The American Recovery & Reinvestment Act and the Rise of Utility-Scale Solar Photovoltaics: How U.S. Public Policy During the Great Recession Launched a Decade-Long Solar Boom

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The AEIC Scaling Innovation Project

This paper is one in a series of case studies examining the role of demonstration projects in the commercialization of new clean energy technologies.

In the first AEIC report, *A Business Plan for America's Energy Future (2010)*, a New Energy Challenge Program was proposed as a way for the U.S. government to support the demonstration and eventual commercialization of new energy technologies. For the United States to meet aggressive mid-century decarbonization commitments, a technology-inclusive portfolio of clean and innovative technologies, including advanced nuclear and renewable energy systems, zero-carbon fuels, long-duration electricity storage, and carbon capture and storage, must be deployed commercially at scale. The initial demonstration of complex technologies is a well-recognized challenge in the energy sector where first-of-kind risks are difficult to manage and projects must operate in highly regulated commodity markets, many of which may not yet appropriately value their advanced attributes. Because of this, the AEIC and many other experts have concluded the federal government has a role to play in overcoming this so-called demonstration "valley of death."

The AEIC believes there is an opportunity – and a need – to strengthen federal policy frameworks in support of scaling innovation to more effectively accelerate the commercialization of new energy technologies. The case studies in this series look back to notable policy efforts in the past to help inform a new policy agenda for the future.

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Key Recommendations

The U.S. government's support for large clean energy demonstration projects through the American Recovery and Reinvestment Act of 2009, or ARRA, sparked a decade-long boom in utility-scale solar photovoltaic, or PV, power plant construction. Policymakers today are once again contemplating a recovery package – this time to respond to the economic fallout of the coronavirus crisis – and have a fresh opportunity to stimulate low-carbon economic growth. To make the most of this opportunity, they should prioritize investments in scaling up emerging clean energy technologies. The success of the ARRA in demonstrating solar PV technology at scale provides important lessons for policymakers to heed:

1. **Large-scale demonstration projects of commercially proven technologies can unlock rapid market growth.** The term "demonstration project" is often used for the first-of-a-kind implementation of a technology that is relatively unproven. Such projects are indeed vital, but they are not the only category of valuable demonstration projects. In this case, the federal government supported the first demonstration at scale of a clean energy technology – solar PV – that was already commercially proven around the world. With the help of federal loan guarantees and cash grants under the ARRA, private developers financed and constructed the first five utility-scale solar PV plants in the United States with power-generating capacity greater than 100 megawatts each. Having gained confidence in solar PV as a bankable technology at power plant scales, the private sector proceeded to finance many more large PV projects after ARRA provisions expired. Looking ahead, policymakers should recognize that large-scale demonstration projects can embolden private investors to rapidly scale up the deployment of new technologies – from hydrogen-producing electrolyzers to long-duration flow batteries – that have already been proven at smaller scales.

2. **To mobilize private investment in clean energy technologies, the government must demonstrate credible technical and financial expertise and collaborate with the private sector.** To provide loan guarantees for these massive and complex solar PV mega-projects, the Department of Energy's Loan Programs Office, or LPO, had to quickly build several competencies. It hired hundreds of people, many of whom were experienced private investors, and it marshalled resources across the federal government to conduct rigorous technical due diligence of proposed projects. Thus, when the LPO convened a consortium of private lenders to collaborate on financing a large-scale solar PV project, those lenders were reassured by the financial certainty of the government loan guarantee as well as by the technical rigor of the due diligence review. Many of the same lenders would draw confidence from this experience to then finance future projects without federal loan guarantees.

3. **The ability of demonstration projects to unlock commercial market growth requires supportive public policies for clean energy deployment.** Although ARRA provisions expired after 2011, the utility-scale solar PV market continued to boom for a decade. Part of the reason was demonstration projects had emboldened private lenders to invest in similar projects. But just as importantly, other state and federal policies

were conducive to continued deployment. State renewable portfolio standards, which required utilities and other buyers to sign long-term contracts for clean energy, created demand for solar power. At the same time, federal tax credits lowered the upfront capital cost of solar plants. Together, these policies provided an off-ramp even as ARRA support for demonstration projects expired. As a result, private investors still found it attractive to scale up solar PV technology in subsequent years.

4. **Government support for research, development, and early-stage demonstration is also critical to seed the pipeline of clean energy technologies ready for rapid scale-up.** By the time the ARRA launched a decade-long solar boom, PV technology had already benefited from more than half a century of technological development, including public funding for research, development, and smaller-scale demonstration projects around the world. Future clean energy technologies must be developed faster, which will require intense investment in all stages of the innovation process. Only once the innovation pipeline has been seeded with an array of promising energy technologies can government support for large-scale demonstration projects provide a final stepping-stone toward rapid commercial growth.

Introduction

Utility-scale solar photovoltaic, or PV, power plants represent the fastest-growing source of electricity in the United States. In 2020, they will generate over 2% of the country's electricity, and solar PV capacity will grow 17% to 85 gigawatts.[1] Yet a decade earlier, not a single utility-scale solar PV plant with more than 100 megawatts of power-generating capacity was in operation. The last decade, therefore, represents a step-change in the progress of solar power in the United States and in the emergence of a commercially compelling technology to reduce U.S. carbon emissions at scale.

Public policy played an essential role in achieving this step-change. Over the last half-century, various public policies – from government funding for research, development, and demonstration, or RD&D, to federal and state incentives for commercial deployment – laid the groundwork for the rise of solar PV. In 2009, the Great Recession prompted adoption of a large federal stimulus package, known as the American Recovery and Reinvestment Act, or ARRA, which provided various forms of public support for clean energy, notably including loan guarantees for large projects. These loan guarantees – in concert with an array of other prevailing federal and state policies – would embolden the private sector to build the first five larger-than-100-MW solar PV installations and kick off a decade-long solar boom that shows no signs of ending.

Clean energy innovation is a complex and nonlinear phenomenon, and although supportive public policy is indisputably essential, clear cases where policy intervention directly resulted in immediate and tangible technology commercialization are rare.[2] The story of how public policy jumpstarted the utility-scale solar PV market from 2009 to 2011 is one of those rare cases. Prior to 2009, PV technology was already commercially viable and had been installed at small and intermediate scales in the United States and around the world. Yet private sector actors – in particular, debt investors – had no experience financing and constructing massive utility-scale solar PV plants. By guaranteeing loans for five of the world's largest-ever PV plants, the federal government gave private investors an opportunity to participate risk-free in demonstrating this technology at the grand scale of hundreds of megawatts. Although the government stopped offering new loan guarantees after 2011, it had opened the floodgates for private investors to continue funding large utility-scale solar PV projects. Meanwhile, other federal and state policies aimed at supporting clean energy deployment would continue to buttress the industry's growth.

To be sure, U.S. policy was not the only driver of the solar boom. The policy push from 2009 to 2011 also coincided with a sharp decline in global prices for solar panels. Indeed, had the price of solar panels not fallen by over 70% between 2008 and 2012, the utility-scale solar boom in the United States might not have happened.[3] But public policy played an important role in jumpstarting the domestic solar boom over and above the favorable effect of falling solar panel prices. Put another way, if not for the raft of federal and state policies that supported solar PV – anchored by the Department of Energy's loan guarantee program from 2009 to 2011 – it would have taken longer for the private sector alone to build the first large utility-scale solar PV projects and cumulative solar PV deployment today would be far lower.

Studying the PV case is instructive for designing policies to advance the commercialization and scale-up of other decarbonization technologies. For example, systems for capturing carbon dioxide from the air and for using electrolysis to produce hydrogen both use modular, capital-intensive technologies – similar in some ways to solar PV technology – and their deployment on a mass scale may be needed to decarbonize global energy systems. One lesson from this solar PV case study is that even after low-carbon technologies are developed and have been successfully demonstrated at small commercial scales, private investors may not yet be comfortable deploying them at much larger scales. To speed up commercial deployment at the scale and speed needed to combat climate change, a decisive public policy push may be needed to fill the gap in capital available for large demonstration projects.[4]

Importantly, this case study will not shed much light on the processes required to bring a technology to the level of maturity at which large demonstration projects can then unlock self-sustaining commercial deployment at massive scale. Innovation is a long and messy process. In the case of solar PV, the first silicon PV cell was invented in 1954 – half a century before solar power began to generate appreciable levels of electricity worldwide. The solar success story of the last decade must be placed in the context of a much more mixed record of policy effectiveness in rapidly stimulating PV technology innovation. Decarbonizing global energy systems will require a portfolio of innovation policies to accelerate the many processes that ultimately enable the emergence of commercially mature clean energy technologies.

Context and Background

A Brief History of the U.S. Solar PV Market, Prior to the Great Recession

The recent emergence of solar PV as the fastest-growing power source in the United States and around the world follows several decades in which solar energy struggled to achieve mainstream status. The first solar cell that could convert more than 1% of incoming sunlight into electricity was invented in 1954 by Bell Labs. As researchers and firms refined the technology for the next two decades, most installed PV capacity was deployed in space on satellites. The oil crisis of 1973 spurred the government to invest heavily in solar as part of a push to develop alternative energy sources. By 1980, publicly funded RD&D to the tune of $157 million had led to significant technology breakthroughs in improving efficiency and reducing cost. Moreover, federal deployment incentives and legislation that required utilities to favorably compensate solar generators supported the early deployment of solar PV and helped further reduce cost.[5]

Yet the fledgling U.S. solar industry was dealt a severe blow in the 1980s. Against a backdrop of falling oil prices and the election of Ronald Reagan, the federal government cut funding for RD&D and let deployment incentives for solar, such as tax credits, expire. Until the early 2000s, the deployment of solar PV in the United States remained anemic, and manufacturers struggled amid weak domestic demand. Meanwhile, Japan and Germany drove the growth of the global solar industry through their own support for RD&D, manufacturing, and PV deployment. Finally, in the early 2000s, the solar market in the United States began to pick up again, driven in large part by state incentives such as the California Solar Initiative. Whereas U.S. solar deployment had grown by less than 10% annually before the turn of the century, from 2001 to 2009 growth averaged 60% per year.[6]

Still, during most of the 2000s the cost of solar power in the United States remained high – much higher than that of conventional fossil-fuel power generation. One reason solar remained expensive was that PV module prices stagnated in the mid-2000s. But another important reason was that before 2007, not a single utility-scale PV installation existed in the United States. Thanks to economies of scale, larger PV installations were 20% to 30% cheaper than smaller installations between 2007 and 2009, but only a handful of projects larger than 10 MW were built during this period, owing to limited funding from investors.[7]

By 2009, solar PV technology was fairly mature. Half a century of RD&D at universities, government laboratories, and private firms in the United States and around the world had led to efficient solar cells. Increasing scale had enabled manufacturers to hone their production processes, and years of field production data from solar installations had shed light on the long-term performance of solar panels. Most installed solar capacity around the world used silicon PV technology, though another technology – using thin films made of cadmium telluride and manufactured by the U.S. firm First Solar – had also achieved meaningful commercial deployment. Yet despite the commercial entry of solar PV technologies, an innovation gap remained: No truly large solar installations – 100 MW or larger – had ever been built anywhere in the world. Before the first large-scale demonstration projects could secure financing, financiers would remain wary of deploying their capital to build solar projects of unprecedented scale. Large utility-scale solar faced the proverbial "chicken-and-egg" problem common to many new technologies.

The outlook for investors to take new risks was grim in 2009. By February 2009, with the Great Recession in full swing, only four U.S. banks were considering financing renewable energy projects – down from eighteen before the recession. Investor sentiment was negative even though the price of solar panels had already begun to decline precipitously. In the second half of 2008, the price of solar panels suddenly dropped 25% and it continued to plummet for years, driven by falling costs of raw material inputs for silicon solar cells and a glut of state-sponsored PV production capacity in China. Nevertheless, given the scarcity of capital in the depths of the recession, trade groups warned in early 2009 that renewable energy installations could fall by 30% to 50%.[8]

U.S. Policy Support for Solar Power Leading Up to the Great Recession

Decisive public policy support for solar power, delivered through the stimulus package, reversed the grim outlook for solar power in 2009 and jumpstarted a decade-long boom. But it is important to first understand the backdrop of federal and state policy support against which the stimulus would prove so effective.

Through the 2000s, state and federal policies worked in tandem to support the deployment of solar PV projects. California was the leading state for solar deployment. Its suite of policies included incentive payments for solar installations as well as a renewable portfolio standard – a mandate that 20% of the state's electricity come from renewable sources by 2020. This mandate prompted the state's utilities to seek to lock in long-term agreements to purchase power from renewable energy projects, creating an important source of demand for new solar projects.

At the federal level, the Energy Policy Act of 2005 established a 30% investment tax credit, or ITC, for solar PV systems. This policy substantially subsidized the upfront capital cost of constructing a new solar PV plant. With the ITC, the owner of a solar project could reduce its taxable income by 30% of project's capital cost. In many cases, however, the project developer would not have enough taxable income to take full advantage of the ITC. To get around this limitation, the solar industry developed innovative financing structures – including "partnership flip" and "sale leaseback" models – to partner with and enable entities such as banks to monetize the federal tax credits. Because project developers had to secure and compensate tax equity investors, the effective subsidy from the ITC was less than a 30% cash grant would have been. Nevertheless, the ITC made the economics of solar power much more attractive. Yet the recession threatened to nullify its impact. Due to the lack of taxable profits across the economy during the recession, very few entities were able to act as tax equity investors. Moreover, the ITC was set to expire in 2008. Thus, despite supportive federal and state policies, the advent of the recession threatened to halt the slow and steady progress that the industry had made.

The ARRA and Support for Large-Scale PV Demonstration Projects

Federal support for the U.S. solar industry, which was by then reeling from the recession, began in 2008. In October of that year, under the outgoing administration of President George W. Bush, Congress passed the Emergency Economic Stabilization Act, which extended the ITC to 2016. This afforded some policy stability to the solar industry, but more meaningful action would come the following year, in 2009, under President Barack Obama. A month after taking office, President Obama signed the American Recovery and Reinvestment Act of 2009 – a $787 billion stimulus package. It included a bevy of initiatives to support clean energy RD&D and deployment, from the creation of the Advanced Research Projects Agency–Energy to the allocation of nearly $17 billion to the DOE Office of Energy Efficiency and Renewable Energy.

Section 1603 Cash Grant and Section 1705 Loan Guarantee Programs

Two ARRA provisions in particular were pivotal to expanding the utility-scale solar PV market, in tandem with the existing landscape of state policies. The first allowed renewable energy projects eligible for tax credits to instead receive a cash grant – known as a Section 1603 grant – from the Treasury Department. A solar project developer could receive 30% of the capital cost of a project in cash up front, rather than needing to find a tax equity partner in the middle of the recession. This provision would support thousands of smaller-scale renewable energy projects and would also serve as an important enabler for financing of some of the biggest solar projects in the world.

The second crucial ARRA provision authorized $6 billion to expand the DOE loan guarantee program in a way that would support large-scale demonstrations of commercially proven technologies, such as solar PV. Section 1703 of the Energy Policy Act of 2005 had established a loan guarantee program to enable innovative energy technologies to raise financing. The 1703 program, however, was not ideal for supporting large-scale solar PV demonstration projects. Its loan guarantees were restricted to projects that "employ new or significantly improved technologies as compared to commercial technologies" – a requirement that a large-scale project slated to use commercially available solar PV equipment would fail to meet.[9] But under the ARRA, DOE was authorized to make loan guarantees for renewable energy projects through a temporary program, Section 1705, even if the projects involved lower-risk technologies than those eligible for loan guarantees under Section 1703. Moreover, Congress appropriated funds to cover credit subsidy costs for Section 1705 loan guarantees. Under Section 1703, the government charged project developers who received loan guarantees a credit subsidy fee to cover the risk-weighted cost of a potential default. Now, under Section 1705, a renewable energy project developer could apply to guarantee the entire loan needed to finance the project without paying any upfront fee.

Taken together, these features of the Section 1705 loan program were very attractive to solar PV project developers. The main limitation of the program was that loan guarantees could be issued only until September 30, 2011. This time limit led to a rush of applicants.

Effects of the ARRA on the Utility-Scale Solar PV Market

The ARRA supported solar power in several ways, but in retrospect, the most consequential provisions were the Section 1705 loan guarantees and the Section 1603 cash grants. Notably, these provisions supported a broader set of projects than just large-scale solar PV demonstrations. More than 80% of the $16 billion in Section 1705 loan guarantees went to some form of solar energy technology, including to innovative manufacturers and solar power generating facilities that used solar thermal rather than solar PV technology. The 1705 program is probably best known for one of its failures: a loan guarantee to thin-film PV manufacturer Solyndra, which later defaulted on its loan. This paper does not attempt to evaluate the overall 1705 program, though it is important to note the full portfolio of DOE loan guarantees has performed well overall and support for higher-risk demonstrations is both critically important and, by its nature, destined to result in some failures as well as successes.[10] Zeroing in on utility-scale solar PV projects, the 1705 program provided nearly $5 billion in loan guarantees for five projects totaling 1.5 GW in installed capacity (Table 1). Some of these projects also took advantage of Section 1603 cash grants, thereby avoiding the need for expensive and complex tax equity financing.[11]

Table 1: Solar PV Projects with Capacity >100MW That Received Section 1705 Loan Guarantees

Project name	Owner(s) and partner(s)	Solar PV module technology	Offtaker	Loan issuance date	Project completion date	Loan guarantee ($ million)	Size (MW_{DC})
Agua Caliente	NRG Solar & MidAmerican Renewables	First Solar thin film CdTe PV modules	PG&E	August 2011	March 2014	$967	290
California Valley Solar Ranch	NRG Energy & NRG Solar	SunPower crystalline silicon PV modules	PG&E	September 2011	October 2013	$1,237	250
Mesquite Solar	Sempra	Suntech crystalline silicon PV modules	PG&E	September 2011	June 2013	$337	170
Antelope Valley Solar Ranch	Exelon	First Solar thin film CdTe PV modules	PG&E	September 2011	April 2014	$646	242
Desert Sunlight	NextEra Energy, GE, and Sumitomo	First Solar thin film CdTe PV modules	PG&E, SCE	September 2011	February 2015	$1,460	550
			Total			**$4,647**	**1,502**

Source: U.S. Department of Energy, *Powering New Markets: Utility-Scale Photovoltaic Solar*, February 2015. Available at: https://www.energy.gov/sites/prod/files/2015/02/f19/DOE _ LPO _ Utility-Scale _ PV _ Solar _ Markets _ February2015.pdf

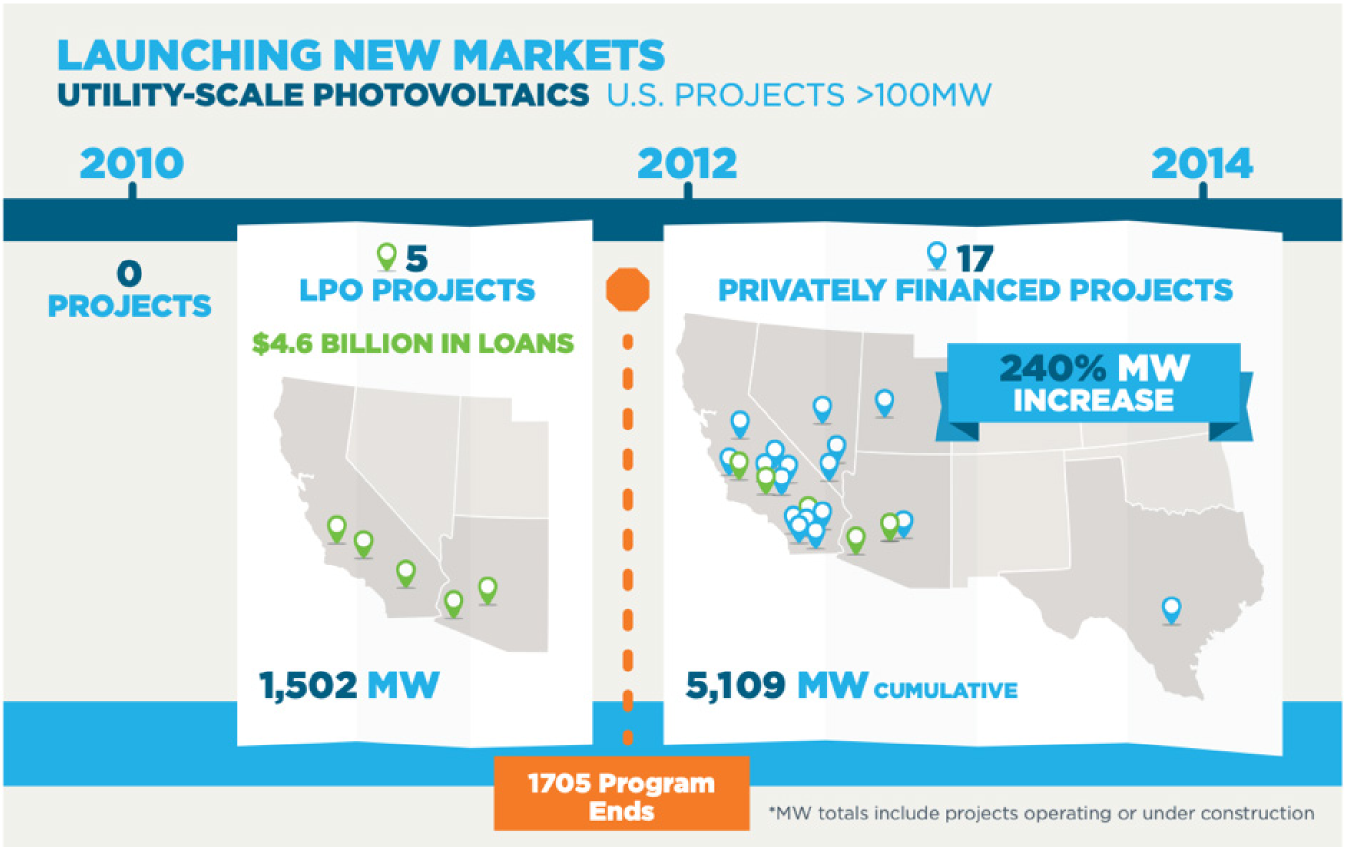
Thanks to Section 1705 loan guarantees, these five projects were the first large – greater than 100 MW – solar PV projects in the United States to close financing. All five projects would ultimately be successfully constructed, and they continue to operate and earn revenue as envisioned in their applications for loan guarantees. To process these applications, DOE's Loan Programs Office, or LPO, had to substantially enhance its capabilities. By the time Section 1705 expired, the LPO employed a staff of more than 250, up from 13 employees before the ARRA, and counted among its ranks many former private-sector professionals. It had also invested more in clean energy than the next ten largest U.S. funds combined.[12] According to Jonathan Silver, who led the office, loan guarantees were only part of the reason that private lenders gained confidence in funding renewable energy projects.[13] In addition, the LPO conducted detailed and sophisticated technical due diligence, taking advantage of extensive government resources, including the expertise of DOE's national laboratories, to evaluate projects. The Government Accountability Office found that private lenders judged the LPO diligence processes to be as or more stringent than those in the private sector.[14] Together, the federal loan guarantee and the imprimatur of DOE technical due diligence helped embolden private lenders to supply debt capital at below-market rates.

Importantly, the LPO also changed the loan guarantee process in ways that encouraged more private lending. Historically, DOE loan guarantees have not only guaranteed loans – that is, committed to repay lenders in the event of a default – but have also arranged financing through the Treasury Department's Federal Financing Bank. As a result, project developers treated the loan guarantee program as source of debt capital rather than as a credit enhancement, and most federal loan guarantees did not directly involve private lenders. For four of the five utility-scale solar PV projects that received a loan guarantee, this model remained in effect, which meant that project sponsors simply received loans from the government. But DOE recognized that a thriving U.S. utility-scale solar PV market would need active private lenders, so it created the Financial Institution Partnership Program, a consortium of fourteen financial institutions that would directly lend debt capital to renewable energy projects. The fifth utility-scale PV project, Desert Sunlight, was financed by private lenders after receiving a loan guarantee from the federal government. These private lenders would go on to finance many more utility-scale solar PV projects without loan guarantees in the future.[15,16]

The Section 1705 loan guarantees and Section 1603 cash grants, while critically important, only addressed the capital needs of new solar projects. For these projects to go forward, there needed to be a market for the power they would generate and a way to generate revenue to pay back the loans. This is where state policies played a vital role. In particular, California's renewable portfolio standard, which mandated the state's investor-owned utilities supply a portion of their customers' electricity with renewable energy, provided the demand for all five projects supported by DOE loan guarantees. As Table 1 shows, Pacific Gas & Electric signed power purchase agreements to buy power from all five projects for 25 years at pre-agreed, attractive prices; another investor-owned utility, Southern California Edison, also signed a partial power purchase agreement for the Desert Sunlight project.[17]

Once the five loan-guarantee-supported solar PV projects closed their financing in 2011, the floodgates opened for private financing of utility-scale solar projects in the United States. Even though Section 1705 and Section 1603 both expired in 2011, private investors drove a rapid expansion of the solar market. By 2014, over 5 GW of projects greater than 100 MW each had closed financing – more than three times the generating capacity the loan guarantee program had supported (Figure 1). State renewable portfolio standards continued to proliferate, and the federal ITC continued to subsidize the construction of new facilities. As costs fell for both equipment and financing, the price of solar power in power purchase agreements dropped to less than $50 per megawatt-hour in 2014, a reduction of more than 60% compared with prices before the loan guarantee program.[18]

Figure 1: Timeline of U.S. Utility-Scale Solar PV Projects with Capacity Greater Than 100 MW



Source: U.S. Department of Energy, *Powering New Markets: Utility-Scale Photovoltaic Solar*, February 2015. Available at: https://www.energy.gov/sites/prod/files/2015/02/f19/DOE_LPO_Utility-Scale_PV_Solar_Markets_February2015.pdf

To summarize, the ARRA helped turn around what was then a grim outlook for solar PV in 2009. The ARRA filled a crucial gap – providing financing for large-scale demonstration projects – to jumpstart a decade-long boom in utility-scale solar PV deployment. Several elements played a role in this success. First, by demonstrating solar PV projects at the scale of hundreds of megawatts could pass rigorous technical due diligence and by facilitating the active participation of lenders to provide project financing, the loan guarantee program emboldened private lenders to invest on their own in new projects. Indeed, many of the same lenders that participated in the loan guarantee program – such as John Hancock, Goldman Sachs, Bank of America, and Citigroup – also financed future projects without loan guarantees.[19] Second, the Section 1603 cash grant program enabled project sponsors to immediately access an upfront subsidy of 30% of a project's capital cost. After Section 1603 expired, most utility-scale solar PV projects would be financed using tax equity, but the ARRA enabled the industry to ride out a period when tax equity investors were scarce, owing to the dearth of taxable profits across the economy. And third, state policies – notably California's renewable energy mandate – bolstered demand for renewable energy and prompted utilities to sign long-term power purchase agreements at attractive prices for electricity from utility-scale solar PV plants. To be sure, dramatic cost declines for solar panels from 2008 to 2012 also played a decisive role. But the importance of government policy in spurring the utility-scale solar PV boom is undeniable.

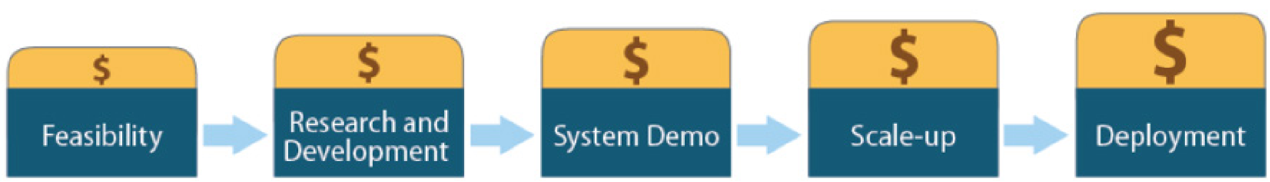
Lessons for Policymakers

Utility-scale solar PV now looks set to continue growing at a rapid clip for the foreseeable future. But decarbonizing the U.S. economy will require the deployment of many more clean energy technologies on a massive scale. Experience from ARRA implementation offers three broad lessons for future efforts to scale up clean energy technologies.

Lesson 1: Large-scale demonstration projects of commercially proven technologies can unlock rapid market growth.

Much of the policy discourse around technology innovation is focused on supporting technologies that have not yet achieved commercial success. Policymakers and scholars are certainly right to design public policies to help innovators bridge the "valleys of death" they face when trying to raise scarce private capital to build a pilot manufacturing line or demonstrate a first-of-a-kind technology in the field. But in this case, solar PV had already been extensively demonstrated – both as a product that could be manufactured at scale and as a technology that could reliably generate power and supply it to the grid, albeit at scales at least an order of magnitude smaller than the projects discussed in this paper.[a] In other words, solar PV presented limited technology risk, but not a single plant at the hundred-megawatt scale had ever been built prior to 2010. This example points to a final gap in the process of bringing a technology to meaningful commercial scale: mobilizing providers of private capital to invest in projects that may be valued in the billions of dollars. (In Figure 2, this gap corresponds to the fourth innovation stage, "scale-up," which is distinct from and subsequent to initial technology demonstrations.) Public support for the first handful of large-scale demonstration projects can unlock private appetite for further projects. Therefore, a balanced portfolio of innovation policies to address urgent decarbonization challenges – from long-duration energy storage to carbon management – should include support for large-scale demonstration projects.

Figure 2: Stylized Schematic of Innovation Stages



Source: Phillip Brown, "Loan Guarantees for Clean Energy Technologies: Goals, Concerns, and Policy Options," Congressional Research Service Report R42152, January 17, 2012. Available at: http://nationalaglawcenter.org/wp-content/uploads/assets/crs/R42152.pdf

a Indeed, the fact that the five large-scale solar PV projects to receive loan guarantees had very low technology risk was actually downplayed by the LPO. Under Section 1705, projects were required to use technologies that are innovative in some aspect. Although each of the five solar PV projects used commercially proven technologies, the LPO took pains to highlight fairly mundane innovations, such as the combination of thin film cadmium telluride panels – a commercially proven technology at the time – with single-axis trackers, another commercially proven technology. See: Dustin Mulvaney, *Solar Power: Innovation, Sustainability, and Environmental Justice* (Berkeley: University of California Press, 2019).

Lesson 2: To mobilize private investment in clean energy technologies, the government must demonstrate credible technical and financial expertise and collaborate with the private sector.

Public support for large-scale demonstration projects should be provided with the objective of emboldening the private sector to take on an increasing share of project risk. To bring private investors along, the LPO first had to credibly demonstrate it had the technical rigor and expertise to conduct due diligence on massive and complex projects. It was critical the office first staff up rapidly, including hiring seasoned private investment professionals and then proceed to conduct rigorous due diligence on prospective projects, drawing on technical expertise from across the federal government. Next, the office made another important advance by convening the Financial Institution Partnership Program, rather than simply lending to project developers directly through the Treasury Department. These two steps together – building federal competencies and collaborating closely with the private sector – emboldened private lenders to finance the subsequent utility-scale solar boom without requiring further federal loan guarantees.

Indeed, the time limits attached to ARRA programs such as Section 1705 and Section 1603 meant loan guarantees and cash grants went to just a handful of large-scale projects, thereby limiting taxpayer exposure. It can be tricky to set appropriate time constraints, capacity limits, or some other type of ceiling for government involvement. All five large-scale solar PV projects that received loan guarantees closed their financing within a month of the Section 1705 expiration date; three of those projects received their loan guarantees on the last day itself. This suggests the LPO faced pressure to get loan guarantees "out the door," which could have compromised the due diligence process. Nevertheless, policymakers should endeavor to set constraints to the best of their ability, balancing the goal of limiting taxpayer exposure with the goals of selecting good projects and demonstrating technologies sufficiently to jumpstart private deployment at scale.

Lesson 3: Support for large-scale demonstration projects must be integrated into a holistic pipeline of RD&D and deployment policies.

On its own, support for large-scale demonstration projects is unlikely to be sufficient to help the private sector bring new technologies to market or to sustain their rapid commercial diffusion at the scale and speed required to decarbonize the U.S. economy. In the case of solar power, the ARRA succeeded in mobilizing private funding for massive solar projects only because of the half-century of RD&D – funded in large part by governments around the world – that had brought solar technology to commercial maturity. Moreover, deployment policies, such as state renewable portfolio standards, complemented the federal government's support for large-scale demonstration projects by creating market demand for the projects' output. Solar PV also benefited from relatively high prices for competing power sources, such as natural gas, which enabled solar generators to sign long-term contracts with utilities at attractive rates.

To support clean energy technologies in the future, policymakers should not view the funding of large-scale demonstration projects as a substitute for robust public support at all stages of the RD&D process. Efficient deployment policies – such as a carbon price and targeted tax incentives to boost the competitiveness of clean energy technologies in the commercial marketplace – will complement demonstration policies and accelerate the diffusion of clean energy technologies, especially once the private sector has the confidence to finance these technologies in large-scale applications.

Conclusion

With these lessons in mind, policymakers can round out an effective portfolio of clean energy innovation policies. The story of how the ARRA catalyzed a boom in utility-scale solar in the United States is both encouraging and cautionary. On the one hand, decisive support for large-scale demonstration projects can launch the meteoric rise of a new technology. On the other hand, we simply do not have the time to wait another half-century – as was the case for solar PV – before other emerging clean energy technologies reach the stage of maturity when policies reminiscent of the ARRA can turbocharge their growth. It is therefore essential to get the full pipeline of innovation support right. Only then can support for large demonstration projects serve as a final stepping-stone to propel the commercialization of clean energy technologies at the scale needed to rapidly decarbonize the economy.

About the Author

Dr. Varun Sivaram is a physicist, bestselling author, and clean energy technology expert with experience spanning the corporate, policy, and academic sectors – most recently as Chief Technology Officer of ReNew Power Limited, a multibillion dollar renewable-energy firm that is India's largest. He is currently a visiting senior fellow at the Columbia University Center for Global Energy Policy, senior fellow at the Information Technology and Innovation Foundation, and a nonresident fellow at the Aspen Institute. He was formerly fellow and director of the energy program at the Council on Foreign Relations, senior energy advisor to the Los Angeles Mayor and New York Governor, professor at Georgetown University, and consultant at McKinsey & Co. TIME Magazine named him to its TIME 100 Next list of the next hundred most influential people in the world, PV Magazine named him the "Hamilton of the Solar Industry," Forbes named him to its 30 under 30, and Grist named him one of its top 50 leaders in sustainability. He is the author of *Taming the Sun: Innovations to Harness Solar Energy and Power the Planet* (MIT Press, 2018) and *Digital Decarbonization: Promoting Digital Innovations to Advance Clean Energy Systems* (CFR Press, 2018).

A Rhodes and Truman Scholar, he holds a Ph.D. in condensed matter physics from Oxford University and undergraduate degrees from Stanford University.

Endnotes

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