Center for American Progress

How to Power the Energy Innovation Lifecycle

Better Policies Can Carry New Energy Sources to Market

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Introduction

Freeing our economy from its dangerous addiction to fossil fuels and averting the calamitous risks of climate change will require a major technological transformation in the way we produce, transmit, and consume energy. Inventing, developing, building, and deploying these new technologies will require a new era of American technological innovation. The result will be new industries and jobs, along with more clean energy and less pollution.

The good news is that we know that innovation is a fundamental driver of economic growth, and America has led the world in innovation for the past two centuries—from the mechanization of textile manufacturing in the late 18th century to the invention of the Internet in the late 20th century. Innovation is America's first and greatest competitive advantage—or, as President Obama said "it's in our DNA." Twenty-first century clean energy technologies are already being designed, built, marketed, and installed to replace more than a century's worth of entrenched fossil fuel infrastructure, and a recent report by the Department of Commerce indicates that there are nearly 2 million clean energy jobs in our economy today, with more on the way.

The bad news, however, is this: the United States lags behind many other countries in these emerging technology sectors because our public policy does not fully recognize the central role that innovation plays in sustaining quality economic growth and job creation. Part of the problem is a lack of understanding about exactly what innovation is, how it works, and more importantly who is involved (see box). Policymakers in particular need to understand how different public and private sector players interact to form innovation networks, and how these networks change over time, which is why we've put together this primer on the energy innovation lifecycle.

We'll first define the different stages of the innovation lifecycle, then describe the network of players engaged at each stage of the process. This "network lifecycle" approach can help us better understand who does innovation, the processes that drive it, and the opportunities for public policy to aid it at various points in the process. As you'll see, our innovation economy in the energy arena needs some key reforms to perform at its peak again.

Defining innovation: new ideas that create value

"Innovation" is a broad and often vague term, and its meaning varies in different policy circles. But no matter what the context, innovation is fundamentally the process of inventing, introducing, and adopting a new product, practice, system, or behavior.

An innovation can be a new product, machine, policy, business model, administrative structure, managerial system, or even a new cultural or social norm that benefits society. But regardless of whether an innovation affects social processes, economic process, or physical and technological processes, what distinguishes an innovation from an idea or a principle is that it creates value and improves society.

This paper focuses on clean energy technology innovation—the invention and propagation of new machines that generate, save, or transmit energy. But as we will show, producing these new devices also requires the use of new modes of manufacturing, which can be thought of as technologies themselves, as well as new business models that can finance, produce, market, and sell these new machines.

Creating a clean energy economy is just as much about "process innovation"—incremental improvements to the materials and manufacturing process of technologies we already know about—as it is about finding new or undiscovered "breakthrough technologies." Understanding the five phases of energy "innovation lifecycles" and the five kinds of participants in "innovation networks" will help show how these seemingly separate goals are actually related.

The vital role of federal policy in catalyzing private sector innovation

Innovation on the scale necessary to solve our climate and energy crises cannot be driven solely by the government—yet key federal policy decisions and investments are needed to catalyze private sector innovation. While countries such as China, Spain, and Germany have pursued rapid energy technology expansion through top-down government spending programs, America's engine of innovation is more bottom up. Innovation in America has always rested with its private sector entrepreneurs, small businesses, inventors, and investors. But that does not mean that the government has no role to play at all.

While the private sector must ultimately supply the bulk of the money and expertise to build the clean energy economy, the government must create the conditions that allow for this by correcting for twin market failures that keep private investment lower than the economically efficient level: the hidden costs of carbon pollution, and the hidden benefits of innovation and knowledge spillover.

Because markets do not recognize these hidden costs and benefits (what economists call negative externalities and positive externalities, respectively), private investors and entrepreneurs tend to underinvest in clean energy innovation. For every $1 million in profits the producer of a new innovation earns, some estimate that "knowledge spillovers" create as much as $4 million in hidden economic benefits for society. These spillover benefits manifest as the creation of new high-wage jobs, the establishment of new businesses that use the new technology, and the benefits to future innovators who can build on the new knowledge in unexpected and advantageous ways. The government is justified in helping companies innovate because of the additional social benefit of innovation that private investors would otherwise ignore.

Many of the technologies on which our modern economy now relies resulted from the unexpected application of knowledge created in part with the help of government innovation programs. Early microchips designed originally for use in the Apollo space vessels and intercontinental ballistic missiles gave rise to the modern microprocessor upon which PC's, mobile phones, and iPods are now built. The Defense Advanced Research Projects Agency, or DARPA, served as a vital incubator for the early computer-to-computer communication technologies that eventually led to the Internet, and early NASA satellite applications in the 1950s helped spur the development and demonstration of photovoltaic solar cells.

This is not to say that government policies should "pick winners"—they should not. Companies and technologies that are the most effective and efficient should compete fairly to provide the clean energy solutions our economy so desperately needs. But smart, targeted, and progressive government policies are needed to ensure that all possible solutions can compete on an even playing field with the incumbent dirty technologies that are entrenched by their existing infrastructure and political clout.

Five phases of the energy "innovation lifecycle"

Energy innovation is not just the process of inventing new technologies and doing research and development in government or university labs. Innovation is actually a set of interrelated processes that can be broken down into five basic phases:

- Discovery
- Development
- Demonstration
- Commercialization
- Maturation

Each phase is undertaken by a different and evolving network of participants, and each has its own distinct policy needs.

The five-phase summary below is a synthesis of numerous academic innovation lifecycle models dating back to Joseph Schumpeter, an Austrian economist born in the late 19th century. It is important to note that rather than discrete or entirely separate categories, the different phases in this generalized model take place along a continuum and sometimes may overlap.

Discovery

Discovery is the process of researching a basic idea or scientific principle that may one day lead to a useful technology, and is done mostly by researchers in universities. This process also goes by the names "basic science," "blue skies research," or "pure research," and the first goal of the process is to expand the store of scientific knowledge. Technologies at this stage in life are not fully formed, and most will never graduate to the next stage of development due to technical or cost-related constraints. Nevertheless, the goal of public policy at this stage is to empower smart researchers to cast as wide a net as possible in the hopes that one idea in a hundred could one day revolutionize industry.

Government grants for university research and funding of federal labs are the primary sources of funding for this early phase of innovation, since there is not yet a functional technology that can produce profits for private investors. The Energy Frontier Research Centers are an excellent example of recent Department of Energy policy that is supporting discovery by putting money in the hands of able researchers with promising ideas on a competitive basis. The discovery phase creates science research and administrative jobs.

Development

Development is the process of linking the basic science of a discovery with functional technology, also sometimes known as "applied research." Universities and government labs often continue to play a lead role during development, although promising technologies may begin to attract the attention of potential entrepreneurs, who seek out "seed funding" to help create startup companies to work on developing the technology or even building functional prototypes.

Because the risks are too great for typical investors, this early jolt of private capital most often comes from angel investors—wealthy individuals who support entrepreneurs with personal funding—or venture capital firms, which do the same with larger pools of funding. Because funding for development is often very scarce, inventors and entrepreneurs themselves sometimes must tap into their personal savings—this is known as "boot-strapping." This phase is also sometimes referred to as the "seed stage," as the potential business generally has not developed a full-grown and profitable business plan.

The Advanced Research Projects Agency-Energy, or ARPA-E, was designed on the same model as its older brother, the Defense Advanced Research Projects Agency, or DARPA. ARPA-E is an initiative of the DOE initially funded by the American Recovery and Reinvestment Act, and is an excellent example of support for development-phase technology innovation. Job creation during development includes both public and private research and administrative jobs, as well as the possibility for business, management, finance, and perhaps small-scale fabrication jobs.

Demonstration

Demonstration is the process of finalizing prototypes and testing them under real-world conditions to assess operability, technical performance, profitability, and in some cases even regulatory issues. This may also be referred to as "proof of concept" or "technology transfer" because this is the phase when technology must begin to move from labs and research institutions to assembly lines and businesses. Both demonstration and early commercialization are sometimes also referred to as "deployment."

Examples might include the construction and operation of a first-of-its-kind advanced nuclear reactor, a demonstration scale cellulosic ethanol biorefinery, or a coal-fired power plant with carbon capture-and-storage technology. All of these are scientifically understood technologies that are undergoing small-sale demonstration as a precursor to wider commercialization. Manufacturers who build, contractors who install, and utilities that operate and monitor the technology become essential parts of the innovation network at this stage, and their interactions with researchers and financiers promote an important kind of real-world knowledge creation called "learning by doing."

Although demonstration projects are rarely profitable in isolation, the primary goal of demonstration is to indicate to the public, potential investors, and the business community that production processes now exist and that the technology is nearing market. As this takes place, the burden of financing begins to shift from basic government research grants to much smaller "proof of concept" development grants and on toward private financing from angel investors and venture capital firms, though the risks are still very high. For capital-intensive, industrial-scale technologies, such as a commercial-scale carbon capture-and-storage coal plant, financing for demonstration may flow directly from established industry players or other large companies.

But private investors need to see a clear path to profitability before investing, and demonstration projects on their own can rarely provide this without public support. In the highly regulated and capital intensive energy industry, the path to profitability often depends on significant government incentives and assurances. This is especially problematic for capital-intensive clean energy technologies that require a lot of upfront investment to develop land, build power lines, and construct and install equipment. The scarcity of private finance is why many in the business and policy community refer to the process of carrying a promising technology from proof of concept through commercialization as crossing the "valley of death."

Commercialization

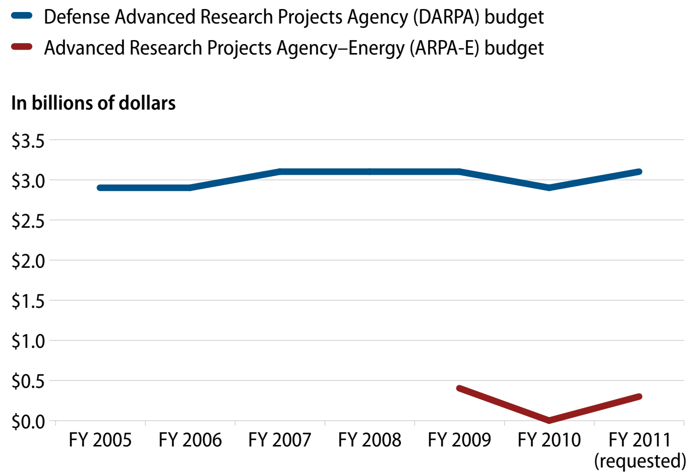
The commercialization phase is when new technologies must meet the market test. Entrepreneurs must prove that they can produce and sell the new products profitably to early adopters and niche markets. This generally involves finalizing production processes, building a factory, obtaining manufacturing equipment, developing relationships with component suppliers, and finding enough potential buyers to make it all a worthwhile investment.

The "valley of death" private financing problem is acute at this stage, too, as new funding is critical to this cash-intensive and often capital-intensive phase of the innovation cycle. Follow-on rounds of venture capital, private equity, and/or debt financing (that is, borrowing from a bank or selling bonds) become increasingly prominent sources of money, as small- to medium- scale manufacturing and services operations are established. Startup companies at this phase are expected to generate some cash flow from sales of the technology, although profitability for the first few years may still depend on government incentives such as tax credits or cash grants for investment and electricity production, loan guarantees, or the sale of Renewable Energy Certificates to utilities who need them to meet state renewable electricity standards.

Commercialization is a critical bottleneck in current U.S. innovation policy because entrepreneurs have a growing backlog of technically proven technologies for which they cannot find affordable financing to grow their operations and achieve the economies of scale necessary to compete with conventional incumbent technologies. A Clean Energy Deployment

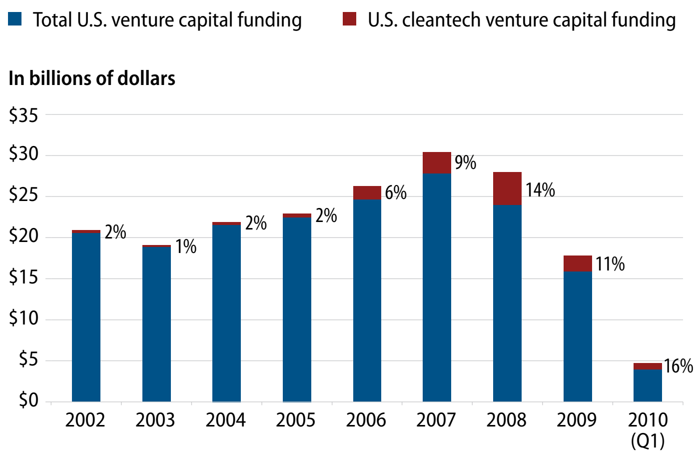
Public funding for development-stage research in defense and energy

While the Defense Advanced Research Projects Agency, or DARPA, has been a titan of research for development-stage defense technologies for decades, the Advanced Research Projects Agency–Energy, or ARPA-E, has only begun to receive a small amount of funding for its operations since the passage of the stimulus bill in 2009. Ensuring the long-term growth of this agency is critical to promoting healthy clean energy innovation networks.



Private venture capital funding for cleantech on the rise

America's engine of innovation is the private sector, and venture capital funds supply billions of dollars to entrepreneurs with big ideas. Over the past decade, these private investors have taken an increasing interest in clean energy technologies. With a little more long-term certainty about future government policies, these new clean energy industries are poised to really take off.



Administration or "Green Bank" that can provide loan guarantees and other credit enhancements is one potential policy response to this market pitfall. The creation of a public-private equity investment partnership could be another way to break this financing bottleneck.

Commercialization creates more permanent manufacturing and construction jobs, as companies increase profitability and invest in and operate new manufacturing facilities, and as clean energy technologies are deployed, installed, and operated.

Maturation

Maturation occurs when new technologies graduate from niche to mainstream markets by scaling up manufacturing, gaining market share, increasing efficiency, and showing that they can compete on cost with incumbent sources of energy. In the case of renewable energy, this often occurs once technologies reach "grid parity"—the point at which the renewable energy is equal to or cheaper in price than existing power sources.

As new technologies become commercially competitive, they gain market share and gradually begin to displace incumbent technologies. This process is sometimes also called "diffusion." Mature innovation networks should ideally become profitable for all participants independent of government incentive programs, although in the case of the incumbent fossil fuel industry, many wasteful subsidies continue to persist due to political pressure. As profitability becomes positive, seed-stage investors, angel investors, and venture capitalists are able to "exit" their investments and make a profit, either by selling their shares at an initial public offering or by selling the entire company to another larger corporation.

The innovation cycle begins anew at this stage as increasingly self-sufficient clean energy manufacturers begin to reinvest their own profits in new research toward incremental improvements to their technology and production process, or seek to acquire smaller companies with promising ideas for how to continue to improve quality or reduce costs. Continuing process innovation remains critical, even for mature technologies, but policymakers all too often ignore this aspect of innovation policy. The bailout of the U.S. auto industry, for example, can be seen as a failure of a mature industry to continue to innovate.

A major goal of public policy at this stage is to ensure that cutting-edge researchers and manufacturers continue to collaborate effectively to organically develop and commercialize the next generation of clean energy manufacturing technologies. But direct government incentives for investment and production of the original technology should begin to sunset on a reliable path.

Five kinds of participants in innovation networks

Innovation is also a network activity. An innovation network is the constellation of all public and private sector organizations participating in the development of a certain technology. Each participant in an innovation network has its own interests and objectives, and different policy tools are needed to help different kinds of participants at different points along the innovation lifecycle.

While there are many different types of participants, for the most part, they can be categorized into five basic groups:

- Researchers (university, government, and corporate R&D researchers)
- Producers (manufacturers of clean energy equipment and components)
- Financiers (public and private investors in clean energy projects and companies)
- Users (utilities, building owners and managers, private power generators, vehicle drivers, or anyone who uses or operates clean energy technology)
- Regulators (those who participate in setting the rules and apportioning public resources for the above mentioned activities)

Sometimes these groups may overlap, such as in the case of a large corporation what does both production and research on energy technology.

A paramount objective of innovation policy is to align the disparate and at times conflicting interests of these different public- and private-sector players to form productive and collaborative innovation networks. Comprehensive innovation policy seeks to maximize the flows of money, information, and risk that act like connective tissue holding these different innovation network participants together. To make sure the policy matches the needs of the network of players at each stage, it is important to understand how the process and the players interact along the way and how policy tools could better link the innovation process and innovation networks to the benefit of our economy and society.

The discovery network

Participants: During the discovery phase, researchers working on basic science in university and government labs are the primary participants in innovation networks. Some of this research is published in scientific journals, creating public knowledge rather than privately owned intellectual property. Ensuring academic independence and freedom of scientific pursuit allows researchers at different institutions to collaborate freely and build on one another's efforts.

Financing: The money that drives discovery mostly flows from government and nonprofit grants and university research budgets. The vast majority of basic science research does not result in marketable technology, which means the risks to private investors at this stage are prohibitively high. Sometimes, however, pioneering angel investors and farsighted larger corporations may dedicate some of their funding toward this early discovery process with the hope of inventing a breakthrough technology that will earn big payback further down the line. Because early-stage research during discovery is usually far away from becoming a viable, marketable, or profitable product, investors and private companies are not usually interested in financing it.

Policy response: Increasing funding for the discovery phase of energy innovation is critical for helping achieve the market-disruptive breakthroughs that could transform our energy economy in the coming decades. Breakthrough innovation, disruptive innovation, or radical innovation are all terms used to refer to these potentially high-impact technologies. But because technology in the discovery phase is neither attractive to investors nor marketable as a source of profits, there is a funding gap that must be filled by public sources.

Public policy currently supporting energy innovation in the discovery stage includes funding and operation of the various DOE national labs, and some grant funding for research within the university system. DOE's Office of Science established its program for Energy Frontier Research Centers, or EFRCs, in August 2009 to provide grants of $2 million to $5 million per year for five years to "universities, national laboratories, nonprofit organizations, and for-profit firms… to develop the scientific foundation for a fundamentally new U.S. energy economy." Of the 46 EFRCs selected for funding, 31 are led by universities, 12 by DOE National Laboratories, two by nonprofit organizations, and one by a corporate research laboratory. Roughly a third of the funding will come from the American Reinvestment and Recovery Act.

Besides helping to fund the vital activities of basic science research, these EFRCs play a crucial role in helping to build the bridge to the next phase of innovation by establishing vital relationships between researchers and government innovation participants. These relationships are needed to cultivate flows of information among researchers, government actors, and potential investors who may be able to provide sources of capital further down the road. Ensuring that the United States maintains its dominant position in basic science research and information networks will drive economic growth and keep the United States competitive in the long run.

Examples: Some examples of the exciting technologies in the discovery stage at these centers include: hybrid synthetic-organic materials research for solar power applications at University of Arizona, Tucson; complex electrochemical processes critical to advancing electrical energy storage at Argonne National Lab in Argonne, Illinois; and investigations of the behavior of metal alloys in extreme radiation environments for applications in nuclear reactors at Oak Ridge National Lab in Oak Ridge, Tennessee.

The development network

Participants: The innovation network expands as technologies move from discovery into development to include potential producers of the new technology and seed-stage financiers in addition to the existing base of researchers in university or government labs. Entrepreneurs seeking to start up companies to produce and market the technology may emerge during the development phase if they can find angel investors willing to take on the risk of funding a technology that may not pay off for many years, if at all. Facilitating the flow of public and private capital and the exchange of information among this growing network of participants is the primary goal of innovation policy at this stage.

Financing: During development, most funding for research activities still comes from public sources such as government grants and research universities because the technology is still not ready for market. But as the technical viability of the science begins to take shape, the possibility of future profits may attract some seed-stage capital from angel investors or large corporations who operate their own research labs seeking to gain a strategic advantage or secure intellectual property rights in the emerging field.

Nonetheless, the survival rate for technologies at this stage is very low, so even high-risk high-reward investors such as seed and early stage venture capital funds are usually hesitant to invest unless the technology seems like it could one day revolutionize the industry. In 2006 for example, seed-stage funding accounted for less than 1.5 percent of the $2.1 billion in overall clean tech venture capital in the United States. This is part of a larger trend of declining funding for startup and early-stage finance relative to later-stage finance that makes it very hard for even good ideas to get off the ground. Creating incentives to increase these early flows of private capital represents a substantial point of leverage for innovation policymakers.

Policy Response: Thanks to the American Recovery and Reinvestment Act, the DOE was able to fund the Advanced Research Projects Agency-Energy, which was originally created by law in the 2007 America COMPETES Act. ARPA-E works to accelerate research and development by linking promising scientific ideas in research universities and government labs with small startup companies seeking to develop these ideas into marketable technologies. This achieves two important goals: increasing interaction and exchange of knowledge among different types of innovation network participants, and increasing capital flows toward innovative ideas.

In its first year of operation, ARPA-E has doled out $151 million in funding to 37 ambitious projects in 17 states. This is small compared to the $3 billion budget of ARPA-E's older brother DARPA, but it is already making a big difference. Of the projects selected for ARPA-E funding, 43 percent were led by small businesses, 35 percent were led by educational institutions, and 19 percent were led by large businesses. Six of the selected applications also included researchers at national labs in their project proposals, and 21 of the selected applications (57 percent) included university participants. This kind of public-private collaboration creates high-level employment opportunities with the potential to blossom further as the technologies move toward commercialization. The closeness of interaction among public and private technology researchers, financiers, and producers is also a critical element of a successful innovation network.

Examples: ARPA-E has funded public-private collaboration around the development of new energy technologies including the development of high-density lithium batteries that could revolutionize electricity storage, smart building energy efficiency systems utilizing information technology, new "DirectWafer" solar cell manufacturing processes that could cut costs by 90 percent, and research for cellulosic and algae-derived second generation biofuels.

The demonstration network

Participants: Demonstration is the first time when participants from all five categories of an innovation network come together: researchers, producers, users, financiers, and regulators. By building a functioning demonstration project that generates electricity (or in the case of efficiency technology, saves it), the innovation network becomes complete by adding both the relevant state and federal regulators who must approve the project, as well at least one user who will operate and derive revenue from the technology.

A bridge too far

Existing programs that try to bridge the financing "valley of death" by facilitating network formation among small businesses and public and researcher organizations are helpful, but limited in scope. They include:

Small Business Innovation Research grants

The Small Business Innovation Development Act of 1982 directs 11 federal agencies (including the Departments of Energy and Defense, the Environmental Protection Agency, NASA, and the National Science Foundation) to reserve a portion of their R&D funding for competitive grants for small business innovation. SBIR grants are provided in two phases—$100,000 over six months, and then $750,000 over to two years—to help small, American-owned business obtain the capital necessary to explore new technological ideas and assess their marketability. This has the effect of helping potential producers join innovation networks and undertake the applied research necessary to move toward demonstration and commercialization.

Small Business Technology Transfer grants

Similar to SBIR grants, STTR grants are funded through the R&D budgets of five federal agencies including the Department of Energy, and are awarded competitively each year to innovators with promising technologies in two phases. The main difference is that STTR grants are awarded specifically to public-private partnerships between small businesses and federally funded research and development centers located in universities or other nonprofit research organizations, rather than to small businesses alone. By design, this creates incentives for researchers and potential producers to form relationships and exchange information, growing innovation networks and moving from development toward demonstration and perhaps commercialization.

Technology Innovation Program

The Technology Innovation Program, or TIP, which was created by the America COMPETES Act of 2007 and is housed within the Department of Commerce's National Institute of Standards and Technology, provides support for innovative high-risk, high-reward research in areas that address key national priorities, such as energy, manufacturing, and civil infrastructure. The program is now hosting its second annual competition to fund and facilitate network formation between researchers and producers with up to $9 million over three years if they can find private financiers who will provide a 50-50 match.

All of these programs, however, are extremely limited in their level of funding and scope, and their already modest resources are divided across many fields besides energy. Requirements that companies successfully shift from laboratory to market in just two or three years puts an arbitrary and at times unfeasible time constraint on the innovation process. Both SBIR and STTR programs explicitly state that finance for actual commercialization after the two-year funding window must come exclusively from private sources. Because not all technologies can meet this requirement, many promising innovations stall or die during this lapse in government support. Furthermore, an apparent lack of coordination among these related programs all within the Department of Commerce limits what they can achieve.

Finance: Demonstration is the first time when extremely limited proof-of-concept funding by the government—via Small Business Innovation Research, or SBIR grants, and Small Business Technology Transfer, or STTR grants (see box on page 13)—is replaced by private sources of capital, which begin to finance a significant portion of innovation activities in the hopes that the new technology will generate revenues and eventually profits. At this stage, venture capitalists begin to take note of new technologies as producers of the technology seek "follow-on" rounds of venture capital or, less commonly, debt finance. Demonstration projects are rarely profitable in isolation, but they are intended to show that the technology can be feasibly fabricated, and that the product can be installed and operated in a way that creates a revenue stream.

The ability to demonstrate not only technical feasibility but also economic feasibility through reliable revenue streams is a critical goal of demonstration projects, since the investment community will not invest until a technology is demonstrably profitable. This revenue stream originates with the sale of electricity, savings on energy bills, or efficiency improvements to existing energy technologies, manufacturing processes, or infrastructure. Without the assurance of this revenue source, utilities, merchant power generators, and building owners will not be willing to purchase the new technology and equipment from manufacturers, and investors likewise will not be willing to finance projects or young companies.

A successful bid to complete a demonstration project usually indicates to potential private-sector financiers that a commercial product is nearly ready, and flows of equity and debt financing from the private equity and venture capital community become more viable. But these investments are still considered very risky, and particularly in our current economic downturn, public financial backing in the form of grants, direct loans, and loan guarantees can be necessary to help technologies secure the private finance—especially debt finance—they need to reach this milestone.

Policy response: Demonstration is an underfunded stage of innovation in current U.S. energy policy. Government-funded pilot programs and demonstration projects can serve multiple purposes:

- To test the technology and facilitate scientific learning about its performance
- To build relationships and flows of communication and capital among researchers, producers, and their suppliers
- To build familiarity among the private investment community

Yet in order to credibly establish all three of these goals, government demonstration programs must be careful to ensure that the projects truly test not only the technical feasibility of the technology, but also its economic viability.

The Department of Energy Innovation Hubs program, and the Energy Regional Innovation Cluster initiative for energy efficiency are two existing programs that are helping solidify relationships among all five types of innovation participants and cement innovation networks around pre-commercial technologies. These two related programs are essential because they help grow the money, information, and risk flows (that connective tissue mentioned earlier) among private researchers, producers, users, and financiers, as well as purpose driven organizations and numerous agencies within the federal government.

These programs, however, are new, small, and only temporarily funded under the American Recovery and Reinvestment Act. In order to be truly effective in catalyzing the formation of innovation networks from the bottom up, these programs will need to be more permanently funded and enshrined within the institutional infrastructure of the federal government.

Examples: Iogen Corporation, with the help of Canadian government and a host of international investors, has been producing cellulosic ethanol from wheat straw (a byproduct of food production) in a small demonstration-sized facility since 2004. As they scale up production in that smaller facility, they are drawing up plans with their partners to build a larger, commercial-scale facility in Saskatchewan.

Then there's FutureGen, a project to demonstrate coal power with carbon capture-and-storage technology in Mattoon, Illinois. Although the project has had a bumpy path forward since the end of the Bush administration (some chiding that there is too much "future," not enough "gen"), both President Obama and Secretary of Energy Steven Chu have indicated that the project holds great promise. Revived by $1 billion from the Recovery Act, the project has brought together all five categories of innovation network players to cooperate, share information, and devise shared public and private financing mechanisms to help build the world's first utility-scale zero-emissions coal-burning power plant.

The availability of government funding in this case serves as an important anchor facilitating collaboration among companies who would not otherwise be able to work together. Once complete, the project will have to demonstrate not only that the technology works, but also that it could one day be profitable to build and operate.

The commercialization network

Participants: During commercialization, small and large manufacturing companies begin to invest in crafting a profitable business model to produce many copies of the technology and market it to users. As the new product goes into commercial use, producers and early-adopting users begin to collaborate more directly, which offers an important opportunity for innovators to identify areas of improvement and respond to consumer needs. As the users actually begin to install and operate the new technologies, they begin to notice what aspects they like, and what aspects of the technology could improve. Fostering this kind of information sharing between users and producers is a key ingredient to innovation network success. In the case of clean energy technologies, users might include:

- Public and privately owned utilities
- Independently contracted operation and maintenance companies that actually operate clean energy technologies
- Independent power producing companies that also may purchase, install, and operate energy generation technologies
- Architects, contractors, and building owners who will incorporate new efficiency technologies into their building designs.

The commercialization stage is also when competition for market share blooms among multiple producers of a technology. Competition gives companies an incentive to drive down costs and try out new ideas to find ever-better and more efficient ways of doing things. Without strong competition, technologies usually cannot move through commercialization and into maturation.

A great example of this would be the four different technologies competing to produce low-cost electricity from concentrating solar power:

- Sterling engine dish designs
- Parabolic trough designs
- Fresnel reactor designs
- Heliostat "power-tower" designs

All of these technologies are aimed at generating solar baseload power using the sun to create heat that drives a turbine or motor to produce electricity, but each approaches it differently, and the competition among them will help ensure that companies explore all the best ideas.

It is possible that certain versions of the technology will be better suited for one kind of application, while other versions may be better suited for another application. It is also possible that knowledge gained through exploration of one offshoot technology could help advance the aims of another competitor (this is a great example of the aforementioned "knowledge spillover"). Competition is an important ingredient in driving innovation through commercialization toward maturation.

Industry employment has the potential to grow exponentially during commercialization, as companies hire workers at all levels of training to build and run factories, and to manufacture, market, monitor, and maintain the technology and equipment. But inherent market barriers around financing and market demand severely restrict the ease with witch promising technologies can jump this gap. There are today a plethora of technically viable clean energy solutions that currently cannot find financing to achieve the economies of scale to make them competitive.

Finance: Commercialization is the beginning of the process of replacing government grants, seed capital, and venture capital as primary sources of funding for innovation activities with more stable forms of financing and eventually profitable revenue streams from the sale of the product. These more stable forms of financing can include mezzanine capital from private equity firms, equity capital, or debt capital (especially if the debt is backed by the government in the form of loan guarantees).

Achieving this transformation is difficult and is the reason why commercialization is a major bottleneck in clean energy innovation policy. The problem lies in a multifaceted chicken-and-egg problem that exists between financing, market demand, infrastructure, and supply capacity. Since technologies for which there is no market demand are not attractive investments for financiers or potential manufacturers, that in turn keeps these technologies from reaching economies of scale or gaining market share, preventing them from finding financing and perpetuating the stagnation.

Policy response: The government has a three-part role to play in bridging this gap by helping both to spur market demand, drive investment in the physical and human infrastructure to meet that demand, and ensure the availability of affordable financing to make it all happen.

- **Markets:** Driving market demand can best be done by delivering incentives to potential users, such as utilities, to encourage them to invest in clean energy products and projects. Existing programs include the production tax credit, the business energy investment tax credit, the residential renewable energy and energy efficiency tax credits, and widespread government procurement of clean energy technologies under President Obama's Executive Order 13514.

Many states have enacted a Renewable Energy Standard that ensures a certain level of demand for commercializing clean energy technologies, though no such policy yet exists on a federal level. The U.S. Export-Import Bank, by helping to find overseas markets and export opportunities for domestically produced clean-energy technologies, also has an important role to play in driving demand. Most important, a price on carbon would help create demand by making clean energy options more competitive with conventional energy as utilities look to replace aging infrastructure and respond to natural increases in energy demand.

- **Infrastructure:** Incentives that help lure manufacturers to invest in producing the technology are currently delivered through the Manufacturing Extension Partnership program. MEP is a program of the National Institute of Standards and Technology that provides consulting, market research, and supply chain coordination services to small- and medium-sized manufacturers to help them achieve continuous improvements, stay abreast of the newest technologies, and help build domestic supply chains. Because the assembly line is just as important of a location of innovation as the lab, these information services are critical to knowledge generation and learning as technologies progress from commercialization and into maturation.

- **Finance:** The Title XVII loan guarantee program is currently the primary vehicle for ensuring the availability of affordable private-sector capital for commercialization, though the program is limited in its reach and longevity. The section 48(c) advanced manufacturing investment tax credit has also been extremely successful in helping facilitate financing for investments in manufacturing facilities for new and innovative clean energy technologies. It would be better, however, for Congress to create an independent Clean Energy Deployment Administration, also referred to as a "Green Bank." A green bank would be able to mitigate the risk perceived by investors through loan guarantees and other kinds of credit enhancements, leveraging large amounts of private capital at relatively low cost to the tax payer. Such programs have been used in the past to great success. Another possibility would be for Congress to create a public-private partnership that could deploy public and private equity investment dollars in promising technologies.

Examples: Some of the more charismatic and well-known clean energy technologies—solar photovoltaic, concentrating solar power, and geothermal—are all considered to be at various points along the commercialization process in that there are some profitable companies already competing to produce the products and sell them to global and domestic markets.

But overall market share is still relatively small, both globally and in the United States because markets are still too reliant on various government incentives and/or niche market applications (such as off-grid installations, or users willing to pay a premium above market rates for the "clean" or "green" attributes of the technology) to operate profitably. Although some companies may be able to operate profitably during commercialization, the technology still has not reached cost competitiveness, or grid parity, with conventional fossil fuel technologies.

The maturation network

Participants: By the time technologies reach maturation, the innovation network has blossomed beyond the five basic categories of researchers, producers, users, financiers, and regulators to also include powerful interest groups such as industry associations, and sources of public information such as industry or trade journals. At this stage innovation has moved all the way from the laboratory to the assembly line, as companies expand their manufacturing operations and compete for market share.

Finance: As economies of scale grow and new clean energy technologies become cost competitive with incumbent dirty energy technologies, producers become more financially self-sufficient. By this point they can rely on revenue from the sale of the technology as their primary source of cash flow, rather than continual infusions of money from multiple rounds capital or government incentives. Early-stage financiers such as angel or venture capital investors will have exited their investment through an initial public offering, or through being acquired by larger companies. To the degree that the government has underwritten any of these investments, this process frees up that public money to recycle back into the system. Mature companies may from time to time take out loans or issue bonds (debt financing) to finance particularly capital intensive projects, but by and large they are self-reliant.

Policy response: There are two major goals of innovation policy at this stage: sunsetting obsolete policy incentives and ensuring ongoing process innovation.

The first goal is to gradually rollback or "sunset" unnecessary subsidies for mature technologies to ensure they can stand on their own feet and do not become permanently dependant on ongoing government handouts. In an ideal world, once a technology matures and reaches cost parity with its incumbent competitors, it is no longer reliant on government support to grow and develop. Public resources should be gradually and predictably withdrawn so that they can be redirected towards younger technologies with more need.

In practice, however, the effective sunsetting of innovation policy incentives is often overlooked due to the political sway of powerful mature industries, or sheer lack of attention from policy makers. CAP's recent report "America's Hidden Power Bill" explains in detail how many long-ignored tax subsidies to the oil and gas industry have helped deepen the entrenchment of those very mature industries while wasting taxpayers' money without social benefit. Eliminating some of these subsidies could save taxpayers $45 billion over the next decade, but the oil and gas industries have spent millions on lobbying, public outreach, and contributions to political candidates to ensure that these unnecessary and wasteful subsidies continue to help their bottom lines.

Unfair competition from foreign technology producers in countries with poor labor and environmental standards, stronger subsidies, and lower costs also complicates the theoretically straightforward process of rolling back unnecessary public financing. Case in point: Because of its low cost of labor, currency manipulation, and an aggressive regime of subsidies, China has been able to capture a disproportionate share of the rapidly growing global export market for certain clean energy technologies like solar PV and wind turbines. The threat of unfair foreign competition will make it harder to rollback unnecessary subsidies for clean energy produced in the United States as these technologies mature. Remedying this will require the United States to get serious about enforcing trade agreements, and proactively helping its own domestic manufacturers continue to innovate and stay competitive.

It is important to note one important exception to the sunset rule: Policies that correct for fundamental market failures, such as the external cost of global warming pollution, should never be scaled back. Putting a price on carbon—which requires polluters to help pay for the damage that their emissions do to our economy and environment rather than forcing the public to foot the bill—is not a direct subsidy to a particular industry. Instead, appropriately priced carbon is remedy to a persisting market failure—a mechanism for the public to be reimbursed for damage for which polluters otherwise would not be held unaccountable. This kind of policy should not be rolled back at all.

The second goal of innovation policy for mature technology networks is ensure that cutting-edge researchers working on ancillary technologies remain connected to the innovation network. Ancillary technologies are new kinds of manufacturing processes, or new kinds of materials and components that are related to the primary technology and that could lead to new and useful applications, improvements in functionality, or reductions in cost.

Hybrid cars, for example, are now reaching maturity, and new lithium air batteries could in theory revolutionize this industry by making batteries cheaper, lighter, more powerful, and longer lasting. Alas, a lithium air battery has never been built, so it must start at the beginning of the innovation cycle, even though the primary technology to which it relates is mature. The failure of the U.S. automobile industry to keep up with innovations such as hybridization, electric-drive engines, and fuel flexibility has been one of the central causes claimed for their recent decline. There is much the government can do to ensure that even companies in mature technology industries are innovating towards socially optimal outcomes.

While mature companies at this stage can and should determine and fund their own research priorities, there is still a role for federal policy to ensure that promising discovery-phase ancillary technologies are able to germinate, just as the original technology that is now mature once did. The Manufacturing Extension Partnership program and the section 48(c) advanced energy manufacturing investment tax credit are key policies that help to facilitate the flow of information, money, and risk amongst the researchers, producers, and financiers of maturing innovation networks. Additionally, the policies at the discovery, development, demonstration, and commercialization phase remain relevant, though they are applied at this phase to new ancillary technologies, rather than the mature technology itself.

Examples: Many energy efficiency technologies for buildings, such as roofing and siding insulation, energy efficient appliances, and modern HVAC (heating, ventilation, air conditioning) equipment are mature, but still are not in widespread use due to market failures around consumer decision making, imperfect information, risk aversion by consumers, and split incentives between building owners and tenants. These market failures represent an opportunity for simple and inexpensive policy changes to open up new markets that can quickly spur business activity, jobs, and economy growth, especially in places that need it most.

Wind energy is also fast approaching, and exceeding in some instances, grid parity with conventional energy. Wind today accounts for more than 35 gigawatts of generating capacity in the United States, enough to power nearly 10 million American homes, and the industry currently supports some 85,000 jobs and growing. Helping this technology by continuing to provide support for incremental cost reductions, manufacturing efficiency, and maintaining long-term market certainty are the main goals of policy at this stage.

Conclusion and policy response

The "network lifecycle" approach outlined in this memo reveals how energy innovation is not a simple process of throwing government money at R&D activities in labs and hoping we solve climate change. Energy innovation is a complex cycle of interrelating activities undertaken by an ever-evolving network of participants that continues long after a technology has left the laboratory and entered the market. These diverse innovation activities include:

- Research and development
- Financing
- Patenting
- Licensing
- Marketing
- Manufacturing
- Workforce training
- Supply chain management
- Construction
- Operation and maintenance
- New incremental innovation

Understanding how all the participants in innovation networks exchange information, money, and risk at different stages of the innovation lifecycle reveals points of leverage for policymakers to help power the clean energy revolution.

State of Play

The existing patchwork of energy innovation-related policies

Discovery: Energy Frontier Research Centers and other grants from the Department of Energy help fund and coordinate important discovery phase research in universities and DOE's 17 national laboratories.

Development: Advanced Research Projects Agency-Energy, Small Business Innovation Research grants, and Small Business Technology Transfer grants all facilitate small grants of a few million dollars over a period of a few years to companies, universities, labs, and consortia thereof and are critical in helping form initial bonds between participants in nascent energy innovation networks.

Demonstration: Technology Innovation Program provides funding between $3 million and $9 million to help nascent innovation networks come together to solve challenges of critical national need such as energy, infrastructure, and manufacturing. However, the program is small and only a portion of the funds will go toward energy and related technologies specifically. Unlike the SBIR and STTR grants, these funds can only be used to fund project implementation directly.

Commercialization: The DOE's Energy Innovation Hubs will provide $122 in funding and programmatic support for complete innovation networks based in regions to invest in infrastructure and form relationships crucial to the exchange of money, information and risk. However, this program is funded largely by American Recovery and Reinvestment Act, and needs a longer term vision in order to be successful. The Title-XVII loan guarantee program, passed under the Energy Policy Act of 2005, as well as production tax credit, investment tax credit, and manufacturing tax credit, are all helping facilitate cost-effective financing to producers and users of clean energy, two groups that must come together during commercialization. The U.S. Export-Import bank also has a role to play in engaging with the clean tech manufacturing sector and helping to drive international demand for U.S-produced goods.

Maturation: The manufacturing investment tax credit can help mature technology companies retool and continue to innovate new methods of producing clean energy technologies and reducing costs. The Manufacturing Extension Partnership is also a major driver of information flow that helps small manufacturers and medium manufacturers stay integrated with larger networks.

There are a number of existing programs that could be expanded, connected, and leveraged more effectively to facilitate bottom-up network formation at every stage of the innovation lifecycle (see box). There is no question that government funding for basic and applied research, such as the grants given under the DOE's Energy Frontier Research Center program and ARPA-E, do much to drive discovery and development processes that are the bedrock of our national innovation system.

Building on these programs, funding through programs like the SBIR, STTR, and TIP could be more effectively designed to facilitate network formation not just among researchers and demonstration-stage producers, but also with the financial community and potential technology users as well. Because it is such a young program, the TIP is still forming its operating guidelines and is actively soliciting outside comment on how to most effectively leverage its existing resources going forward. This provides an excellent opportunity for policymakers to shape the program in a way that integrates with existing and potential future energy innovation policy.

The Energy Innovation Hubs and Energy Regional Innovation Cluster programs are great examples of what a comprehensive approach to energy innovation networks could look like, but these programs too are brand new and may not have a long-term future once the stimulus bill wears off. The Department of Energy and the Department of Commerce, where these programs are housed, could collaborate more to integrate all of the aforementioned programs. Including incentives to drive exchanges of knowledge, money, and risk among researchers, public and private financiers, and companies engaging in early-stage production and demonstration would go a long way toward helping build productive innovation networks.

To bridge the commercialization gap requires a three-pronged approach that brings all five kinds of network participants together by driving demand, sustaining growth of supply, and facilitating financing for both.

On the supply side, incentives for producers of clean energy technology need to be expanded in scope to ensure that manufacturers both large and small as well as their component suppliers are actively engaged innovation process. Policies that facilitate information flows such as those delivered through the MEP and NIST should be integrated with funding opportunities such as the section 48c manufacturing tax credit, and SBIR, STTR, and TIP grants to ensure that companies receiving funds for advanced clean energy manufacturing are interacting with each other, with government researchers and regulators, and with networks that include other innovation participants.

On the demand side, policy tools that make it easier for utilities to purchase, install, and successfully operate clean energy technologies are necessary to ensure the robust market demand and predictable long-term growth that manufacturers need to continue to invest in their manufacturing processes and create jobs.

Policies such as the investment tax credit for clean energy deployment, and the per kilowatt production tax credit for clean electricity generation are all too often ignored by policymakers who believe innovation is synonymous with "R&D." Much to the contrary, 70 percent of private R&D spending is actually targeted at the assembly line, and policies like the ITC and PTC that engage utilities in innovation networks and drive demand for manufactured goods are crucial to forming complete innovation networks.

To create long-term certainty needed for companies to make long-term investments in innovation, demand-driving policies such as the ITC and PTC need to be strengthened and extended into the foreseeable future. The Section 1603 Treasury Grant Program, which under the Recovery Act empowers the Treasury Department to issue grants in lieu of a tax credit for some of these programs, needs to be extended to broaden the circle of potential financiers who can invest in innovation beyond those with an appetite for tax equity.

A strong federal renewable electricity standard that would require utilities to invest in generating a certain proportion of their electricity from clean sources would also help bring larger companies' long-term plans in line with innovation networks. This would go a long way toward ensuring a baseline level of market demand that can help lure private investors to innovation networks.

On the finance side, a Clean Energy Deployment Administration or "Green Bank" capitalized at $10 billion could help drive $50 billion or more in private sector finance each year and create thousands of new innovation jobs in the clean energy economy. Such an institution could also act as a vehicle for coordinating many of the disparate programs listed above, helping to craft a more comprehensive policy framework. Another possible program Congress should consider is a public-private partnership to target public and private equity investments into innovative new technologies to help bridge the financing "valley of death."

Finally, finding a price for carbon that finally holds polluters accountable for the damages they cause would be the largest and most important long-term driver of private sector finance for clean energy activities. It would signal to the investment community that the clean energy sector is ripe for long-term growth, and unleash billions of dollars of in private, profitable investment in new businesses, new infrastructure, and new jobs.

Study after study after study has shown that these kinds of policies have big benefits for the economy, both because clean energy investments create two to three times more jobs per dollar than dirty energy, and also because innovation at every stage of its lifecycle is an intrinsic driver of economic growth.