American Energy Innovation Council

A BUSINESS PLAN FOR AMERICA'S ENERGY FUTURE

ABOUT THE AMERICAN ENERGY INNOVATION COUNCIL

www. americanenergyinnovation.org

Who we are

American Energy Innovation Council members include: **Norm Augustine**, former chairman and chief executive officer of Lockheed Martin; **Ursula Burns**, chief executive officer of Xerox; **John Doerr**, partner at Kleiner Perkins Caufield & Byers; **Bill Gates**, chairman and former chief executive officer of Microsoft; **Chad Holliday**, chairman of Bank of America and former chairman and chief executive officer of DuPont; **Jeff Immelt**, chairman and chief executive officer of GE; and **Tim Solso**, chairman and chief executive officer of Cummins Inc. The Council is advised by a technical review panel consisting of preeminent energy and innovation experts and is staffed jointly by the Bipartisan Policy Center and the ClimateWorks Foundation.

Our mission

The mission of the American Energy Innovation Council is to foster strong economic growth, create jobs in new industries, and reestablish America's energy technology leadership through robust, public investment in the development of clean energy technologies.

About the Bipartisan Policy Center

In 2007, former U.S. Senate Majority Leaders Howard Baker, Tom Daschle, Bob Dole and George Mitchell formed the Bipartisan Policy Center (BPC) to develop and promote solutions that can attract the public support and political momentum to achieve real progress. Currently, the BPC focuses on issues including health care, energy, national and homeland security, transportation, science and economic policy. For more information, please visit www.bipartisanpolicy.org.

About the ClimateWorks Foundation

The ClimateWorks Foundation supports public policies that prevent dangerous climate change and catalyze sustainable global prosperity. The ClimateWorks network includes partner organizations across the world, aligned to support smart policies in the regions and sectors that have the greatest potential for reducing greenhouse gas emissions. For more information, please visit www.climateworks.org.

About Us

ACKNOWLEDGEMENTS

The American Energy Innovation Council (AEIC) gratefully acknowledges the important contributions and guidance provided by the following members of its Technical Review Committee:

Chair – Maxine Savitz, former general manager of technology partnerships at Honeywell; member of the President's Council of Advisors on Science and Technology; Vice President, National Academy of Engineering

- Ken Caldeira – Department of Global Ecology, Carnegie Institution of Washington
- David Garman – Former Under Secretary of Energy and Assistant Secretary of Energy Efficiency and Renewable Energy at the Department of Energy
- Rebecca Henderson – Senator John Heinz professor of environmental management, Harvard Business School
- David Keith – Professor and director of ISEEE Energy and Environmental Systems Group at the University of Calgary
- Richard Lester – Director of the Industrial Performance Center and professor and head of the department of nuclear science and engineering at MIT
- Nate Lewis – George L. Argyros professor of chemistry at the California Institute of Technology
- Ernie Moniz – Cecil and Ida Green professor of physics and engineering systems and director of the MIT Lab for Energy and Environment and of the MIT Energy Initiative, MIT; member of the President's Council of Advisors on Science and Technology
- Franklin Orr – professor of petroleum engineering, Stanford University
- Allen Pfeffer – Vice President of technology, Alstom Power
- Dan Sarewitz – Director, Consortium for Science, Policy, and Outcomes, Arizona State University
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A BUSINESS PLAN FOR AMERICA'S ENERGY FUTURE

PRELUDE

It may seem surprising that a group of business leaders who are not primarily in the energy field would make a strong statement on energy innovation and the need for a more vigorous public commitment. We have two reasons for speaking out on this issue:

First, the energy challenge is much worse than most people realize. The problem is already imposing a heavy burden on our nation—a burden that will become even more costly. The economic, national security, environmental and climate costs of our current energy system will condemn our children to a seriously constrained future unless America makes significant changes to current policies and trends.

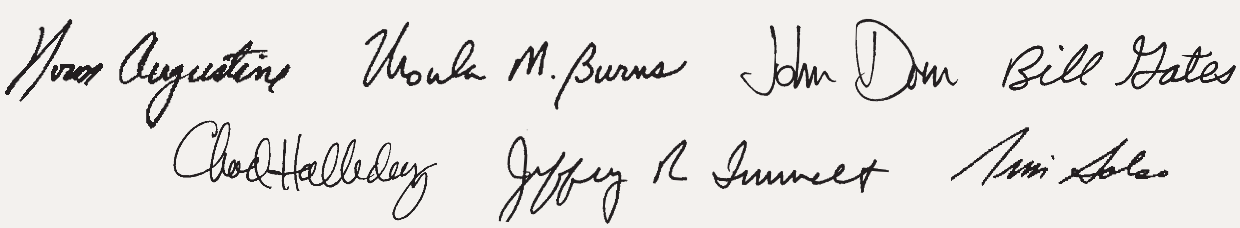
Second, there is vast, but neglected, potential to produce and spread innovation in the energy sector. Most of the technologies that underlie the current energy system were invented decades ago, and are increasingly costly, brittle, and incompatible with a clean future. In almost every realm of energy, we can develop and deploy new technologies that are more efficient, secure, and clean. Technology can be a game changer.

The scale of these threats—and the wealth of opportunities to do better—make the message clear: It is time we invent our future.

In developing a plan for how to do that, we called upon our experience managing large innovation programs in our companies. Our staff read dozens of reports from the field and interviewed another hundred experts. And we took a hard look at what has worked to promote innovation in defense, medicine, information technology and other fields.

We are convinced that America has a great deal to gain from smart, ambitious investments in clean energy innovation. As business leaders, we know how the private sector can be mobilized to attack these problems, but we also know the government must step up to protect the public interest. We set forth here the necessary actions that the public sector must take to unlock the ingenuity and capital of the American marketplace in pursuit of the nation's clean energy goals.

We hope that the President, Congress, and American public pay heed to the findings we present in this report.



Prelude

It is time we invent our future.

EXECUTIVE SUMMARY

As business leaders, we feel that America's current energy system is deficient in ways that cause serious harm to our economy, our national security, and our environment. To correct these deficiencies, we must make a serious commitment to modernizing our energy system with cleaner, more efficient technologies.

Such a commitment should include both robust, public investments in innovative energy technologies as well as policy reforms to deploy these technologies on a large scale. By tapping America's entrepreneurial spirit and long-standing leadership in technology innovation, we can set a course for a prosperous, sustainable economy—and take control of our energy future.

Conversely, if we continue with the energy status quo, we will expose ourselves to risks that pose significant threats to our way of life.

Innovation without implementation has no value.

–Tim Solso

Executive Summary

The need for government involvement in energy

There are two reasons the government must play a key role in accelerating energy innovation.

First, innovations in energy technology can generate **significant, quantifiable public benefits** that are not reflected in the market price of energy. These benefits include cleaner air and improved public health, enhanced national security and international diplomacy, reduced risk of dangerous climate change, and protection from energy price shocks and related economic disruptions. Currently, these benefits are neither recognized nor rewarded by the free market.

Second, the energy business requires **investments of capital at a scale** that is beyond the risk threshold of most private-sector investors. This high level of risk, when combined with existing market structures, limits the rate of energy equipment turnover. A slow turnover rate exacerbates the historic dearth of investments in new ideas, creating a vicious cycle of status quo behavior.

The government must therefore act to spur investments in energy innovation and mitigate risk for large-scale energy projects. By heeding the following five recommendations, we feel the government can unleash the nation's technology potential.

RECOMMENDATION 1: Create an independent national Energy Strategy Board

The United States does not have a national energy strategy. Without such a strategy, there is no way to assess the effectiveness of energy policies, nor is there a coherent framework for the development of new energy technologies. The results of this neglect have included oil-driven recessions, environmental degradation, trade deficits, national security problems, increasing CO_2 emissions, and a deficit in energy innovation.

We recommend the creation of a congressionally mandated Energy Strategy Board charged with (1) developing and monitoring a National Energy Plan for Congress and the executive branch, and (2) oversight of a New Energy Challenge Program (see Recommendation 5). The board should be external to the U.S. government, should include experts in energy technologies and associated markets, and should be politically neutral.

RECOMMENDATION 2: Invest $16 billion per year in clean energy innovation

In order to maintain America's competitive edge and keep our economy strong, the United States needs sizable, sustained investments in clean energy innovation. We believe that $16 billion per year – an increase of $11 billion over current annual investments of about $5 billion – is the minimum level required. This funding should be set with multi-year commitments, managed according to well-defined performance goals, focused on technologies that can achieve significant scale, and be freed from political interference and earmarking.

If Recommendation 2 is not adopted, our other recommendations will not matter much. Reliance on incrementalism will not do the job.

This $16 billion figure covers all of the recommendations we make in this report.

RECOMMENDATION 3: Create Centers of Excellence with strong domain expertise

Technology innovation requires expensive equipment, well-trained scientists, multi-year time horizons and flexibility in allocating funds. This can be done most efficiently and effectively if the institutions engaged in innovation are located in close proximity to each other, share operational objectives and are accountable to each other for results. Resources should not be spread thinly across many institutions working on the same problem.

To provide the above attributes to the energy industry, we recommend the creation of national Centers of Excellence in energy innovation. The Department of Energy's newly created Energy Innovation Hubs are a good start at such centers, but are not sufficiently funded to achieve the desired results. Additional centers of excellence need to be supported with an annual budget of $150 to $250 million each. To function effectively and deliver results, each of these centers will need the flexibility to pursue promising developments and eliminate dead-end efforts.

RECOMMENDATION 4: Fund ARPA-E at $1 billion per year

The creation of the Advanced Research Projects Agency-Energy (ARPA-E) has provided a significant boost to energy innovation. ARPA-E focuses exclusively on high-risk, high-payoff technologies that can change the way energy is generated, stored, and used, and has challenged innovators to come up with truly novel ideas and "game changers." The program has high potential for long-term success, but only if it is given the autonomy, budget, and clear signals of support to implement needed projects. It will need long-horizon funds on a scale commensurate with its goals, and a life extension beyond the current federal stimulus. We recommend a $1 billion annual commitment to ARPA-E.

RECOMMENDATION 5: Establish and fund a New Energy Challenge Program to build large-scale pilot projects

America's energy innovation system lacks a mechanism to turn large-scale ideas or prototypes into commercial-scale facilities. We recommend the creation of a New Energy Challenge Program to fund, build and accelerate the commercialization of advanced energy technologies—such as fourth generation nuclear power and carbon capture and storage coal plants.

This program should be structured as a partnership between the federal government and the energy industry, and should operate as an independent corporation outside of the federal government. It should report to the Energy Strategy Board (see Recommendation 1) and focus on the transition from pre-commercial, large-scale energy systems to integrated, full-size system tests. The public sector should initially commit $20 billion over 10 years through a single federal appropriation, which would unleash significant private sector resources as projects are developed.

Summary

In the defense, health, agriculture, and information technology industries, this country has made a deliberate choice to use intelligent federal investments to unleash profound innovation. As a result, the country leads in all those realms. In energy, however, the United States has failed the grade, and is paying a heavy price for that failure. We are optimistic about the potential for dramatic change in the energy realm. To seize this opportunity, America must put aside partisan interests and make a strong, bold commitment.

Introduction

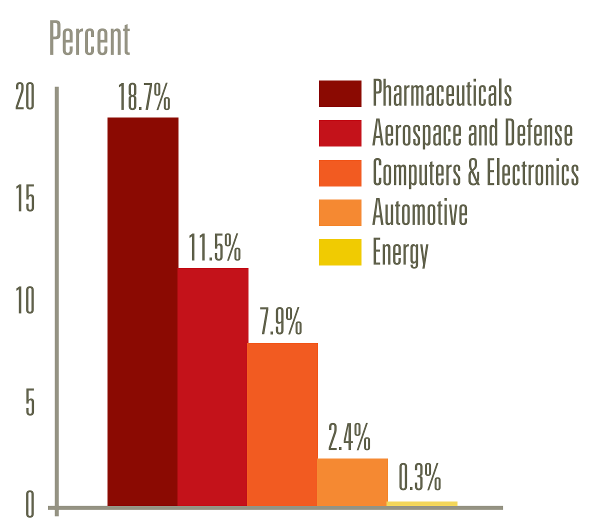
As business leaders, we have had the privilege of building companies that lead their respective fields and employ hundreds of thousands of American workers. Our experience has given us an unshakable belief in the power of innovation.

Each of our companies achieved prominence because we invested heavily and steadily in new ideas, new technologies, new processes and new products.

Indeed, **innovation is the essence of America's economic strength**. It has been our nation's economic engine for centuries. Our leadership in information technology, medicine, aviation, agriculture, biotech and dozens of other fields is the result of our enduring commitment to innovation.

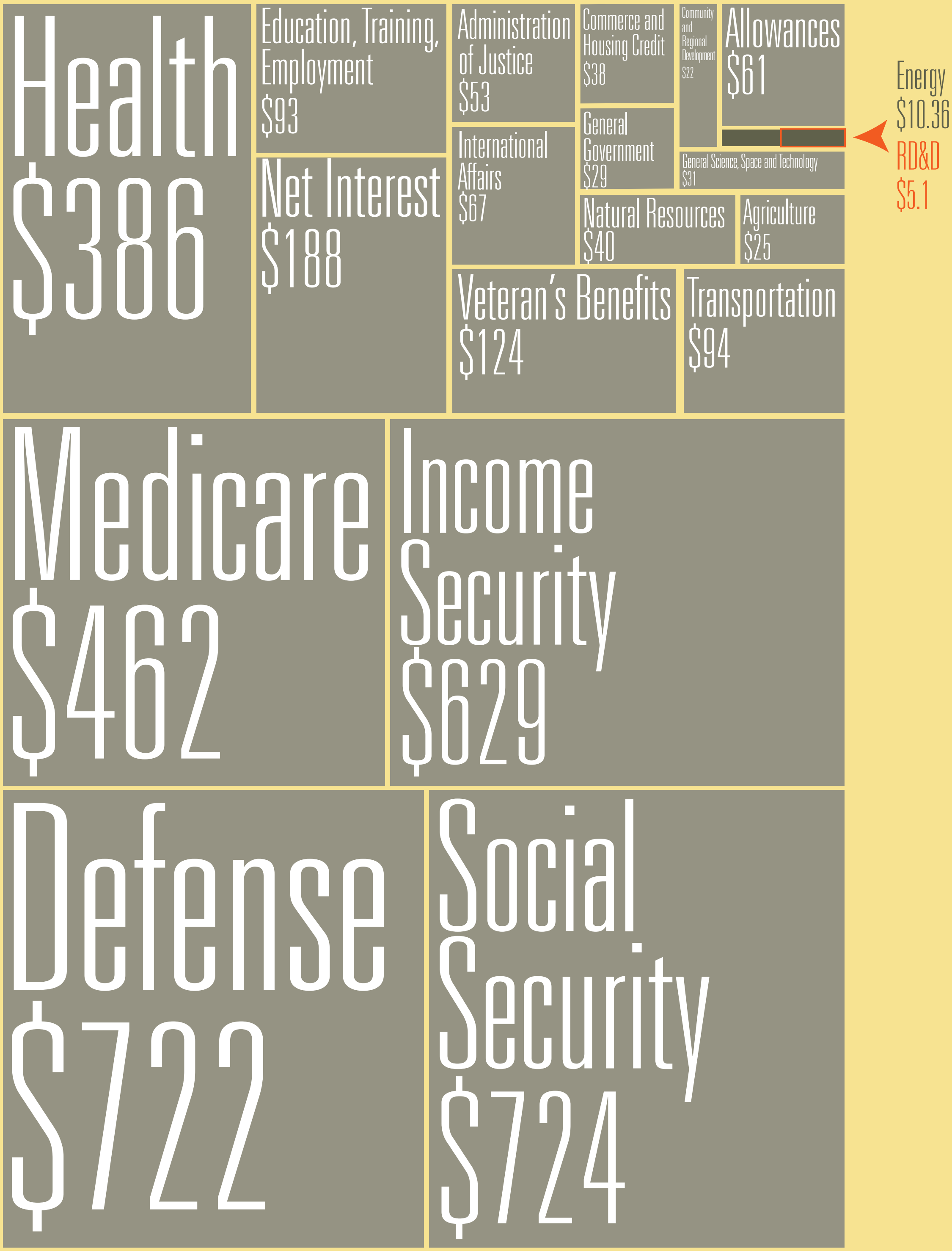
But in one realm central to America's economic, national security, and environmental future, our commitment to innovation is sorely lacking: energy. Investment in energy innovation, from both the public and private sectors, is tiny—less than one-half of one percent of the national energy bill. This neglect carries serious consequences.

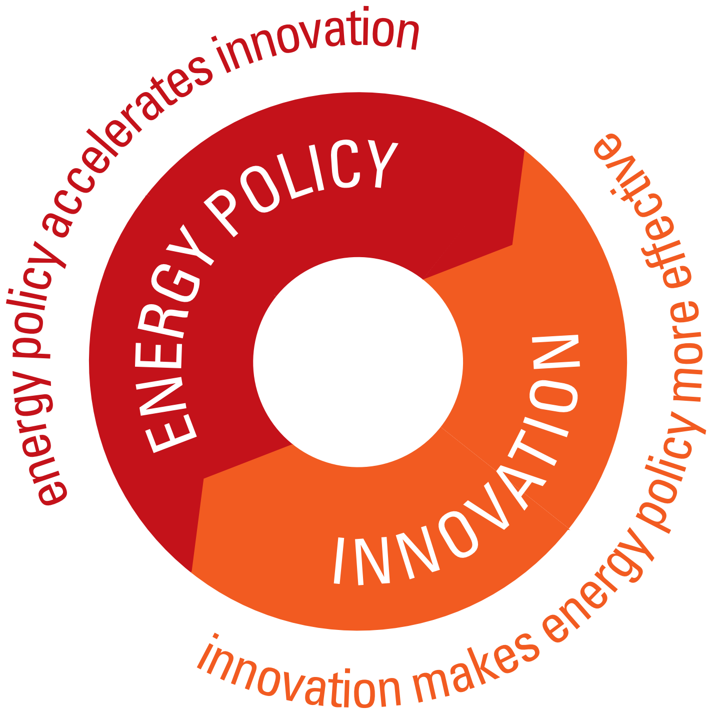
R&D Spending as a Share of Sales



Of all major technology-dependent sectors, the energy sector spends the smallest portion of its sales on research and development.[1]

2010 Federal Budget
$3.60 Trillion (in billions)





Due to our lack of energy options, our **economy** is vulnerable to price shocks—in oil, natural gas, and even electricity. The United States sends about $1 billion overseas every day for imported oil, an expenditure that represents the biggest part of the trade deficit and often causes hardship for American consumers and businesses. Our foreign oil reliance undermines **national security** by enriching hostile regimes, while our military forces are often deployed to protect access to oil. And the **environmental** costs are steep and growing, with both conventional pollution and climate change harming human health, threatening lives and livelihoods, and imperiling the natural systems upon which we rely for food, water, and clean air.

As business leaders who have constantly faced competitive threats, we see a clear and compelling need for a vigorous response to these energy challenges. The nation must not sit back and let these problems grow. America must take control of its energy future with the right combination of smart investments and smart policy.

If this nation gets serious about energy innovation, we are optimistic about the prospects. There are dozens of opportunities in the energy field where a serious commitment to technology is very likely to reap great rewards. Solar cells, dropping in price, can become an affordable, mainstream power source. The next generation of nuclear power has the potential to be safer and less expensive. Advanced biofuels could provide a viable alternative to oil. And energy efficiency—in devices and whole systems—can reduce waste and cut demand by half, or even more, in many sectors.

But if the nation is to succeed, the government must help lead the way. We remain convinced that a free-enterprise system led by the private sector is by far the most powerful driving force for innovation. But in energy, as in defense, aviation, and health care, the nation needs a coordinated effort between business and the government if it is to accelerate the innovation engine and create real options for our energy future. Today, the U.S. has no comprehensive national energy strategy.

There are many well-known precedents for this kind of public-private collaboration. Federal programs have been responsible for a wide range of game-changing technologies: new unmanned aircraft systems save the lives of American soldiers serving overseas; the Internet was born from military programs; and many of the most important medical breakthroughs of the last century came from our world-leading investments in medical science research at our universities and laboratories.

Conditions for success in energy innovation

Successful energy innovation has three prerequisites: the first is a pipeline of new inventions; the second is a suite of policy reforms that will stimulate market demand for these new inventions; and the third is a highly skilled workforce with the ability to create and deploy these inventions.

This plan addresses the first. Ours is a strategy to fill the American energy innovation pipeline with new technologies designed to deliver a more secure, sustainable future.

But we recognize that research, development and deployment (RD&D) needs complementary energy policies to advance innovation and drive market adoption of new technologies. Innovation without implementation has no value. A strong market signal will increase the intensity of energy research, add large private-sector commitments, reduce barriers between the lab and market, and ensure technologies perform better and cost less over time. Those policies may include some combination of a price or cap on CO_2, a clean energy or renewable energy portfolio requirement, and technology performance standards.

Regardless of the specific mechanisms that are chosen, successful energy policy will share three main characteristics:

1. It will provide long-term price or market signals. On-again, off-again policies hinder progress and scare away private sector investors.
2. It will encourage competition among technologies. Performance standards that allow the market to choose winners based on good technology and low cost are very powerful drivers of innovation.
3. It will reward steady improvements in performance. Credible, predictable and periodic adjustments in performance requirements will stimulate research and ensure continued innovation.

The effect of such policies would be to create a large, sustained market for new energy technology. Our nation cannot succeed without it.

RD&D = research, development and deployment

Bill Gates

Chairman, Microsoft Corp.
Co-chairman, Bill & Melinda Gates Foundation

The world faces many challenges, but none more important than taking immediate and decisive action to develop new, inexpensive clean-energy sources that avoid the negative effects of climate change. Low-cost clean energy is the single most important way to lift poor countries out of poverty and create more stable societies. The whole world would benefit from this, and the United States can and should lead the way.

Decreasing our dependence on coal, oil, and natural gas also will reduce the greenhouse gas pollution that is causing the earth to warm. If we do not dramatically reduce CO_2 pollution associated with the use of high-carbon fuels, the earth will continue to get hotter, causing the sea to rise and creating unpredictable weather patterns with potentially catastrophic consequences.

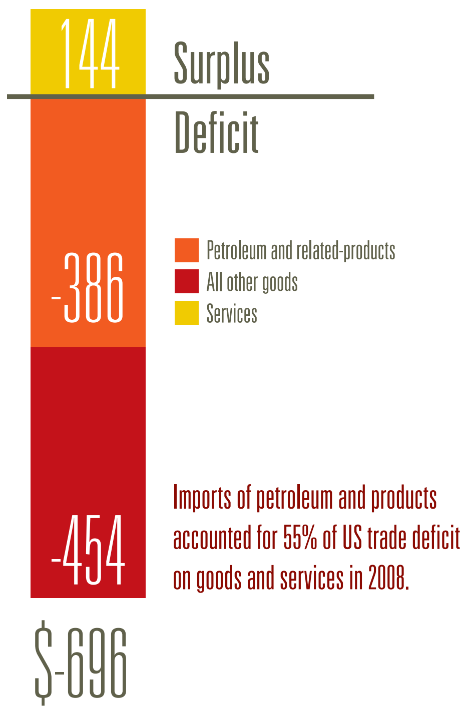
While none of us will be immune from these adverse effects, they will be particularly devastating for the world's poorest people. Increased droughts and floods, for example, could mean the difference between a harvest that sustains life and a crop failure that ends it.

I'm optimistic about our ability to meet this challenge, but the longer we delay, the more difficult it will be. Delay locks in expensive investments that have huge environmental consequences. Around the world, new coal-fired energy plants that will each emit 300 million tons of CO_2 over their 50-year lifetime are being built to meet the world's growing energy demand. At the same time, developing large amounts of low-cost and reliable clean energy will require time: 10 to 20 years of research and discovery, and, at the very least, another 20 years to build our new energy infrastructure. If we are to meet 2050 targets of reducing CO_2 emissions by 80 percent, we must begin now.

With innovation and determination, we can develop the low-cost clean-energy technologies so critically needed by the world's poor and so essential to ensuring a sustainable planet for all of humanity. Increased federal investment in energy R&D is an essential first step. The time for action is now.

US Trade Balance for Goods and Services

Billion USD in 2008



Source: Bureau of Economic Analysis, International Economic Accounts

The world faces many challenges, but none more important than taking immediate and decisive action to develop new, inexpensive clean-energy sources that avoid the negative effects of climate change.

–Bill Gates

Finally, it is clear that to succeed in energy, the nation needs a workforce with deep grounding in science and engineering. We refer to the educational recommendations outlined in the National Academies' *Rising Above the Gathering Storm* report to provide guidance on how to revitalize our science and technology education system in the United States.

A few of us were involved in the writing of the *Gathering Storm* report, and many of us have been involved in the political progress that stemmed from its call to action. That report made four pointed recommendations:

- Vastly improve K-12 science and mathematics education.
- Sustain and strengthen the nation's commitment to long-term basic research that has the potential to be transformational.
- Make the United States the most attractive setting in which to study and perform research. Attach a green card to the diploma for international students who pursue higher education in science, technology, engineering or math in the United States.
- Ensure that America is the premier place in the world to innovate; invest in manufacturing and marketing; and create high-paying jobs based on innovation.

Complementary market policy and education reform are vital to the energy innovation ecosystem. This report focuses on America's immediate opportunity to invest in energy innovation—and how to seize it.

THE HIGH PRICE OF INACTION

There is no part of our economy that can operate without access to reliable, affordable energy. Our nation has built an energy system that is miraculous in its breadth and power, but in its current incarnation, exacts steep costs in four ways:

1. **Faltering economic competitiveness** in the $5 trillion global energy industry, as vast new markets for clean energy technologies are expanding rapidly in Asia and Europe, rather than in the United States.
2. **Direct economic** costs of constrained energy choices, from (a) price volatility, which has driven two recessions and several economic shocks, including the 2008 shock that cost our economy $500 billion in one year alone and (b) the trade deficit, driven by about $1 billion per day sent overseas to pay for imported oil.

Tim Solso

CEO, Cummins Inc.

The energy and climate challenges facing the world are huge, and they demand both increased energy innovation and sound strategies to get those technologies into the market. Cummins is a leader in clean engine technology for three reasons: We take the long view, work with public and private partners whose expertise complements our own, and embrace clear and responsible regulations which drive the innovation that can lead to a competitive advantage.

Technology innovation does not happen overnight. We invest hundreds of millions of dollars each year in R&D, because without technology leadership, we cannot compete. Our innovation has to be dependable since our customers often count on our engines to run for more than a million miles.

Nor does technology innovation happen in isolation. Cummins was able to develop the technology for high-efficiency, low-emissions engines through partnerships with the Department of Energy. We worked with combustion experts at Sandia National Laboratory and with catalyst experts at Oak Ridge and Pacific Northwest National Labs to develop the technologies that allowed us to meet the 2010 diesel engine emission standards three years early in Dodge Ram pickup trucks. This kind of development requires a view towards product implementation from the outset. Cummins brings application knowledge, and laboratory partners bring sophisticated physical analysis tools. Together we deliver innovative technologies that work well in the hands of the customer. At Cummins, we call that "Innovation You Can Depend On."

Finally, regulations can help make sure these innovations get to the market. When our engineers are challenged with tough, long-term performance standards, they know how to orient their research. As CEO, I know that meeting or beating these standards gives Cummins a market advantage. And when we deliver cleaner, more efficient engines than our competitors, our company prospers.

Jeff Immelt

Chairman & CEO, General Electric

GE is fortunate to have some of the world's best engineers, innovators, and technology experts working under our roof. We invest heavily so that they can drive the most advanced ideas off the drawing board and into development.

For some of the markets where we do business, like healthcare, a really good idea can gain market share simply by solving a new problem or by outsmarting the competition. But in energy, we don't have that kind of dynamic market situation; a big year in the U.S. electricity market is 2 percent or 3 percent growth. The current energy markets don't favor cleaner technology or low-carbon; they stop at affordability and reliability.

For a challenge as mammoth as energy, innovation must adapt – and policy must encourage it. Since I started at GE in 1982, our health care division has evolved through a half dozen advances in technology. Over that same period, energy technology has hardly budged. This has nothing to do with the quality of our engineers, but it has everything to do with the marketplace where they do business.

No business will invest when there is no certainty about what a market will look like two, five or 10 years into the future. If we're serious about transforming our energy markets, we must send the right signals and create demand for the technologies that solve these problems.

For a challenge as mammoth as energy, innovation must adapt — and policy must encourage it.

3. **National security** problems from (a) sending vast sums of money into global petroleum markets that support nations hostile to the United States and (b) relying on an energy system that is increasingly vulnerable to blackouts or supply disruptions.
4. **Environmental** dangers, from both (a) air pollution that negatively impacts human health, water quality and ecosystems; and (b) climate change from greenhouse gas emissions, which are largely the byproduct of fossil fuel combustion.

This is a serious nexus of problems. Each individually would merit national attention; together, they should be at the top of the national agenda. Fortunately, serious investments in new energy technologies offer leverage against all these problems.

GOALS FOR AMERICAN ENERGY

We believe America should have four intersecting energy goals, directly aimed at the costs above.

1. Fuel the American engine to compete in the global market for energy and energy technology. Create modern industries with modern jobs.
2. Power the domestic economy with clean, affordable energy.
3. Reduce national security threats from disruption of energy sources, whether domestic or international.
4. Protect public health and mitigate the very real threat of climate change.

To achieve those goals, the United States will need to rapidly develop and deploy a rich array of technologies. Energy is fundamentally a technology business, in its extraction, production, transformation, storage, and use. Advanced technologies can improve every one of these phases, sometimes radically. The United States needs a concrete strategy for achieving these clear goals.

Why can't the private sector solve this problem?

The private sector has underinvested in energy innovation, and it cannot achieve these goals alone. There are fundamental differences between energy and most other economic sectors, and these differences limit the ability of the private sector to solve large-scale energy problems on its own.

First, the high price of inaction highlights the need for the public to invest in better energy options. National security, national economic strength, and the environment are not primary drivers for private sector investments, but they are critical for the health of our country. They merit a public commitment.

Second, large-scale deployment of many new energy technologies requires massive capital expenditures that are too risky for private investors. A new generation of microwave technology might cost $10 million to develop and can be built on existing assembly lines. That risk-reward calculus makes business sense. In contrast, a new electric power source can cost several billion dollars to develop, yet still will carry risk of technology failure or regulatory changes. And the product, electricity, is sold into a generic market that does not differentiate between clean and dirty sources. So that investment does not make sense for most companies.

Third, America's long-term corporate R&D budgets, especially those run by utilities, have been in decline for several decades.

Fourth, the turnover in the electrical generation system is very slow. Power plants last 50 years or more and are relatively cheap to run once built, so there is little market for new models. Moreover, patents for replacement technology last only 20 years, so the slow power plant turnover considerably reduces the reward for inventors.

Combine these elements and it becomes clear why private sector investments in clean energy technology development have been so small. Once businesses see a market situation that reduces their technology development risk and rewards clean energy sources, they will invest.

America must take control of its energy future with the right combination of smart investments and smart policy.

HOW INNOVATION REDUCES THE PRICE OF NEW TECHNOLOGY

The main purpose of RD&D investment is to make new technologies affordable. That means it is necessary to understand what drives down the price of new technology. Getting this right is the key to designing good programs.

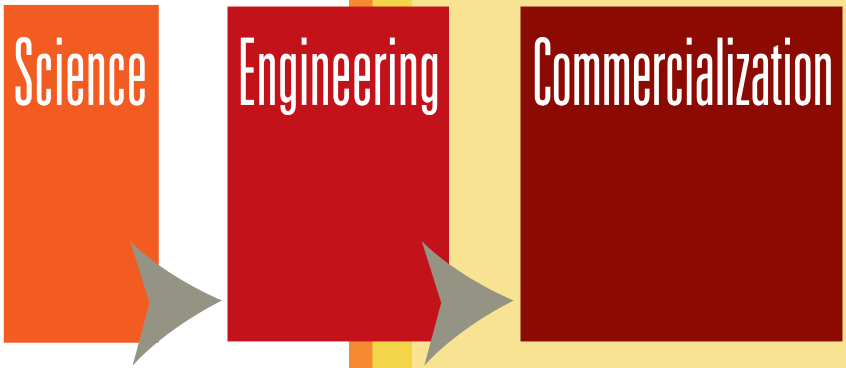
The United States has a history of great success in driving down the price of new technology. Indeed, this is the basis of its prosperity. Computer chips are the most famous example. Their costs have come down by a factor of more than four million since 1975.[2] For perspective, if today's chips were the same size and cost as they were in 1975, Apple's iPod would cost $1 billion and be the size of a building.

Other technologies, from cars to consumer goods to energy, follow the same kind of price reduction. Solar photovoltaic cells, for example, have dropped by about 22 percent in cost with each doubling of capacity. This is known as the "learning curve" for solar. But falling prices are not an axiomatic result of time passing, or even of more installed solar arrays. The drivers of this progress are worth unpacking.

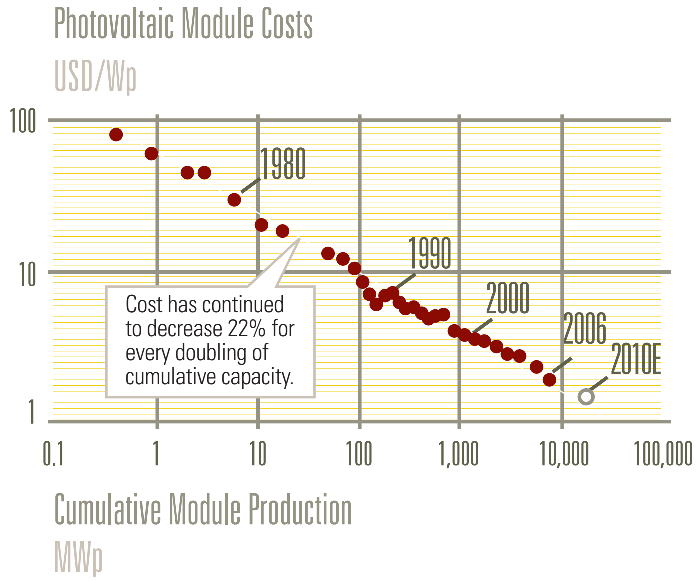
There are three basic phases of technology development: science, engineering, and commercialization. Employing best practices in each of these realms is the key to bringing down costs—and thus these best practices drive the recommendations in this report.

Stuck between science and engineering

Sometimes moving from science to engineering requires large sums of money, while other times the needs are small. At Lawrence Berkeley National Laboratory, scientists have made important steps for advanced lithium-ion (Li-ion) batteries – but they are caught in a budget trap. Researchers at the lab found that if silicon were used instead of graphite in batteries, total battery life would be expanded significantly—for example, more than doubling the number of recharge cycles for electric vehicle batteries. But silicon use requires creation of an expensive new manufacturing production line. Gao Liu, a staff scientist at Berkeley Lab, found an alternative: He has test results showing a new silicon method that uses the same manufacturing production lines as graphite Li-ion batteries. He needs minimal engineering assistance to carry out the next round of complex tests to see if this production will work. But national laboratories have a heavy focus on basic scientific research rather than applied research, and Gao Liu's scientific research has already been successfully published. So for now, at least, this promising energy technology remains an idea rather than a reality.



Cost Reduction of Silicon Solar



Public and private investments in science, engineering, and commercialization have led to dramatic reductions in the cost of solar power.[3]

The role of basic science

The first stage of technology innovation comprises research and development in the basic sciences. For example, grid-scale energy storage would make renewable power far more useful, but making electricity storage affordable will require fundamental advances in electrochemistry. Indeed, many of the most urgently needed innovations still depend on fundamental advances in biology, chemistry, materials science or thermodynamics. Today's basic science research will provide the foundation for tomorrow's energy technologies; we need to commit to these investments.

Several principles differentiate the successful science programs from the unsuccessful. The National Academies, Government Accountability Office, and President's Committee of Advisors on Science and Technology have undertaken numerous assessments of national energy RD&D programs.[4]

The lessons stressed by these studies:

- Overall research goals and desired social benefits should be explicit.
- Peer review should be built into research selection and evaluation.
- Programs should tolerate failure, because it is not research if the outcomes are known in advance.
- Funds should be concentrated in centers of excellence rather than spread across many institutions.
- Funding risk should be minimized through periodic check-ins, or "performance gates," in which well-defined milestones must be met or the project gets shut down.

Engineering: From the lab to the shop floor

Engineering turns research into practice by converting science into workable products. For example, a cup of algal biofuel turns into a running system for oil production at scale, or a solar cell prototype transforms into a workable module that can be mass produced. The engineering phase must be informed by what is required to take a new technology to industrial scale, make it easy to manufacture, and integrate into existing systems. The engineering phase also solves problems associated with constructing large, first-of-a-kind pilot projects.

Best practices in engineering include:

- Ensure that the ultimate goal is within the realm of the possible, in terms of cost, performance and reliability. Set clear performance gates for technologies in the engineering stage.
- Bring many disciplines together to tackle system-wide energy engineering questions.
- Dispatch engineers and production experts to complement the scientists who already focus on R&D.
- Enable large-scale pilot projects. Focus on whether a project is replicable: learning how to engineer and build the first energy project should be about learning how to build the next ten projects.

Commercialization: Closing the sale

For innovations to be commercialized, private sector manufacturers must anticipate large-scale, long-term markets. For example, renewable portfolio standards created the large market that was required to drive the cost of wind power from 40 cents per kilowatt-hour to 8 cents. That investment yielded a clean source of power that is increasingly competitive with traditional electricity prices. The standard did double duty: It bought a lot of wind power, and by helping drive down the cost of wind, it created a viable new energy technology option.

Best practices in commercialization include:

- Clear, long-term market signals to create market pull for innovation. Examples include renewable performance standards, feed-in tariffs, and reverse auctions. Such policies must reward performance, not investment.
- Projects should include private sector participants with "skin in the game." The power of competitive markets is crucial to real-world discipline that avoids waste.
- Projects at the commercialization stage should also have performance gates. Such clear markers are central to private sector innovation, and they will help in the public sector as well.

Regardless of the specific mechanism, all policy options for supporting the commercialization phase must share one characteristic: They must operate over timeframes long enough to send appropriate signals to the private sector.

If today's computer chips were the same size and cost as they were in 1975, Apple's iPod would cost $1 billion and be the size of a building.

Ursula Burns

CEO, Xerox

Many people equate innovation with a "Eureka" moment. Someone comes up with a sudden, amazing idea, investors show up, and that's that.

But in the quickly evolving technology business, your shareholders are unlikely to accept "Eureka" as a business strategy. The reality at Xerox is that we spend a significant amount of our time and resources cultivating and managing innovation. We never stop the innovation process, because without a continual stream of new ideas and technologies, our business will become obsolete.

At any one time, we have numerous innovation programs underway and we guide our efforts according to four principles:

1. **Unify innovation efforts with a clearly articulated *vision and strategic goals* for our global teams to rally around.**
2. **Guide progress by creating *roadmaps* based on global and industry trends as well as technology trends.**
3. **Involve the best global *partners and a diverse set of customers* early and throughout the end-to-end innovation process.**
4. **Invest in a *balanced portfolio*, having a mix of early-stage research and products ready for mass deployment. We need a mix of technologies that are truly disruptive, and we need refinements to our existing platforms.**

Adhering to these four principles—no matter what field you're working in—delivers results. I strongly believe we should be applying this multifaceted approach to renewable energy innovation. Instead of a series of fractured challenges and solutions, we should actively manage the future of our energy system as the integrated whole that it is, building a pipeline of technologies that will solve the serious problems our world is facing.

THE PLAN: OUR RECOMMENDATIONS

Recommendation One:

Create an independent national Energy Strategy Board.

The United States does not have a realistic, technically robust, long-term energy strategy. Without such a strategy, there is no coherent way to assess energy, environmental or climate policy, nor is there a coordinated framework for developing new technologies. The result of this neglect is reflected in our nation's history—with oil-driven recessions, trade deficits, national security problems, increasing CO_2 emissions, and a deficit in energy innovation.

It is time to address our energy future with more serious purpose. To do so, we call for the creation of a congressionally mandated Energy Strategy Board. This would be a high-level board of experts charged with development and monitoring of a National Energy Plan for Congress and the executive branch, and oversight of a New Energy Challenge Program (see Recommendation 5).

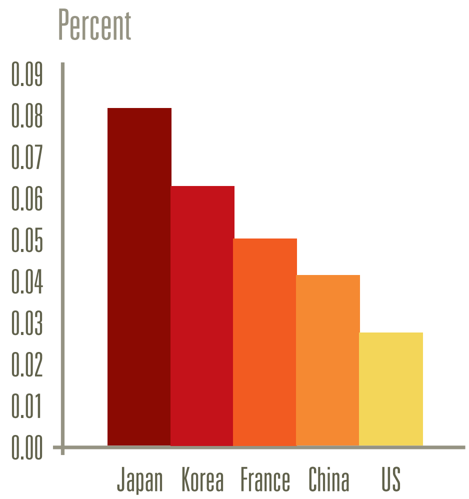
National Energy Plan

The country needs a National Energy Plan. Such a plan would assess problems and opportunities, establish clear objectives, and chart a course toward achieving them. It would serve as a benchmark for national energy, climate, and environmental policy, and would guide and coordinate energy research investments by the Department of Energy, the New Energy Challenge Program[5], and the Clean Energy Deployment Administration[6].

The National Energy Plan should provide an ambitious but achievable strategy. The plan should contain concrete and measurable energy objectives and then allow technologies and markets to compete to meet them. For example, the United States is dependent on petroleum for 97 percent of transportation fuels. The nation would benefit from having a target to reduce that single-source dependence, and a realistic plan to get there. The National Energy Plan would

It is time to address our energy future with more serious purpose.

Public Energy RD&D Spending as a Share of GDP, 2007



Among its major trading partners and competitors, the United States spends the smallest fraction of its GDP on energy RD&D.[7]

map out both the policies and energy technology strategies to achieve these goals. The plan would include metrics against which progress can be measured.

The plan would also assess political path dependence questions that require resolution if the United States is serious about taking on our energy challenge. The government's decisions on these fundamental issues should drive America's energy technology strategy. For example:

- Is the federal government willing to take on long-term liability for storing CO_2 through carbon capture and storage (CCS)? Or for storing nuclear waste?
- Can the utility industries be reformed to align with the nation's 21st century aspirations of deploying innovative energy technologies and creating a robust, modern grid?

A National Energy Plan cannot just be the sum of the advocacy of different energy interests. It needs to be built upon an in-depth assessment of end uses (transportation, housing, industry, etc.) and their potential for improvement; a complementary assessment of energy supply options (electric, liquid, and gaseous fuel sources as well as the technologies used in power generation); and a plan for the infrastructure that conveys that energy (storage, transmission, and distribution). For each realm, the analysts must understand technical potential, cost curves, research frontiers, economics, scaling potential, and siting characteristics. They will also need a keen sense of the effects and side effects of various energy policies.

All of that option-specific work will then need optimization. Many technologies depend on each other. For example, massive renewables deployment will require some combination of enhanced electric transmission capacity, storage, back-up capacity, and demand control. It makes little sense to push renewables without developing an intelligent combination of these four complementary technologies. Today, these technologies are developed largely in isolation from each other.

Naturally, the plan must take advantage of the dynamics of the private sector, which is the best engine for innovation and for allocation of capital. This report makes clear that we believe the federal government has a crucial role—in setting energy policy, undertaking research and development, and demonstrating large-scale technologies. But that work, and the National Energy Plan, will all fail if the government does not help unleash large private sector commitments and innovation. The National Energy Plan must be cognizant of the conditions that accelerate private investment.

The Energy Strategy Board would be responsible for generating the Plan and updating it every three years. It would produce a formal report to the federal government, and would require the U.S. secretary of energy and other relevant agency administrators to respond.

The Energy Strategy Board would also charge the Energy Information Administration (EIA) with scoring how energy policy affects the nation's energy future. Today, the Office of Management and Budget and the Congressional Budget Office track the fiscal impacts of various policies with an overall budgetary strategy in mind. The EIA currently has no overall strategy against which to track the energy impacts of energy bills. This needs repair, and the Energy Strategy Board would be ideally positioned for the job.

Today's basic science research will provide the foundation for tomorrow's energy technologies; we need to commit to these investments.

New Energy Challenge Program

This report argues for a special federally chartered corporation to develop and demonstrate large-scale energy technologies, such as advanced nuclear power, or carbon capture and storage for coal. Without such an institution, these options will stagnate—as they have in the United States—for decades.

The New Energy Challenge Program (NECP) is described in more detail as Recommendation 5. We envision an independent institution tasked with demonstrating advanced energy technologies at commercial scale. The NECP would be a subsidiary organization of the Energy Strategy Board, with its own small executive management authority. The NECP would be organized around the Board's stated technology priorities.

Staffing and funding

The Energy Strategy Board would be a small, politically-neutral, high-level group, with a lean operating budget and a focused mandate. It would have one federally-appointed chair and about 15 members made up of preeminent figures in the energy domain, such as leaders of the National Academies and relevant company executives. The members of the Board would be selected by their peers, rather than the political process. Slots on the board should be reserved for the sitting directors of ARPA-E and the Clean Energy Deployment Administration, as well as the President of the New Energy Challenge Program (see Recommendation 5). Other positions would be filled with experts on technology development, such as Chief Technology Officers and experts in energy policy. The Energy Strategy Board would require a small, highly competent staff for production of the National Energy Plan, and it would have broad authority over the budget of the New Energy Challenge Program.

John Doerr

Partner, Kleiner Perkins Caufield & Byers

"My venture capital firm, Kleiner Perkins, helps entrepreneurs turn breakthrough innovations into new technology companies, creating more than 400,000 new jobs. American entrepreneurs have literally created the biotechnology and information technology industries, resulting overall in 12 million American jobs and worldwide prosperity.

Today, American companies are the world leaders in biotech and information technology. However, in new energy technologies, America has fallen well behind.

If you look at today's top companies in clean energy technology—in wind, solar, and advanced batteries—only 4 out of 30 are American. Comparing to IT, it's as if Microsoft, Apple, Google, and Intel were headquartered in Asia or Europe, and only Amazon was in the United States.

Why are we lagging so far behind? A key reason is inadequate energy technology research and development. Energy is a $1 trillion part of the $14 trillion U.S. economy. But America spends only about $5 billion—about half a percent—per year on new energy RD&D. That compares with $30 billion spending per year of bio/medical R&D, or nearly 8 percent of our national health budget. Sadly, America spends more on potato chips than we do on our new energy RD&D.

To create and bring new technologies to market, the country also needs strong performance standards for autos, buildings, and utilities, and a carbon price signal to let companies know that polluting is not forever free. I am convinced these policies will usher a vast array of new technologies, and give our country the energy options we need.

We can no longer afford to neglect energy technology or climate policy. The economic stakes are enormous. And the climate threats are far more serious and more urgent than most people realize. If left unanswered, we confront catastrophic and irreversible climate change.

My partners and I believe new clean energy is the next great global industry. The world needs much more investment in and commitment to energy innovation. America must suit up, step up, and get serious about energy RD&D if we're going to be a winner in this race.

Sadly, America spends more on potato chips than we do on our new energy RD&D.

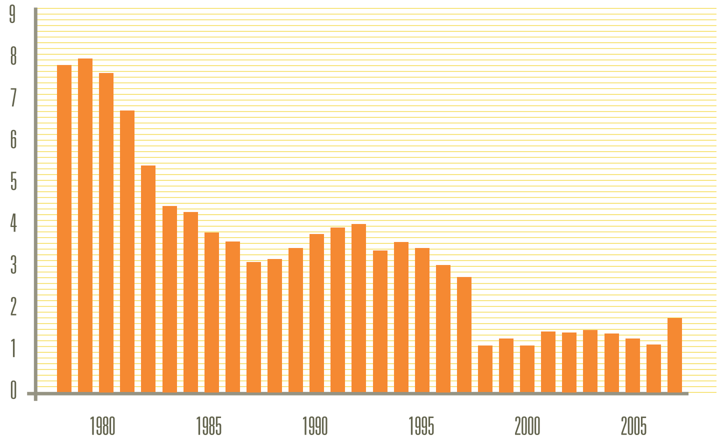
THE PLAN: OUR RECOMMENDATIONS

Recommendation Two:

Invest $16 billion per year in clean energy innovation.

Public Energy R&D Spending, 1978-2007

Billion 2005 USD



Public spending on energy research and development has been in decline for 30 years, and is currently one-quarter of its high point in 1979.[8]

Innovation spending must relate the size of our energy market and its importance in driving our economy. We argue that our current underinvestment should be scaled to a minimum of $16 billion per year. This is about $11 billion more than we now spend in a typical year, and will put energy research, development and deployment (RD&D) closer to (though still well short of) other technologically intensive sectors; bring U.S. investment in line with those of its trading partners and competitors; and meet the bottom-up needs of major technologies.

The benefits of this investment will far outweigh the costs. By comparison, the United States sends $16 billion overseas for petroleum every 16 days. Our recommended RD&D commitment represents about 3 percent of what the nation spent on the 2008 oil price shock in that year alone. At just 1.5 percent of U.S. energy sales, this figure still represents a significantly smaller share than most high-tech industries re-invest into innovation.

If this recommendation is not adopted, the others will not do much good. Incrementalism will neither fill the gaps, nor create the sweeping change this nation needs in energy. Bold action is required.

Numerous groups, from the National Academy of Sciences to the President's Committee of Advisors on Science and Technology, have studied energy innovation spending; all agree that large increases are necessary.

Model budget:

To allow time for establishing the appropriate programmatic infrastructure, we envision a sustained budget ramp-up. Model five-year numbers are included below, with additional explanation in the Budget Details available online at http://www.americanenergyinnovation.org.

Model RD&D Budget (millions 2005$)	2009	2009 ARRA	2010	2011 Request	Model Budget in 5 years
Basic Energy Science (with increases directed to Energy Frontier Research Centers, Innovation Hubs and other Centers of Excellence)	1,390	502	1,468	1,627	2,600
Nuclear Fission (advanced reactor technologies, fuel cycles, new modeling and simulation capabilities and waste management	508	0	464	502	1,000
Nuclear Fusion	357	82	382	337	400
Efficiency (including buildings, transportation and industrial sectors)	716	648	844	823	2,100
Renewables (including solar, wind, bioenergy, geothermal and hydropower)	763	1,450	891	846	2,400
Fossil Energy (including carbon capture and storage, clean coal, natural gas and hydrates)	771	3,075	577	511	1,300
Electricity Transmission and Distribution (including electricity storage, smart grid, transmission and distribution	111	654	143	154	1,200
ARPA-E	8	352	0	266	1,000
RD&D Subtotal	4,624	6,763	4,769	5,066	12,000
New Energy Challenge Program	NA	NA	NA	NA	$2,000
Clean Energy Deployment Administration	NA	NA	NA	NA	$2,000
Grand Total					$16,000

How much money is needed?

Several perspectives can help determine how much financing is needed to advance new energy technologies. All point to roughly the same total. We examine our nation's own annual energy expenditures along with the proportion devoted to R&D compared with other sectors of the economy; we compare R&D spending in the United States to that of other nations; and we examine the projected costs for several important technologies. The Report Notes have further details on each of these methodologies, as well as a justification for each of our budget's line items.[9]

How can the nation ensure this money is spent well?

America's track record of substantial, sustained money for health and defense research is instructive. Building on that experience, plus our own, we have learned what works:

1. Support for RD&D must have multi-year commitments, which translate to multi-year appropriations. It is impossible to do serious RD&D without assembling top-notch talent, building or buying equipment, conducting experiments, and validating results. None of this can be done well with year-at-a-time funding.

2. Research can be managed and tracked through pre-defined performance gates, to ensure that projects on course keep receiving support and those failing get terminated.

3. Support must be given to technologies that have real potential to scale. The federal government should focus on supporting technologies with potential for national impact—the sectors where there is a major gap between the best technologies available and the technical and economic potential.

4. Earmarks are counter-productive. Congress should fund broad programmatic areas rather than particular projects in specific districts. Competition within broader categories is healthy. This structure increases the likelihood that the best proposals will move forward.

5. Concentrated effort increases success rates. Our analysis of current federal energy RD&D suggests that many programs fail, or are slow to succeed, because funds for RD&D are spread across dozens of laboratories and universities. Program managers must be able to concentrate their resources in order to succeed.

Incrementalism will not fill the gaps nor create the sweeping change this nation needs in energy.

Innovation in health and defense has created jobs and economic growth

The health and defense sectors show how America can spend innovation money effectively. The National Institutes of Health (NIH) is well funded out of the federal budget at around $30 billion per year—which is about 75 percent of *global* spending in basic medical science. This commitment has developed many medicines that are now central to our people's health, and has also made America the leader in this vast industry. The budget of the NIH more than doubled in recent years, and the growth of NIH is instructive in thinking about how to build energy RD&D. For example, the Institutes maintained a healthy level of competition for research grants throughout its period of budget expansion, ensuring that the quality and productivity of research was maintained or even increased.

Fully 80 percent of NIH's annual research budget supports work performed at university laboratories.[10] All resulting papers must be publicly available, thus allowing collaborations to emerge across disciplines and fueling innovation. As a result, NIH was instrumental in funding 15 of the 21 major breakthrough drugs from 1965 to 1992.[11] For example, Gleevec, arguably the most effective cancer drug of the past decade, was nearly abandoned by its private sector backer. Under NIH support, a cancer specialist at the Oregon Health and Science University continued the research that led to the drug's ultimate commercialization.

Another great story comes from the Defense Advanced Research Projects Agency (DARPA), which has been able to produce large-scale technologies in record time through its agile funding model and its risk-tolerant, idea-driven, outcome-oriented culture. The agency exemplifies the benefits of multi-year funding and relative insulation from the political process. DARPA made investments in the technology and infrastructure that gave birth to the Internet. This required collaboration with professors at MIT and UCLA, as well as several private companies, and that required an innovation model that encourages such collaboration.

Last year, more than 30 Nobel laureates called

the President's attention to the need for a sustained increase in federal clean energy innovation spending, emphasizing that "stable R&D spending is not a luxury." This group of prominent American scientists also recommended that the federal government spend $15 billion per year on clean energy innovation.

Many other expert panels and respected studies have called for sustained increases in federal investment in energy innovation:

2x The President's Council of Advisors on Science and Technology and the National Commission on Energy Policy in 1997 and 2005 recommended a doubling of spending.

4x Several studies between 1999 and 2003 looking at options value and risk mitigation recommended a fourfold spending increase.

3x-6x The International Energy Agency in 2009 recommended a three- to sixfold increase for all countries in the Major Economies Forum.

6x-9x The Intergovernmental Panel on Climate Change recommended in 2000 a six- to ninefold global increase.

5x-10x A University of California analysis in 2006 recommended a five- to tenfold increase for the United States.

3x Our report, by way of comparison, recommends an increase to about three times today's levels.

THE PLAN: OUR RECOMMENDATIONS

Recommendation Three:

3

Create Centers of Excellence with strong domain expertise.

Concentrating resources and intelligence will drive new technology development. Innovation in the energy field relies on many factors—expensive equipment, corps of well-trained scientists and engineers, strong leadership, the ability to attract the best young minds, flexibility in the allocation of research funds, and multi-year time horizons. These are all necessary for the scale and speed of innovation required. Development can slow or stall for a specific technology if its research budget is spread across a dozen national laboratories. Success requires a point of confluence for new ideas.

America's great research universities can serve as natural homes for these Centers. National labs can also provide homes for these Centers of Excellence – they allow open access to testing equipment and partner with the private sector through Cooperative Research and Development Agreements.

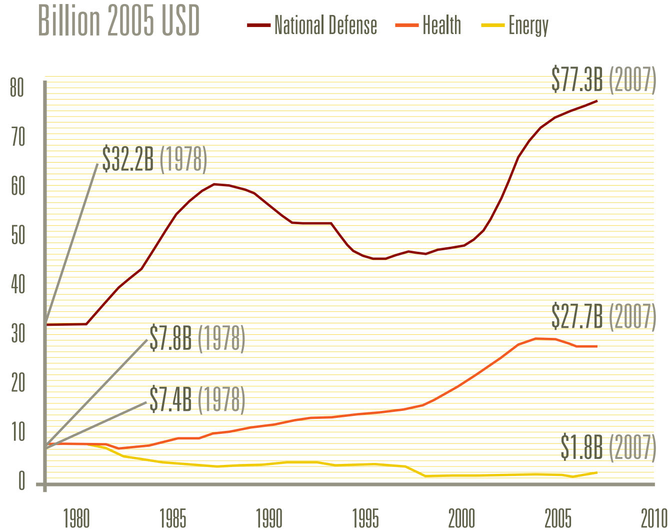
Success requires a point of confluence for new ideas.

One example of a university-centered Center of Excellence is North Carolina's Research Triangle. Anchored by three universities with significant R&D programs, the Triangle attracts major public (e.g., the National Environmental Health Science Center) and private (e.g., DuPont, GlaxoSmithKline and Burroughs Wellcome) research attention. The region features some $1.2 billion in annual research, as well as the infrastructure and skilled labor pool resulting from the critical mass of expertise. Among the most significant local accomplishments are the discoveries of the anti-cancer drug Taxol, and AZT, a drug to fight HIV-AIDS.

These concentrations can also surround the Department of Energy's national labs. The Combustion Research Facility (CRF) at Sandia National Laboratory provides an example. With advanced equipment to analyze engine combustion conditions, the CRF has become the world leader in the field, and has made significant advances in vehicle fuel economy and vehicle emissions reductions. Its industrial partnerships have enabled American companies to lead in the truck engine business.

Federal spending on defense R&D is more than 30 times greater than spending on energy R&D; health care spending is 10 times greater.[12]

Federal R&D Spending in National Defense, Health, and Energy



Similar success could be had for other energy technologies. To this end, we applaud the strategic direction of the Department of Energy's newly created Energy Innovation Hubs, which have been funded with $22 million in 2010 and $25 million annually for subsequent years. However, these hubs and additional centers of excellence need to be supported with real money—hundreds of millions of dollars, not tens of millions.

Structured along the lines described above, these centers can drive technologies down all three phases of the learning curve: funding for pilot-scale energy research will encourage breakthroughs; labs and equipment—made available to academics and private industry alike—will test the scalability of new energy technologies; and partnerships to share intellectual property will help bring technologies to market. Program managers at these centers need the power to make quick decisions in order to follow the most promising leads and abandon dead ends.

Energy Centers of Excellence should focus on a handful of specific technology areas with great promise, including solar photovoltaics, concentrated solar power, wind power, advanced energy storage, clean vehicles, transportation systems, and carbon capture and sequestration, in addition to the Energy Innovation Hubs selected by the Department of Energy for 2010 (fuels from sunlight, efficient energy buildings systems design, and modeling and simulation for nuclear reactors).

In order to function effectively and deliver results, each of these centers will require annual funding in the range of $150 million to $250 million as a part of the total $16 billion energy innovation budget.

THE PLAN: OUR RECOMMENDATIONS

Recommendation Four:

4

Fund ARPA-E at $1 billion per year.

The Defense Advanced Research Projects Agency (DARPA) is legendary for its innovation. As the research arm of the Department of Defense, it is responsible for early investments in computer networking, the Internet, virtual reality, and artificial intelligence. Several factors explain DARPA's success:

- The review process for funding technology is internal, lean and fast.
- It has a risk-taking culture, and it is idea-driven and outcome-oriented.
- Congress grants it significant money but remains relatively hands-off. The work is not constrained by earmarks or excessive scrutiny; this freedom fosters creativity.
- Its bottom-up governance focuses on hiring an eclectic, world-class managerial and technical staff.

The Advanced Research Projects Agency-Energy (ARPA-E) applies the same principles to the energy sector that have made DARPA successful in the defense sector. ARPA-E, a recommendation of the *Gathering Storm* report, was established by the Department of Energy. It focuses exclusively on high-risk, high-payoff technologies that can change the way energy is generated, stored, and used. Projects are selected for their potential to make rapid progress toward commercialization, and funds are not extended without demonstrable progress within two or three years.

ARPA-E is designed to follow DARPA's highly entrepreneurial approach to RD&D by funding scientists and technologists to accelerate immature energy technologies with exceptional potential. ARPA-E does not fund discovery science, nor does it

In ARPA-E's first year of operation, the agency only had funds to support 37 of the 3,700 proposals it received——just 1 percent.

support incremental improvements to current technologies. Its managers take a hands-on approach to managing the funded program activities. Authorized in 2007 without an initial budget, ARPA-E received stimulus funding of $400 million for two years over 2009 and 2010. For 2011, the Department of Energy has requested $300 million.

ARPA-E provides support for early-stage energy innovation. Administrators especially hope to receive proposals from companies, laboratories, and universities that have formed interdisciplinary partnerships. The amount of ARPA-E funding provided to a particular project can range from $500,000 to $10 million. In ARPA-E's first year of operation, the agency only had funds to support 37 of the 3,700 proposals it received—just 1 percent. The second round of awards funded less than 7 percent of applicants in just three focus areas—biofuels, carbon capture, and batteries for electric vehicles.

For example, ARPA-E is supporting Nalco Co. of Napierville, IL, to develop a new process to capture carbon in the smokestacks of coal-fired power plants, building on a partnership the company already has with Argonne National Laboratory. The objective of the project is to use less energy to capture 90 percent of a coal plant's CO_2 emissions at a lower cost. If successful, this new technology will cut carbon capture costs at coal-fired power plants by as much as half, making it more affordable for such plants to clean up their emissions.

ARPA-E is asking innovators to come up with truly novel ideas; it is looking for "game changers." The program has high potential for long-term success, but only if it is given the autonomy, budget, clear signals of support, and ability to implement needed projects. We believe a multi-year commitment at a $1 billion annual level would be well invested as a part of the recommended $16 billion total.

Norman R. Augustine

Retired Chairman and CEO, Lockheed Martin Corp.
Former Undersecretary of the Army

Among the more likely causes of future military conflicts are disruptions in the supply of energy and environmental change. The latter includes, but is not limited to, massive human migrations due to rising ocean levels, shortages of water and the emergence of arid regions no longer suitable for the production of food. As history has shown, desperate people take desperate measures, which can portend a highly unstable political/military situation on our planet.

Properly channeled, technology can present part of the answer to such a turbulent global circumstance by providing clean, affordable, sustainable and secure sources of energy. But this can only be accomplished by investing in research and development—particularly research and development that has high potential payoff but of the type that, unfortunately, is often accompanied by high risk. Endeavors of this type are generally unattractive investments for the private sector, yet clearly serve the public good. This is exactly the kind of effort for which government must step in and provide the needed financial investment.

This is particularly true in transitioning concepts with promising results but substantial remaining risk from the exploratory phase into the prototype phase—and eventually into the operational phase. The "gaps" inherent in this process are often referred to as the "Valley of Death," due to the difficulty of obtaining commercial funding—not to mention the technical challenges to be met.

One highly successful approach to bridging these gaps is the Department of Defense's Advanced Research Projects Agency (DARPA). It is there that such concepts as stealth and the Internet were spawned. The Department of Energy has now created a corresponding activity known as ARPA-E ("Energy"), which, if adequately funded promises disproportionately great returns.

One thing that is clear based upon my own career in industry and government is that when faced with major challenges of high technological content in a time of austerity, the last thing one should under-fund is R&D…to do so is the equivalent to removing an engine from an overloaded aircraft in order to reduce its weight.

THE PLAN: OUR RECOMMENDATIONS

Recommendation Five:

Establish and fund a New Energy Challenge Program to build large-scale pilot projects.

America's energy innovation ecosystem lacks a mechanism to build, test, and refine large-scale technologies.

Many technologies that need demonstration assistance are too big, expensive or risky to go forward by traditional means. A single nuclear plant, or a coal plant that captures and stores carbon, can cost several billion dollars. Large scale projects carrying significant technology risk, when combined with public resources, create high visibility and intense scrutiny—which in turn add the chance of political interference. Simply put, the United States does not have the capacity to rapidly demonstrate large-scale, capital-intensive energy technologies. The nation needs to fix these institutional challenges or it will not develop the large-scale energy options that our system so urgently needs.

We propose a new institution, the New Energy Challenge Program, to accelerate advanced energy technologies to commercial or near-commercial scale. This program would operate as a publicly owned, private corporation outside of the federal government, and it would report to the Energy Strategy Board. It would apply specifically to energy projects with large system sizes, and it would focus on the transition from pre-commercial, scalable energy systems to integrated, full size system tests. The New Energy Challenge Program would draw on a broad range of expert perspectives and a set of financial, technical and management tools, with two main tasks: 1) to create detailed technology commercialization roadmaps for priority technologies determined by the Energy Strategy Board, with the specific roadmaps to inform the National Energy Plan as well as particular demonstration projects; and (2) to commission, finance and build first-of-kind commercial scale advanced energy facilities.

Staff and funding

We recommend funding the New Energy Challenge Program with a single appropriation of $20 billion over 10 years. This commitment of resources, while decidedly large, should be weighed against the private sector investments it would unleash to transform our energy system over the next half century. The New Energy Challenge Program would leverage public resources to attract private capital and would participate in profits generated from successful activities. Private dollars would be committed on a per-project basis and individually negotiated once its strategic plan is established.

The New Energy Challenge Program would need strong support from the highest levels of industry and government. As discussed in Recommendation 1, it would employ a small management team and bring in top professionals from all relevant fields—scientists, engineers, financiers, risk managers, and the like. Much like DARPA, ARPA-E and other engines of innovation, the New Energy Challenge Program would explicitly not be a long-term career destination for its staff, but rather a place for the best and brightest professionals to interact with the most talented minds in the industry and work on high-priority national projects.

Structure and operations

The New Energy Challenge Program would have two areas of focus:

1. **Technology Assessment Working Groups** would be charged with developing and updating commercialization plans for the high priority technology arenas determined by the Energy Strategy Board. Modeled on the effective public-private technology collaboration that SEMATECH achieved in the semiconductor industry, this group would engage leaders from the relevant technology domains (e.g. advanced nuclear, CCS, wind, solar, etc.) and develop detailed technology development plans or roadmaps. The working groups would need a high degree of independence from industry lobbying, and political forces. Best-in-class analytical and research capabilities will be necessary. Within this structure, key activities would include:

- Assessing the long-term potential of various energy technologies, including price performance and scalability
- Developing roadmaps for the most promising options
- Engaging with international partners on their activities and identifying opportunities for collaboration

The Technology Assessment Working Groups would hire only a small core staff, supported by program teams recruited from industry, finance and academia and seconded by DOE offices, the national labs, and other federal government departments.

2. **The Technology Demonstration Initiative** would be the heart of the New Energy Challenge Program's effort. These Demonstration Initiatives would be set up to commission (through competitive proposals), fund, and facilitate the construction of the large-scale energy demonstration technologies identified by the Energy Strategy Board. These projects would be designed to test multiple technology pathways and move forward large-scale demonstrations of the most promising options. Discretion to undertake projects that are smaller or more pilot in nature would also be allowed to resolve important stumbling blocks. Other attributes of the Technology Demonstration Initiative would include:

- Each Initiative would be overseen by New Energy Challenge Program management, but program teams would have a great degree of decision-making autonomy.
- The programs must be designed to bring in private sector partners without inhibiting the sharing of relevant information to the public.
- Each Initiative would be authorized to pursue beneficial international cooperation.

In addition to these elements, The New Energy Challenge Program should have flexibility to employ a range of financial tools, but it would prioritize direct equity investments negotiated on a case-specific basis with private sector partners.This organization should have explicit support from the White House and Congress to freely seek independent partnership opportunities with other government agencies and with industry. Through its private-sector partners, the Technology Demonstration Initiative would offer project management services and technical resources to help accelerate and improve the design and construction of facilities. It would work to enable fast-track siting and construction opportunities within utilities or public power agencies (e.g., TVA), on federal or military lands, or even overseas through international partners in some cases.

The United States currently does not have the capacity to rapidly demonstrate large-scale, capital-intensive energy technologies.

FUNDING RD&D

There is no way to make the progress this country requires on energy technology without increasing RD&D budgets. The federal deficit means that it is very tough to find those funds. This section suggests methods to meet the challenge.

First and most important, we believe that underfunding RD&D is an exercise in gross fiscal irresponsibility. The oil embargoes of the 1970s caused recessions that cost this nation more than a trillion dollars—yet we invest tiny sums in reducing petroleum dependence. The country sends $1 billion overseas *every day* to purchase oil, but publicly funded research in advanced vehicles and alternative fuels totals just $680 million annually —about 16 hours worth of oil imports. Blackouts cost the economy over $1 billion each, yet the nation typically spends only $170 million per year on electricity delivery and reliability. We will not save money by starving ourselves of future options.

Second, we believe that energy innovation should be financed from within the energy system. Our recommendations would total just 1.5 percent of the U.S. energy bill. This is a healthy jump from today's levels, but is still about one-tenth as much, as a fraction of sales, as other high technology industries.

The energy system should finance its own innovation—for three reasons:

- It is good economics to peg investments to the systems that generate social costs.
- Funding RD&D from sales is the normal way to build new technologies. The costs are more a user fee than a tax.
- Investment success in RD&D will pay off through lower energy bills.

There are several options for financing this investment. When there is a system to reduce greenhouse gas emission in the United States, it will likely generate revenue—in the form of permit sales, for example. The first $16 billion of these greenhouse gas revenues should be devoted to RD&D—because new technologies will make it far cheaper to reduce emissions. This is a virtuous cycle.

The United States employs other user fees on the energy system today that could be expanded. Wires charges (a small fee on electricity sales) are a natural way to finance improvement in the electric sector, just as gasoline taxes pay for transportation infrastructure. Reducing today's subsidies to fossil fuel industries could also cover much of the distance.

The essential requirements, though, are that we make the basic investment, and that we commit these funds, steadily, over the long term.

MEASURING SUCCESS

Monitoring progress in stimulating energy innovation will be critical for adjusting to new conditions, making midcourse corrections, and maintaining accountability. Below we outline metrics to chart progress in the short, medium, and long term for each of our five recommendations.

America's energy innovation ecosystem lacks a mechanism to turn advanced ideas or prototypes into commercial-scale facilities.

Recommendation 1: Create an independent national Energy Strategy Board.

Short term: Have we convened the Energy Strategy Board? Is it appropriately independent and does it have access to capital?
Medium term: Has the Energy Strategy Board developed a National Energy Plan with concrete and measurable goals? Has it provided guidance to the New Energy Challenge Program to deploy large-scale pilot energy projects? Has the secretary of energy responded to the National Energy Plan? Has Congress reviewed the plan and begun to adjust policy accordingly? Has the energy innovation community responded to the Plan?
Long term: Has the Plan been updated to account for new technologies? Have the Plan's goals been met?

Recommendation 2: Invest $16 billion per year in clean energy innovation.

Short term: How much money is the nation investing in energy RD&D?
Medium term: Are investments driving down prices for the most critical energy technologies? Have the technologies met and passed performance gates?
Long term: Are key technologies being built and sold at a reasonable price? Are low-carbon technologies being deployed at sufficient scale?

Recommendation 3: Create Centers of Excellence with strong domain expertise.

Short term: How many Centers of Excellence have been created? How much funding are they receiving?
Medium term: What innovations have been pioneered by the Centers of Excellence? Are they using funds efficiently? Are the Centers catalyzing productive relations between government bodies, universities and the private sector?
Long term: Are technologies developed by the Centers for Excellence competitive in price and being deployed widely? Are the Centers the nucleation points for industry? Are they, in effect, new Research Triangles or Silicon Valleys for energy?

Recommendation 4: Fund ARPA-E at $1 billion per year.

Short term: How much funding is ARPA-E receiving? How many projects is it supporting?
Medium term: What innovations have been pioneered by ARPA-E? Is the project using funds efficiently?
Long term: Are technologies developed by ARPA-E competitive in price and being deployed widely?

Recommendation 5: Establish and fund a New Energy Challenge Program to build large-scale pilot projects.

Short term: Has a New Energy Challenge Program been established and funded? Does it have Congressional and White House support to operate nimbly and quickly? Has it successfully assembled a group of experts and launched a series of roadmaps? Has it brought in private sector resources to support its mission?
Medium term: Have the technology roadmaps successfully informed the National Energy Plan and the Technology Demonstration Initiatives? Are the initiated projects meeting cost, performance and schedule milestones? Has the NECP established international partnerships? Is the Program maintaining an appropriate risk profile?
Long term: Are there follow-on projects from the Program's first-of-kind projects? Has the organization maintained strong private sector participation and financial support? Are supported projects operating at capacity, generating clean power for the American economy and sequestering harmful greenhouse gases?

Chad Holliday

Former Chairman and CEO, DuPont
Chairman, Bank of America

The Montreal Protocol was an international treaty that worked: it saved the ozone layer from destruction. The crisis was real, the science was clear, and the culprit—in the form of fluorinated gases, called CFCs—was obvious.

We knew the world had to stop producing CFCs, and fast. DuPont was the world's leader in making these chemicals, so our business confronted a defining challenge. DuPont used this emergency to invent entire new businesses. We found substitutes for CFCs, and these new substitutes formed the core of a half-dozen new business lines. In fact, we beat every target we set.

The point is that a serious goal, supported by strong public policy, made our mission clear, and with a clear mission, American businesses can do just about anything. To be sure, our energy and climate challenges are far tougher than the ozone hole. But that makes it even more important to get going now, to create smart policies, and to let our businesses get to work. As with the ozone hole, time is of the essence. Our options for dealing with the climate challenge diminish every year—so let's get started.

The point is that a serious goal, supported by strong public policy, made our mission clear, and with a clear mission, American businesses can do just about anything.

CONCLUSION AND PAYOFF

Energy innovation is a commitment to long-term prosperity. If the United States invests in its clean energy future now, our nation can reap immense benefits. We have seen this work in other sectors, and it can work in energy. Public- and private-sector innovators have made miracles happen right here on home soil—Americans developed the computer and the Internet, delivered air and space travel and decoded the human genome. Standing on their shoulders, we can see a clean energy future within reach. By scaling the good technologies of today and discovering new technologies that do not yet exist, we have an opportunity to achieve a similar miracle in energy.

On the other hand, if we starve energy research, there is no doubt that this country will have constrained future options. The national energy system is almost unfathomably large, and it will take many decades for its sunk investments to turn over. Today's investment decisions on transportation systems, power plants, buildings, and factories have the effect of locking in long-term consequences for our economy, national security, and environment. There is vast room for improvement in our energy system.

The American way is to invent our future, to seize control of our destiny. In the energy realm, that means a step-function change in the way we innovate. As Americans, we all need to create new patterns in power, transportation, manufacturing, and housing that strengthen—rather than undermine—our national security and economic health.

The recommendations in this report are specific and affordable. They are not especially difficult, and they need not inspire a partisan battle. The recommendations reflect hundreds of years of private sector management experience, and the seasoned advice of scientists, academic leaders, government lab directors, and energy specialists.

We call upon the Congress and the president to act on these recommendations. We stand ready to help with further consultation, design, and implementation.

ENDNOTES

1. Figure Source: (1) National Science Foundation Data table 36. Federal research and development obligations, budget authority, and budget authority for basic research, by budget function: FY 1955–2009. http://www.nsf.gov/statistics/nsf08315/content.cfm?pub_id=3880&id=2
   (2) G.F. Nemet, D.M. Kammen, *U.S. energy research and development: Declining investment, increasing need, and the feasibility of expansion,* Energy Policy 35 (2007) 746–755.
   (3) Pharmaceutical Research and Manufacturers of America (PhRMA), Pharmaceutical Industry Profile 2008. Washington DC. http://www.phrma.org/files/attachments/2008%20Profile.pdf
   (4) National Science Foundation's Science and Engineering Indicators 2010, www.nsf.gov/statistics/seind10/pdf/c04.pdf
2. Martin, Dan. The PV Learning Curve: How Does it Compare with Semiconductors? SEMI, 2009. http://www.pvgroup.org/AboutPVGroup/ctr_029584
3. Figure Source: European Photovoltaic Industry Association and A.T. Kearny. SET for 2020. Published 2009. http://www.setfor2020.eu/
4. National Academies. Energy Research at DOE: Was it worth it? National Academy Press: Washington, DC. 2001.
   President's Council of Advisors on Science and Technology. Assessing the U.S. R&D Investment. October 16, 2002.
   United States Government Accountability Office. Department of Energy: Key Challenges Remain for Developing and Deploying Advanced Energy Technologies to Meet Future Needs. Report to Congressional Requesters, December 2006.
5. This program described in Recommendation 5.
6. The Clean Energy Deployment Administration (CEDA) is a proposed new public financial institution that would facilitate the deployment of advanced energy technologies into the marketplace. A bill authorizing this institution was passed in the House of Representatives and is currently pending in the Senate.
7. Figure sources: (1) Energy Technology RD&D 2009 Edition, International Energy Agency, http://wds.iea.org (2) The world fact book, Central Intelligence Agency, https://www.cia.gov/library/publications/the-world-factbook.(3) China Statistical Yearbook on Science and Technology, 2008.
8. Figure source: National Science Foundation Data table 36. Federal research and development obligations, budget authority, and budget authority for basic research, by budget function: FY 1955–2009 (adjusted to 2005 USD), http://www.nsf.gov/statistics/nsf08315/content.cfm?pub_id=3880&id=2. Note: The National Science Foundation estimate of public energy R&D spending is smaller than the DOE number reported in our model budget because the NSF uses a stricter definition for what constitutes energy R&D.
9. See http://www.americanenergyinnovation.org for these details.
10. Mowery, David C., Richard R. Nelson and Ben Martin. Technology Policy and Global Warming. National Endowment for Science, Technology, and the Arts. October 2009.
11. United States Senate. The Benefits of Medical Research and the Role of the NIH. May 2000.http://www.asbmb.org/uploadedFiles/Advocacy/Senate%20Report%20on%20the%20Benefits%20of%20Medical%20Research.pdf
12. Figure source: National Science Foundation Data table 36. Federal research and development obligations, budget authority, and budget authority for basic research, by budget function: FY 1955–2009 (adjusted to 2005 USD). http://www.nsf.gov/statistics/nsf08315/content.cfm?pub_id=3880&id=2.

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American Energy
Innovation Council

American Energy Innovation Council
(202) 480-9121
info@americanenergyinnovation.org