TESTIMONY OF JESSE D. JENKINS
DIRECTOR OF ENERGY AND CLIMATE POLICY
BREAKTHROUGH INSTITUTE

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES
UNITED STATES SENATE

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Chairman Bingaman, Ranking Member Murkowski, distinguished members of the Committee, I thank you for the opportunity to appear before you today to discuss the role of the government in the process of energy innovation. It is an honor and a privilege to speak with you on a topic so critical to the nation's energy, economic, and environmental future.

I am the Director of the Energy and Climate Program at the Breakthrough Institute, an independent public policy research institute in Oakland, California (see http://thebreakthrough.org/energy.shtml). The Breakthrough Institute is non-partisan and accepts only charitable contributions from individuals and foundations without a direct economic interest in our research and analysis. The Institute's Energy and Climate Program focuses centrally on identifying and advancing the optimal policies to accelerate innovation to ensure that advanced energy technologies become affordable, reliable, and scalable. This objective is essential to securely and sustainably fueling the national economy, improving public health and environmental outcomes, and ensuring U.S. technological leadership in the multi-trillion dollar global energy markets of the 21st century.

I am here today to share key findings and recommendations derived from several recent reports and analyses published by the Breakthrough Institute, as this Committee takes a hard look at identifying a limited and direct role for the government in accelerating advanced energy innovation.

Government Policy Buoys Recent Advanced Energy Industry Progress

Driven by private innovation and entrepreneurship as well as critical public sector support in the form of tax credits, grants, and loan guarantees, several advanced energy technology segments (often referred to collectively as "clean tech") have grown robustly in recent years while making progress on cost and performance.[1]

Electricity generation from renewable sources (excluding hydropower) doubled from 2006 to 2011.[2] Construction is now under way on the nation's first new nuclear power plants in decades. And American manufacturers are regaining market share in advanced batteries and vehicles.[3] Private sector investment in U.S. clean tech sectors (excluding nuclear energy) grew 42 percent to $48 billion in 2011, the first year the United States has commanded the lead in global clean tech investing since 2008.[4] Meanwhile, employment across advanced energy sectors expanded by almost 12 percent from 2007 to 2010, adding more than 70,000 jobs even as overall U.S. employment stagnated during the height of the recession.[5]

Perhaps a more important measure of technological and industry maturation is that prices for solar, wind, and other advanced energy technologies fell in recent years, moving these technologies closer to cost competitiveness with conventional energy technologies. The global average cost of solar installations fell more than 50 percent between 2007 and 2011, while wind turbine costs fell 27

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[1] Advanced energy technology or "clean tech" industry segments are defined variously. Unless otherwise noted, this testimony refers to the following industry segments when discussing advanced energy technology or clean tech sectors: solar, wind, geothermal, biomass, and nuclear power technologies; fuel cells; combined heat and power (CHP); energy efficient technologies, appliances, and building practices; smart grid; carbon capture and sequestration (CCS); alternative fuels (alcohol fuels, biofuels, biodiesel); advanced batteries; hybrid and electric vehicles; and high speed rail.

[2] Non-hydro U.S. renewable electricity generation increased from 96 million megawatt-hours in 2006 to 195 million megawatt-hours in 2011. See: U.S. Energy Information Administration, "Electric Power Monthly," March 27, 2012, http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_1. Accessed April 4, 2012.

[3] Up from 2 percent in 2008, the United States is expected to make up 40 percent of the market for advanced batteries by 2014. See: "Transforming America's Transportation Sector: Batteries and Electric Vehicles," U.S. Department of Energy, July 2010.

[4] Investment figures include the following sectors: renewable energy, biofuels, energy efficiency, smart grid, energy storage, advanced transportation, carbon capture and storage, and clean energy services. See: "Who's Winning the Clean Energy Race? 2011 Edition," Pew Charitable Trusts, April 2012.

[5] Employment grew by a total of 71,633 jobs from 2007 to 2010 in the following sectors: renewable energy, nuclear energy, carbon storage and management, fuel cells, energy efficiency (including buildings, lighting, and consumer products and appliances), smart grid, and electric vehicle technologies and advanced vehicle batteries. See: Mark Muro, Jonathan Rothwell, and Devashree Saha, "Sizing the Clean Economy: A National and Regional Green Jobs Assessment," Brookings Institution and Battelle Technology Partnership Practice, 2011.

percent from 2008 to 2011.[6] The price of lithium-ion batteries used in electric vehicles also fell 30 percent since 2009 and dropped by 14 percent last year alone.[7] Finally, the cost of advanced "drop-in" biofuel replacements for petroleum-based military fuels (jet fuel, etc.) declined 82 percent from 2009 to 2011, as procurement by the U.S. Navy catalyzed a 10-fold increase in demand for these advanced fuels.[8]

The role of government policy has been crucial to recent advanced energy industry growth and progress. Advanced energy technology segments, from renewable and nuclear power plants to alternative transportation technologies and fuels, receive a variety of federal incentives, including direct grants, tax credits, financing guarantees, and other subsidy programs. Similarly, nearly all clean energy research and development benefits from some form of federal support. These federal incentives help clean energy segments gain a foothold in energy markets by overcoming the higher costs or risks these nascent technologies currently face relative to highly mature fossil fuels or vehicle technologies. We should acknowledge that this federal support is by no means unique to today's advanced energy sectors. Conventional fossil energy sources have enjoyed substantial public R&D funding, favorable tax and regulatory treatment, and production subsidies ongoing to this day.[9]

The recent growth of advanced energy sectors is due in large part to a parallel increase in federal investment via this range of public policy mechanisms. Cumulative federal support for advanced energy technology sectors totaled an estimated $44 billion over the 2002-2008 period.[10] That level compares to a cumulative $150 billion invested between 2009-2014 (see Figure 1), according to an original analysis of 92 distinct federal programs supporting advanced energy/clean tech sectors conducted by the Breakthrough Institute and published as the April 2012 report, "Beyond Boom

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[6] For solar cost trends, see: Ron Pernick, Clint Wilder, and Trevor Winnie, "Clean Energy Trends 2012," Clean Edge, March 2012. For wind cost trends, see: Mark Bolinger and Ryan Wiser, "Understanding Trends in Wind Turbine Prices Over the Past Decade," Lawrence Berkeley National Laboratory, October 2011.

[7] Justin Doom, "Battery Prices for Electric Vehicles Fall 14%, BNEF Says," *Bloomberg*, April 16, 2012.

[8] Breakthrough Institute analysis of data provided by the Office of the U.S. Secretary of the Navy, May 2012.

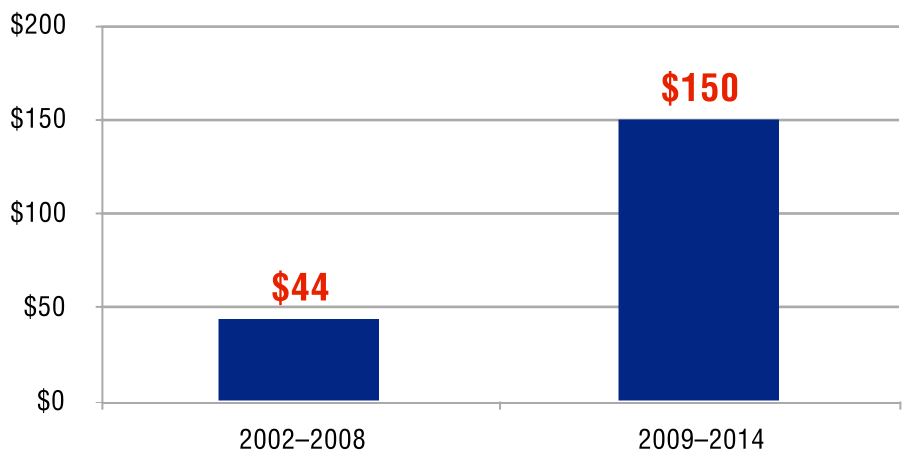
[9] See: "60 Years of Energy Incentives: Analysis of Federal Expenditures for Energy Development," Management Information Services Inc, October 2011; and Nancy Pfund and Ben Healey, "What Would Jefferson Do: The Historic Role of Federal Subsidies in Shaping America's Energy Future," DBL Investors, September 2011.

[10] Figure derived from "Estimating U.S. Government Subsidies to Energy Sources: 2002-2008," Environmental Law Institute, 2009 with RD&D data added from Information Technology and Innovation Foundation, "The Energy Innovation Tracker," www.energyinnovation.U.S. Accessed April 4, 2012.

and Bust: Putting Clean Tech on a Path to Subsidy Independence."[11] Furthermore, we estimate these initial public expenditures will leverage an overall cumulative public and private sector investment of $327 billion to $622 billion in U.S. advanced energy sectors from 2009-2014.

Figure 1

Cumulative Federal Spending on Clean Tech by Period (billions)



Source: "Beyond Boom and Bust."

From Clean Tech Boom to Federal Spending Bust

Despite recent cost declines, nearly all advanced energy sectors currently rely on public policy support and subsidy to gain an expanding foothold in well-established energy markets. That support is now poised to decline precipitously, presenting new challenges and raising the possibility of market turmoil ahead for several U.S. clean tech markets.

In summary, our research finds that annual federal clean tech spending peaked in 2009 at $44.3 billion and has already declined steadily through 2011 to $30.7 billion. Yet the sharpest reductions in federal support for these advanced energy sectors are still ahead: absent Congressional action, total federal clean tech expenditures will be cut nearly in half from 2011 to 2012 and will fall to just one-quarter of 2009 levels by 2014 (see Figure 2).

In the absence of legislative action to extend or replace current subsidies, America's system of policy support for nascent advanced energy sectors will have been largely dismantled by the end of

[11] The report was authored by Jesse Jenkins, Ted Nordhaus, Michael Shellenberger, and Alex Trembath of the Breakthrough Institute along with Mark Muro of the Brookings Institution and Letha Tawney of the World Resources Institute. See: http://thebreakthrough.org/blog/Beyond_Boom_and_Bust.pdf

2014, a casualty of the scheduled expiration of 70 percent of all federal clean tech policies. Examples of expired or soon to expire policies include:

- The Section 48C tax credit for manufacturers of advanced energy technologies and components (volumetric cap reached as of January 2010).
- The Section 1705 DOE Loan Guarantee Program for advanced energy technologies (expired September 2011).
- The Section 1603 Treasury Grants for renewable electricity projects (expired end of 2011).
- The Volumetric Ethanol Excise Tax Credit (expired end of 2011).
- The Production Tax Credit (PTC) enjoyed by wind power and other renewable electricity sources (expires at the end of 2012 for wind and at the end of 2013 for other technologies).
- A total of $51 billion in temporary clean energy expenditures under programs created or expanded by the Recovery Act (note that this total includes the Section 48C, 1705, and 1603 programs noted above).

Furthermore, many of the remaining programs will end shortly after 2014. The solar industry, for example, will be left with just two more years before the 30 percent federal Investment Tax Credit (ITC) buoying solar markets expires at the end of 2016. The only other ongoing programs left after 2014 include the nation's underfunded energy RD&D programs and a handful of tax credits and grant programs for energy efficiency and conservation.[12]

This impending mass-expiration of federal policy support comes at a time of corresponding subsidy declines in many European markets as well as heightened competition from both foreign clean tech manufacturers and record-low prices for natural gas — the chief domestic competitor to many clean electricity generation technologies, from wind and solar to nuclear power. Without action, the combination of these forces could see recent years of clean tech boom go bust – with significant effects to the economy and American competitiveness – and they will certainly present new challenges and headwinds for advanced energy sectors in the years ahead.

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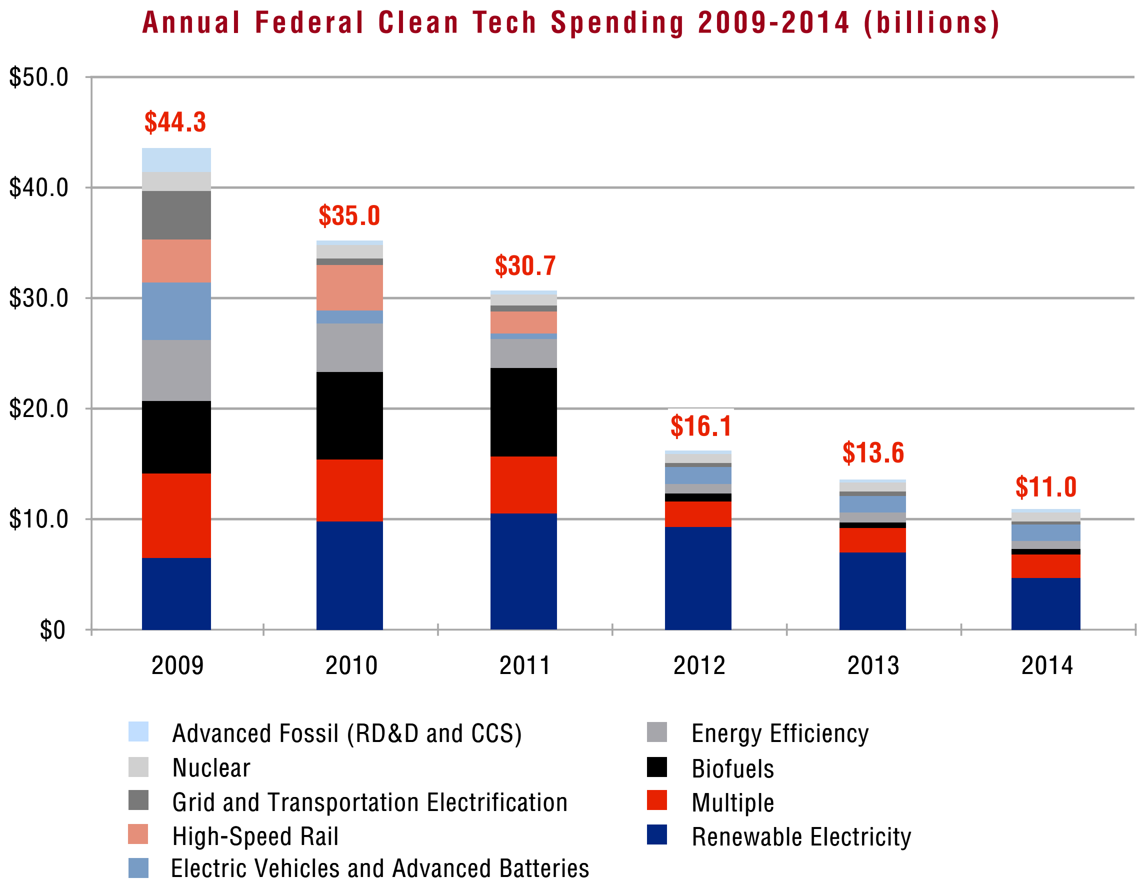
[12] See "Beyond Boom and Bust" for more detailed analysis of federal clean tech expenditures and programs.

Figure 2



Source: "Beyond Boom and Bust."

Federal Funding Cliff and Cheap Gas Challenge Advanced Energy Segments

The expiration of key federal programs, including the Section 1603 renewable energy grant program and other ARRA-created programs, has already begun to impact advanced energy technology markets and investments. Furthermore, the scheduled expiration of other programs, including the wind PTC at the end of 2012 and the broader collapse in funding scheduled to unfold by 2014, are all well within the time horizon relevant to investment decisions being made today by advanced energy firms and financiers.

This policy uncertainty is thus already having a chilling effect on private sector investment in advanced energy sectors. After setting a record in 2011, global clean tech investment plunged in the first quarter of 2012, diving to the lowest levels since the depths of the global recession in 2009.[13]

With virtually all advanced energy segments dependent in one way or another on policy support, how this emerging industry will weather this policy collapse remains to be seen. Market impacts will certainly vary by industry segment, and "Beyond Boom and Bust" closely examines the outlook for wind, solar, and nuclear power, as well as corn and cellulosic biofuels, and plug-in hybrid/electric vehicles and advanced batteries.

To summarize our findings, we conclude that clean electricity sources competing directly with gas-fired power plants may face the most severe economic challenges, as low natural gas prices coincide with declining federal incentives (see Figure 3). Below I discuss the outlook for wind, nuclear, and solar markets.

WIND POWER

Absent subsidy, the levelized cost of electricity from wind power facilities is now competitive with combined-cycle natural gas-fired power plants only at locations with the best wind speeds and ready access to existing transmission capacity. The PTC thus remains critical to ensure wind power is cost competitive and can expand in a broad range of locations. If the PTC expires without any replacement, market analysts expect annual wind energy installations to contract by as much as 85 percent from a projected peak of 8-10.5 gigawatts (GW) in 2012 to just 1.5-2 GW in 2013.[14]

NUCLEAR POWER

Given the expected construction costs of the two new nuclear reactors under construction by Georgia Power at Plant Vogtle, the levelized cost of electricity from new nuclear reactors may fall in the range of $95-130 per MWh, assuming amortization of capital costs over a 30-year period.

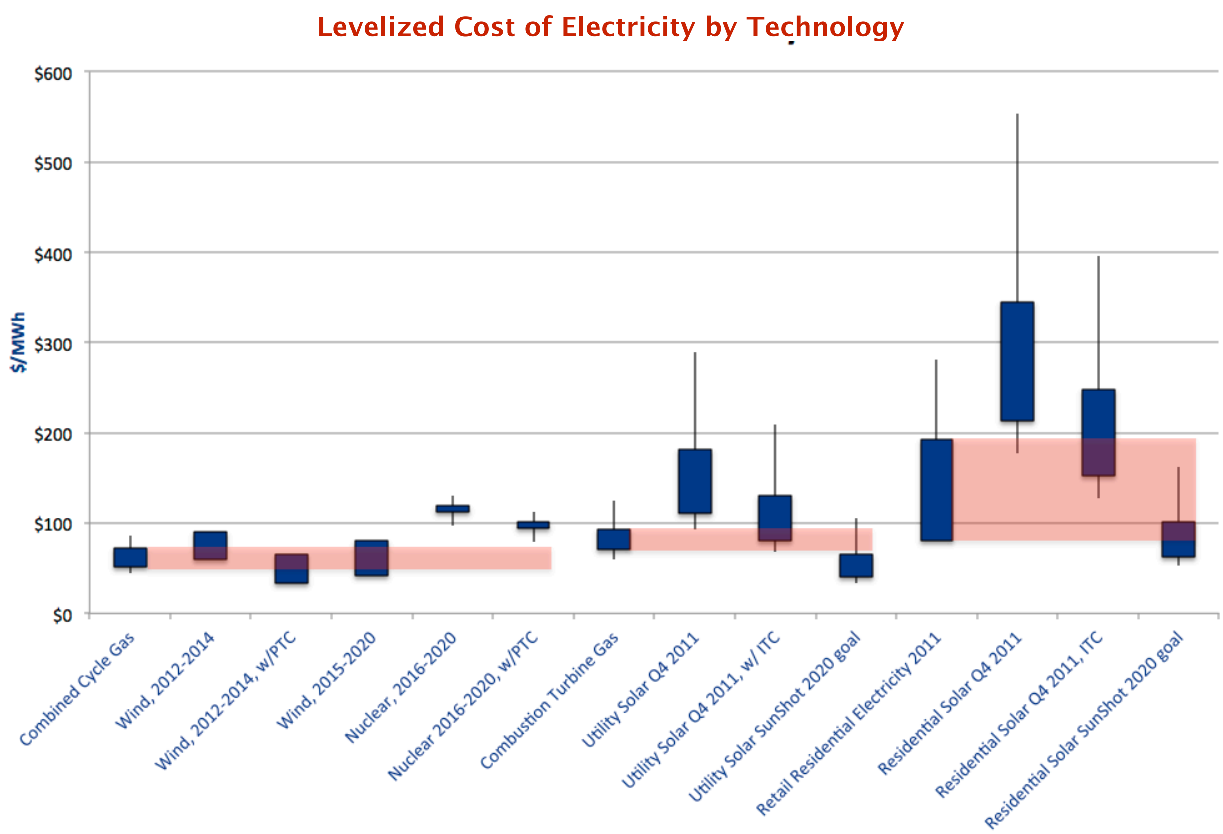
While financial incentives offered by the Energy Policy Act of 2005 will help reduce these costs somewhat for the first 6 GW of new nuclear builds, these unsubsidized cost estimates are roughly

[13] "Q1 2012 clean energy investment squeezed by policy uncertainty," Bloomberg New Energy Finance, April 12, 2012, http://www.bnef.com/PressReleases/view/208, accessed May 16, 2012.

[14] Felicity Carus, "Wind Rush: U.S. Industry Hurdles Towards a Cliff Without Production Tax Credit," AOL Energy, November 14 2011; "Impact of the Production Tax Credit on the U.S. Wind Market," Navigant Consulting, December 2011.

twice the current costs of electricity from new combined-cycle gas-fired plants, significantly dampening the interest of investors and utilities for new reactor construction. It is worth noting however, that the levelized cost of electricity from nuclear power plants is very sensitive to the cost of financing. Furthermore, the new AP1000 reactors under construction at Vogtle are designed to operate for 60 years and may operate well into the 2080s if not beyond. Comparisons of such long-lived assets to the cost of gas-fired power plants at current gas prices thus unfairly value the longevity and price predictability of new nuclear power plants.

Figure 3

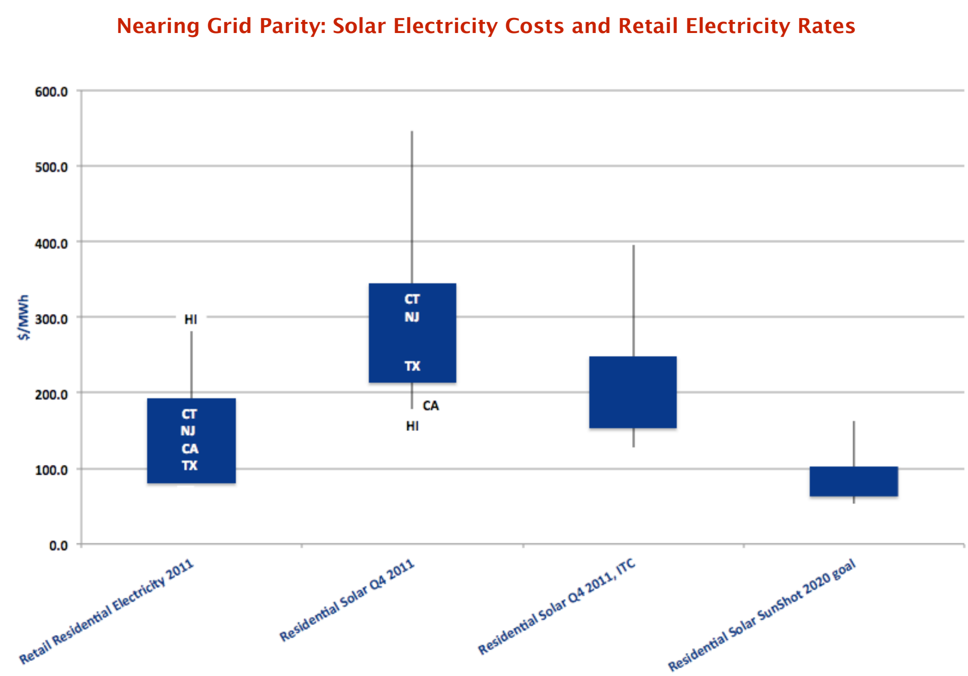


Source: "Gas Boom Poses Challenges for Renewables and Nuclear." Red bars indicate the price ranges clean electricity sources compete most closely with. Costs for gas-fired generation correspond to fuel costs ranging from $3-6 per million BTUs, with outliers ranging from $2-8 per million BTUs.

SOLAR POWER

Finally, solar panels installed on residential and commercial rooftops do not have to compete directly with the wholesale cost of power from natural gas-fired plants. Given much higher retail electricity rates, more long-term federal incentives, and additional aid in several states, the outlook for solar power may be stronger. After significant recent cost reductions, rooftop solar installations on residential or commercial buildings have now reached unsubsidized prices that are competitive with retail electricity rates in Hawaii, where average residential electricity prices are quite high. Depending on the pace of innovation and cost reductions, rooftop solar is also within range of cost parity in certain U.S. retail markets with high average electricity prices and/or high solar irradiance, including California, Texas, Florida, and Nevada. Solar is approaching retail cost parity in a set of Northeastern states as well (Connecticut, New York, New Hampshire, and New Jersey), where retail rates exceed $160 per MWh and solar irradiance is modestly high (see Figure 4). The federal ITC for solar currently combines with numerous state and local inventive programs to open up wider opportunities for solar in select markets.

Figure 4



Source: "Gas Boom Poses Challenges for Renewables and Nuclear." State residential electricity prices are from EIA data. Estimates for state solar energy costs are approximations based on an index of residential electricity rates, average solar irradiance, and maximum capacity factors.

Large, utility-scale solar power plants must compete more directly with gas-fired generating units in wholesale power markets. While utility-scale solar installations typically achieve lower costs than rooftop installations due to greater economies of scale, solar power remains more costly (absent subsidies) than new gas-fired generation in wholesale power markets, except perhaps in regions with the highest solar resource (see Figure 3). Utility-scale solar installations thus currently rely on the federal ITC and other state incentives to be competitive in most U.S. markets.

Further Cost Reductions Key to Moving Clean Tech Beyond Boom and Bust

This is not the first time booming clean tech markets in America have been on the brink of a bust. U.S. markets for clean tech segments from wind, nuclear, and solar power to electric vehicles and alternative fuels have each surged and declined in the past. While a drawdown of federal subsidies is most often the immediate trigger of clean tech market turmoil, the root cause remains the same each time: the higher cost and risk of U.S. advanced energy technologies relative to either mature fossil energy technologies or lower-cost international competitors, which make U.S. clean tech sectors dependent on subsidy and policy support.

New industry sectors are often volatile, as innovative technology firms must challenge both established incumbents and competing upstarts. Advanced energy technologies are no exception.

Yet in energy, unlike biotechnology or information technology, price is king. Like steel or copper, energy is a commodity, principally valued not for its own qualities but for the services and products derived from it. As such, while new drugs, software, or consumer electronics command a price premium from customers by offering new value-added features, new energy technologies must routinely compete on price alone, even if they offer other long-term benefits.[15] It would be a difficult feat for any nascent technology to enter a commodity market and compete immediately on cost, but clean tech sectors face a particularly challenging rival: well-entrenched fossil fuel incumbents that have had more than a century to develop their supply chains – aided by government subsidies and support – and make incremental innovations to achieve high levels of efficiency.

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[15] For more on the challenges facing nascent advanced energy sectors, see: "Bridging the Clean Energy Valleys of Death." Full citation in references at end of this testimony. See also: Richard Lester and David Hart, *Unlocking Energy Innovation: How America Can Build a Low-Cost, Low-Carbon Energy System* (Cambridge: MIT Press 2011); Karsten Neuhoff, "Large-scale Deployment of Renewables for Electricity Generation," *Oxford Review of Economic Policy,* Vol 21, No 1, 2005.

The immediate cessation of advanced energy subsidies would not be in the national interest. These advanced energy sectors are still emerging and maturing and must compete against well-entrenched fossil energy sources. Supporting the development of a new portfolio of cost-competitive, scalable advanced energy technologies offers substantial opportunities for enhanced American energy security, economic growth, new technology exports, and improved public health. But this process *will* take time. Policy continuity, which provides assurance to the market and attracts private investment, is thus critical.

Fortunately, energy technology experts at the International Energy Agency point to numerous remaining technical opportunities to achieve significant cost reductions and performance improvements across a range of advanced energy technologies, from wind and solar power to enhanced geothermal energy systems, advanced nuclear designs, and improved vehicle technologies and fuels.[16] If costs continue to fall over the next several years, for example, rooftop solar PV installations will become fully cost competitive without subsidy in a growing number of retail electricity markets. Line-of-site innovations and improvements in both PV module and non-module costs could also bring utility-scale solar costs down to $40-102 per MWh by the end of the decade, making solar power subsidy independent in wholesale markets across much of the United States.[17] Analysts similarly project incremental turbine technology improvements have the potential to decrease wind energy costs by 10-30 percent in the 2015-2020 period, bringing the unsubsidized levelized cost into the $42-67 per MWh range and making wind power broadly competitive in that time frame.[18]

Full cost competitiveness with fossil fuels should be achievable in the near- to medium-term for a variety of advanced energy technologies. The steady process of innovation is the key.

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[16] See: *Energy Technology Perspectives 2010,* International Energy Agency, 2010.

[17] See: "Gas Boom Poses Challenges for Renewables and Nuclear." Full citation in references at end of this testimony. See also: D.M. Powell, et al., "Crystalline silicon photovoltaics: a cost framework for determining technology pathways to reach baseload electricity costs," *Energy & Environmental Science*, 2012, 5, 5874; and "SunShot Vision Study," United States Department of Energy SunShot Initiative, February 2012.

[18] See: "Gas Boom Poses Challenges for Renewables and Nuclear." See also: Ryan Wiser et al., "Wind Energy," in *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation,* 2011, Cambridge University Press; and "2010 Wind Technologies Market Report," U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, July 2011.

As with prior energy innovations from gas turbines and nuclear reactors to shale gas extraction techniques,[19] sustained government policies will be critical to support private entrepreneurs and firms in driving further cost reductions and moving today's advanced energy technologies towards full maturity.

At the same time, the reality is that until technological innovation and cost declines can secure independence from ongoing subsidy, advanced energy technologies will remain continually imperiled by the threat of subsidy expiration and political uncertainty. Meanwhile, public tolerance for significant energy subsidies or the internalization of higher prices for energy is limited. If nascent energy technologies scale up without corresponding declines in price, this limited tolerance will eventually be expended, leading to another market bust. This means that the simple, perpetual extension of today's advanced energy subsidies and policies, with its passive approach to innovation, does not offer a sustainable path beyond a cycle of clean tech boom and bust.

The time has come then to craft a new energy policy framework specifically designed to accelerate technology improvements and cost reductions in advanced energy sectors, ensure scarce public resources are used wisely to drive technologies towards subsidy independence as soon as possible, and continue the growth and maturation of America's advanced energy industries.

With the U.S. advanced energy policy system set to be effectively wiped clean in the coming years, the time for smart reform is now, and this Committee will no doubt play a leading role in such efforts.

To these ends, my colleagues and I recommend policy reform on two critical fronts, detailed in "Beyond Boom and Bust" and summarized in the sections below.

I. Reform Advanced Energy Deployment Subsidies to Reward Technology Improvement and Cost Declines

Expiring policies and programs are poised to wipe away the large bulk of today's advanced energy deployment regime. This creates a clear and urgent need for policy reforms that sustain market opportunities for advanced energy technologies, more effectively deploy limited public resources, and support innovative entrepreneurs and firms.

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[19] See: "Where Good Technologies Come From" and "Where the Shale Gas Revolution Came From." Full citation in references at end of this testimony.

Whatever form it takes, a new suite of advanced energy deployment policies must simultaneously drive market demand *and* continual innovation.

By and large, today's energy subsidies do not do enough to support America's innovators, and they have not yet succeeded in driving down the costs of advanced energy technologies far enough to compete with conventional fuels. For example:

- *Many of today's clean energy subsidies are focused primarily on supporting the deployment of existing energy technologies at current prices, and most provide no clear pathway to subsidy independence.* The federal renewable electricity PTC, for example, has provided the same level of subsidy to wind power since initial enactment in 1992. Subsidy levels increase each year at the rate of inflation, keeping per MWh subsidy levels constant in real dollar terms and providing no clear incentive for continual cost declines or pathway to eventual subsidy independence.

- *If not designed with care, deployment policies can also lock out more promising but higher risk technologies from markets, slowing their development.* This is a challenge in particular for the renewable portfolio standard and clean energy standard policies given serious consideration by this Committee. These policies typically encourage deployment of the lowest-cost qualifying energy technology available—generally wind power or biomass, or in the case of a proposed CES, natural gas-fired plants. Yet if designed in this manner, RPS or CES policies may do little to drive down the price of other advanced energy technologies, such as solar or advanced nuclear reactor designs, that may have higher costs now but hold the potential to become much cheaper in the long-run.

- *Intermittent and haphazard policy support can also wreak havoc with the business confidence necessary for the long-term investments required to develop new and improved products*. The PTC for wind power, for example, was first enacted in 1992, but has since expired three times, and has been renewed a total of seven times, often with less than a month to spare before pending expiration. Other clean tech subsidies, including key tax credits for solar, biofuels, energy efficient products, and other segments have experienced similarly erratic expirations. The market effects are chilling, and many private firms are forced to focus principally on ramping-up production for subsidized markets while they last, rather than pioneering next-generation designs and manufacturing processes for the long-term. The intermittent nature of many advanced energy support policies thus slows the pace of innovation in these sectors and actually prolongs the amount of time these sectors remain reliant on public subsidy.

The United States can do better than this. Deployment subsidies and policies should be reformed and designed from the beginning to better support innovative U.S. firms and reward companies for developing, producing, and improving advanced technologies that can ultimately compete on price with both fossil fuels and international competitors alike. Each dollar of federal support today should be optimized to move maturing advanced energy technology sectors towards eventual subsidy independence as soon as possible.

Recognizing that investment horizons, technology development cycles, and market conditions vary across advanced energy technology segments, precise policy mechanisms will likely differ from sector to sector. Yet whether through production or investment subsidies, consumer rebates, market-creating regulations or standards, or other market incentives, we recommend that any advanced energy deployment subsidies meet the following policy design criteria. Reformed policies should:

1. ESTABLISH A COMPETITIVE MARKET.
   Deployment policies should create market opportunities for advanced clean energy technologies while fostering competition between technology firms.
2. DRIVE COST REDUCTIONS AND PERFORMANCE IMPROVEMENTS.
   Deployment policies should create market incentives and structures that demand and reward continual improvement in technology performance and cost.
3. PROVIDE TARGETED AND TEMPORARY SUPPORT FOR MATURING TECHNOLOGIES.
   Deployment policies must not operate in perpetuity, but rather should be terminated if technology segments either fail to improve in price and performance or become competitive without subsidy.
4. REDUCE SUBSIDY LEVELS IN RESPONSE TO CHANGING TECHNOLOGY COSTS. Deployment incentives should decline as technologies improve in price and performance to both conserve limited taxpayer and consumer resources and provide clear incentives for continued technology improvement.
5. AVOID TECHNOLOGY LOCK-OUT AND PROMOTE A DIVERSE ENERGY PORTFOLIO.
   Deployment incentives should be structured to create market opportunities for energy

technologies at different levels of maturity, including new market entrants, to ensure that each has a chance to mature while allowing technologies of similar maturity levels to compete amongst themselves.

6. PROVIDE SUFFICIENT BUSINESS CERTAINTY.
   While deployment incentives should be temporary, they must still provide sufficient certainty to support key business decisions by private firms and investors.
7. MAXIMIZE THE IMPACT OF TAXPAYER RESOURCES AND PROVIDE READY ACCESS TO AFFORDABLE PRIVATE CAPITAL.
   Deployment incentives should be designed to avoid creating unnecessarily high transaction costs while opening up clean tech investment to broader private capital markets.

Several policies could be structured to meet these criteria, including:

- *Competitive deployment incentives* could be created for various clean tech segments of similar maturity, with incentives for each segment falling steadily over time to demand and reward continual innovation and price improvements.[20]
- *Steadily improving performance-based standards* could create both market demand and spur consistent technology improvement.[21]
- "*Top-runner" programs* competitively establish performance standards or financial incentive levels based on the leading industry performers in each market segment, forcing other firms to steadily innovate to stay competitive in the market.[22]

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[20] See "Post-Partisan Power," page 22-23. Full citation in references at end of this testimony.

[21] Corporate Average Fuel Economy standards (CAFE) for passenger and freight vehicles or Emissions Performance Standards for new power plants each demand progressively improved technology performance. Similar standards could be designed to drive improvements in key factors determining technology costs or performance, such as the electric conversion efficiency of power plants.

[22] Japan's "top-runner" or "front-runner" energy efficiency program, for example, sets minimum standards for the energy efficiency of a variety of appliances, personal and freight vehicles, and lighting technologies. These standards are automatically revised on a periodic basis with new performance standards set based on the real performance of the most efficient products the market in each technology segment. Market leaders thus set the bar for the next performance standard, and competing firms must improve their technology performance to keep pace, driving market competition, innovation, and steady improvement in performance across each technology segment. See "Top Runner Program: Developing the World's Best Energy-Efficient Appliances," Ministry of Economy, Trade, and Industry of Japan, March 2010.

Environmental and air quality regulations requiring the implementation of "best available control technology" (i.e. certain New Source Review regulations implementing the Clean Air Act) operate on similar principles as well, requiring steady improvement in performance as available technologies improve.

- *Demanding federal procurement opportunities* could be created to drive both market opportunities and ensure steady improvement of each successive generation of product, particularly when advanced energy technology products align with strategic military needs.[23]
- *Reverse auction incentives* could be established for varying technologies to drive industry competition and innovation.[24]

If structured to adhere to these criteria, a new era of advanced energy deployment policies will neither select "winners and losers" *a priori,* nor create permanently subsidized industries. Rather, these policies will provide opportunity for all emerging advanced energy technologies to demonstrate progress in price and performance, foster competitive markets within a diverse energy portfolio, and put these segments on track to full subsidy independence.

II. Strengthen the National Energy Innovation System

Subsidy reform by itself will not be sufficient to drive the needed technology innovation and subsequent adoption of affordable advanced energy technologies. For that reason, energy policy reform to secure an internationally competitive, subsidy-independent advanced energy technology sector must harness America's strengths as an innovator.

The United States is home to world-class universities, generations of trained scientists and engineers, potent centers of entrepreneurship, finance, and advanced manufacturing, and a creative culture capable of attracting talent from around the world. Yet when it comes to energy, America's

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[23] See "Post-Partisan Power," page 23-24. See also: Daniel Sarewitz and Sam Thernstrom, "Energy Innovation at the Department of Defense: Assessing the Opportunities," Consortium for Science, Policy, and Outcomes and Clean Air Task Force, March 2012.

[24] Reverse auction programs are now in place in California for utility procurement of rooftop solar power installations and have been used in India and China to determine accurate market prices for later feed-in tariff subsidies. These programs provide strong incentive for market competition and reward firms who set the bar for price and performance with expanded market opportunities. The reverse auction mechanism for solar in California have secured record low contract prices. See: "Update to RAM Contract – 145 MW Total," Vote Solar Initiative," http://votesolar.org/2012/04/update-to-ram-contracts-145-mw-total/, accessed May 16, 2012.

For Congressional proposals establishing reverse auction mechanisms, see: H.R.909 (112th Congress), "A Roadmap for America's Energy Future," Title III, "Reverse Auction Mechanism for Renewable Energy Generation and for Renewable Fuel Production," sponsored by Representative Devin Nunes (R-CA-21); S.3434 (111th Congress), "Practical Energy and Climate Plan," Title I, Subtitle B, Sec. 111, "Production Incentives for Renewable Fuels," sponsored by Senator Richard Lugar (R-ID).

innovation system falls short.[25] Policy makers must strengthen the U.S. energy innovation system to catalyze advanced energy breakthroughs and support continual technology improvement.

Along with the key reforms to deployment policies discussed above, the nation should pursue policy reform along three additional fronts:

STEADILY INCREASE INVESTMENT IN RD&D WHILE REFORMING AND STRENGTHENING THE U.S. ENERGY INNOVATION SYSTEM

Stepped up investment in energy RD&D is sorely needed to both invent new technologies and improve the cost and performance of existing ones to make them more competitive with conventional energy sources. Yet neither the private nor the public sector currently invests the resources required to accelerate energy innovation and drive down the cost of advanced energy technologies.

Multiple barriers prevent firms from adequately investing in the development of new, high-risk energy technologies. These include: knowledge spillover risks from private investment in research; the commodity nature of most energy markets, which prevent nascent, higher cost energy technologies from charging a premium; inherent technology and policy risks in energy markets; the financial scale and long time horizon of many clean energy projects; and a lack of wide-spread enabling infrastructure. As a result of these and other barriers, U.S. energy firms reinvest well below one percent of revenues in RD&D. This stands in stark contrast to firms in the information technology, semiconductor, and pharmaceuticals sectors, which typically reinvest 15 to 20 percent of their revenue in RD&D and new product development.[26]

This private sector gap is due in part to an analogous one in the public sector. Federal energy RD&D spending has stood in the $4-6 billion range in recent years.[27] By contrast, the United States invests almost $19 billion per year in the National Aeronautic and Space Administration (NASA) and $33.5 billion each year into health research (primarily through the National Institutes of Health), while defense related R&D now approaches $80 billion annually. At 10 percent of total economic activity,

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[25] See: "Post-Partisan Power," pages 13-16.

[26] See: "Bridging the Clean Energy Valleys of Death," pages 7-10. Full citation in references at the end of this testimony.

[27] See: "Energy Innovation Tracker," http://energyinnovation.us, Information Technology and Innovation Foundation.

the vast size and critical importance of the energy sector to the U.S. economy and national security calls for investments in advanced energy innovation of a similar order of magnitude.

As such, a broad consensus has emerged among energy sector analysts — including the business leaders of the American Energy Innovation Council, the members of the Presidential Council of Advisors on Science and Technology, and a set of think tanks with diverse ideological backgrounds[28] — that **energy RD&D investment should roughly triple** over time to at least $15 billion annually.

At the same time, **America's energy innovation system must also be modernized** to leverage regional innovation opportunities and strengthen new institutional models at the federal level. Examples of recent institutional innovations at DOE include the creation of the Energy Frontier Research Centers (EFRCs), the Advanced Research Projects Agency-Energy (ARPA-E), and the Energy Innovation Hubs. Such efforts should be continued and expanded. Similarly, efforts to build public-private partnerships responsive to both industry needs and regional strengths should continue to be encouraged across the DOE and particularly in the National Labs in order to ensure a maximum return on the federal investment in RD&D.[29]

IMPLEMENT EFFECTIVE POLICIES TO ACCELERATE COMMERCIALIZATION OF ADVANCED ENERGY TECHNOLOGIES

To ensure a fully competitive energy market, the federal government must also do more to speed the demonstration and commercialization of new advanced energy technologies. Due to multiple market barriers, private sector financing is typically insufficient to move new energy innovations from early-stage laboratory research on to proof-of-concept prototype and then to full commercial scale. There are two financing gaps, in particular, that kill off too many promising new technologies

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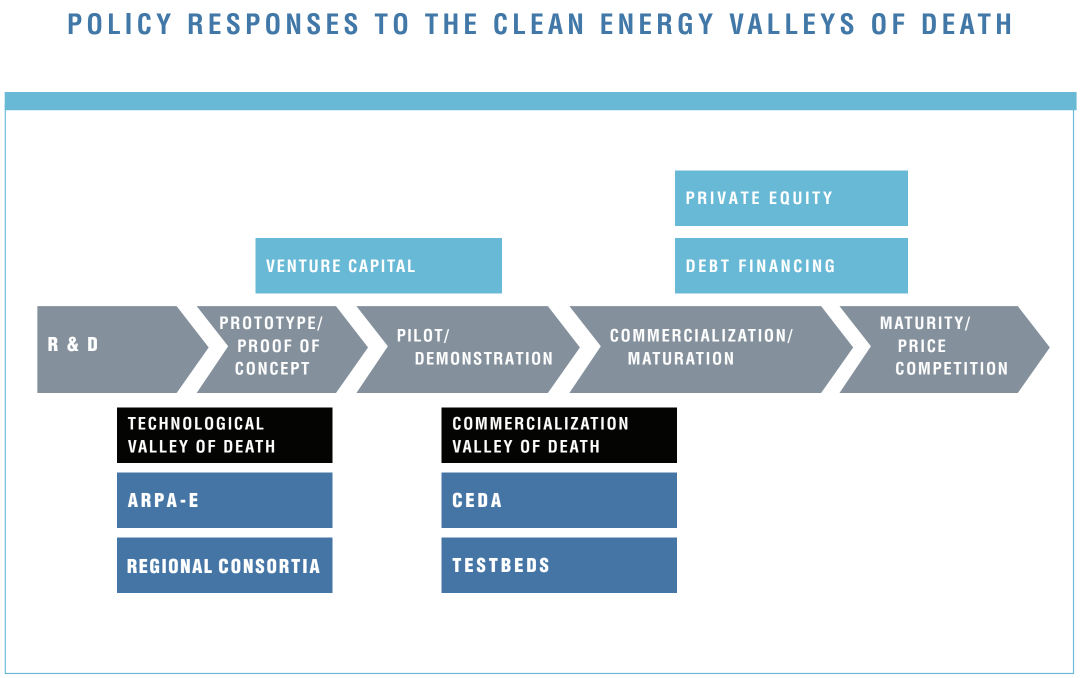
[28] See for example: "A Business Plan for America's Energy Future" from the American Energy Innovation Council (AEIC); "Report to the President on Accelerating the Pace of Change in Energy Technologies Through an Integrated Federal Energy Policy" from the President's Council of Advisors on Science and Technology (PCAST)and "Post-Partisan Power," authored by scholars at the American Enterprise Institute, Breakthrough Institute, and Brookings Institution.

[29] See: "Post-Partisan Power." Full citation in references at end of this testimony. See also: Duderstadt et al, *Energy Discovery-Innovation Institutes: A Step Towards America's Energy Sustainability,* Brookings Institution, February 2009; and Jesse Jenkins, Joshua Freed, and Avi Zevin, "Jumpstarting a Clean Energy Revolution with a National Institutes of Energy," Breakthrough Institute and Third Way, September 2009.

before they have a chance to develop. These are known as the early-stage “Technological Valley of Death” and the later- stage “Commercialization Valley of Death” (see Figure 5).[30]

Figure 5



Source: “Bridging the Clean Energy Valleys of Death.”

The Technology Valley of Death occurs early in the development of a technology, as breakthrough research and technological concepts aim to develop commercially viable products. Investors are typically reluctant to fund early-stage research and product development, and many entrepreneurial start-ups fail to attract sufficient capital to see their research concepts translated into commercial products. New institutional arrangements for federal research support discussed above can help address this Technology Valley of Death, including ARPA-E and new regional innovation consortia.

The Commercialization Valley of Death exists between the pilot/demonstration and commercialization phases of the technological development cycle. This financial gap plagues advanced energy technologies that have already demonstrated proof of concept but still require large amounts of capital—often on the order of hundreds of millions of dollars—to demonstrate

[30] See: “Bridging the Clean Energy Valleys of Death.” Full citation in references at the end of this testimony.

that their design and manufacturing processes can be brought to full commercial scale. This scale of funding exhausts the comparatively limited resources of typical venture capital-led financing rounds, and many VCs are beginning to eschew these nascent and capital-intensive energy technologies in favor of companies with more timely returns to investment.

Advanced energy policy reform should be extended to policies designed to address this Commercialization Valley of Death, including the DOE's Loan Programs Office. The LPO was created in part to help address this Valley of Death, yet the office was soon caught in a mix of competing objectives, including job creation, near-term economic stimulus, and long-term innovation. The LPO should now be replaced by a more flexible, independent, and sophisticated suite of financial tools and other mechanisms designed to draw private capital into advanced energy projects through a variety of investment, credit, securitization, insurance, and standardization activities. Whether delivered through a **Clean Energy Deployment Administration** (CEDA) or other entities or programs, the clear mission of these activities would be to accelerate the commercialization and deployment of critical advanced energy technologies.[31]

A **National Clean Energy Testbeds** program (N-CET) could also be established to take advantage of public lands to accelerate technology demonstration and commercialization. This new program would provide access to pre-approved, monitored, and grid-connected public lands and waters ideal for demonstration of innovative energy technologies, thereby reducing the cost, time, and permitting challenges associated with technology commercialization.[32]

The power of **military procurement** should also be leveraged to drive demanding early markets for advanced energy technologies that meet tactical and strategic military needs and may have later commercial applications. Energy technologies with dual-use military and commercial potential include advanced vehicle technologies, aviation biofuels, advanced solar power, improved batteries, and small modular nuclear reactors.[33]

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[31] See: Jesse Jenkins and Sara Mansur, "A Clean Energy Deployment Administration: Unlocking Advanced Energy Innovation and Commercialization," November 2011. http://thebreakthrough.org/blog/CEDA.pdf

[32] See: Jesse Jenkins, Sara Mansur, Alexandra Tweedie, and Paul Sharfenberger, "A National Clean Energy Testbeds Program: Using Public Lands to Accelerate Advanced Energy Innovation and Commercialization," November 2011. http://thebreakthrough.org/blog/Testbeds.pdf

[33] See "Post-Partisan Power," page 23-24. See also: Daniel Sarewitz and Sam Thernstrom 2012, op cit. note 21.

HARNESS ADVANCED MANUFACTURING, REGIONAL INDUSTRY CLUSTERS, AND A WORLD-CLASS ENERGY WORKFORCE TO ENHANCE AMERICA'S INNOVATIVE EDGE

Advanced manufacturing is an integral part of the innovation system and a key area for cost reductions and performance improvements in emerging technologies. Innovation thus suffers when divorced from manufacturing activities. U.S. advanced manufacturing must play a key role in accelerating energy innovation. Technical support programs, public-private research consortia, and other strategic policies can help domestic manufacturers of advanced energy technologies remain at the cutting edge.[34]

Likewise, the nation needs to develop more potent, catalytic ways to leverage and enhance regional **advanced energy industry clusters**. Such industry clustering has been shown to accelerate growth by promoting innovation, entrepreneurship, and job creation. Policy makers should increase investment in competitive grants to support smart regional cluster initiatives, designed not in Washington but on the ground close to the "bottom up" innovation that has broken out in numerous states and metropolitan areas.[35]

Finally, American energy technology leadership will require a highly educated, globally competitive **advanced energy workforce**. The nation must make new investments in energy science, technology, engineering, and mathematics education and make smart reforms to immigration policies to ensure America remains the destination of choice for the world's best entrepreneurs and innovators.[36]

Shale Gas Revolution Demonstrates Importance of Government Role in Advanced Energy Innovation

As we consider policy reforms to accelerate energy innovation and move advanced energy technologies towards full maturity, we can look no further than the shale gas boom that has revolutionized U.S. energy markets for an important precedent for the key role of government in advanced energy innovation.

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[34] See: Ryan McConaghy and Devon Swezey, "Manufacturing Growth: Advanced Manufacturing and the Future of the American Economy," Breakthrough Institute and Third Way, October 2011. http://thebreakthrough.org/blog/BTI_Third_Way_Idea_Brief_-_Manufacturing_Growth_.pdf

[35] See: Mark Muro and Bruce Katz, "The New `Cluster Moment:' How Regional Innovation Clusters Can Foster the Next economy," Brookings Institution, 2010.

[36] See: "Post-Partisan Power," pages 18-20. Full citation in references at end of this testimony.

Shales now produce over 25 percent of domestic natural gas resources, up from 2 percent in 2001. The shale boom has also pushed natural gas's contribution to America's electricity generation portfolio from 20 percent to nearly 30 percent in the last few years alone. Natural gas resources in shale, once thought to be unrecoverable and until this past decade prohibitively expensive to extract on a full commercial scale, are now accessible and abundant. The shale boom has expanded domestic energy production, pushed down wholesale electricity prices to record lows, and accelerated the retirement of America's aging coal plant fleet, significantly improving public health. These advances were made possible by technological innovations resulting from a sustained partnership between the gas industry and the American federal government.

In a series of investigations and interviews with historians, gas industry executives, engineers, and federal researchers, the Breakthrough Institute uncovered the historical role of the federal government in the development of cost-effective shale gas extraction technologies.[37] We consistently found that innovation and progress in the development of hydraulic fracturing and other key gas recovery technologies arose from public-private research and commercialization efforts. From basic science to applied R&D to technological demonstration to tax policy support and cost-sharing partnerships with private industry, federal programs proved essential to gas industry engineers in figuring out how to map, drill, and recover shale gas – and, most importantly, how to do it cost effectively.

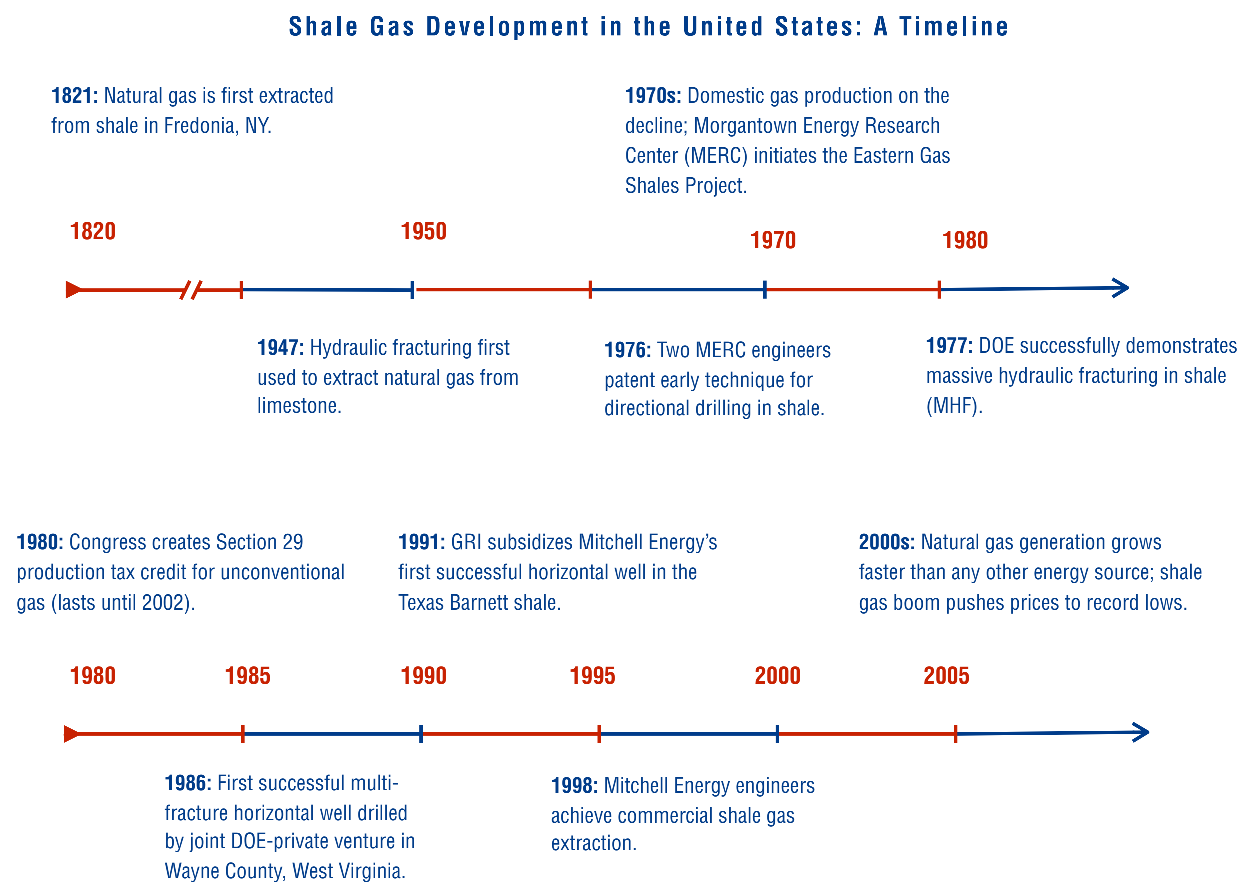
In summary, federal investments and involvement in the development of shale gas extraction technologies spanned three decades (see Figure 6) and were comprised of:

- The Eastern Gas Shales Project, a series of public-private shale drilling demonstration projects in the 1970s;
- Collaboration with the Gas Research Institute (GRI), an industry research consortia that received partial funding and R&D oversight from the Federal Energy Regulatory Committee (FERC);
- Early shale fracturing and directional drilling technologies developed by the Energy Research & Development Administration (later the Department of Energy), the Bureau of Mines, and the Morgantown Energy Research Center (later the National Energy Technology Laboratory);

[37] See: "Where the Shale Gas Revolution Came From." Full citation in references at the end of this testimony.

- The Section 29 production tax credit for unconventional gas, in effect from 1980-2002;
- Public subsidization and cost-sharing for demonstration projects, including the first successful multi- fracture horizontal drilling play in Wayne County, West Virginia in 1986, and Mitchell Energy's first horizontal well in the Texas Barnett shale in 1991;
- Three-dimensional microseismic imaging, a geologic mapping technology developed for applications in coal mines by Sandia National Laboratories.

Figure 6



Source: "Where the Shale Gas Revolution Came From."

It's clear that these government investment and research worked to drive innovations and cost declines in shale gas extraction technologies. Nevertheless, skeptics may wonder whether the private sector would have achieved these gains without any public support. Luckily, history puts this counterfactual to the test: there are plenty of countries with sizable shale deposits — including Russia, China, Poland, South Africa, Britain, and others — where active oil and gas industries did not make congruent investments in shale fracturing technologies. Instead, it was the United States that first cracked the shale gas challenge through decades of research and commercialization; shale fracturing operations in other countries are only now getting off the ground. The U.S. partnership between both public and private sectors was the key to America's shale gas leadership.

The importance of this government role should come as no surprise. Because private companies have difficulty monetizing and capturing all the benefits of energy technology research, it is consistently the case that federal coordination and investment is required to drive high-level technological innovation in the energy sector. As documented in the Breakthrough Institute's 2010 report "Where Good Technologies Come From," the American federal government has historically played a leading role in the development a broad range of other innovative technologies, including microchips, jet turbines, nuclear power reactors, and the Internet.[38]

The gas industry itself has spoken on behalf of the importance of federal research efforts. As Fred Julander, head of Julander Energy and member of the National Petroleum Council, notes: "The Department of Energy was there with research funding when no one else was interested and today we are all reaping the benefits. Early DOE R&D in tight gas sands, gas shales, and coalbed methane helped to catalyze the development of technologies that we [in the industry] are applying today."[39]

"The DOE started it, and other people took the ball and ran with it," Mitchell Energy's former Vice President Dan Steward told Breakthrough Institute. "You cannot diminish DOE's involvement."[40]

Conclusions

The American shale gas boom has brought bountiful new energy reserves, low prices, and thousands of new jobs. As we have seen, government policies — including federal R&D funding, public-private demonstration initiatives, and production incentives for maturing, pre-competitive energy technologies — played a critical role in advancing the key energy innovations required to unlock U.S. shale gas reserves.

Yet America's energy appetites are vast, and new uses for gas — from expanded chemicals production and gas-fired power generation to demand from new natural gas vehicles and export

[38] See: "Where Good Technologies Come From." Full citation in references at end of this testimony.

[39] See: "Shale Gas: Applying Technology to Solve America's Energy Challenges," US National Energy Technology Laboratory, http://www.netl.doe.gov/technologies/oilhgas/publica5ons/brochures/Shale_Gas_March_2011.pdf

[40] See: "Where the Shale Gas Revolution Came From."

markets — will quickly take up new production. Rather than rest on our shale gas laurels, U.S. economic growth and energy security are best served by a diversified energy strategy that builds on the success of the shale boom to steadily expand — and make cleaner — domestic energy supplies.

As with government support for nascent unconventional gas technologies, the revamped U.S. energy strategy discussed in this testimony could establish a suite of limited and targeted policies principally focused on driving innovation and cost declines to improve advanced energy technologies and unlock vast new domestic energy resources. These policies can accelerate technology improvements and cost reductions in advanced energy sectors, ensure scarce public resources are used wisely to drive technologies towards subsidy independence as soon as possible, and continue the growth and maturation of America's clean tech industries.

I thank you for considering these recommendations.

References

This testimony relies centrally on the following publications, which may provide further resources and which may be read into the Hearing Report at the Committee's discretion:

- Alex Trembath, Jesse Jenkins, Ted Nordhaus, and Michael Shellenberger, "Where the Shale Gas Revolution Came From: The Role of Government in the Development of Hydraulic Fracturing in Shale," May 2012. http://thebreakthrough.org/blog/Where_the_Shale_Gas_Revolution_Came_From.pdf

- Jesse Jenkins, Mark Muro, Ted Nordhaus, Letha Tawney, and Alex Trembath. "Beyond Boom and Bust: Putting Clean Tech on a Path to Subsidy Independence," April 2012. http://thebreakthrough.org/blog/Beyond_Boom_and_Bust.pdf

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- Steven F. Hayward, Mark Muro, Ted Nordhaus, and Michael Shellenberger, "Post-Partisan Power; How a Limited and Direct Approach to Energy Innovation Can Deliver Clean, Cheap Energy, Economic Productivity, and National Prosperity," October 2010. http://thebreakthrough.org/blog/Post-Partisan%20Power.pdf