LIMITED AND DIRECT APPROACH TO ENERGY INNOVATION CAN DELIVER CLEAN, CHEAP ENERGY, ECONOMIC PRODUCTIVITY AND NATIONAL PROSPERITY

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→ INTRODUCTION ←

If ever there were a time to hit the reset button on energy policy, it is today. Congress is set to adjourn without taking substantive, long-term action on either climate or energy. While conservatives may be celebrating the death of cap and trade, the truth is that the right's longstanding hopes for the expansion of nuclear power and oil production have also run aground, foundering on the high cost of constructing new nuclear plants and the impacts of the devastating oil spill in the Gulf of Mexico. As a result, energy policy is at a standstill, despite overwhelming public support for accelerating the move to clean, affordable energy sources and tapping fast-growing clean energy industries to create jobs and wealth in the United States.

Today, few issues in American political life are as polarized as energy policy, with both left and right entrenched in old worldviews that no longer make sense. For the better part of two decades, much of the right has speculated darkly about global warming as a United Nations-inspired conspiracy to destroy American sovereignty, all while passing off chants of "drill, baby, drill" as real energy policy. During the same period much of the left has oscillated incoherently between exhortations that avoiding the end of the world demands shared sacrifice, and contradictory assertions that today's renewable energy and efficiency technologies can eliminate fossil fuels at no significant cost. All the while, America's dependence on fossil fuels continues unabated and political gridlock deepens, preventing real progress towards a safer, cleaner, more secure energy system.

The extremes have so dominated mainstream thinking on energy that it is easy to forget how much reasonable liberals and conservatives can actually agree on. Fossil fuels have undeniably been critical to American prosperity and development, but we can gradually move toward cleaner, healthier, and safer energy sources. Indeed, throughout history, as we have become a more prosperous nation, we have steadily moved to cleaner energy sources, from wood and dung to coal to oil to natural gas, hydropower, and nuclear energy.[1] Our goal today should be to make new clean energy sources much cheaper so they can steadily displace fossil fuels, continuing this ongoing process. If we structure this transition correctly, new energy industries could be an important driver of long-term economic growth.

Arriving at a new post-partisan consensus will require liberals and conservatives, alike, to take a renewed look at key facts, which challenge some long-standing assumptions about energy.

For liberals this means acknowledging that today's renewable energy technologies are, by and large, too expensive and difficult to scale to meet the energy needs of the nation, much less a rapidly growing global population.[2] New mandates, carbon pricing systems such as cap and trade, and today's mess of subsidies are not going to deliver the kind of clean energy innovation required.[3] And nuclear power, long reviled by many on the left, is far cleaner and safer than most liberals imagine, and holds enormous potential to displace low-cost but high-polluting coal power.[4]

For conservatives this means acknowledging that fossil fuels have serious health,[5] safety,[6] and security consequences[7] aside from any risks global warming might pose. The biggest obstacle facing nuclear power is not environmental policy but rather public opposition, high construction costs, and associated financial risks.[8] And while many faults can be found with ethanol and synfuels investments, the bulk of historic federal investments in energy technology — from hydro and nuclear to solar, wind, and electric vehicles — have been an overwhelming success.[9]

This white paper is the product of a more than yearlong dialogue between scholars situated at divergent points on the political compass. Drawing on America's bipartisan history of successful federal investment to catalyze technology innovation by the U.S. military, universities, private corporations, and entrepreneurs, the heart of this proposal is a $25 billion per year investment channeled through a reformed energy innovation system.

This new system is built on a four-part energy framework:

1. **Invest in Energy Science and Education**
2. **Overhaul the Energy Innovation System**
3. **Reform Energy Subsidies and Use Military Procurement and Competitive Deployment to Drive Innovation and Price Declines**
4. **Internalize the Cost of Energy Modernization and Ensure Investments Do Not Add to the National Debt**

To accelerate energy innovation and modernization, we propose a role for government that is both limited and direct. It is limited because it is focused, not on reorganizing our entire highly complex energy economy, but rather on specific strategies to drive down the real cost of clean energy technologies. Instead of subsidizing existing technologies hoping that as they scale up, costs will decline, or providing tax credits to indirectly incentivize research at private firms, this framework is direct because the federal government would directly drive innovation and adoption through basic research, development, and procurement in the same way it did with computers, pharmaceutical drugs, radios, microchips, and many other technologies.

Time and again, when confronted with compelling national innovation priorities, the United States has summoned the resources necessary to secure American technological leadership by investing in breakthrough science and world-class education. The United States responded vigorously to the Soviet launch of Sputnik by investing the resources necessary to ensure American innovators, entrepreneurs, and firms would lead the world in aerospace, IT, and computing technologies, igniting prosperous new industries in the process. Today, we invest $30 billion annually in pursuit of new cures to deadly diseases and new biomedical innovations that can extend the lives and welfare of Americans. We similarly devote more than $80 billion annually to military innovations that can help secure our borders.[10] We propose a similar national commitment to energy sciences and education, which have languished without the funding deserving of a national innovation priority.[11] At the same, this proposal is based on what we know about successful public-private partnerships to build and strengthen regional hubs of innovation, such as the one that evolved into Silicon Valley. Therefore, we propose investment in a national network of regional clusters of universities, entrepreneurs, private investors, and technology companies.[12]

While the left wants to cut fossil fuel and nuclear subsidies and the right wants to cut renewable energy subsidies, we propose across-the-board energy subsidy reform, disciplining all incentives for technology deployment and adoption to a new framework that rewards innovation — as measured through real declines in the cost of generating energy — not simply producing more of the same. Today's federal investments — whether for solar and wind or ethanol and nuclear — are structured around scale and quantity, not innovation. The innovation system we propose builds on the successes of military procurement to purchase and prove advanced energy systems while providing competitive markets for emerging energy technologies, which can facilitate mass manufacture, demand progressive innovation, and bring down the real, unsubsidized cost of clean and secure energy alternatives.

These productive investments have the potential to raise America's economic growth over the long term and thus help reduce the budget deficit. America's $1.3 trillion budget deficit is largely a consequence of low growth and the increasing cost of structural entitlement programs, but it can be overcome by a combination of higher growth, responsible entitlement reform, and targeted spending cuts. Achieving higher growth will require continued federal investments in productive enterprises, including health, information technology, and energy. Furthermore, fear of technology failure should not paralyze strategic investments in innovation, since some amount of failure is inevitable and essential to such a disruptive and non-linear process.

To ensure that these limited, targeted new investments do not add to the federal deficit, we propose a suite of options that Congress and the President can use to finance energy innovation. These include cutting existing energy subsidies, charging new royalties for oil drilling, small surcharges on oil imports or electricity sales, and a very low carbon price. While each of these mechanisms may bother some on both the left and right, all should agree that exacerbating the national debt is unwise. Revenues must be found in order to make these productive investments, which have long-term potential to revitalize the economy.

Increasing investment in energy technology and innovation, as we advocate, remains exceedingly popular with Americans of all political stripes. Of all energy policy proposals, from carbon pricing and cap and trade to new oil and gas drilling, expanding production and lowering the price of clean, innovative energy technologies is the most popular approach, regularly receiving support from 65 to 90 percent of Americans in independent news polls, Gallup surveys, and other opinion research.[13] This public support is consistent over time, and reflects the historical willingness of publics to pay slightly more for cleaner and safer energy sources.[14]

In the pages that follow, we aim to present a practical and bipartisan approach to American energy policy. The time has come for a fresh start that can bring our nation into the future through a pragmatic drive to make clean energy cheap and abundant.

→ SUMMARY OF RECOMMENDATIONS ←

1
Invest in Energy Science and Education

- Secure funding necessary to complete the doubling of Department of Energy (DOE) Office of Science budgets. Direct a significant portion of new funds to programs related to energy sciences, including roughly $300 million in annual funding to scale up the Energy Frontier Research Centers (EFRC) program over the coming years.

- Invest roughly $500 million annually to support K-12 curriculum and teacher training, energy education scholarships, post-doctoral fellowships, and graduate research grants. Just as the United States rose to the Cold War challenge by enacting the National Defense Education Act and leveling critical investments in science, technology, engineering, and mathematics education, a new national commitment is needed today to train, educate, and inspire a generation of energy innovators, engineers, and entrepreneurs.

2
Overhaul the Energy Innovation System

- Help reform the U.S. energy innovation system by investing up to $5 billion annually to establish a robust national network of regional energy innovation institutes bringing together private sector, university, and government researchers alongside investors and private sector customers. Funded at $50-300 million annually, each institute will foster competitive centers of clean energy innovation and entrepreneurship while accelerating the translation of research insights into commercial products.

- Bring the Advanced Research Projects Agency for Energy (ARPA-E) to scale by providing $1.5 billion annually, while dedicating a significant portion of new funding to dual-use energy technology innovations with the potential to enhance energy security and strengthen the U.S. military. The Department of Defense (DOD) should work actively with ARPA-E to determine and select dual-use breakthrough energy innovations for funding through the ARPA-E program and potential adoption and procurement by the DOD.

3
Reform Energy Subsidies and Use Military Procurement and Competitive Deployment Incentives to Drive Price Declines

→ Reform the nation's morass of energy subsidies. Instead of open-ended subsidies that reward firms for producing more of the same product, employ a new strategy of competitive deployment incentives, disciplined by cost reductions and optimized to drive steady improvements in the price and performance of a suite of emerging energy technologies. Create incentives for various classes of energy technologies to ensure that each has a chance to mature. Decrease incentive levels until emerging technologies become competitive with mature, entrenched competitors to avoid creating permanently subsidized industries or picking winners and losers, *a priori*.

→ Expand DOD efforts to procure, demonstrate, test, validate, and improve a suite of cutting-edge energy technologies. New, innovative energy alternatives are necessary to secure the national defense, enhance energy security, and improve the operational capabilities of the U.S. military. Provide up to $5 billion annually in new appropriations to ensure the Pentagon has the resources to pursue this critical effort without infringing on funds required for current military operations.

→ Recognize the potential for nuclear power — particularly innovative, smaller reactor designs — to enhance American energy security, reduce pollution, and supply affordable power. America cannot afford to bank on one technology alone, however, and must pursue all paths to clean, affordable energy, supporting all innovative, emerging clean energy sources, from advanced wind, geothermal, and solar to electric vehicles and advanced batteries, allowing winners to emerge over time.

4
Internalize the Cost of Energy Modernization and Ensure Investments Do Not Add to the Deficit

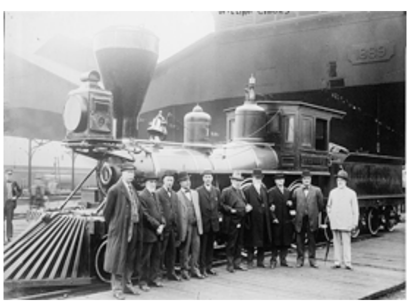
→ Secure revenues to ensure these productive new investments do not exacerbate the national debt, through one or a combination of the following means: phase out unproductive energy subsidies, which have not sufficiently driven innovation; direct revenues from oil and gas leasing to energy innovation; implement a small fee on imported oil to drive energy innovation and enhance American energy security; establish a small surcharge on electricity sales to fund energy modernization, similar to the Highway Trust Fund; and/or dedicate revenues from a very small carbon price to finance necessary investments in clean energy technology.

→ THE BIPARTISAN HISTORY OF AMERICAN PROSPERITY ←

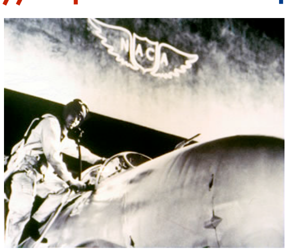
Throughout American history, strategic government investments in areas like education, technology, infrastructure, and energy catalyzed the entrepreneurship and innovation that has paved the way for so many of the great American technological and economic successes of the 20th century.[15] In the words of conservative *New York Times* columnist David Brooks, the American story is one of "limited but energetic governments that used aggressive federal power to promote growth."[16]

Federal investment led to the development of the railroads under Abraham Lincoln and the federal highway system under Dwight D. Eisenhower. Technologies leading to the wide-scale use of nuclear power were developed in government labs and initially deployed under the auspices of the U.S. Navy and Atomic Energy Commission, after active support from Presidents Roosevelt, Truman, and Eisenhower. Early, sustained investments in R&D, education, computer science, and infrastructure through programs like the GI Bill, National Defense Education Act, and Apollo space program laid the foundation for the emergence of the aerospace, computing, and information technology industries. The United States Department of Defense (DOD) has long acted as an initial funder and early adopter of key technologies like radios, semiconductors, computers, software, and the Internet. And federal investments in health research through the National Institutes of Health have enabled scientists to map the entire human genome, making way for path-breaking advances in biotechnology.

In education and technology, federal investments have repaid themselves many times over in the form of greater economic growth, increased tax revenues, and high-paying domestic jobs. Every dollar invested in



1862 — Republican President Abraham Lincoln signs the Pacific Railway Act, financing the expansion of a national rail network that leads to the industrialization of the West.



1915 — Under Democratic President Woodrow Wilson, military procurement and cutting edge R&D performed by the National Advisory Committee for Aeronautics builds the modern American aviation industry and propels U.S. firms ahead of international competitors.

1930s — Begun under Republican President Herbert Hoover and expanded under Democrat Franklin Delano Roosevelt, America begins an era of large-scale investment in hydroelectric dams, providing clean, cheap electricity to power economic development in the Southeast and American West.

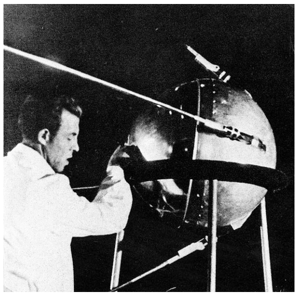
1942-1945 — Under FDR, the United States invests $20 billion (in 2003 dollars) in the Manhattan Project. A decade later, Republican Dwight D. Eisenhower harnesses "Atoms for Peace," launching a public-private partnership to build the first commercial nuclear reactor.

education by the GI Bill following World War II returned just over $5 in greater economic growth and $1.83 in greater tax revenues over the following 35 years, according to a Congressional report.[17] Likewise, federal investment in R&D is a key driver of productivity gains and economic growth, and studies routinely conclude that there is a significant rate of return on such investments to the national economy and the tax base.[18]

Economist Robert Solow received a Nobel Prize in economics in part for demonstrating that over 80 percent of economic growth in the first half of the 20th century was driven by advances in technology, and later economists confirmed that technology innovation played a similarly outsized role in economic progress in the later half of the century.[19] Just as federal investment has driven innovation in countless industries over the last century, so too will federal investment in energy technology be central to catalyzing private sector innovation and entrepreneurship in the 21st century energy sector, creating new industries and jobs.

In an era of fiscal constraint, it is important to distinguish between government spending, some of which is clearly unproductive and wasteful, and dynamic public investments that yield long-term economic returns. Fiscal deficits are an increasing concern, particularly as the federal bureaucracy has grown to record levels in recent years. Certainly, at least some government expansions are unnecessary or duplicative, and discontinuing ineffective and wasteful programs can help restore some fiscal balance. But not all federal programs should be painted with a broad, deficit-cutting brush. Indeed, federal investments in areas like science and technology have been a long-term driver of national prosperity under presidents both Democrat and Republican.

Far from being an unnecessary strain on the federal budget, federal investments in energy technology innovation are thus a critical component of an effective and responsible strategy to reduce the national debt and generate a new era of sustained economic prosperity.



1958 After the Soviet launch of Sputnik, President Eisenhower signs the National Defense Education Act, committing $7.2 billion (in today's dollars) over four years to train a cadre of skilled scientists and engineers and secure American leadership in aerospace, IT, and computing.

1961 Democratic President John F. Kennedy commits America to the Space Race and begins the Minuteman missile program. The Air Force and NASA buy virtually every microchip that firms can produce, giving rise to the modern semiconductor industry and catapulting the world into the Silicon Age.

1987 Facing aggressive Japanese competition, Republican President Ronald Reagan's Defense Department finances the creation of SEMATECH, a public-private partnership to restore U.S. leadership in the global semiconductor industry.

1995-2008 Under both Democratic President Bill Clinton and Republican President George W. Bush, the budget for the National Institutes of Health (NIH) is nearly tripled from $11.3 billion in 1995 to $29.4 billion in 2008.

→ THE CHALLENGE ←

As we chart a clear path forward that breaks from the stagnation of the past, we begin with two premises.

First

America will make little sustained progress in transforming the U.S. energy economy or fully capturing the economic opportunities in new clean energy export markets until alternatives to conventional fossil fuels become cheaper.

High cost continues to be the largest barrier to the scalability of emerging clean energy technologies. Relative to fossil fuels, clean energy technologies are still too expensive and their performance too unreliable to be widely adopted on either a national or global scale. Solar panels still suffer from low conversions of sunlight to electricity and high installation costs. Both wind and solar thermal power require enormous amounts of land to generate large amounts of electricity, often demand transmission infrastructure to send power across vast distances, and incur additional storage costs if they are to reliably provide power for more than a few hours today. Next generation biofuels, still in the demonstration phase, are roughly twice as expensive as gasoline. Nuclear power is energy dense and can generate power continuously throughout the day, but remains unpopular and very capital intensive, making the cost of new plant construction high and new construction ventures risky to investors.[20]

For more than two decades, most governments have advocated a policy response — substantially raising the price of fossil fuels either through a high carbon tax or cap and trade regime — that has failed repeatedly. Sanctioned by neoclassical economic theory, such a strategy seems reasonable on its surface but in reality leaves much to be desired. In practice, governments face stiff political resistance to raising energy prices, which has ensured that any price on carbon has been too low to quickly increase the supply of new clean energy technologies.[21] In fact, many developed economies that have put a price on carbon are still building new coal-fired power plants[22]—all while continuing to depend on large subsidies to drive clean energy technology adoption.[23]

Conventional energy and climate policies thus lead us to a dead end: Policymakers are unwilling to raise the price of carbon to politically unsustainable levels, and ongoing subsidies for clean energy will become prohibitively expensive as clean energy technologies make up a greater share of the overall energy mix.

Likewise, in the developing world — where the large majority of energy demand will originate over the next 50 years — economic development priorities supersede decisions to pay a premium for higher-cost, low-carbon energy. Indeed, even 'cheap' fossil fuels are still too expensive for roughly 2.4 billion people around the world who still rely on wood, dung, and other primitive 'biomass' as their primary energy source.[24]

The only true solution to replacing fossil fuels on a meaningful scale is to make clean energy cheap in real, unsubsidized terms. Accomplishing this task will not only reduce our fossil fuel reliance but will also allow U.S. companies to tap the multi-trillion dollar export opportunity inherent in meeting the rapidly growing demand for energy in the developing world.

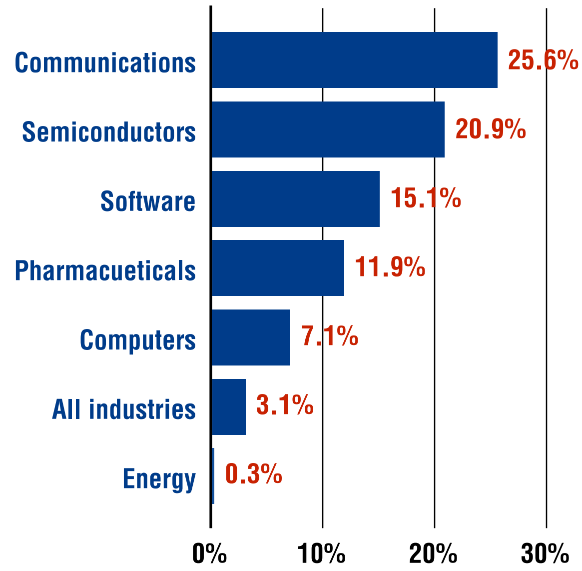
Second
The only path to accomplishing this key objective – making clean energy cheap – is vastly expanded research, development, and early stage commercialization and deployment of clean energy technology.

Making clean energy cheap and reliable enough to be widely scaled around the world will require both revolutionary and incremental advances in clean energy technologies that are only possible through innovation. Secretary of Energy Steven Chu has noted that "Nobel-level breakthroughs" are required in areas like solar energy, advanced batteries, biofuels, and energy storage.[25] Accelerating innovation in these and other clean energy technologies will require major investments in research to create the next generation of advanced technologies, materials, and practices, as well as ways to quickly demonstrate new technologies, scale them up to commercial scale, and bring them down in price.[26]

Despite this clear innovation imperative, neither the private nor the public sector currently invests the resources required to accelerate clean energy innovation and drive down the cost of clean energy.

Multiple barriers prevent private firms from adequately investing in the development of new, high-risk energy technologies. These include: the higher price of clean energy technologies; knowledge spillover risks from private investment in research; inherent technology and policy risks in energy markets; the scale and long time-horizon of many clean energy projects; and a lack of wide-spread enabling clean energy infrastructure.[27] As a result of these and other barriers, U.S. energy firms reinvest well below one percent of their revenues in R&D, with much of that amount chiefly spent on improving current technologies instead of developing new ones. This stands in stark contrast to the 10 to 20 percent or more of revenues that innovation-intensive industries such as information technology, semiconductors, and pharmaceuticals routinely reinvest in research and new product development (see Figure 1).

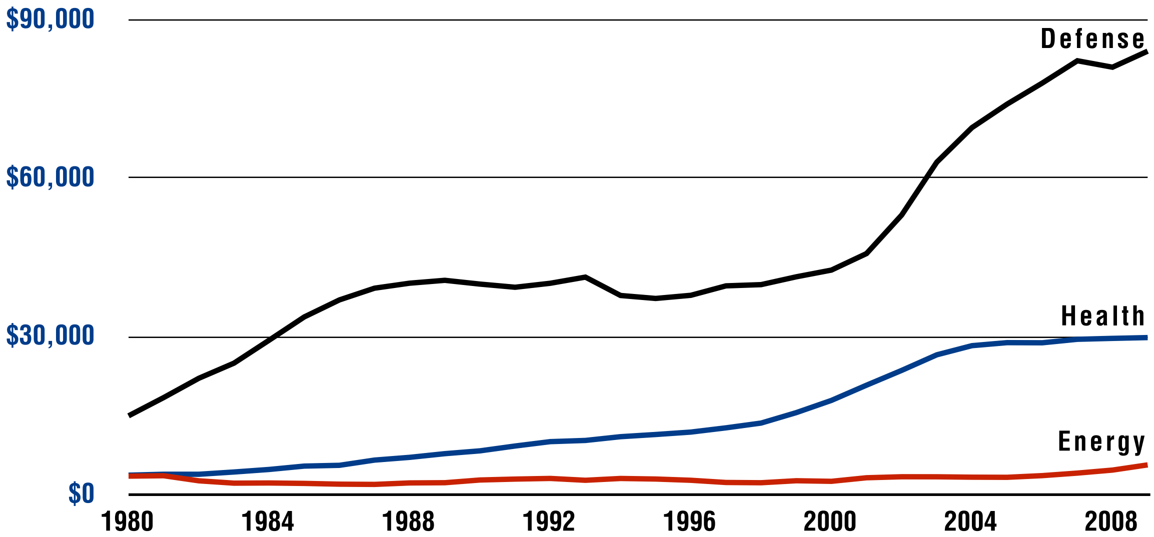
Figure 1
Industry R&D Spending as a Percent of Domestic Sales[28]



This private sector investment gap is due in part to an analogous one in the public sector. Federal energy R&D spending, which rose modestly under stimulus investments in 2009 and 2010, will drop to less than $5 billion in 2011. By contrast, we invest $30 billion each year into research through the National Institutes of Health, even as private sector firms invest nearly $60 billion of their own funds in health and biomedical R&D.[29]

Meanwhile, we invest little in energy science and engineering scholarships and fellowships, thus failing to recruit or train the best and the brightest minds to solve specific energy innovation challenges. The large majority of U.S. universities lack degree programs focused on energy. According to the Department of Energy (DOE), "at all levels, from elementary to post-doctorate programs … students and educators do not have the resources to develop curricula, educational programs, and research opportunities to meet this need."[30] This presents major problems for the future of the U.S. energy sector, as the energy industry expects up to half of its current employees to retire over the next five to ten years.[31]

Figure 2
U.S. Federal R&D Expenditures, 1980-2009 (million nominal dollars)[32]



Despite the importance of science and education, energy innovation is not the sole domain of the laboratory or university. The demonstration of high-risk, high-payoff, "first of its kind" technologies is an equally critical phase of the innovation process. Demonstration is necessary to test the viability of new energy technologies at commercial scale, accelerate learning, and bridge the infamous "technology valley of death" between R&D and commercial production. Yet private firms, especially in the energy sector, are reluctant to commit funding to these capital-intensive projects on their own.

The public sector, therefore, has a critical role to play in accelerating the demonstration of promising new clean energy technologies.[33] Throughout America's history, the federal government, particularly the DOD, has played a pivotal role in demonstrating high-risk technologies through direct procurement. In

1954, for example, the federal government created the modern nuclear power industry when the Atomic Energy Commission announced the Power Demonstration Reactor Program to demonstrate a first-generation commercial nuclear reactor in Pennsylvania.[34] Similar models must be employed today.

More must also be done to accelerate the early commercialization of promising energy technologies with high potential to reduce American dependence on oil, lower carbon emissions, and strengthen America's economic competitiveness. As new technologies are deployed at scale, they routinely come down in price as they gain economies of scale, supply chain efficiencies, and market experience that further inform ongoing technology research efforts. Here, federal and military procurement efforts can also play a key role, as they have throughout the nation's history. The DOD and NASA were central to the birth of the modern semiconductor industry, acting as an early demanding customer for microchips. Throughout the early 1960s, the federal government bought virtually every microchip that firms could produce. The price of a chip fell from $1,000 per unit to between $20 and $30 in a matter of years, spurring the birth of Silicon Valley and laying the foundation for the Information Technology Revolution decades later.[35]

Unfortunately, today's hodgepodge of energy subsidies and deployment policies remain disconnected from research activities and provide weak incentives for innovation. Current federal tax incentives for wind and solar power, for example, are primarily focused on supporting the deployment of existing energy technologies at current prices, rather than on driving technology improvements to reduce their unsubsidized cost. Renewable portfolio standards, which require utilities to purchase a certain percentage of electricity generation from renewable sources, encourage deployment of the lowest-cost renewable energy technology available — generally wind power — while doing little to drive down the price of other, higher-cost clean energy technologies, such as solar panels, that may have the potential to become much cheaper in the long-term.

New federal efforts to commercialize innovative clean energy technologies should not take the form of open-ended subsidies. In contrast to current clean energy deployment policies, new "competitive deployment" efforts should be disciplined around a clear goal of reducing the costs and improving the performance of advanced energy technologies. In this way, this effort should be considered part of the technology innovation process with explicit technology improvement objectives, and it should be distinguished from the morass of existing energy subsidies.

Lastly, the federal government must help facilitate the transfer of new technologies from the laboratory to the marketplace, as well as strengthen linkages between government and the private sector in order to accelerate technology commercialization. Too often, it is assumed that basic research is effortlessly translated into commercial products. Unfortunately, commercialization does not happen so easily and the process is plagued by multiple barriers, including information breakdowns, institutional inertia, and coordination problems.[36] The government can help remove these barriers by more closely integrating research efforts and military procurement needs, and facilitating the development of clean energy clusters—dense networks of firms, suppliers, universities, and local government officials that enhance collaboration in clean energy R&D and production activities and increase the commercialization of new technologies.[37]

With pervasive policy deficiencies and substantive technological barriers to widespread clean energy adoption, there is little wonder that the United States remains dependent on the same fossil energy sources that have powered our nation since the 19th century.

→ THE OPPORTUNITY ←

A POST-PARTISAN PATH TO SAFE, CLEAN, AND SECURE AMERICAN ENERGY

We propose a pragmatic, bipartisan strategy that can put the United States on a path to transforming and modernizing the energy system for the 21st century. It is our objective to break free from the current energy stalemate besetting the nation, overcome the substantial deficiencies in current U.S. energy policy, and seize the opportunity to build a cleaner, safer, and more secure American energy system.

1

Invest in Energy Science and Education

Frontier Energy Science

The first step in this new post-partisan energy framework is an overdue increase in energy science and research funding—something that liberals and conservatives have long agreed is necessary. Launched by the Bush Administration in 2001, the DOE's Office of Basic Energy Science held a series of workshops with the nation's leading energy scientists that identified a set of key energy science and research priorities for the 21st Century.[38] In 2005, bipartisan requests from the House and Senate prompted the National Academies to conduct a thorough study of the United States' position in the 21st century global marketplace. The resulting report recommended a doubling of critical national investments in science and technology innovation, including the budgets of the DOE's Office of Science.[39] In 2007, with strong bipartisan support, Congress passed and President Bush signed the America COMPETES Act, writing into law many of the recommendations of the National Academies and the Bush Administration's review of energy science priorities.

The authorizations provided by the America COMPETES Act of 2007 are set to expire at the end of 2010, however, and a renewed national commitment to energy science and research funding is needed to meet national energy imperatives. To ensure that America remains a leader in clean energy innovation, Congress should provide new and sustained funding targeted to solve the well-known obstacles to energy technology improvement. An expansion of 'use-inspired' basic science at the frontiers of energy, materials, supercomputing, and biotechnology is critical to generate potentially game-changing new options for energy. Cutting-edge advances in materials sciences could result in future generations of far more efficient solar panels, more powerful batteries, and a new generation of safe, efficient, and economical nuclear power plants. Genetic engineering and advances in biology are required to manufacture clean-burning biofuels more cheaply.[40]

The America COMPETES Act authorized a scale-up in funding for the DOE Office of Science that would put it on track to double over ten years, an increase of roughly $3.6 billion. New, long-term authorization and annual budget appropriations to keep the Office of Science on track to double its budget would be an effective way to scale-up funding for basic and frontier energy research. While the Office of Science funds a variety of basic research not directly related to energy, Congress should ensure that the large bulk of new funds are dedicated to energy-related frontier science through the office of Basic Energy Science and energy-related research at the programs for Biological and Environmental Research (which performs cutting edge biosciences research related to biomass and synthetic hydrocarbons from biological processes), Fusion Energy Sciences, and Advanced Scientific Computing Research (which supports advanced modeling efforts to aid the exploration of nuclear fission and fusion designs, materials sciences, and other key capabilities).

In particular, we recommend a doubling of funding levels for the Office of Basic Energy Science's Energy Frontier Research Centers (EFRC) program over the next three to five years from current levels of about $150 million in annual project support[41] to at least $300 million per year; funding could increase further if qualified research applications are being turned down.[42] The EFRC program was created to address the key frontier science research needs identified under the Bush Administration by funding small, collaborative groups of researchers working to unlock breakthroughs that solve specific scientific problems blocking clean energy development. Research performed at EFRC-supported centers may be critical to unlocking new technology pathways to make clean energy more reliable and affordable. This recommended funding would be sufficient to support an expansion of the EFRC network from 46 research centers today to 60 to 150 ongoing EFRC projects at any given time.[43]

Educating the Energy Generation

Today, the race for dominance in clean energy technology sectors pits the United States against the greatest international competition for a key emerging technology field than in any era since the Cold War race to lead in aerospace, computing, communications, and IT fields.[44] China alone is reportedly poised to invest roughly $750 billion (5 trillion yuan) over the next ten years to solidify the nation's growing lead in new energy technologies.[45] Meanwhile, South Korea has committed one percent of the nation's GDP to a national investment in clean and efficient energy technology sectors.[46]

The United States cannot hope to rise to this global challenge or confront pressing energy innovation imperatives without a new national investment to train and inspire the next generation of intrepid American scientists, engineers, and entrepreneurs. Today, the United States ranks just 29th out of 109 countries in the percentage of 24-year-olds with a math or science degree.[47] Only 15 percent of undergraduate degrees in the United States are earned in science, technology, engineering, or mathematics (STEM) fields compared with 64 percent in Japan and 52 percent in China.[48] Even South

Korea — a nation with a population one-sixth the size of the United States — graduates more engineers annually.[49]

The situation is particularly dire in energy technology, with roughly half of the U.S. energy industry workforce expected to retire over the next decade. Meanwhile, demand for workers in the renewable electricity industry is expected to more than triple from 127,000 in 2006 to more than 400,000 in 2018.[50] The anticipated, large-scale ramp-up of the U.S. nuclear power industry would similarly require the industry to hire tens of thousands of new nuclear engineers and related positions annually. Yet today, from elementary school through post-doctorate programs, students and educators lack the resources to develop new curricula and educational programs, recieve key training, or expand research opportunities to meet this national challenge.[51]

The United States has overcome such challenges in the past. After the Soviet launch of Sputnik, the United States swiftly enacted the National Defense Education Act of 1958, leveling national investments totaling $7.2 billion over four years (in today's dollars), to support K-12 science, technology, engineering, and mathematics education, establish university programs in computer science, aerospace, and other new fields across the nation, and train the generation of innovators and entrepreneurs that led the IT Revolution.

Today, we propose a comparatively modest, yet equally critical national commitment of roughly $500 million annually to support K-12 curriculum and teacher training, energy education scholarships, post-doctoral fellowships, and graduate research grants, including:

→ $30 million in support for K-12 teacher training and curriculum development related to energy literacy, science, technology, engineering, and mathematics.

→ $40 million for the development of interdisciplinary clean energy innovation programs at undergraduate and graduate institutions across the country.[52] Funding would also help establish and support new professional masters degree programs in interdisciplinary "Energy Studies" and "Professional Energy Sciences," or similar programs.[53]

→ $200 million to provide competitive financial aid, including scholarships, federally subsidized loans, or loan forgiveness, sufficient to support at least 10,000 undergraduate students per year entering energy-related fields.[54] Students receiving these awards could apply for competitive summer internship placements with universities, companies, and DOE offices and National Laboratories focused on clean energy science, technology, and policy.[55]

→ $180 million to provide competitive, portable three-year graduate fellowships for at least 3,000 graduates annually in energy engineering, science, and related research fields. The National Science Foundation and DOE's Offices of Science, Energy Efficiency and Renewable Energy, and Nuclear Energy could jointly administer these fellowship programs.[56]

→ $50 million to provide post-doctorate research awards to support at least 330 early-career researchers in cutting-edge, clean energy-related science and innovation fields each year.[57]

Ramping up over a five-year period, a national energy education investment of this scale would total roughly $1.5 billion and would have a significant impact on the availability of a trained and highly skilled energy workforce.[58] This national energy education investment program will be critical to accelerating energy innovation and securing America's clean energy competitiveness while supplying a steady stream of new, talented researchers and engineers to support the other energy initiatives below.

2
Overhaul the Energy Innovation System

Second, we need to transform the way that energy innovation is executed to more effectively leverage federal resources, catalyze entrepreneurship, and accelerate the commercialization and adoption of new energy innovations. Currently, most energy research is pursued in settings and through programs divorced from the demands and dynamics of the private sector and from the growing procurement needs of the U.S. military. Universities and national laboratories need to work more closely with private firms, entrepreneurs, and investors, and research programs need to be aligned with the procurement needs of the DOD. New approaches in Washington are necessary to make that happen.

Energy Innovation Institutes

The need to transform America's energy innovation system has been broadly recognized in a slew of recent reports.[59] While Energy Secretary Steven Chu has done much to make the DOE a more effective funder of breakthrough research, the DOE is not particularly well set up to translate new scientific insights into commercializable innovations or stay closely attuned to the needs of the private sector firms that ultimately take new technologies to commercial scale.

In important ways, the DOE remains shackled by its historic legacy as a collection of nuclear weapons-related programs. The DOE was first cobbled together from the Manhattan Project research labs and the Atomic Energy Commission. To this day, the majority of the Department's funding and attention remains focused on managing — and cleaning up after — the nation's sprawling nuclear weapons arsenal, rather than on the kind of commercially focused energy innovation the nation needs today. The bulk of DOE-led energy research is centered at the national laboratories, which remain primarily focused on fundamental scientific research such as particle physics. Meanwhile the DOE offices managing technology research more centrally aimed at commercial applications, such as the Office of Energy Efficiency and Renewable Energy, are overly stove-piped, centralized in Washington DC, and lack a clear mission.[60]

Regardless of what we may call them — Energy Discovery-Innovation Institutes,[61] the National Institutes of Energy,[62] or something else — the recipe for reform is clear: to reduce ineffective, even wasteful energy research spending and more effectively utilize federal resources, America needs to create a national network of decentralized energy innovation institutes that can bring private sector, university, and government researchers together alongside investors (e.g. venture capitalists) and private sector customers to tackle big energy challenges, translate basic science insights into commercial innovation, and strengthen diverse regional clean tech clusters.

Modeled after sustained federal investments made in the 1940's, 50's, and 60's that led to the rise of Silicon Valley, this critical effort would require investments scaling up over several years time to roughly $5 billion per year. Each energy innovation institute would be similar in size to both existing national laboratories and National Institutes of Health-funded research institutes, with regional consortia of universities, government and private research centers, and technology firms competitively awarded federal grants on the order of $50-300 million annually. Over time, this program would establish a robust network of roughly two dozen energy innovation clusters of varying sizes that would leverage federal funding by securing significant additional state government, university, and private sector investment. These institutes would anchor the emergence of dozens of high-powered regional energy innovation industry clusters—crucial private sector concentrations of productivity. Such clusters will help foster the fluid flow of ideas, personnel, and financing between universities, private labs, spin-off and start-up companies, and major private firms that characterize the most successful and competitive regional centers of U.S. innovation and entrepreneurship, including Silicon Valley, the Research Triangle, the Boston area, and many others.[63]

The DARPA Model for Energy Innovation

In addition to fostering stronger linkages between government-funded research centers and private sector investors, entrepreneurs, and customers, the DOD can work to more closely connect research efforts and the growing energy innovation needs of the U.S. military.

This close relationship between research efforts and DOD procurement and technology needs was central to the successful history of the Defense Advanced Research Projects Agency (DARPA), famous for inventing the Internet, GPS, and countless other technologies that have both improved the fighting capabilities of the U.S. military and launched many spin-off technologies American consumers and businesses now take for granted. DARPA program managers had a keen awareness of the technologies and innovations that could improve military capabilities and funded breakthrough innovations aligned with those needs. Once innovations matured into potentially useful technologies, the DOD was there as an early customer for these products, allowing entrepreneurial firms to secure market demand, scale-up production, and continue to improve their products.

Congress made the right move in creating and funding an Advanced Research Projects Agency for Energy (ARPA-E) program modeled after the historic success of DARPA. ARPA-E resides within the DOE, however, which is not set up to be a major user of energy technologies. By contrast, DOD has both the opportunity and the urgent need to use many of these technologies.[64] The DOD can and should play a greater role in administering ARPA-E and making sure that breakthrough energy discoveries become real-world technologies that can strengthen American energy security, enhance the capabilities of the U.S. military, and spin off to broader commercial use.

Fiscal year 2011 funding requests for the ARPA-E program are currently a modest $300 million, just one-tenth the annual budget for DARPA research.[65] Truly bringing the DARPA model to the energy sector would imply scaling ARPA-E up to match DARPA. Given the multi-trillion dollar scale of the energy industry, only funding levels on this order of magnitude will have a significant impact on the pace of energy innovation and entrepreneurship.

We recommend scaling up funding for ARPA-E over the next five years to $1.5 billion annually, with a significant portion of this funding dedicated to dual-use energy technology innovations with the potential to enhance energy security and strengthen the U.S. military. DOD and DOE should extend and expand their current Memorandum of Understanding, established in July 2010,[66] and launch an active partnership between ARPA-E and DOD to determine and select nascent dual-use breakthrough energy innovations for funding through the ARPA-E program and potential adoption and procurement by the DOD.

3
Reform Energy Subsidies and Use Military Procurement and Competitive Deployment Incentives to Drive Price Declines

The government has a long history of successfully driving innovation and price declines in emerging technologies by acting directly as a demanding customer to spur the early commercialization and large-scale deployment of cutting-edge technologies. From radios and microchips to lasers and camera lenses, the federal government, in particular the DOD, has helped catalyze the improvement of countless innovative technologies and supported the emergence of vibrant American industries in the process.[67]

Yet today's mess of open-ended energy subsidies reward production of more of the same product, not innovation. The federal government showers subsidies across many energy options, from oil and coal to ethanol and wind power. None of these efforts, however, are designed or optimized to drive and reward innovation and ensure the prices of these technologies fall over time, making the subsidies effectively permanent. This must change.

Competitive Deployment Incentives

The current energy subsidy and deployment framework should be turned on its head. Government investments succeed not when they are blanket subsidies but rather when they are narrowly targeted to specific outcomes, such as developing computers to allow for rocket systems, building a communications network to survive a nuclear attack, or creating increasingly efficient and powerful jet engines. These public investments paid off handsomely in personal computers, the Internet, and gas turbines used in both commercial air travel as well as modern natural gas power plants.[68]

In an era of expanding federal debt, across-the-board energy subsidy reform should be pursued. Incentives for energy technology deployment should be targeted and disciplined. Technologies should receive competitive deployment incentives only to the extent that they are becoming cheaper in unsubsidized terms over time.

The strategy that we propose would be aimed at low-carbon technologies that, at a minimum, satisfy the following criteria:

→ The technology has been demonstrated and has proven technical feasibility at commercial scale;

→ Is currently priced above normal market rates and is locked out of markets by more mature, entrenched technology competitors;

→ Has potential for significant and sustained cost and performance improvements during deployment and scale-up;

→ Has strong prospects for significant market penetration once the technology reaches competitive prices.

Targeted and competitive deployment incentives could be created for various classes of energy technologies to ensure that each has a chance to mature. Incentive levels should fall at regular intervals, terminating if the technology class either fails to improve in price or reaches cost parity in the absence of any further incentives.

Structured in this manner, reformed national energy deployment incentives will not select winners and losers, nor will it create permanently subsidized industries. These public investments will instead provide opportunity for all emerging low-carbon energy technologies to demonstrate progress toward competitive costs while increasing the rate at which early-stage clean and affordable energy technologies are commercialized.

Military Procurement

In addition to reforming energy deployment subsidies and launching a new competitive deployment strategy, the nation should once again leverage the power of federal procurement to establish demanding requirements to drive innovation and improvement in new energy technologies. The DOD has a long track record of using the power of procurement to successfully drive the commercialization and improvement of new technologies, many of which later spun off into broader commercial adoption.

In contrast, the DOE has no way to either procure or use energy technologies at commercial scale. The DOD should help fill this void, once again using procurement to advance a range of potential dual-use energy innovations.

The Pentagon's 2010 "Quadrennial Defense Review" prioritizes expanded DOD involvement in energy innovation—and with good reason.[69] The U.S. military today uses more oil than Sweden and more electricity than Denmark. Every $10 increase in the price of oil costs the DOD more than $1 billion dollars, sapping money that should be used to equip our troops for critical missions at home and abroad.[70] With fuel convoys costing both lives and money every day in Iraq and Afghanistan, questions of energy are understandably high on the list of Pentagon priorities, and a growing community of national security experts, including both active and retired generals and flag officers, has identified the development of new energy alternatives that can both reduce America's exposure to volatile oil markets and enhance military operational capabilities as key to securing the nation's defense.[71]

Congress should provide new funds necessary to secure America's energy future and national defense, providing up to $5 billion annually (as needed) to support DOD efforts to procure, demonstrate, test, validate, and improve a suite of cutting-edge energy technologies with potential to enhance American energy security or improve the strategic and tactical capabilities of the American armed forces. Energy technologies with clear dual-use commercial and military potential well suited to DOD procurement could include: advanced biofuels, including aviation fuels; advanced solar thermal and photovoltaic power technologies; improved batteries; electric vehicles; and new, modular nuclear reactors (discussed in greater detail below).

As discussed above, DOD should work closely with ARPA-E and other research initiatives in both DOD and DOE to ensure a steady flow of energy innovation geared towards military needs. Procurement contracts should require continued innovation and cost improvements from supplying firms and should be competitively awarded. New efforts should be pursued to ensure that innovative firms both large and small can participate in procurement contracts and the military can benefit from the best American innovations, no matter where they arise.[72]

Embrace the Potential of Nuclear — But Pursue a Portfolio

A new generation of smaller, innovative nuclear reactors holds great promise in providing affordable, reliable, zero-carbon power and heat to utilities of all sizes, industrial facilities, and military bases. For decades, small reactors between one-tenth to one-twentieth the size of existing commercial nuclear plants have powered U.S. aircraft carriers and submarine fleets. New modular commercial reactor designs based on the same reliable technology are smaller, safer, and less expensive than older designs and have the potential to be affordably mass-manufactured. Such technologies also offer the possibility of greater applicability globally and could potentially represent a new high-value, export-oriented manufacturing industry for the U.S. economy. A new generation of more advanced designs may hold even greater promise for the future.[73] Modular reactor designs should receive priority attention from the Departments of Energy and Defense, who can each work to research advanced reactor technologies, license and approve new commercial modular reactor designs, and procure and demonstrate small modular reactors at DOE nuclear facilities and DOD military bases.

Long-time opponents of nuclear power must rethink their opposition given the potential for new nuclear plants to help solve several energy challenges — economic, environmental, health, and safety — at once. However, nuclear proponents must also recognize that America cannot bank everything on a single technology or design. A full portfolio of clean, affordable, and reliable energy technologies will be necessary to fully confront the nation's energy challenges. The DOE and DOD should therefore have the budget to develop and procure all promising energy technologies, from advanced solar and geothermal to biofuels and batteries.

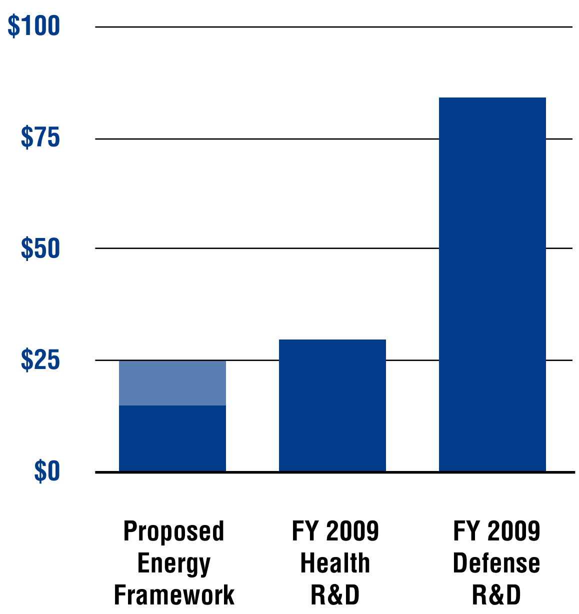
4
Internalize the Cost of Energy Modernization and Ensure Investments are Deficit Neutral

This new post-partisan framework to make clean energy cheap and abundant and secure America's energy future would require investments totaling between $15 and $25 billion per year—a relatively modest sum that amounts to less than one-third of what we spend on defense-related research alone (see Figure 3).

While defense and health research are paid for through general revenues, this new initiative should not add to the federal debt. The cost of a major national commitment to energy innovation could be internalized within America's energy economy in any number of ways, including:

- Phasing out current subsidies for wind, solar, ethanol, and fossil fuels alike, which have not created sufficiently strong incentives for innovation and price declines. Billions of dollars in annual revenues can be freed up for productive re-investment in clean energy innovation.[75]
- Modestly increase the royalties charged to oil and gas companies and direct revenues to new energy technology. This could include revenues from any expansion of oil and gas production and could build on prior Republican proposals.[76]

Figure 3
Proposed and Actual U.S. Federal Innovation Investments (billion dollars)[74]



- Implement a small fee on imported oil to pay for efforts to drive energy innovation and enhance American energy security.[77]

- Establish a small surcharge on electricity sales, known as a wires fee. Implemented in this manner, this energy modernization fee could serve a similar function as the Highway Trust Fund, providing critical revenues to modernize the U.S. energy system and drive the invention and commercialization of new clean energy alternatives.

- Dedicate revenues from a very small carbon price to finance the necessary investments in clean energy technology. A roughly $4-5 fee per ton of CO2 — the equivalent of less than a nickel per gallon increase in gasoline prices and just a third of what recent proposed cap and trade legislation would have cost consumers and businesses[78] — would be sufficient to pay for an ambitious federal clean energy research, development, and procurement program.

Any one of these funding sources could raise sufficient funds from within the energy sector itself without appreciably increasing energy prices or impacting American firms or consumers. Different approaches may be combined and tailored to different energy sectors, piece-by-piece, rather than seeking a one-size-fits-all approach.

→ CONCLUSION ←

America is once again at an energy crossroads, but the choices it faces are not those that many aligned with either the right or the left have imagined. The choice is not, as liberals often maintain, between global warming apocalypse or mandating the widespread adoption of today's solar, wind, and electric car technologies. Nor is the choice, as conservatives have argued, between an economy wrecked by liberal global warming policies or expanding oil drilling and nuclear power. The choice is whether America will focus on what really matters when it comes to energy technology and on what the vast majority of Americans want: innovation.

Though Washington and policy elites were polarized by the 'climate wars' of the last decade, Americans as a whole remain largely united in their attitudes toward energy policy. They are grateful for cheap fossil energy and are willing to pay modestly more for affordable, cleaner energy sources. The most popular and effective energy policy is technology innovation aimed at making clean energy sources better and cheaper. This white paper is our contribution to advancing a new public policy consensus that starts from this place of post-partisan agreement.

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→ NOTES AND CITATIONS ←

[1] Vaclav Smil, Energy Transitions: History, Requirements, Prospects, (Santa Barbara, CA: Praeger, 2010).

[2] According to the U.S. Energy Information Administration, the levelized costs of new renewable electricity technologies remain substantially higher than conventional coal and natural gas-fired fossil power plants: onshore wind power is 49% more costly than generation from conventional coal plants and 80% more expensive than conventional gas-fired combined cycle plants; offshore wind is even more costly; solar thermal power is 2.5-times more expensive than conventional coal-fired power and 84% more expensive than conventional gas combustion turbines; and solar photovoltaic power plants are nearly three-times more expensive than conventional gas combustion turbines and five-times more expensive than conventional gas-fired combined cycle power plants. “2016 Levelized Cost of New Generation Resources from the Annual Energy Outlook 2010,” U.S. Department of Energy, Energy Information Administration, last modified January 12, 2010, accessed October 5, 2010, http://www.eia.doe.gov/oiaf/aeo/electricity_generation.html

The International Energy Agency similarly writes that “a global revolution is needed in the ways that energy is supplied and used,” outlining detailed roadmaps for both dramatic and incremental innovations required across all available low-carbon energy technologies to enable “all countries to put in motion a transition to a more secure, lower-carbon energy [system], without undermining economic growth.” International Energy Agency, *Energy Technology Perspectives 2008*, (Paris: IEA, June 2011), http://www.iea.org/w/bookshop/add.aspx?id=330

See also notes 3 and 4 below.

[3] Apart from their higher cost, many other barriers prevent the widespread adoption of clean energy technologies. First, clean energy technologies are very capital intensive. The upfront cost of a low-carbon energy demonstration project is typically on the order of hundreds of millions of dollars, which is typically too big for most venture capitalists to finance, and presents a huge financing challenge to capital-starved start-up firms. Second, the scale and long-time horizon of many clean energy projects, combined with considerable market and technology uncertainty, makes it extremely difficult for firms to assess expected returns on investment. Many private investors prefer to fund less risky projects in other sectors of the economy because the risk/return calculation is more predictable. Third, the widespread adoption of clean energy technologies will require massive amounts of new energy infrastructure, such as new transmission lines and electric vehicle charging stations, which are unlikely to be financed by private investors on their own, and will not emerge as a result of carbon pricing. Lastly, as a result of each of these previous barriers, the private sector invests very little in energy R&D–far less than other innovative sectors of the economy. Yet much greater investment in R&D is exactly what’s needed to develop cheaper and more reliable clean energy technologies. Targeted investments to overcome these barriers will be required to catalyze the level of private-sector innovation necessary to transform the energy sector.

See Rob Atkinson et al., “Barriers to Widespread Clean Energy Adoption and the Public Investment Imperative,” in “Rising Tigers, Sleeping Giant: Asian Nations Set to Dominate the Clean Energy Race by Out-Investing the United States,” (Breakthrough Institute and Information Technology and Innovation Foundation, November 2009); Michael Shellenberger et al., “Fast, Clean, & Cheap: Cutting Global Warming's Gordian Knot,” *Harvard Law and Policy Review* (2008) 2: 93-118, http://thebreakthrough.org/blog/2008/01/fast_clean_cheap_cutting_globa.shtml; Karsten Neuhoff, “Large-Scale Deployment of Renewables for Electricity Generation,” *Oxford Review of Economic Policy* (2005) 21.

[4] In fact, generating the massive quantities of low-carbon power worldwide required to mitigate the risks of climate change may prove impossible without a substantial increase in global nuclear power generation. According to a scenario published by the International Energy Agency (IEA), stabilizing global atmospheric CO2 levels at 450-ppm would, by the year 2030, require a more than 16-fold increase in global wind-power capacity, a 5.6-fold increase in biomass and waste combustion for electricity, a 4.7-fold increase in geothermal power, a near doubling of already substantial global hydropower capacity (1.8-fold increase), and a 170-fold increase in solar power. This enormous quantity of new, low-carbon power is required *in addition* to an unprecedented pace of energy efficiency improvement already factored into IEA's expectations of future energy demand. And while these massive expansions of renewable energy and energy efficiency may strain belief, the International Energy Agency predicts that a *doubling* of current nuclear power capacity is required as well, to put the world on track to stabilize the climate. In fact, the IEA projects that nuclear power will be required to provide the same share of global low-carbon power needs in 2030 as the entirety of all other renewable electricity sources, excepting hydropower. Authors calculations based on International Energy Agency, "BLUE MAP Scenario," in *World Energy Outlook 2009* (Paris: IEA, November 2009), http://www.iea.org/W/bookshop/add.aspx?id=388

[5] Fossil fuel combustion is the leading contributor to air pollution in the United States, responsible for pollutants that cause or exacerbate asthma, lung disease, cardiovascular ailments, and cancer, and create acid rain, smog, and toxic mercury pollution. According to a 2004 report by the Clean Air Task Force, pollution from fossil-fired U.S. power plants contributes to 24,000 premature deaths, 38,200 non-fatal heart attacks, and tens of thousands of hospital visits and asthma attacks each year. Meanwhile, coal combustion at power plants and industrial facilities is the leading source of mercury pollution, contributing to an estimated 300,000 to 630,000 American children born each year with blood mercury levels high enough to impair mental performance cause lifelong loss of intelligence. All told, the economic damage wrought by air pollution may cost the U.S. economy on the order of $340 billion annually, or more than 2% of total U.S. Gross Domestic Product.

Sources: Clean Air Task Force, "Dirty Air, Dirty Power: Mortality and Health Damage Due to Air Pollution from Power Plants" (CATF, June 2004), http://www.catf.us/publications/view/24; Alan Lockwood, Kristen Welker-Hood, Molly Rauch, Barbara Gottlieb, "Coal's Assault on Human Health," (Physicians for Social Responsibility, November 2009), http://www.psr.org/resources/coals-assault-on-human-health.html; Trent Yang, Kira Matus, Sergey Paltsev and John Reilly, "Economic Benefits of Air Pollution Regulation in the USA: An Integrated Approach," (Cambridge, MA: Massachusetts Institute of Technology, July 2004, Revised January 2005), http://www.sehn.org/.../regulation%20benefits%20air%20pollution%20MIT.pdf

[6] Explosions and disasters at fossil fuel power plants, drilling rigs, mines, and refineries are commonplace, killing dozens of Americans annually. In 2010 alone, explosions at the Big Branch coal mine in West Virginia killed 29, the explosion at the Deepwater Horizon drilling rig in the gulf cost the lives of 11, an explosion at a gas-fired power plant under construction in Middletown, Connecticut killed five, while a gas line explosion in San Bruno, California killed at least eight, destroyed 37 homes & damaged 120.

[7] The nation's over-reliance on fossil fuels threatens the security of the economy and the nation, and puts our servicemen and women overseas in danger every day. For every 24 fuel convoys that set out in Iraq and Afghanistan, one soldier or civilian engaged in fuel transport has been killed, according to one Army study. Reducing the U.S. military's reliance on fossil fuels to power combat operations "increases the range and endurance of forces in the field and can reduce the number of combat forces diverted to protect energy supply lines, which are vulnerable to both asymmetric and conventional attacks and disruptions," according to the 2010 Pentagon Quadrennial Defense Review. The U.S. armed forces spent roughly $20 billion on energy in 2008 and every $10 increase in the price of a barrel of oil costs the Defense Department $1.3 billion, sapping critical funds that could be used to protect American troops and successful achieve combat objectives. Furthermore, "continued over-reliance on fossil fuels will increase the risks to America's future economic prosperity and will thereby diminish the military's ability to meet the security challenges of the rapidly changing global strategic environment," according to a 2010 report published by the CNA Military Advisory Board.

Sources: David Eady, Steven Siegel, R. Steven Bell, and Scott Dicke, "Sustain the Mission Project: Casualty Factors for Fuel and Water Resupply Convoys," (Arlington, VA: U.S. Army Environmental Policy Institute, September 2009); U.S. Department of Defense, "2010 Quadrennial Defense Review," (Arlington, VA: U.S. Department of Defense, February 2010), http://www.comw.org/qdr/fulltext/1002QDR2010.pdf; CNA Military Advisory Board, "Powering America's Economy: Energy Innovation at the Crossroads of National Security Challenges," (CNA, July 2010), http://www.cna.org/research/2010/powering-americas-economy-energy-innovation

[8] Matt Bennett, Joshua Freed, and Jeremy Ershow. "Breaking the Nuclear Financing Barrier." (Third Way, February 2010), http://thirdway.org/programs/clean_energy_program/publications/265

[9] Zachary Arnold et al., "Case Studies in American Innovation: A New Look at Government Involvement in Technological Development," (Breakthrough Institute, April 2009), http://thebreakthrough.org/blog/2009/04/breakthrough_report_case_studi.shtml

[10] American Association for the Advancement of Science, "Research and Development, FY 2011," (AAAS, June 2010), http://www.aaas.org/spp/rd/rdreport2011/

[11] See Duderstadt et al., "Energy Discovery-Innovation Institutes: A Step toward America's Energy Sustainability," (Brookings Institution, 2008), http://www.brookings.edu/reports/2009/0209_energy_innovation_muro.aspx; Joshua Freed, Avi Zevin, and Jesse Jenkins, "Jumpstarting a Clean Energy Revolution with a National Institutes of Energy," (Third Way and the Breakthrough Institute, September 2009), http://thebreakthrough.org/blog/2010/04/jumpstarting_a_clean_energy_re_1.shtml

[12] See Mark Muro and Bruce Katz, "The New Cluster Moment: How Regional Innovation Clusters Can Foster the Next Economy," (Brookings Institution, September 2010), http://www.brookings.edu/papers/2010/0921_clusters_muro_katz.aspx

[13] A 2010 Yale University segmentation analysis of the U.S. public found 86% of Americans support policies to "fund more research into renewable energy sources, such as solar and wind power," including strong majorities across segments of the U.S. public who are doubtful (81% support) or dismissive (62% support) of the possible risks of unchecked climate change, the highest support for any government actions tested. Yale Project on Climate Change Communication, "Global Warming's Six Americas," (Yale University, July 2010), http://environment.yale.edu/climate/news/global-warmings-six-americas-june-2010/

Gallup tracking polls show strong and consistent support for expanded financial support for alternative energy sources such as wind and solar (77% support in March 2009) and increasingly strong majorities in support of expanded nuclear power production (at 62% in 20010). "Energy." Gallup, 2010, accessed October 5, 2010, http://www.gallup.com/poll/2167/energy.aspx

An April 2007 CBS News/New York Times poll showed 64% of Americans would even 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." New York Times and CBS News, "The New York Times/CBS Poll April 20–24," (New York Times, April 2007), http://graphics8.nytimes.com/packages/pdf/national/20070424_poll.pdf

A Gallup poll also taken in April 2007 asked a battery of questions about what the government should do to address global warming, with 65% of Americans responding that 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. "Americans Assess What They Can Do To Reduce Global Warming," Gallup, 2007, accessed October 5, 2010, http://www.gallup.com/poll/27298/Americans-Assess-What-They-Can-Reduce-Global-Warming.aspx

A 2007 national survey commissioned by the Nathan Cummings Foundation found over two thirds (68%) of Americans strongly support efforts to make clean energy sources such as solar and wind energy cost less, with nearly three quarters (74%) of American voters supporting federal incentives for expanded clean energy production, and even more (84%) willing to support funding a massive, $300 billion, ten year, federal research and development effort to develop new clean energy technologies. Whether emphasis is placed on energy innovation to reduce pollution or end dependence on imported oil once and for all, equally large portions of the public support such investments. Nathan Cummings Foundation, EMC Research, and American Environics, "Survey of Public Opinion on Global Warming and Policy Approaches." (American Environics, September 2007), http://thebreakthrough.org/blog/2007/06/survey_of_public_opinion_on_gl.shtml

[14] Smil, *Energy Transitions*; Evan Johnson and Gregory Nemet, "Willingness to Pay for Climate Policy: A Review of Estimates," La Follette School Working Paper No. 2010-011 (Madison, WI: University of Wisconsin-Madison, 2010), http://www.lafollette.wisc.edu/publications/workingpapers/index.html#2010-011

[15] Arnold et al. "Case Studies in American Innovation," Breakthrough Institute, 2009. See also: Fareed Zakaria. "Is America Losing Its Mojo?" *Newsweek*, November 14, 2009, http://www.newsweek.com/2009/11/13/is-america-losing-its-mojo.html

[16] David Brooks, "The Day After Tomorrow," *New York Times*, September 13, 2010, http://www.nytimes.com/2010/09/14/opinion/14brooks.html

[17] Subcommittee on Education and Health of the Joint Economic Committee, "A Cost-Benefit Analysis of Government Investment in Post-Secondary Education Under the World War II GI Bill," (Washington DC: United States Congress, December 14, 1988).

[18] Rob Atkinson, *The Past and Future of America's Economy: Waves of Innovation that Power Cycles of Growth*, (Northampton, MA: Edward Elgar, 2005), 272.

[19] Solow found that only 19 percent of long-run change in labor productivity was due to increased capital intensity, with the remainder due to technical changes. Robert M. Solow, "Technical Change and the Aggregate Production Function," *The Review of Economics and Statistics*, (1957) 39(3): 312-320.

Michael Boskin and Lawrence Lau review common growth accounting models and estimated that half of economic growth comes from technical progress, while Charles Jones reaches similar conclusions for the U.S. economy from 1950 to 1993, adding that an additional 30 percent of economic growth stems from higher levels of education. Michael Boskin and Lawrence Lau, "Capital, Technology, and Economic Growth," in Nathan Rosenberg, Ralph Landau, and David C Mowery (eds), *Technology and the Wealth of Nations* (Stanford CA: Stanford University Press, 1992); Charles Jones, "Sources of US Economic Growth in a World of Ideas," *American Economic Review* (2002) 92 (1): 220-239.

[20] See endnote 2, Energy Information Administration "2016 Levelized Cost of New Generation" and International Energy Agency, *Energy Technology Perspectives 2008.*

[21] Publics in America and abroad are unwilling to support significant increases in energy costs in order to support cleaner energy and reduce global warming pollution and/or dependence on foreign oil. A survey of 27 different analyses of public's willingness to pay for energy policy found support eroded quickly as a price tag was attached to climate proposals, with majorities in more than half of the studies opposing energy prices increases that would cost the average household more than $135 per year, or the equivalent of little more than a $4 per ton CO2 price, given median U.S. household carbon footprints. Johnson and Nemet, "Willingness to Pay for Climate Policy."

[22] As of April 2008, European nations planned to construct 50 new coal-fired power plants over the next five years, even as the EU Emissions Trading Scheme tightened requirements on greenhouse gas emissions. Elisabeth Rosenthal, "Europe Turns Back to Coal, Raising Climate Fears," *New York Times*, April 23, 2008, http://www.nytimes.com/2008/04/23/world/europe/23coal.html

[23] Feed-in tariff policies widely employed to incentivize renewable energy adoption throughout Europe are typical several degrees larger than the equivalent incentive for renewable energy provided by the EU ETS. Jesse Jenkins, "Comparing Clean Energy Incentives," Breakthrough Institute, March 2, 2010, accessed October 5, 2010, http://thebreakthrough.org/blog/Energy%20Policy%20Comparison%20Graph.shtml

[24] International Energy Agency, *World Energy Outlook 2009.*

[25] John Broder and Matthew Wald, "Big Science Role Is Seen as Global Warming Cure," *New York Times*, February 11, 2009, http://www.nytimes.com/2009/02/12/us/politics/12chu.html

[26] Shellenberger, et al., "Fast, Clean, & Cheap,"

[27] See note 3. Atkinson et al, "Barriers to Widespread Clean Energy."

[28] For Figure 1, all sectors excepting energy: Raymond M. Wolfe, "U.S. Businesses Report 2008 Worldwide R&D Expense of $330 Billion: Findings from New NSF Survey," NSF 10-322, (National Science Foundation, May 2010), see Table 1. Figures are 2008 domestic expenditures for R&D performed by companies as a share of domestic sales, as reported to the Business R&D and Innovation Survey of the National Science Foundation and U.S. Census Bureau.

Energy R&D expenditures as percent of sales not specified in NSF survey and sourced from: Charles Weiss and William Bonvillian, *Structuring and Energy Technology Revolution,* (Cambridge, MA: Massachusetts University Press, April 2009).

[29] American Association for the Advancement of Science, "Research and Development, FY 2011."

[30] U.S. Department of Energy, "FY 2010 Budget Proposal for RE-ENERGYSE," (DOE Office of Energy Efficiency and Renewable Energy, 2009).

[31] National Commission on Energy Policy, "Task Force on America's Future Energy Jobs," (Bipartisan Policy Center, October 2009); "Current and Potential Green Jobs in the U.S. Economy," (U.S. Council of Mayors, 2008), http://www.usmayors.org/pressreleases/uploads/GreenJobsReport.pdf

[32] For Figure 2. All values are nominal dollars, unadjusted for inflation. Source for health and defense R&D: National Science Foundation, "Federal R&D Funding by Budget Function: 2007-09, Detailed Statistical Tables," Table 36, NSF 08-315 (National Science Foundation: September 2008), http://www.nsf.gov/statistics/nsf08315/content.cfm?pub_id=3880&id=2

Source for energy R&D: K.S. Gallagher and L.D. Anadon, "DOE Budget Authority for Energy Research, Development, and Demonstration Database," (Harvard University, June 22, 2009). http://belfercenter.ksg.harvard.edu/publication/19119/doe_budget_authority_for_energy_research_development_demonstration_database.html Figures include budgets for all DOE applied RD&D, Office of Basic Energy Science, Fusion Energy Sciences, and Biological and Environmental Sciences research programs (some of which are non-energy related).

[33] Clean Energy Group and Bloomberg New Energy Finance, "Crossing the Valley of Death: Solutions to the next generation clean energy project financing gap," (Clean Energy Group, July 2010), http://www.cleanegroup.org/Reports/CEG_BNEF-2010-06-21_valleyofdeath.pdf

[34] Arnold et al., "Case Studies in American Innovation.".

[35] ibid.

[36] See, for example, Rob Atkinson and Howard Wial, "Boosting Productivity, Innovation, and Growth Though a National Innovation Foundation, (Brookings Institution and Information Technology and Innovation Foundation, 2008), http://www.brookings.edu/reports/2008/04_federal_role_atkinson_wial.aspx

[37] Atkinson et al., "Asia Seeks First-Mover Advantage Through Investments in Clusters," in "Rising Tigers Sleeping Giant"; Duderstadt et al., "Energy Discovery-Innovation Institutes."

[38] U.S. Department of Energy, "The Basic Research Needs Workshop Series," (US DOE, April 2007), http://www.sc.doe.gov/bes/reports/files/BRN_workshops.pdf

[39] National Academies, *Rising Above the Gathering Storm*, (Washington D.C.: National Academies Press, 2007).

[40] "BES Basic Research Needs," U.S. Department of Energy, accessed September 27, 2010, http://www.sc.doe.gov/bes/reports/list.html

[41] EFRC awarded grants to 46 applicants in 2009 for a total 5-year commitment of $777 million in awards, or $155.4 million annually. The FY2010 DOE budget included $100 million for ongoing support for EFRC-supported research centers, and the FY2011 request allotted $100 million in ongoing support to existing centers and $40 million to fund new centers, with a focus on cutting-edge materials science. "Energy Frontier Research Centers," U.S. Department of Energy, Office of Science, accessed October 5, 2010, http://www.er.doe.gov/bes/EFRC/index.html

[42] The EFRC program's first solicitation for applications in late 2008 received approximately 260 applications involving 385 institutions. The total requested budget for all applications over the 5-year project period was approximately $4.9 billion; the annualized request for all applications was approximately $980 million. Assuming even a portion (1/5th) of these applications are worthy of funding and assuming future solicitations receive greater response (as potential applicants become aware of this new program), we approximate that within three-five years, roughly $300 million per year will be necessary to fulfill the budgetary requests of qualified applications. Ibid.

[43] EFRC awards would be provided in the $2–5 million range annually for an initial 5-year period for fundamental scientific research projects addressing key energy innovation challenges.

[44] Atkinson et al. "Rising Tigers Sleeping Giant."

[45] "China develops 5-trillion-yuan alternative energy plan," *People's Daily Online*, July 22, 2010, http://english.peopledaily.com.cn/90001/90778/90862/7076933.html

[46] Atkinson et al., "Rising Tigers Sleeping Giant."

[47] Rob Atkinson, "8 Ideas for Improving the America COMPETES Act," (Information Technology and Innovation Foundation, March 2010), http://www.itif.org/files/2010-america-competes.pdf

[48] Jeffrey J. Kuenzi, "Stem Education: Background, Federal Policy, and Legislative Action," (Congressional Research Service, 2008), http://www.fas.org/sgp/crs/misc/RL33434.pdf

[49] National Science Foundation, "Science and Engineering Indicators," (NSF, 2008), http://www.nsf.gov/statistics/seind08/pdfstart.htm

[50] U.S. Council of Mayors, "Current and Potential Green Jobs in the U.S. Economy."

[51] U.S. Department of Energy, "FY2010 Budget Proposal for RE-ENERGYSE."

[52] This estimate is based on funding 40-80 university programs at $0.5 million to $1 million each. The program would be administered by the Department of Energy with grants awarded for up to five years to institutes of higher education on a competitive, merit-reviewed basis based on proposed programs to expand energy sciences, engineering, technical and multidisciplinary training programs; attract and retain specialized faculty; develop new minors, majors, graduate programs, certificates and other courses of study in energy fields; and attract and retain new students for such programs.

[53] This interdisciplinary energy studies program could be modeled after the program described in the Department of Energy's RE-ENERGYSE proposal to support interdisciplinary energy curriculum development, equip laboratories, develop faculty lecture series, and encourage energy-focused research by masters students. The professional energy science masters program could also be modeled after the Sloan Foundation's Professional Science Masters initiative, an innovative, new graduate degree program designed to allow students to pursue advanced training in science, while simultaneously developing workplace skills highly valued by employers.

[54] DOE and the Department of Education should administer the financial assistance program. At minimum, funding at this level would be sufficient to provide four year scholarships valued at $5,000 per year to 10,000 students annually, but could potentially reach more students with a combination of less direct aid (subsidized loans, loan forgiveness, etc.) or smaller scholarships (e.g. $2,500) per year. Eligible fields could include energy-related STEM fields, energy-related policy and public planning studies, and related programs.

[55] Similar programs are already managed by the DOE Office of Science's Office of Workforce Development and the Office of Energy Efficiency and Renewable Energy, which could be applied here to strengthen energy STEM placement opportunities.

[56] This would be sufficient to provide $20,000 fellowships for up to three years per student for 1,000 students. The National Academies report, *Rising Above the Gathering Storm*, calls for the creation of 5,000 new graduate fellowships providing $20,000 per year for tuition and fees. A fellowship at $40,000 per year would bring them more in line with Graduate Research Fellowship Program offered by the National Science Foundation. The Association of American Universities also calls for 5,000 new graduate fellowships administered through existing programs as well as the creation of 1,000 new graduate fellowships specifically in energy innovation in their 2006 proposal [Association of American Universities, "National Defense Education and Innovation Initiative," (AAU, January 2006), http://www.aau.edu/reports/NDEII.pdf]. Masters and doctoral fellowships could be provided through DOE's Protecting America's Competitive Edge (PACE) program authorized by America COMPETES (Section 5009), under NSF graduate fellowship programs, new professional masters degree programs in energy related fields, or similar programs.

[57] Awards currently authorized under America COMPETES for Department of Energy early career awards for science, engineering, and mathematics researchers (Section 5006) range from $80,000 and $150,000 per year. $50 million annually would be sufficient to grant awards supporting between 333 and 625 post-doc students in any given year. Awards would be granted for up five years for any individual.

[58] Over five years time, this proposed investment in energy education would: train and support hundreds of K-12 educators to provide critical curriculum and educational programs in energy literacy and energy STEM fields; help establish dozens of new energy innovation related graduate and undergraduate centers, curriculum and certification programs, and professional masters programs across the nation; help educate and train at least 30,000 undergraduates in energy sciences, engineering, and related fields; fund the graduate-level education and research of at least 9,000 energy scientists and engineers; and provide at least 1,000 post-doctorate research awards for cutting-edge energy innovation.

[59] See Duderstadt et al. "Energy Discovery-Innovation Institutes." Freed, Zevin, and Jenkins, "Jumpstarting a Clean Energy Revolution;" New England Clean Energy Council, "Energy Innovation Consortia," (New England Clean Energy Council, 2009), http://www.energyinnovationconsortia.org/

[60] ibid.

[61] See Duderstadt et al. "Energy Discovery-Innovation Institutes."

[62] See Freed et al, "Jumpstarting a Clean Energy Revolution with a National Institutes of Energy," September 2009, www.thebreakthrough.org/blog/2010/04/jumpstarting_a_clean_energy_re_1.shtml.

[63] Muro and Katz, "The New Cluster Moment."

[64] See CNA Military Advisory Board, "Powering America's Defense: Energy and the Risks to National Security," (CNA, 2008), http://www.cna.org/reports/energy; and CNA Military Advisory Board "Powering America's Economy."

[65] DARPA received $2.9 billion in FY2010 and the FY2011 request is for $3.1 billion. "DARPA Budget," Defense Advanced Research Projects Agency, accessed October 5, 2010, http://www.darpa.mil/budget.html

[66] "Energy and Defense Departments Announce Agreement to Enhance Cooperation on Clean Energy and Strengthen Energy Security," U.S. Department of Energy, July 27, 2010, accessed October 6, 2010, http://www.energy.gov/news/9278.htm

[67] Arnold et al., "Case Studies of American Innovation."

[68] ibid.

[69] US Department of Defense, "Quadrennial Defense Review"

[70] CNA Military Advisory Board, "Powering America's Defense."

[71] See for example the series of reports of the CNA Military Advisory Board (http://www.cna.org/centers/military-board) and the Energy Security Leadership Council of the Securing America's Future Energy coalition (http://www.secureenergy.org/node/37).

[72] See CNA Military Advisory Board, "Powering America's Economy."

[73] Joshua Freed, Elizabeth Horowitz and Jeremy Ershow, "Thinking Small on Nuclear Power," (Third Way, October 2010), http://thirdway.org/programs/clean_energy_program/publications/340

[74] For Figure 3: Health and Defense R&D expenditures for FY 2009, from National Science Foundation, "Federal R&D Funding by Budget Function: 2007-09

[75] Total ongoing federal energy subsidies and support to all energy forms were at least $16 billion annually in 2007, according to the U.S. Energy Information Administration, and have increased steadily for both fossil energy and renewables since 2007. "Federal Financial Interventions and Subsidies in Energy Markets 2007." U.S. Department of Energy, Energy Information Administration, April 2008, accessed October 5, 2010, http://www.eia.doe.gov/oiaf/servicerpt/subsidy2/index.html; "U.S. energy subsidies estimated in a EIA report, figures criticized as low," Global Subsidies Initiative, 2008, accessed October 5, 2010, http://www.globalsubsidies.org/en/subsidy-watch/studies/us-energy-subsidies-estimated-a-eia-report-figures-criticized-low

[76] For example, Rep. Devin Nunes' (R-Calif.) introduced the bill, in late July, to use a reverse auction process to allocate future federal oil royalties to renewable energy projects and technologies through a competitive process. Trevor Curwin, "Legislation Seeks Green Payoff to Offshore Drilling," *CNBC*, August 19, 2010, http://www.cnbc.com/id/38735373

A similar trust fund for clean energy technology was a feature of the GOP "American Energy Act" proposal. "Republicans Introduce the American Energy Act," GOP.gov, June 10, 2009, accessed October 5, 2010, http://www.gop.gov/energy

[77] Annual U.S. crude oil and refined product imports have ranged between 4.2 billion and 5 billion barrels annually from 2004-2009. A $5 per barrel fee on imported oil would thus raise roughly $20-25 billion annually. If applied to all crude oil sold in the United States (both domestic production and imports), a roughly $3.50 per barrel fee would be sufficient to raise $25 billion in revenues and would increase gasoline prices at the pump by less than a dime per gallon. "U.S. Imports by Country of Origin," U.S. Department of Energy, Energy Information Administration, July 29, 2010, accessed October 5, 2010, http://www.eia.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbbl_a.htm

[78] According to the Congressional Budget Office, CO2 prices under the House-passed American Clean Energy and Security Act (HR 2454) would have ranged from $15-26 per ton of CO2 from 2011-2019, increasing thereafter. Congressional Budget Office, "H.R. 2454 American Clean Energy and Security Act of 2009," (CBO, June 5, 2009).

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