American Energy Innovation Council

BIPARTISAN POLICY CENTER

U.S. Energy R&D Architecture: Discreet Roles of Major Innovation Institutions

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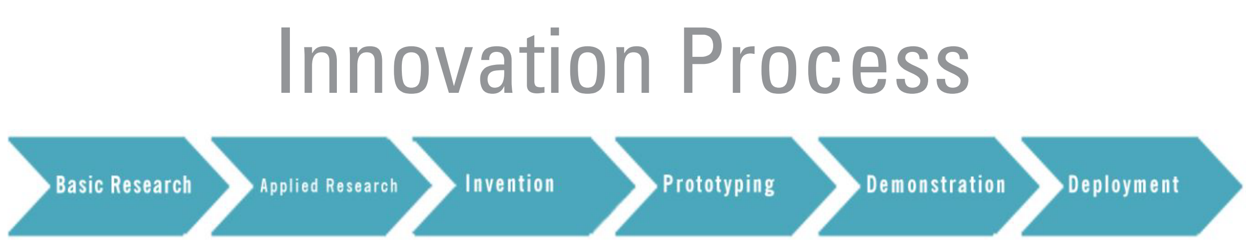
The National Innovation Landscape

Innovation is the beating heart of the American economy, and nowhere is that more true than in the energy industry. While the private sector plays the dominant role in commercializing the new technologies that will reinvent the energy sector, smart federal investments should seek to address critical gaps in the innovation process.

Energy is, for the most part, a low-cost commodity product. Generally, companies wishing to offer energy services in the marketplace face high capital requirements, long lead times, and daunting regulatory hurdles—all in pursuit of comparatively modest profit margins. Not surprisingly, these challenges mean energy providers tend to underinvest in disruptive new energy technologies. Consequently, government can play a critical and appropriate role by partnering with industry to help reduce the costs of cleaner energy through innovation.

Because energy underpins every facet of modern society, the importance of ensuring clean, affordable, reliable energy is clear. As nations around the world race to muster available resources to meet that challenge, energy access, security, and environmental benefits are critically important. The economic opportunity presented by a well-functioning energy innovation ecosystem is easily in the *trillions of dollars.* The United States' energy research and development architecture, housed primarily within the Department of Energy (DOE), has historically positioned the nation as a global leader in energy innovation. That position will not, however, sustain itself without an understanding and commitment from both government and the private sector to ensure the United States realizes its full potential to reap the enormous environmental, security, and economic benefits of energy innovation.

The innovation process for breakthrough technologies is often described as a pipeline, with basic research leading to applied research, followed by invention, prototyping, demonstration, and finally deployment.



This model is helpful for understanding the general flow of a technology from origination to the marketplace, although interactions between individuals working at different stages of the process are not included. In the course of this journey, any number of difficulties can prevent a promising technology from realizing its potential. Two distinct "valleys of death" serve as the most significant of these obstacles.

The first valley is technical—taking a research or technical concept from the laboratory and creating a viable technology. Typically, investors are hesitant to provide the large sums of capital necessary at this stage of development due to high technical risks, long time horizons, and management uncertainties. As a result, many technologies never proceed past this stage of development.

The second valley is commercial and exists between the pilot/demonstration and commercialization stages, represented by the gap between venture capital and project finance/debt equity. At this stage, technologies have demonstrated their technical viability, but developing the manufacturing processes, supply chain logistics, and other elements key to commercial viability requires enormous infusions of capital—often hundreds of millions of dollars.[i] Further, new energy technologies can often take ten to 15 years to navigate this innovation process, requiring significant technical and financial support to reach commercialization.

Providing vital research and funding support is critical to reducing project risks and attracting the private sector funding necessary to bring a project to market. Increasingly, the institutions that support this federal R&D mission are working with the private sector to develop a better understanding of market needs and to integrate anticipated commercial challenges earlier in the development stages. The recently created Office of Technology Transitions, tasked with expanding the commercial impact of DOE's research portfolio, is just one of the ways the agency is working to better align public and private sector priorities. For the reader looking for a better understanding of the scope and scale of this broader shift towards economic productivity, this white paper will examine the differing and complementary roles played by the major innovation institutions within the energy innovation ecosystem.

The National Labs

Today's national labs have roots in early atomic research. In 1942, the Manhattan Project was established, under the supervision of the U.S. Army Corps of Engineers, to develop an atomic weapon. In 1946, the Atomic Energy Commission was created to assume responsibility for the scientific complex that focused largely on nuclear weapons and nuclear submarines. That mission changed when the energy crisis of the 1970s highlighted the need for a more comprehensive national energy strategy. A series of organizations tasked with managing federal research resources, nuclear safety, and energy strategy quickly evolved from the Energy Policy Office created by President Nixon in 1973, including the Energy Research and Development Administration, the immediate precursor to the Department of Energy. Activated on October 1st, 1977, DOE consolidated entities from a dozen departments and agencies, laying the foundation for today's National Laboratory system.

Today, there are 17 National Laboratories working to ensure that the United States is at the forefront of physical, chemical, biological, computational, and information sciences. Doing so requires the design, construction, and operation of cutting-edge scientific instrumentation and facilities, a core programmatic responsibility for the Labs. The Labs also work to ensure the safety and reliability of our nuclear deterrent, while supporting efforts to prevent the proliferation of nuclear weapons across the globe. Critical to the energy sector, the National Labs are pursuing ways to strengthen U.S. energy security and leadership in the development of technologies that can provide clean, reliable, and affordable energy. These objectives cumulatively drive the National Labs' four missions: nuclear security, science, energy, and environmental stewardship.

The National Labs approach this extraordinary mission through a unique configuration that can sometimes be confusing. In order to fully appreciate the diverse contributions the National Labs continue to make to our nation, it is important to understand the general landscape of this ecosystem.

All but one of the Labs are government owned, contractor operated (GOCO) federally funded research and development centers (FFRDCs). FFRDCs exist within numerous federal agencies. The GOCO model is designed to harness the best of both the public and private sectors. Staffing flexibility for highly specialized technical talent is paired with best management practices from the private sector to compliment the government's ability to pursue complex, risky research focused on critical national priorities. Contractors are awarded management and operating (M&O) contracts, generally on a competitive basis, and are often limited liability companies formed by partners like the University of Tennessee and Battelle, who together manage the Oak Ridge National Lab (ORNL). Unlike the other National Labs, the National Energy Technology Lab (NETL), which focuses on fossil energy research, is the only National Lab that is operated by the government, rather than a private contractor (called a government owned, government operated, or "GOGO" lab).

An impressive list of inventions, including the first commercial nuclear reactors, high-efficiency wind turbines, and safer, more cost-efficient batteries used in electric cars, points to the considerable value generated by research and development conducted at the Labs. Still, considerable attention has been paid to the ways in which the management of the National Labs could be improved to *maximize* their impact. A number of reforms have been suggested, including those of the Commission to Review the Effectiveness of the National Energy Laboratories in late 2015. The commission focused heavily on the need to re-establish trust between DOE and the Labs, as well as ways to improve operations. Finding balance between providing contractors the flexibility necessary for optimal performance while holding them accountable to acceptable public standards has been a central challenge. Department of Energy Secretary Ernest Moniz has prioritized improving the performance and management of the labs, focusing on improving partnerships between the public and private sectors. In particular, technology transfer, or the process through which information is shared among those who may contribute to the commercialization of a product, has been a priority for DOE.[ii]

Developments that contributed significantly to the rise of unconventional oil and gas exploration are a perfect example of the potential impacts of these partnerships. As part of DOE's Unconventional Gas Research Program, launched in 1976, the Eastern Shales Gas Project helped to map unconventional resources and financed experimental wells. Drill bits developed by Sandia National Lab greatly improved the economy and efficiency of drilling operations and a number of other Lab-driven R&D efforts built a foundation on which private sector partners like George Mitchell were able to fully commercialize hydraulic fracturing technology.[iii]

The portfolio of research underway at the National Labs is as expansive as it is potentially transformative. To overcome the stovepipes that have often isolated programs, limited information-sharing, and hindered progress, a number of crosscutting initiatives have also been implemented at DOE. These include initiatives such as: Grid Modernization, Supercritical Carbon Dioxide Technology, Subsurface Technology and Engineering, Energy-Water Nexus, Exascale Computing, Cybersecurity, and Advanced Materials for Energy Innovation. By facilitating better flows of information between projects as well as technology transfer, crosscutting programs are an important method for ensuring efficient use of taxpayer dollars.

The Labs are pursuing technological breakthroughs that have the potential to transform the way we produce and consume energy. Energy storage is one such breakthrough that receives a great deal of warranted attention. With tremendous implications for the way the electric power grid operates—including the integration of renewable energy sources—as well as the potential to dramatically alter the transportation sector, breakthroughs in energy storage are often viewed as the Holy Grail for energy technologies. Yet energy storage is hardly the only transformative technology being explored at the National Labs. Nuclear fusion is one such technology, promising the zero-carbon electricity currently provided by nuclear fission without key drawbacks like proliferation and nuclear waste.

Instead of splitting atoms, as nuclear fission does, nuclear fusion works to combine abundant, low-cost elements like hydrogen. Fusion could provide an energy source that is virtually inexhaustible and environmentally benign, producing no combustion products, greenhouse gases, or radioactive waste. Critics who argue that a breakthrough in fusion is always "just around the corner" fail to recognize that over the last several decades a great number of technical challenges have been solved and that we are now capable of creating a controlled fusion reaction.[iv] The challenges that remain center largely on our ability to surpass the breakeven energy point, where the reaction itself produces more energy than it takes to create it. As with many other federally-supported breakthrough technologies like hydraulic fracturing, success in fusion will be built on the patience of those with a long-term perspective.

In addition to pursuing innovative, breakthrough energy technologies, the National Labs have also actively developed new institutional models that can increase their efficacy. One such example, Cyclotron Road, was launched in 2014 and acts as a technology-to-market program that seeks to bridge the gap between early-stage energy technology invention and commercial outcomes. Cyclotron Road bridges this gap by focusing on human capital, offering a home to top entrepreneurial researchers from across the country to advance technologies until they can succeed beyond the lab. The organization runs a national competition to select project leaders with high-impact technology ideas that would be unlikely to receive private sector support for the early stage of research and development. Cyclotron Road embeds these innovators at the Lawrence Berkeley National Lab for up to two years in a mentored technology entrepreneurship program. During that time, the program guides its cohort members as they work to achieve focused technology development objectives in a discrete period of time to facilitate the transition from lab to market.

Specifically, Cyclotron Road provides:

- *Salary and seed funding for up to two years*
- *Dedicated lab and office space*
- *Support obtaining additional project funds*
- *Critical technology and manufacturing guidance*
- *Advisory network support and mentorship*
- *Connections to commercial partners and investors*

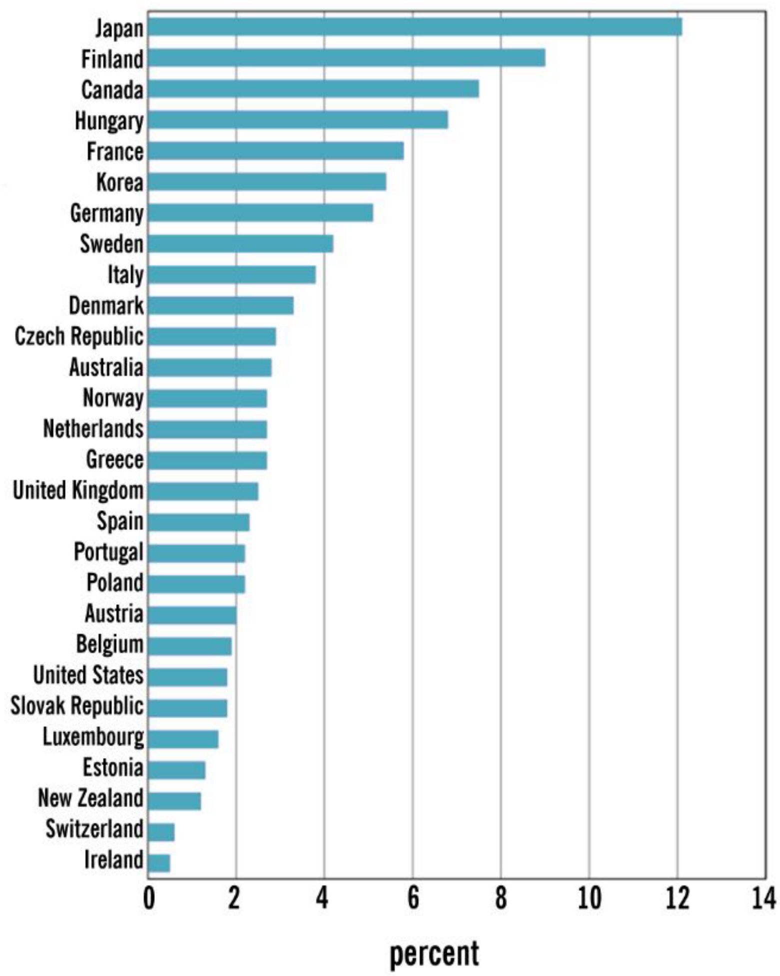
By embedding innovators at the Lawrence Berkeley National Lab, Cyclotron Road seeks to provide them with resources and an environment that allows them to explore technology opportunities and viable commercial pathways to bring their ideas to scale. By doing so, Cyclotron Road improves the risk and reward profile for innovators and investors, reduces the cost and risk of early stage development, and leverages seed investment. This innovative institutional model helps to attract America's best and brightest to the pursuit of solutions to our collective energy challenges, while increasing the likelihood that they'll develop the next breakthrough energy technology. The program is supported by the DOE Office of Energy Efficiency and Renewable Energy's (EERE) Advanced Manufacturing Office.

Despite these innovative and commercially focused approaches, funding for the National Labs has remained relatively flat since 1976, decreasing significantly as a percentage of our national research and development budget.

After reaching 18 percent in 1979, R&D spending directed toward DOE has held steady between six and nine percent of the total federal R&D funding across all categories. Considering the impact that energy affordability, reliability, and environmental concerns related to energy production have on our economy, it is astonishing that DOE's R&D budget is 0.066 percent, or less than one thousandth, of the nation's GDP.[v]

By comparison, the R&D budget for the National Institutes of Health is roughly three and a half times larger.[vi] In FY 2015, appropriations for the National Labs were $11.7 billion, a figure that encompasses all four research missions, not just energy. Funding for the national labs increased for FY 2016 to $12.3 billion, but our investment in energy R&D still lags far behind the share of investment that other nations are directing toward this pervasive technology sector.

Share of Energy in Total R&D in 2014



International Energy Agency. 2015. Data from Energy Technology RD&D Budgets Database. (September) http://wds.iea.org/wds/pdf/IEA_RDD_Factsheet_2015.pdf

The good news is that our National Labs and broader U.S. innovation ecosystem, which includes our public and private research universities, are world-class. This remains a structural advantage for the United States that we must further leverage. To that end, the National Labs are becoming a focal point for many of the new collaborative innovation models discussed later in this paper. With a combination of scientific and engineering talent, diagnostic tools, and user facilities that cannot be found anywhere else in the world, the Labs are envisioning how they might play larger roles as technology incubators and as sponsors of testbeds for new hardware. In the hyper-competitive global economy, we cannot take our labs and their role in the innovation ecosystem for granted. Ensuring we maintain that advantage as other nations increase support for their own innovation institutions will require a serious commitment to funding American ingenuity.

"In the hyper-competitive global economy, we cannot take our labs and their role in the innovation ecosystem for granted."

ARPA-E

The Advanced Research Projects Agency-Energy (ARPA-E) is an agency within DOE that funds high-risk, high-reward energy research caught in the technological valley of death. ARPA-E focuses on medium- to long-term projects that have the potential to radically improve U.S. economic security, national security, and environmental well-being. ARPA-E seeks to fund collaborative projects involving government labs, private industry, and universities and to empower researchers with funding, technical assistance, and market readiness.

ARPA-E was modeled after the successful Defense Advanced Research Projects Agency (DARPA) in the Department of Defense, which is credited with the creation of GPS, the stealth fighter, and computer networking. The agency was first established by the America COMPETES Act of 2007 as a way to enhance American competitiveness in science and technology. As part of the COMPETES Act, Congress directed ARPA-E to establish project milestones, initiate research projects quickly, and just as quickly terminate or restructure projects if such milestones aren't achieved. Typically, ARPA-E competitively funds and supports projects for one to three years, with the amount of funding varying by project. This structure enables projects that demonstrate promise to move forward while replacing ineffective projects with new areas of exploration. In addition to strict performance metrics, ARPA-E's focus on commercialization begins as soon as a project enters the program. These processes allow ARPA-E projects to better anticipate and address obstacles to commercialization.

Although ARPA-E was first established in 2007, it did not receive funding until 2009. Since then, congressional appropriations for ARPA-E have fluctuated dramatically from year to year, with annual appropriations ranging from $0 to $400 million. The American Energy Innovation Council recommends funding ARPA-E at a level of $1 billion annually, as the agency is currently only able to accept around 2 percent of projects that apply for funding, leaving numerous promising technologies without critical support. Funding levels should be at least $300 million per year to maintain the current level of success. In FY 2015, ARPA-E received $280 million in appropriations, followed by $291 million in FY 2016. DOE's most recent congressional budget request has a proposed funding level of $350 million in FY 2017, plus new mandatory spending of $150 million.

Since 2009, ARPA-E has funded over 475 new energy projects. At this early stage in the life of the program, 45 of these projects have attracted more than $1.25 billion in private sector follow-on funding. Further, at least 36 ARPA-E project teams have formed new companies to advance their technologies. ARPA-E has already achieved immense success, but it could arguably do much more with better and more consistent funding.

Past ARPA-E awardees have achieved remarkable technical feats that may dramatically shape and improve the U.S. energy economy, such as:

- *The development of a new, simplified method for manufacturing silicon wafers that reduces module costs by 50%*
- *Engineered microbes that use hydrogen and carbon dioxide to make liquid transportation fuel*
- *The development of an airborne wind turbine with 90 percent less mass than existing turbines that is capable of operating at an altitude that expands accessible wind resources in the United States by a factor of five.*

These facts clearly support the view of ARPA-E as a model for federal support of high-risk, high-reward energy projects. It fills a unique place in the innovation process through two types of solicitations: program solicitations, which target specific technology gaps, and open solicitations, which enable potentially transformative energy projects of any kind to receive critical assistance across the technological valley of death.

Energy Frontier Research Centers (EFRCs)

DOE's Office of Science established the Energy Frontier Research Center (EFRC) program in 2009 as a way to accelerate transformative discoveries of the energy technologies of the future. The EFRCs operate under the Basic Energy Sciences (BES) program in the Office of Science and seek to harness the most basic and advanced research to establish the scientific foundation for a fundamentally new U.S. energy economy. The program consists of integrated, multi-investigator centers and involves partnerships among universities, national labs, nonprofits, and for-profit firms to conduct fundamental research. The research conducted at the EFRCs tends to focus on one or more "grand challenge" or "basic research need" identified in strategic planning efforts b the scientific community.

Grand challenges include pressing questions about the nature of energy systems, such as:

- *How do we control materials processes at the level of electrons?*
- *How can we master energy and information on the nanoscale to create new technologies with capabilities rivaling those of living things?*
- *How do we characterize and control matter away—especially very far away—from equilibrium?*

The basic research focus of EFRCs does not focus on bridging either of the valleys of death. Instead, they perform the basic research that provides the foundation on which technologies will later be developed. The Photosynthetic Antenna Research Center (PARC) recently announced the design of a small protein that can convert light energy into electrical energy.[vii] This discovery does not have immediate commercial value, but could lead to scientists being able to harness proteins with distinct functions that can combine to perform complex chemical reactions, including fuel production. The private sector cannot fully capture the society-wide benefits created by this type of basic research, particularly at the cost and time horizons involved in translating basic research all the way to a deployed product. For that reason, the EFRCs fill a critical gap in the innovation ecosystem.

Universities, national labs, nonprofits, and private firms are all eligible to compete for awards and are encouraged to form multi-disciplinary research teams across organizations. At the inception of the program, 46 centers were selected based on scientific review and were funded at $2.5 million per year for a five-year initial award period. In 2014 there was an open re-competition of the program, which distributed four-year awards to 32 centers, 22 of which were renewals of existing EFRCs. The goal is that awardees will help lay the scientific groundwork for new energy technology and includes, but is not limited to, advances in electricity storage, solar energy, carbon capture and storage, nuclear energy, etc. The EFRCs received $55.8 million in funding in FY 2016, and DOE has requested the same funding level for the program for FY 2017.

Energy Innovation Hubs

The energy innovation hub program seeks to address energy challenges that have been the most resistant to solution by conventional R&D management structures. The hubs focus on combining basic research with engineering to accelerate scientific discovery and unlike the EFRCs, each hub focuses on only a single topic. Highly collaborative, the hubs were first established in 2010 and modeled after the Manhattan Project and AT&T Bell Labs. Composed of integrated teams with expertise across multiple scientific disciplines, engineering fields, and technology areas, the hubs bring together talent from universities, private industry, nonprofits, and government labs.

These robust links to industry and larger interdisciplinary teams differentiate the hubs from other programs within the Department of Energy innovation apparatus. Bridging both the technological and commercial valleys of death depend on those links and the energy innovation hubs have already demonstrated an ability to accelerate the innovation process. The Critical Materials Institute (CMI), founded in 2013, has already developed a commercial technology: U.S. Rare Earths Inc. has purchased the license for a solvent that enables a single-step process to recover rare-earth elements from scrap magnets with significant environmental advantages over conventional processes. Moreover, each of the hubs operate and are funded by different DOE offices.

There are currently four innovation hubs, each with a unique focus:

- *The Consortium for Advanced Simulation of Light Water Reactors (CASL) seeks to accelerate nuclear energy modeling and simulation (M&S) R&D and operates out of DOE's Office of Nuclear Energy;*
- *The Joint Center for Artificial Photosynthesis (JCAP) seeks to find new and effective ways to produce fuels using only sunlight, water, and carbon dioxide. It operates out of the Basic Energy Sciences (BES) program within DOE's Office of Science;*
- *The Joint Center for Energy Storage Research (JCESR) seeks to establish next-generation electricity storage and focuses exclusively on beyond-lithium-ion energy storage. JCESR also operates within BES;*
- *CMI focuses on developing technologies that make better use of materials and eliminate the need for materials that are subject to supply disruptions. CMI is part of the Advanced Manufacturing program within DOE's Office of Energy Efficiency and Renewable Energy (EERE).*

For FY 2016, these four hubs received a combined $88.44 million in federal funding. The request for FY 2017 decreases the funding for these four hubs to $83.39 million, with $5 million of those reductions coming from CMI. However, DOE proposed $25 million in its FY 2017 budget request to help launch a fifth innovation hub, focused on energy-water desalination.

National Network for Manufacturing Innovation (NNMIs)

The National Network for Manufacturing Innovation (NNMI) program is managed by the interagency Advanced Manufacturing National Program Office (AMNPO), and the first institute was launched in 2012. The Department of Energy (DOE) is a participating agency, along with the Department of Defense, NASA, the National Science Foundation, the Department of Commerce, and other agencies. There are currently 7 NNMIs in operation, with 2 more currently pending. The goal of each institute is to foster innovation and to become a self-sustaining center of technical excellence.

The NNMI program partners with industry to develop innovative manufacturing technologies and processes that can reinvigorate America's manufacturing sector. The NNMI network provides a research infrastructure where U.S. industry and academia can collaborate to solve industry-relevant manufacturing challenges. This network approach allows institutes to complement each other's research, and benefit from shared approaches. Each institute is regionally focused, but all share a common goal to create, showcase, and deploy new capabilities and manufacturing processes and to stimulate the manufacturing sector as a whole.

Working with the Institute for Advanced Composites Manufacturing Innovation at Oak Ridge National Laboratories, Local Motors, Cincinnati Incorporated, Oak Ridge Associated Universities, and students at the University of Tennessee developed a prototype vehicle manufactured by three-dimensional printing. The two-seat electric vehicle is produced with carbon-fiber-reinforced plastic, which is a versatile, strong, and relatively cheap material that could enable some new approaches to safety and is so lightweight that it does not require power steering. The Strati 3D is built in layers squirted from the nozzles of a massive printer, and two Local Motors plants employing 100 people are expected to begin manufacturing it this year. Three-dimensional manufacturing is just one of the ways in which the NNMIs are helping America to reinvent its manufacturing sector. Doing so would help the United States reclaim the economic prosperity that accompanies that kind of global leadership.

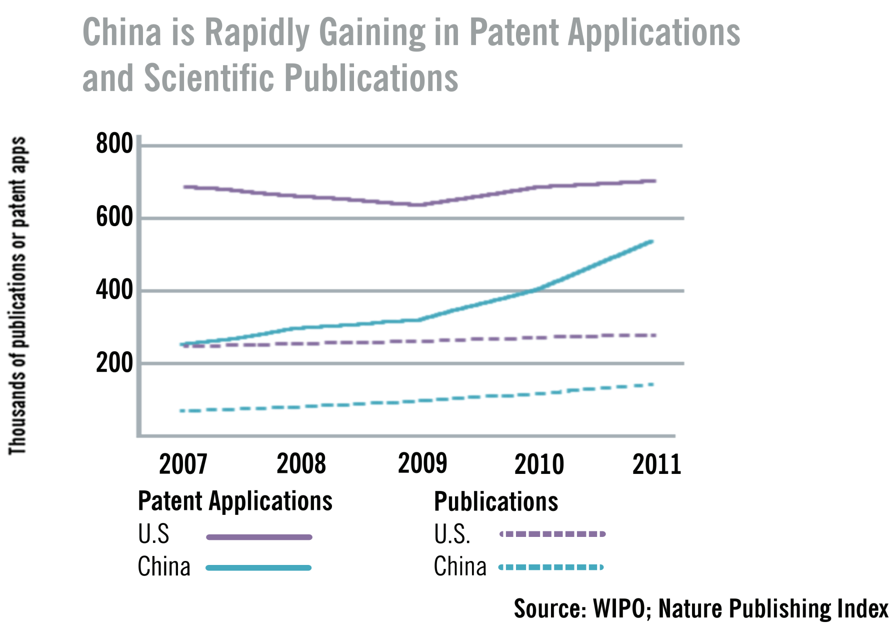
DOE funds the Clean Energy Manufacturing Innovation Institutes as the energy-focused centers of the NNMI program. DOE intends to invest $70 million over five years into each new institute, which translates into roughly $14 million a year for each. The Clean Energy Manufacturing Innovation Institutes operate within DOE's Advanced Manufacturing program within EERE. For FY 2016, Congress appropriated $56 million for four existing institutes and an additional $14 million to help launch a new institute. In its FY 2017 budget request, DOE requested $70 million to help fund five existing institutes and an additional $14 million for a new institute.

While the other facilities and programs focus on basic research or bridging the valleys of death, the manufacturing institutes conduct basic and applied research in manufacturing processes that enable competitive commercialization. NNMIs exemplify the increasingly blurred lines between basic and applied research and better enable us to develop competitive domestic manufacturing processes that can reinvigorate this crucial sector of our economy.

U.S. Competitiveness

There is a tremendous economic opportunity in the $6 trillion global energy market as energy demand is projected to grow substantially in the next several decades.[viii ix] Seizing this multi-trillion dollar opportunity could improve the American economy in profound ways, but the ability of U.S. businesses to be competitive in this rapidly evolving technology sector will be key. Throughout the 20th Century, U.S. prosperity was driven by technological innovation, establishing a widely recognized model for economic growth.[x]

Global competitors, especially in Europe and Asia, are investing heavily in innovation as a way to build their own economies. Strategic investments in innovation, especially in the science and technology sector, have enabled rapid growth in South Korea over the last 30 years.[xi] Combined with a number of factors, including the return of students educated in the United States and an increasing tolerance for risk, South Korea has established itself as a global leader in battery technology, which is projected to grow into a $100 billion to $150 billion market in the United States alone.[xii] European nations such as Germany, Finland, Sweden and Denmark reinvest greater percentages of their GDP into R&D and the United States is at risk of losing ground in key global markets.[xiii] In the cases of catalysis ($500 billion) and semiconductors ($300 billion), significant and strategic investments in basic research by Germany, China, Japan and others threaten the dominant hold the U.S once had on these industries.[xiv] At current rates of growth and investment, China will surpass the United States in total R&D funding by 2022.[xv]



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Yet the United States still maintains several key advantages in the global race to develop innovative energy technologies. The United States still leads the world in total energy R&D investments, has world-class entrepreneurs, a sophisticated financial industry, a robust legal system to protect contracts, as well as large technology and energy companies with both the skills and a desire to contribute to our ability to innovate. Further, the energy R&D architecture in the United States, including world-class facilities and scientists, provides a foundation from which we can extend our technological dominance into the 21st Century.

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Notes

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Disclaimer

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