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Less Certain Than Death: Using Tax Incentives to Drive Clean Energy Innovation

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Tax incentives can play an important role in accelerating the innovations needed for a low-carbon future, but only if the incentives reward innovators rather than support well-entrenched incumbents.

KEY TAKEAWAYS

- If properly targeted, tax incentives have the potential to accelerate innovation in clean energy technologies that are poised to be adopted rapidly.
- Tax incentives intended to accelerate the deployment of clean-energy technologies were expanded significantly in the 2000s. However, design flaws and tinkering by Congress has limited their impact on innovation.
- The U.S. tax system should be a more powerful tool to accelerate clean energy innovation. Congress should target opportunities when they are ripe, drive the market forward, and sunset federal support as technologies mature.

INTRODUCTION

The global energy system, the main source of the carbon emissions that are fueling climate change, is enormous and intricate. Policymakers will therefore have to use a wide array of tools to steer this complex system to a low-carbon future. Taxation, a unique and important power of governments, should figure prominently in their tool kit.

Tax policy has shaped the energy mix for decades, helping to lock in today's unsustainable high-carbon system. Since 2005, the federal government has used incentives to accelerate the deployment of a number of low-carbon energy technologies. This report explores the impact of these incentives on innovation across three major sectors: power, building, and transportation.

We find that the policy has significant flaws. For instance, incentives sometimes simply reward well-established incumbent technologies without driving improvement. At other times, incentives have little impact, targeting technologies that would be better served by research grants or first-of-a-kind demonstration projects—or focusing on actors that are poorly positioned to innovate.

In addition, incentive policy is frequently erratic, and prone to arbitrary stoppages and exclusions. Congress is caught in an unhealthy cycle, unable to create a dynamic system that targets opportunities when they are ripe, drives the market forward, and then sunsets federal support as technologies mature, so resources can be devoted to the next wave of opportunities.

Our case studies lay the foundation for five principles to guide a thorough revamping of energy-technology tax-incentive policy in the future. Congress should:

1. Apply tax incentives when clean energy technologies are approaching readiness for large-scale adoption—not before—and remove them after the target technology has had a fair chance to establish a strong user base.
2. Absent a carbon price or other overarching climate policy, apply a tiered incentive system that provides next-generation, emerging clean-energy technologies with a more generous incentive than it does for already widely deployed technologies.
3. Set the broad framework for tax incentives through the legislative process, but delegate detailed decisions about eligibility and duration to the executive branch.
4. Reward risk-taking by targeting tax incentives at early adopters, benefiting the innovators that offer these early adopters the most compelling products.
5. Use the whole policy toolbox and the right policy tool for each task to ensure low-carbon energy innovations mature as quickly as possible.

This report begins by framing the clean energy innovation challenge and identifying the barriers to innovation tax incentives may help to overcome. It then turns to the history of federal energy technology tax incentives and three case studies, followed by a discussion of the principles. The report ends with a call for Congress to break the cycle that has led to a significantly flawed incentive policy.

CLEAN ENERGY INNOVATION: THE KEY TO AVERTING CLIMATE CHANGE

Climate change is harming society and damaging the environment. This harm will grow increasingly worse as time passes unless carbon emissions are reduced dramatically. The economic costs of more frequent extreme weather events, rising sea levels, and more intense wildfires are already evident to casual observers. Less visible, but more profound, are deleterious changes to ecosystems, negative impacts on human health, and disruptions to food and water supplies.[1]

Unfortunately, global carbon emissions are trending up. And as long as fossil fuels continue to provide energy services more cheaply than clean energy resources, this trend will continue—global meetings and national commitments notwithstanding. The declining costs of technologies such as solar power and electric vehicles (EVs) are slowing emissions growth, but not reversing it. Without further innovation in clean energy technology and the termination of policies that privilege "dirty" energy, the world risks falling into a cul-de-sac in which the opportunities to mitigate climate change are slowly exhausted well before the problem gets solved.[2]

The innovation challenge spans all major end-use sectors. In electricity, low-carbon solutions are lacking for at least a third of all generation globally due to the seasonal variability of renewable resources and the high cost of firmer resources, such as natural gas with carbon capture and sequestration and nuclear power. Improved technologies are also needed to make the grid smarter in order to integrate the increasingly diverse array of generation resources and end users connected to it. Solutions for the building and light-duty transportation sectors, which account for about a quarter of emissions, will depend to a large extent on electrifying these end uses and supplying them with low-carbon electricity.[3]

Shipping, aviation, and heavy-duty trucking will be difficult to electrify and therefore need different solutions, such as hydrogen fuel cells or low-carbon liquid fuels, than those for light-duty vehicles. In the industrial sector, which accounts for 20 percent of worldwide emissions, few options yet exist to provide high-temperature heat for making metals and chemicals, or to eliminate carbon emissions as a byproduct of cement production.[4]

The Reference Technology Scenario developed by the International Energy Agency (IEA) sums up the situation. It assumes continued cost reductions and performance improvements in renewables and other established technologies, and that new clean energy technologies that are near the end of the innovation pipeline will be commercialized. The scenario also assumes all the nations that signed the Paris Agreement will meet their targets. Even under these optimistic assumptions, IEA still projects global emissions will increase through 2050.[5]

CLEAN ENERGY INNOVATION POLICY: MORE THAN JUST A CARBON PRICE

Although market-based competition drives innovation in many sectors, it will not drive enough clean energy innovation—or drive it fast enough—to halt climate change. One reason is obvious: Energy markets do not incorporate the damage caused by climate change into prices. Firms motivated solely by profits have little incentive to decrease this damage, and are therefore unlikely to undertake innovation for this purpose. In the jargon of economics, climate change is a negative externality that imposes costs on the public.

Many economists recommend fixing this externality by putting a price on carbon emissions. Ideally, a carbon price would shift the cost burden of climate change from the public at large to only the consumers who benefit from creating emissions, thereby "internalizing" these costs within the market. A rational consumer would respond by cutting their emissions impact whenever the cost of doing so would be less than paying the carbon price.[6]

Carbon pricing would trigger some clean energy innovation—particularly incremental rather than radical innovation. For example, factory managers facing a carbon price would be motivated to undertake process innovations in order to reduce energy waste. Consumers, similarly, would become more likely to buy fuel-efficient cars, thereby inducing automakers to develop new ones.[7]

Carbon pricing is rarely a popular policy, because it raises the price of energy. Even where it has been implemented, carbon prices have almost always been far below the expected costs of climate change. Yet, even if a carbon price were perfectly calibrated to fully internalize these costs, it would not stimulate enough clean energy innovation fast enough. Many barriers other than the failure to include the cost of pollution in market prices impede innovation in the energy sector.[8]

For instance, scientific and engineering research, which may generate knowledge that leads to breakthrough innovations, is usually underfunded by firms. The payoffs from such investments are too slow and uncertain, and are not necessarily reaped by the firms making them. Public funding of research, such as that which led to the invention of the lithium-ion battery and light emitting diode (LED) lightbulbs, is one means of overcoming this barrier.[9]

A different sort of barrier to innovation arises when promising technologies are themselves complex systems, as is usually the case with energy. The diverse components of such systems, which are common in the power, transportation, and industrial sectors, may interact at full scale in ways that cannot be anticipated at the laboratory bench or even in pilot plants. But few firms are willing to take the risk of building first-of-a-kind, full-scale systems to find out how well they work, particularly if such systems are capital intensive (e.g., power plants). Public programs that share this risk with the private sector, through funding or guarantees for demonstration and first-of-a-kind commercial projects, can overcome this barrier, as the histories of nuclear power and utility-scale solar photovoltaics show.[10]

This list of barriers to clean energy innovation is illustrative, not exhaustive. Yet even this partial list shows that energy-innovation policymakers must be able to draw upon a range of tools in order to be effective. There is no silver bullet. Neither carbon pricing, public support for research, nor any other single policy will do the job alone.[11]

TAX INCENTIVES AS ENERGY INNOVATION POLICY

Taxation is one of the most powerful tools in the policy tool kit. As the old saying goes, along with death, it is one of only two certainties in the human experience. Yet, like all such admonitions, this one is not always true. Indeed, the power to exempt an activity from taxation is almost as potent a tool as taxation itself.

U.S. lawmakers have long recognized and utilized this tool. Many policies that are implemented directly by governments in other countries are carried out through tax incentives in the United

States. The federal tax code contains a large array of provisions that support particular activities, industries, professions, and other groups of taxpayers.

Although some of these incentives make little economic sense, this tool can be a powerful and efficient one to drive innovation and growth. For instance, tax incentives can and should be used to stimulate firms to support research that benefits their competitors or the public, as well as themselves. Such incentives compensate firms for the risk that the research they fund may "spill over" in this fashion. Virtually all leading countries performing research and development (R&D) provide tax incentives for private research spending. The United States was the first to enact such a policy, but its generosity now lags well behind its competitors.[12]

Similarly, tax incentives for capital goods may lead to private investments that spill over to the rest of society. Firms purchasing new capital equipment receive only about half of the returns these investments provide. Customers, workers, other industries, and even competitors share in the gains.[13]

A similar line of thought allows us to identify when tax incentives are most likely to drive clean energy innovation. If a tax incentive encourages economic actors to carry out an activity that benefits society as well as themselves, then it is well targeted. If the activity only benefits the economic actor, then it is most likely an unwarranted subsidy.

The technology adoption "S curve" provides a framework for making this distinction. As pictured in figure 1, the curve shows that the uptake of a new technology is very slow in its early stages, when the costs and risk of adoption are high. As the technology becomes better, cheaper, and more familiar, it may hit the takeoff stage, when the pace of adoption is quickest. As the market becomes saturated and the technology matures, the pace slows again.

Figure 1: The technology adoption "S curve"

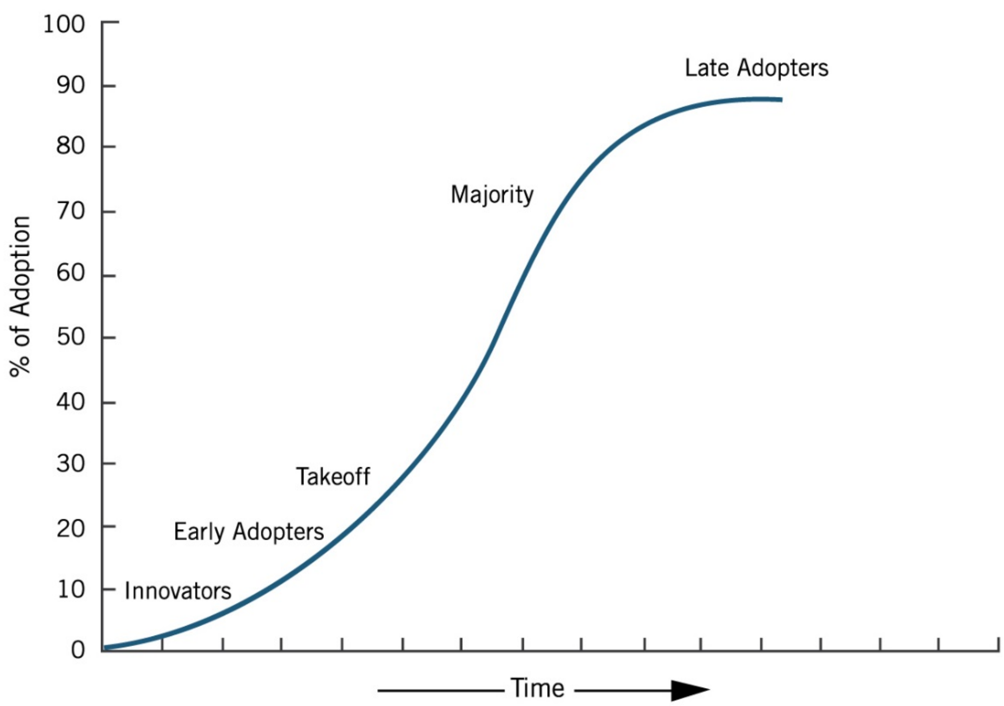


Figure 1 is highly stylized. The slope of the curve varies dramatically across technologies. Some technologies are widely adopted in just a few years, while others take decades. Some never reach takeoff, flatlining instead. Still other technologies go through a series of S curves, regularly reinvigorated by successive technological breakthroughs.

The sources of technological progress change as one moves along the curve. To the left of the curve, in the early stages of adoption, R&D investments are the driving force, and may be made by the public or private sector (aided by R&D tax incentives), or both. To the right of the curve, in the late stages of adoption, mass production leads to cost reduction through economies of scale. Profits and private investments provided by capital markets typically fuel these stages.

In the middle, as technologies move through the takeoff stage and enter the steepest part of the curve, the sources of progress are more numerous and complex. They include learning by doing in production and implementation, and learning through feedback from early adopters, as well as R&D and scale-up. Ideally, adoption and innovation feed off one another in this stage, thereby forming a virtuous cycle.[14]

However, takeoff may be slowed or interrupted for a variety of reasons, such as when capital is scarce, as is likely when the market is small, or if imitation is cheap, thereby discouraging risk-taking. Technology-specific tax incentives may overcome such obstacles by reducing the risks of adoption in this stage, as they give the buyers of early versions of innovations a discount. Lower prices mean higher sales. Higher sales provide funding for R&D, learning, and scaling up, all of which, in turn, should lead to further innovation, resulting in even lower prices and better performance.

Public-private risk sharing in the takeoff stage of clean energy innovation makes sense because the public benefits along with private investors—assuming large-scale adoption can be unlocked and the curve made steeper. In the earlier stages of adoption, the public must bear most of the risk because the benefits are difficult for private investors to capture. In the later stages, the benefits are largely privatized, as long as there is a carbon price or regulatory policy that addresses the environmental externality.

Proper targeting of tax incentives therefore strongly influences their effectiveness. Some innovations are not mature enough to respond quickly to the market signals incentives provide. In such cases, the problems encountered by early adopters do not lead to learning, and few mainstream adopters are drawn into the market. In these cases, developers must go back to the drawing board and do more R&D. Innovations that have already taken off, on the other hand, are so far up the adoption curve that the incremental market growth provided by incentives does relatively little to drive down costs or improve performance. Rather, they subsidize private interests without creating a public benefit.

This tool, then, fits into a policy sequence. Government spending on clean energy research, development, and demonstration (RD&D) can aid in bringing innovations, to the point they are ready to benefit from a targeted tax incentive. Once the incentive has done its job, and the growth of the market no longer generates much knowledge or scales benefits that improve or reduce the cost of the targeted innovation through the takeoff stage, the incentive should be removed. Carbon pricing should continue to apply to any technology, because the negative externality of carbon emissions never goes away.[15]

ENERGY TECHNOLOGY TAX INCENTIVES IN PRACTICE

Tax incentives have shaped the energy industry for more than a century. They target three types of activities:

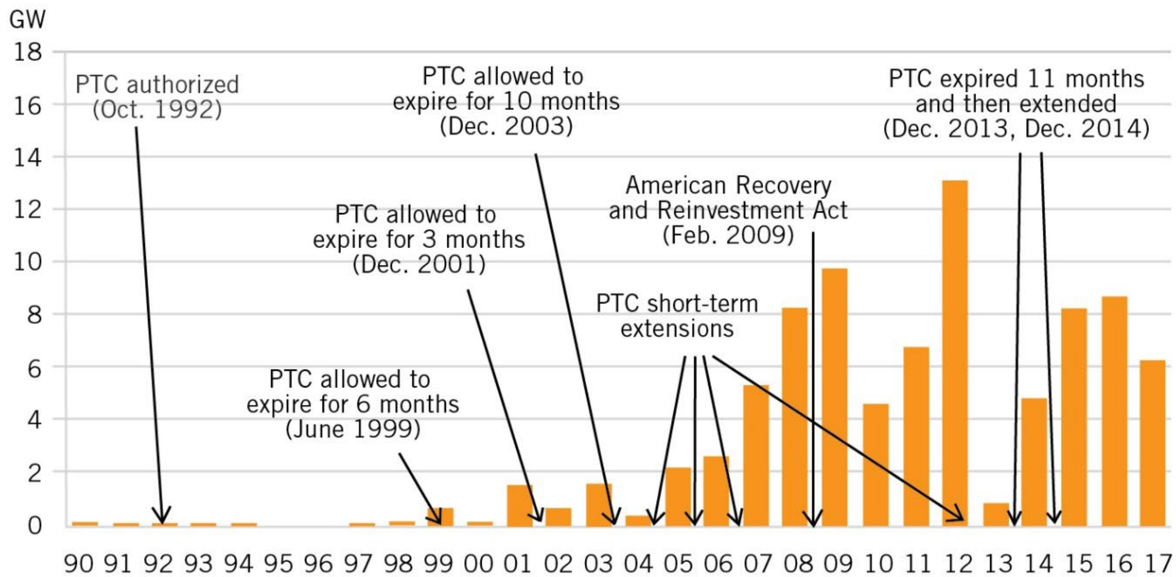
- Production tax credits reward power generation.
- Investment tax credits are based on initial capital expenditures.
- Sales tax credits directly reduce purchase prices.

Provisions intended to accelerate oil and gas production and make it more profitable, such as the expensing of intangible drilling costs, date back to 1916—just three years after the U.S. Constitution was amended to permit federal income taxation. Tax incentives meant to break fossil fuel dependence by stimulating solar power and energy efficiency were proposed in the wake of the oil crisis and incorporated into the National Energy Act of 1978. However, when oil prices crashed in the 1980s, most of the more recent incentives were removed, while the older ones benefiting fossil fuels remained.[16]

The Energy Policy Act of 1992, which passed with bipartisan support, revived the approach by providing a production tax credit (PTC) for electricity generated by wind, biomass, or geothermal technologies, as well as an income tax deduction for clean-fuel-powered vehicles. Energy efficiency innovation was targeted again by the Energy Policy Act of 2005, which included a suite of incentives for appliances and building-envelope components such as windows and doors. Virtually every piece of tax and budget legislation since then has involved some adjustment of eligibility, deduction, and credit levels, along with other features of energy-technology tax-incentive policy.[17]

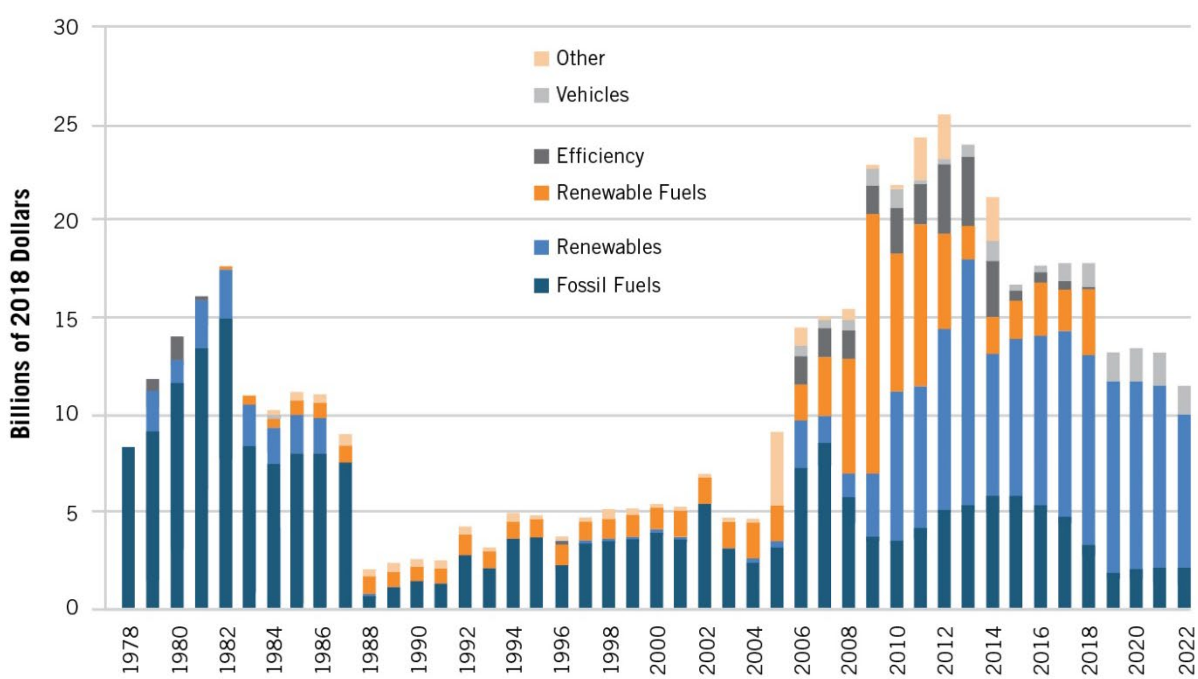
Congressional tinkering has reduced the policy's impact. Lawmakers regularly allow incentives to lapse or suffer lengthy delays before being extended at the last minute—sometimes retroactively. For example, the PTC expired 10 times and lapsed 5 times between 1992 and 2015.[18] The uncertainty created by such erratic behavior may have deterred some investors, thereby reducing market growth. A looming expiration date, on the other hand, may prompt a burst of investment activity to lock in preferential treatment. (See figure 2.) In either case, unstable, uncertain policies fail to provide the steady, predictable risk sharing that would most expeditiously move technologies through the takeoff stage of the adoption curve.

Figure 2: U.S. wind capacity additions and PTC expirations and extensions, 1990–2017[19]



Taxpayers have nonetheless taken increasing advantage of energy technology incentives over the years. From a low of about $2 billion (in 2018 dollars) at the end of the Reagan administration, energy technology "tax expenditures" (as the foregone revenue caused by incentives is known) rose to over $25 billion in fiscal year 2012 before falling to about $18 billion in recent years. (See figure 3.) Their composition also changed substantially. Whereas the bulk of the benefits went to fossil-fuel-related investments until 2007, renewables, renewable fuels, and alternative-technology vehicles have accounted for the majority since then.

Figure 3: Energy-related tax expenditures, FY 1978–2022E[20]



The production tax credit, which is taken predominantly by wind-farm owners, is the most costly single provision today (at about $5 billion per year), followed by the investment tax credit (at about $2.5 billion annually), which mainly benefits solar power. To put this in context, in 2018, investment in renewable energy and energy-smart technologies in the United States topped $64 billion, which was 19.3 percent of the global total. Tax incentives for fossil-fuel-related investments, on the other hand, totaled just over $3 billion.[21] (Fossil fuel interests receive an estimated $20 billion in benefits from all provisions in the tax code combined, as discussed in box 1.)

A closer look at the history and impact of specific provisions provides insights into policy design and implementation that go beyond these broad observations.

Box 1: Tax Subsidies for Fossil Fuel Producers

Numerous permanent provisions in the federal tax code subsidize the production of fossil fuels. Some of these subsidies have been around for a century and now are out of step with our national needs. While these provisions may have been defensible at the time they were implemented, circumstances have changed considerably. Today's domestic coal, oil, and natural gas industries are mature and have proven quite capable of supporting incremental innovation without federal risk sharing. More important, while their impact on climate was long unknown or poorly understood, it is now clear this impact is massive and detrimental.

Conservative estimates put direct U.S. subsidies to fossil fuel producers at roughly $20 billion per year. Twenty percent of this benefit accrues to the coal industry, and 80 percent to oil and natural gas.[22] Three of the largest and most noteworthy direct subsidies[23] are:

- Intangible drilling costs ($880 million per year). Companies may deduct a majority of the costs incurred from drilling new wells domestically.
- Enhanced oil recovery ($730 million per year). Companies are credited 15 percent of their costs on U.S. projects.
- Percentage depletion ($640 billion per year). This is an accounting method that allows businesses to deduct a certain amount from their taxable income to reflect declining production from a reserve over time.

Fossil fuel producers are also eligible for tax preferences that operate indirectly and are not available to most of their clean energy competitors. They include:

- Last in, first out accounting, which allows firms to sell their most expensive reserves first, thereby reducing the value of their inventory for tax purposes.
- Master limited partnerships, which are financial structures that combine the investment advantages of publicly traded corporations with the tax benefits of partnerships.

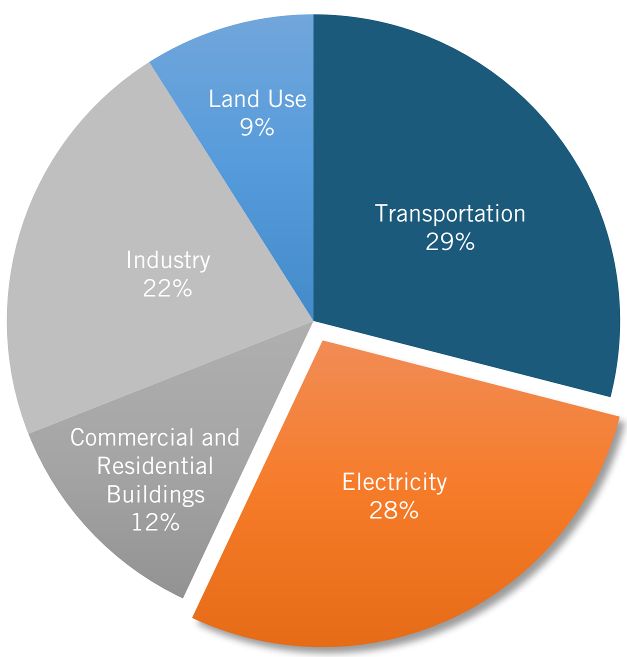
In addition to direct and indirect subsidies, coal, oil, and natural gas firms receive federal support in the form of project loans, grants, and guarantees from the Overseas Private Investment Corporation (OPIC) and the U.S. Export-Import Bank (EXIM). OPIC and EXIM provide capital and financial security for investments in emerging markets. For example, in 2017, OPIC funded a natural gas project in Jordan that was expected to emit the equivalent of 617,000 tons of carbon dioxide per year. EXIM lent or issued grants worth $14.8 billion for 78 projects in the petroleum sector between 2001 and 2018.[24]

The impact of the tax code extends far beyond credits and deductions. Tax policy has shaped energy investments on a large scale for many decades. Fully unpacking these impacts is a subject for additional research.

ELECTRIC POWER TECHNOLOGY TAX INCENTIVES

The United States emitted greenhouse gases equivalent to about 6.5 million metric tons of carbon dioxide in 2017. (About 80 percent of this total was carbon dioxide itself, with methane and other greenhouse gases accounting for the rest.) The electric power sector is the second-largest source. (See figure 4.) Coal, the most carbon-intensive fuel used in the power sector, generated 27 percent of the nation's electricity in 2018. Natural gas, which is about half as carbon intensive as coal, surpassed it a couple of years ago as the nation's most important electricity resource, accounting for 35 percent last year. Although power-sector emissions have declined as a result of this switch, natural gas must be replaced by even cleaner resources such as wind, solar, nuclear, and hydro—or else carbon emissions from fossil fuel combustion must be captured—if this decline is to continue.[25]

Figure 4: U.S. greenhouse gas emissions from electricity generation in 2017[26]



Tax policy since 2006 has targeted solar and wind power. Our research suggests incentives helped the now-dominant solar and wind technologies take off, contributing to innovation as they did. However, the current incentive structure is not conducive to further innovation within these fields. The policy strengthens well-established technologies, but does little to further the next generation.

The first incentive to target a clean energy technology was a 10 percent investment tax credit (ITC) for solar power, established in 1978 under Section 48 of the tax code. In 2006, the ITC was temporarily increased to 30 percent, and was extended by the Emergency Economic Stabilization Act of 2008 through the end of 2016.[27] Another extension was provided in 2015, with a phase-down to the original 10 percent level scheduled to begin in 2020. The solar industry is currently campaigning to delay or eliminate the phase-down.

The Energy Policy Act of 1992 established a PTC for wind, biomass, and geothermal power under Section 45. As shown in figure 2, it has been in and out of the code frequently in the ensuing years. Under current law, the PTC will be phased out for projects that commence construction after 2020. The wind industry recently pivoted from accepting this phase-out to pushing to be included in the ITC extension advocated for by the solar industry.[28]

The ITC and PTC differ in important ways. The ITC is based on the initial capital expenditure in the qualifying project and is received by the taxpayer in the same year the expenditure is made. The PTC is based on the power the qualifying project generates and is received for the first 10 years it generates. Neither design is intrinsically more favorable for innovation, as each must be translated into power purchase agreements that determine the expected return on any project. However, the PTC sometimes leads to negative prices for electricity that are disruptive in wholesale markets.

A third, temporary mechanism emerged in the wake of the 2008 financial crisis and ensuing recession. The American Recovery and Reinvestment Act gave projects eligible for the ITC or PTC the option to elect a 30 percent nontaxable cash grant in lieu of either credit. The program bridged what would have been a major drop in uptake of these incentives. The recession's devastating impact on economic activity brought with it a decline in tax liability, which in turn limited the pool of capital that could be drawn in by incentives. Cash grants supplied the same amount of capital the projects would have received in normal economic times. The cash grant program expired in 2011.[29]

The monetary benefits of the ITC and PTC flow to project investors that have tax liabilities they would like to reduce. These "tax equity investors" are typically large financial institutions that have the ability to assess and structure renewable energy deals. In 2017, there were some 35 players in this market.[30]

Despite the complexity and inconsistency of these policies, the ITC and PTC, along with other policies in the United States and abroad, have helped accelerate the growth of wind and solar power. U.S. solar power capacity grew from under 1 gigawatt (GW) in 2006 (less than 0.1 percent of the national total) when the ITC was increased to 7 GW (less than 1 percent) in 2012 to 69 GW (6 percent) today. U.S. wind power capacity grew from 11.5 GW (about 1 percent) in 2006 to 60 GW (5 percent) in 2012 to 100 GW (8 percent) today.[31]

This rapid growth of deployment, which was enabled by prior R&D over a period of decades, in turn, contributed to innovation. Standard crystalline-silicon (c-Si) solar panel prices decreased by 92 percent over the past decade. The efficiency of these panels in turning sunlight into power per unit of surface area increased by about 40 percent, while automation and other improvements in equipment have lowered the costs of setting up and running factories to produce them. Economies of scale have also contributed substantially to this cost-reduction trend. Balance of system costs (other than for the panels themselves) have come down as well, though not as quickly. As a result, electricity delivered from utility-scale solar projects was 74 percent cheaper in 2017 than in 2008, surprising even optimistic forecasters.[32]

In wind turbines, the technological trajectory fueled in part by tax incentives has been toward taller turbines and larger blades on a horizontal axis that produce power more efficiently. The average capacity factor (that is, the share of actual power output compared with potential output) rose from 31 percent for projects built between 2004 and 2011 to 42 percent for those built from 2014 to 2017. Average installed costs declined 40 percent in this period as well, while the national average price for power from wind projects fell below 2 cents per kilowatt-hour from 7 cents a decade ago (although both prices are aided by the PTC).[33]

Assessments of how far up the adoption curve these technologies have climbed in the United States vary. Some forecasters project solar and wind will become the predominant resources for power generation by 2050, while others anticipate they will level off as a large but still minority share of the mix. Which view prevails will depend on many factors, including competition from other resources, regulatory structures, the cost of energy storage, and the build-out of the transmission system, as well as tax policy. A major challenge with variable resources such as wind and solar power is "value deflation." When the sun is shining brightly and the wind is blowing hard, these resources tend to produce a lot of power, thereby driving down prices. The higher the proportion of these resources in a grid, the further prices go down.

If tax policy does not distinguish within the solar and wind categories to favor technologies such as these that may be approaching takeoff, it will not accelerate innovation.

What seems clear is that the dominant designs for these systems—c-Si solar panels and horizontal-axis wind turbines—have moved through the takeoff phase. A recent study by the U.S. National Renewable Energy Laboratory (NREL), for instance, shows little difference in the slope of cost reductions in these technologies during the 2020s, regardless of whether the ITC or PTC are extended. In other words, while maintaining the ITC and PTC might spur further deployment, such a policy would not lead to new wind and solar technologies.[34]

Yet, there are still significant opportunities and a need for innovation in these fields. New materials such as perovskites and quantum dots have the potential to radically increase the efficiency of solar panels, while also enabling new applications such as solar paint and landfill coverings. Floating offshore wind turbines, which will be required wherever seabeds drop off sharply near shore, such as on the West Coast of the United States, are just beginning to be offered commercially. Small, vertical-axis turbines that could drastically increase the efficiency and lower the cost of land-based wind farms are also under development.[35]

If tax policy does not distinguish within the solar and wind categories to favor technologies such as these that may be approaching takeoff, it will not accelerate innovation. Instead, the incentives will be mostly reaped by relatively mature technologies that are already on the steep slope of the adoption curve, backed by large, well-capitalized producers that sell into established markets. Such a policy may reduce carbon emissions in the absence of a carbon price, although according to the NREL study, that impact may depend more heavily on natural gas prices, which are unaffected by incentives, than by an ITC or PTC extension.[36]

Other technologies that are eligible for the ITC or PTC have not reaped much benefit from these incentives. For example, nuclear reactors have been eligible for the PTC since 2005, but no reactor that qualifies has been built, in large part because new nuclear designs still require further substantial RD&D before they will be primed for takeoff. (See box 2 for a discussion of fuel cells.)

Box 2: Fuel Cell Technology and the ITC

Fuel cells, which convert diverse fuels such as hydrogen into electricity without combustion, may be a valuable element of a broad portfolio for building a competitive, secure, and sustainable clean energy economy. They have the potential to solve such critical challenges as energy storage, distributed combined heat and power, portable power, and auxiliary power for heavy-duty land transportation and aviation.

Fuel cells have long been the focus of significant federal R&D investment. Over the past decade, fuel cell costs have declined by nearly 50 percent, and cell life has quadrupled. Federal investment has led to some 650 hydrogen and fuel-cell-related patents and contributed to industry bringing more than 30 technologies to market. Tax incentives, however, have made uneven contributions to this progress, and the opportunity to accelerate fuel cells through the takeoff phase has not been fully realized.

When fuel cells were made eligible for the ITC in 2005, there were few commercial products available to take advantage of it. More products were on the market by 2009, but by then the financial crisis had made it difficult to find investors and customers. The Recovery Act responded to this situation by expanding the amount eligible for the ITC to $200,000, establishing a program to provide grants in lieu of the tax credit, and significantly expanding fuel cell R&D funding and federal procurement.

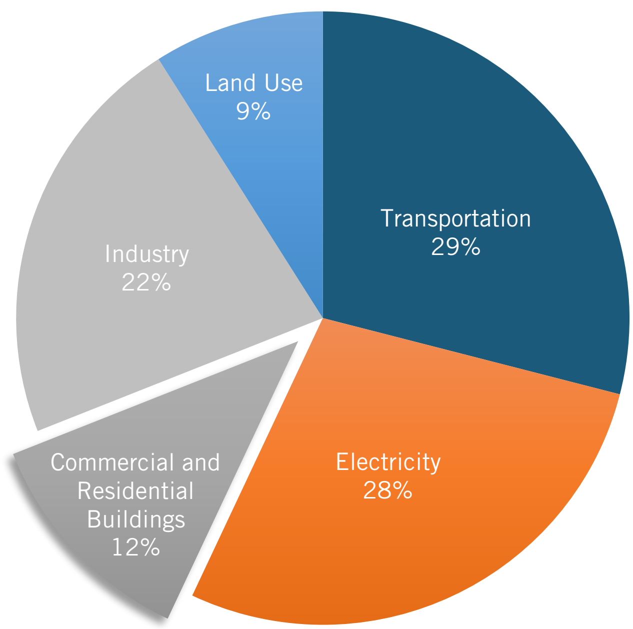
Plug Power is an example of a company that was able to use both direct stimulus funding and the ITC to innovate and expand the fuel cell market while reducing costs. The company has grown from 87 employees in 2010 to more than 600 in 2019. The Recovery Act funded its partnership with FedEx and Air Products to deploy 35 systems in electric lift trucks—a new application of the technology—at FedEx's service center in Springfield, Missouri. The ITC allowed it to leverage the learning acquired during this partnership to build a new customer base and develop a modular product architecture to serve the broader transportation industry. The incentive also stimulated business-model innovation with an equipment-leasing program.[37]

Congress allowed the ITC for fuel cells to lapse in 2016, even though it was extended for solar power. This inaction made it more difficult to access capital, and sent an inaccurate signal to the market that fuel cells were no longer a promising technology. The credit was finally extended retroactively in 2018. Although fuel cell technology and some of its markets had matured enough for the lapse not to be crippling, the ITC's reinstatement has already led to further innovation, such as the development of North America's first fuel-cell-powered electric delivery van for on-road use.[38]

ENERGY-EFFICIENT APPLIANCE AND BUILDING TAX INCENTIVES

Commercial and residential buildings directly account for 12 percent of U.S. greenhouse gas emissions, primarily from fossil fuels burned for heat. The building sector is also indirectly responsible for an additional 19 percent of emissions as the largest consumer of electricity, a majority of which is provided by coal and natural gas.[39] (See figure 5.) While decarbonizing electricity supply is a key pathway to provide such energy services as heat and light with fewer emissions, innovation that makes appliances and building components more efficient would reduce emissions as decarbonization proceeds, reduce demand to make decarbonization easier, and limit direct emissions from services that cannot be electrified.[40]

Figure 5: U.S. greenhouse gas emissions from buildings in 2017[41]



Takeoff for energy-efficient appliances and buildings is plagued by barriers that do not impact the power sector, including information asymmetry (wherein the buyer knows little about a product's performance), short time horizons, and split incentives (wherein the person paying an energy bill is not the person purchasing the equipment). Rigorous codes and standards, along with consumer-information programs, are often crucial in order to surmount these barriers, although tax incentives could play a significant role as well.[42] Our research suggests the federal tax incentive for appliances ("45M") did so, not only accelerating the adoption of energy-efficient products, but also contributing to innovation. The incentive for energy-efficient new homes ("45L"), on the other hand, accelerated adoption of mature technologies without sparking innovation, while the commercial buildings incentive ("179D") had little impact at all.[43]

45M was enacted in 2005. It provided credits to manufacturers for producing their most efficient refrigerators, clothes washers, dishwashers, and other home appliances. The credit allowed models meeting the eligibility standards to become affordable to a wider segment of customers than they would have been otherwise—and worthy of pushing through marketing and promotions. Increased sales, in turn, created economies of scale that brought prices down further and encouraged producers to innovate by developing more-efficient products and diversifying their product lines.

For example, incentive-eligible models of clothes washers doubled their share of the market, from 21 percent in 2005 to 42 percent in 2007. The number of models meeting the eligibility criteria nearly doubled as well. When the tax credit was extended in 2008, there was a marked increase in eligible models. Market data for dishwashers, clothes washers, and refrigerators shows the total potential units eligible for the tax credit increased by 120 percent between 2008 and 2009.[44]

45M had an important design feature that sustained innovation. Qualifying models had to meet the standards of Energy Star—an efficiency certification program managed jointly by the Environmental Protection Agency (EPA) and Department of Energy (DOE)—rather than efficiency levels written into the statute. Because Energy Star is regularly reviewed and ratcheted up, so too is the baseline for incentives. Indeed, the efficiency levels required to receive incentives in 2005 became the basis for new minimum efficiency standards adopted by DOE in 2012.[45] Performance levels that were once a stretch had become routine, while new generations of appliances achieved efficiencies that had not previously been considered realistic.

The 45L incentive for new homes, which was also put in place in 2005, provided a credit for homes that used 50 percent less energy for space heating and cooling than required by the 2004 supplement to the International Energy Conservation Code (IECC). Homebuilders expressed skepticism that this standard could be met, anticipating buyers would resist the increased cost of qualifying homes. Yet, both the total number and percentage of new homes qualifying for the credit grew significantly in the initial years after the code was enacted. In 2006, before the credit came into effect, just over 7,000 new homes nationwide were efficient enough to qualify. The figure more than tripled in absolute terms in the following year, and rose to 37,000 by 2009. Despite a severe decrease in new home sales due to the economic recession, the percentage of qualifying new homes hit 11 percent in 2011.[46]

Homebuilders had great flexibility with respect to how they could qualify for 45L. The available data, while limited, suggests most improvements focused on such building-envelope improvements as air sealing and insulation. These solutions were based on equipment and materials that were already on the market but had been underutilized.[47] The uptick in adoption prompted by 45L, however, did not trigger further innovation, as was the case with 45M. One reason was 45L lapsed in 2010, 2012, and 2014. Uncertainty created by this instability discouraged participation, while the retroactive extensions that followed these lapses were ambiguous signals at best for potential innovators.

A more important reason the incentive fell short was the standard for qualification stagnated. Unlike 45M, wherein standards were ratcheted up as manufacturers demonstrated success, 45L stuck with the 2004 IECC, even though this code was tightened considerably every three years from 2006 on.[48] If the credit had been tied to newer versions of the code as they were adopted, a virtuous cycle supporting innovation might have been established. Instead, many qualifying homes in recent years reflect little innovation at all. Yet, even though homebuilders were not innovating, they were, of course, enthusiastic advocates for retaining the credit. In short, the credit reduced the cost of energy-efficiency solutions, but did little to spur energy-efficiency innovation.

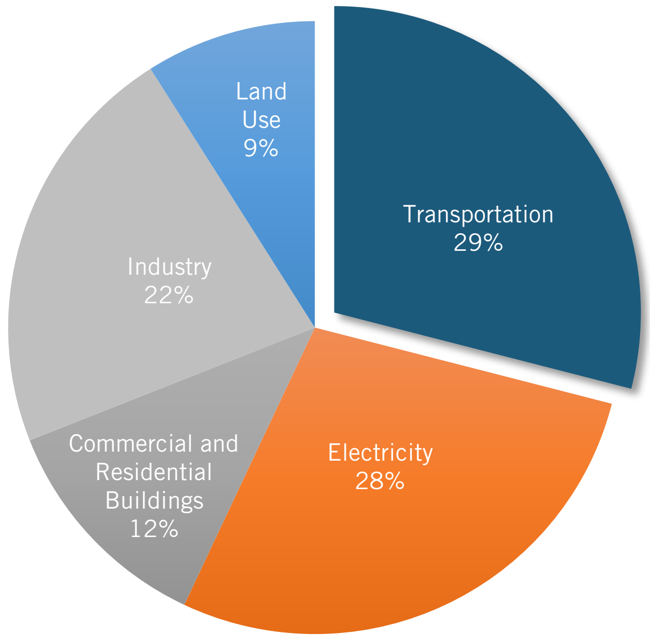
The 179D deduction for commercial buildings was even less successful than 45L. This incentive sought to encourage commercial building owners to make improvements that would reduce energy consumption by 50 percent compared with Standard 90.1-2001 set by the American Society of Heating, Refrigeration, and Air Conditioning Engineers. The reductions could be achieved by investing in more interior lighting; heating, ventilation, and air conditioning (HVAC) systems; water heating; and building envelopes that are energy efficient.

179D was not taken up widely, mainly because the deduction was assigned to the building owner—and most ownership entities were not eligible by virtue of their financial structure or lack of tax liability.[49] Ironically, it was taken up far more readily by public building projects than the privately owned commercial buildings that make up 98 percent of the commercial building stock. A provision in the statute allowed public buildings to assign eligibility for the credit to the architect (i.e., a private party with tax liability).[50] In addition, over 90 percent of projects that qualified for 179D were for lighting only.[51] The policy increased the adoption of advanced commercial lighting products more widely but did very little for innovation.

TRANSPORTATION TECHNOLOGY TAX INCENTIVES

The transportation sector creates 29 percent of U.S. greenhouse gas emissions, recently surpassing the power sector as the largest source. (See figure 6.) The vast majority of these emissions come from internal combustion engines burning petroleum-based fuels for cars, trucks, ships, trains, and airplanes. Dramatic reductions will, to a great extent, require the electrification of the transportation sector and the development of zero-carbon fuels for hard-to-abate end uses such as heavy-duty trucking and long-distance maritime vessels and aviation.

Figure 6: U.S. greenhouse gas emissions from transportation in 2017[52]



Light-duty vehicles—cars, SUVs, and pickup trucks—are both the largest segment of transportation emissions and the easiest to electrify. Federal tax incentives that aim to move EVs through the takeoff stage of the adoption curve were for many years ineffective because the technology was too immature. But recent signs suggest takeoff may be near.

The incentive policy dates back to the Energy Policy Act of 1992. This law established an income tax credit for purchasing an EV, and a deduction for purchasing vehicles powered by other fuels, including natural gas, hydrogen, and 85 percent alcohol. The incentive followed California's institution of the first zero emissions vehicle mandate in 1990, which required EVs to comprise a rising percentage of each automaker's sales in that state beginning in 1998. It became clear in the first half of the 1990s that EVs would not meet the market test, so the incentive was allowed to expire.[53]

The EV tax credit was revived by the Emergency Economic Stabilization Act of 2008. This version allowed a larger amount per vehicle (up to $7,500), but was capped at 250,000 vehicles in total. The cap was raised by the Recovery Act in the following year to 200,000 vehicles per manufacturer. The approach of allotting credits by manufacturer was intended to support the incumbent Big Three U.S. automakers (Chrysler/Fiat, Ford, and GM), which were lagging behind their foreign competitors in EV development.[54] The inability of taxpayers to carry the credit forward to future years also limits its effectiveness and makes the policy more regressive. Low-income households with a federal tax liability that is less than the amount of the credit cannot gain the full benefit, while higher-income households can.

Just one million EVs were sold in the United States between 2010 and 2018, indicating the credit's impact was modest. However, the Edison Electric Institute forecasts that the next million will be on the road in less than three years.55 Innovation underpins this acceleration. EVs have improved in a variety of ways, such as using lighter materials, faster charging, and integrated design. But the key factor has been better and cheaper batteries, which provide their power. Battery prices have declined by 82 percent since 2010.[56] This decline has been made possible by such production innovations as improved cell chemistries and more-sophisticated modules and packs, as well as process innovations supported by growing economies of scale as the market has expanded.

This emerging feedback between adoption and innovation is likely to get stronger. Researchers with the International Council for Clean Transportation gathered technical analyses and automaker statements and concluded that unit costs for battery packs will continue to decline by about 7 percent per year. At that pace, the initial cost of an EV will be below that of a conventional car by the mid- to late-2020s, depending on the model and location. Factoring in lower operating costs for EVs, the study found that the crossover for the total cost of ownership will occur a year or two earlier. However, without the tax credit, price parity would not be reached until roughly 2029. Yet, as with solar and wind power, continued battery innovation, such as solid-state lithium-ion batteries or perhaps alternative chemistries, should be incentivized in order to sustain improvements in cost and performance.[57]

Moreover, the per-manufacturer cap is a weakness in the design of the EV credit, as it penalizes first movers by making their products more expensive after 200,000 of them have been sold. Raising or removing this provision would reward first movers for taking on the most risk in the industry, leading the way up the adoption curve, and creating spillover benefits for later entrants. Tesla, for example, was the first manufacturer to hit the cap, followed by General Motors.[58] Buyers should also be able to carry forward a portion of the tax credit to subsequent tax years if they do not have a large enough federal tax liability in the year of purchase to use the credit fully.

In the case of EVs, Congress should also factor international competitiveness into its assessment of tax credits. China has become a global leader in EVs, and uses a much wider array of policies—including direct production subsidies—to support the EV industry than the United States does. Such policies have the potential to not only hurt auto production in the United States, but also discourage innovation—a form of "innovation mercantilism," which ITIF has documented in other sectors.[59]

PRINCIPLES FOR ENERGY TECHNOLOGY TAX INCENTIVE POLICY

The U.S. federal tax system should be a more powerful tool to accelerate clean energy innovation than it has been in the past. Our case studies, as well as other research on this topic, suggest five principles tax policymakers should heed when designing energy innovation incentives:

1. Apply tax incentives when clean energy technologies are approaching readiness for large-scale adoption—not before—and remove them after the target technology has had a fair chance to establish a strong user base.
2. Absent a carbon price or other overarching climate policy, apply a tiered incentive system that provides next-generation, emerging clean-energy technologies with a more-generous incentive than it does for already widely deployed technologies.
3. Set the broad framework for tax incentives through the legislative process, but delegate detailed decisions about eligibility and duration to the executive branch.

4. Reward risk-taking by targeting tax incentives at early adopters, benefiting the innovators that offer these early adopters the most compelling products.

5. Use the whole policy toolbox and the right policy tool for each task to ensure that low-carbon energy innovations mature as quickly as possible.

Apply Tax Incentives When Technologies Are Ready to Take Off

Our look back at the history of U.S. energy technology tax incentive policy shows that timing matters. When tax incentives are applied after a technology has been commercialized, but before it has been adopted widely, they can help accelerate takeoff, thereby creating a positive feedback to innovation that fuels further adoption in a virtuous cycle as costs decline and performance improves. However, when tax incentives are offered before a technology is mature enough to attract users, even at a discounted cost, they will go unused. And, if they remain available after a technology has been widely adopted, they may spur continued adoption—but are likely to have little impact on innovation in that technology, and may become costly barriers to innovation in other technologies.

All three of these patterns can be observed in the cases of wind and solar power. When the ITC was created in 1978, solar panels were far too expensive for any mass market to emerge; the modest discount provided by the incentive made little difference. Similarly, when the wind PTC was established in 1992, few buyers were ready to build wind farms. These technologies were brought to the point of takeoff primarily by investments made by governments and companies in Japan, Germany, Denmark, and elsewhere in the 1990s and early 2000s.[60]

However, as these technologies matured in the late 2000s and early 2010s, federal tax incentives helped a rapidly increasing number of projects pencil out. The growing market, in turn, contributed to product innovation in the form of more efficient c-Si solar panels and ever-larger, horizontal-axis wind turbines, as well as process innovations that have brought the unit price of these products down rapidly. This virtuous cycle has made solar and wind power competitive in many locations, even if the subsidies are to be phased out, as is currently planned. Non-hydropower renewables generated 10 percent of U.S. utility-scale electricity in 2018.[61]

The tax incentive habit, however, has proven hard for these industries to kick, even though product innovation has slowed in recent years. After all, why would any industry want to give up such a benefit? Technologies within these fields that may be primed for takeoff, such as solar panels made of flexible materials, or small, vertical-axis wind turbines, do not get much of a boost from the incentives because most buyers would rather purchase more-mature, less-expensive rigid c-Si panels or jumbo turbines that receive exactly the same discount. While these incumbents continue to receive subsidies, innovations with the potential to improve on them are stranded.

Other cases teach similar lessons. New home builders were more than happy to receive subsidies for energy efficiency even when the technology required for qualifying homes was far behind the frontier. In contrast, energy-efficient appliances continued to be improved because the requirements to qualify for incentives were regularly tightened. EVs now stand on the threshold of a virtuous cycle of adoption and innovation, but for many years, tax incentives for purchasing them were little used, because few buyers wanted them—even at a discount—because their performance was not good enough.

Making tax incentives available to technologies before they are mature enough to benefit does less damage than continuing to offer them well after takeoff. In the former case, the costs to the Treasury are very limited. In the latter case, not only may some promising technologies be stranded, but the revenue foregone is likely to be substantial and growing, since the subsidized product is on the steep part of the adoption curve. Both the PTC and ITC doubled in cost between 2016 and 2018 alone.[62]

Put in Place Tiered Incentives

An additional complication arises in clean energy innovation. In the absence of a long-term, sector- or economy-wide climate policy solution, such as a carbon price or clean energy standard, tax incentives that promote the adoption of mature low-carbon technologies may provide emissions reduction benefits, even if they no longer stimulate innovation. Phasing down incentives in a market in which their "dirty" competitors can still pollute for free places clean technologies at an unfair disadvantage. Until this gap is filled, the debate over energy technology tax incentives—especially how to make them more dynamic, so new generations of clean technologies can take off—will remain confused.

One solution to this dilemma is the creation of a tiered system of incentives. As clean energy technologies rise up the adoption curve, the incentive levels would be phased down, based on the level of market penetration and performance improvement. Similarly, policymakers could structure energy efficiency tax incentives to increase as deeper energy savings are reached. Rather than phasing out completely, however, a floor-level incentive might be continued until a climate policy is enacted.[63] (A time limit might also be imposed to withdraw incentives for technologies that are not taking off.)

For example, in the case of solar power, the ITC is scheduled to phase down to the 10 percent level initially enacted in 1978. Tax policymakers should follow through with the phase down, at least to a level commensurate with the emissions-reduction benefits of deploying more units of the current generation of solar panels. However, they should keep the higher level for more-innovative products to provide an incentive to drive them through the takeoff phase.

Delegate Detailed Decisions

A key reason energy technology tax incentives often outlive their usefulness (or never have any to begin with) is Congress makes detailed decisions about which technologies qualify, at what levels, and for how long—and it often does so poorly. Despite sometimes-heroic efforts by hard-working congressional staff, legislators usually lack adequate expertise to understand rapidly changing technologies and markets. The outcomes of their decisions often turn instead on political factors at the moment that deals are made. And they are subject to pressure from the beneficiaries of existing incentives, while those who would benefit from accelerated innovation may have little or no voice.

Our cases illustrate the messiness of the legislative process. The levels set for the PTC and ITC seem to have been set without any analytical rationale. Discussions with industry stakeholders suggest they were settled on through purely political negotiations. In 2015, Congress also extended the PTC only for wind, and the ITC only for solar, but allowed these incentives to expire for clean energy technologies, such as geothermal power and fuel cells, that might have benefited far more from this market signal.

Congress is also poorly positioned to adjust tax incentives to keep pace with new developments and trends. In the case of the 45L new homes credit, homebuilders were easily able to meet the standard for earning the incentive just a few years after it was implemented. In order to catalyze further innovation, the standard should have become more stringent. However, such an update would have required congressional action, which was fended off by a rent-seeking homebuilding industry, rather than based on evidence and analysis.

The nation would be better served if Congress sets the framework for tax incentives, including broad fiscal and policy parameters, but delegates detailed decisions about eligibility and duration to an executive branch agency with input from nongovernmental advisors and stakeholders. Such an approach would bring more expertise into decision-making, avoid arbitrary political decisions, limit the power of incumbent stakeholders, and raise the odds of incentives being phased out as technologies mature—as well as extended anew as promising technologies emerge.

Reward Risk-Taking

Tax incentives will not drive energy innovations unless they lead to clear, stable market signals in the form of lower prices. If innovators are confident potential buyers will receive such signals, they are more likely to be willing to take the risk of scaling production and investing in R&D in the hope of moving rapidly up the adoption curve and seizing market share. Early adopters will then be in a position to reward the most compelling innovators through their purchasing behavior.

The EV tax incentive's cumulative cap of 200,000 vehicles per manufacturer illustrates that point. When production volumes were well below the cap, it was irrelevant, and Tesla established a first mover advantage, largely as a result of its innovative products. Tesla's growth helped drive down battery costs, benefiting all EV manufacturers. However, as Tesla (and other companies) reach the cap, their products will be disadvantaged in the market, and the policy will penalize them for having taken risks to build a market. Potential investors who anticipate that this penalty will kick in may be dissuaded from funding first movers in such cases.

Of course, potential investors that think the cap will be lifted retroactively will simply ignore it. But many are likely to see some risk of Congress not acting, and adjust their behavior accordingly. Congressional unpredictability thus distorts market signals, with knock-on effects for innovators and early adopters. The pattern is all too common in our case studies. Virtually all of the tax incentives reviewed expired and were reinstated, sometimes retroactively.

Finally, tax incentives sometimes target the wrong players in a market, weakening the pull on innovation as a result. The 179D commercial building efficiency credit, for instance, was available primarily to real estate investors who did not have a tax liability and therefore could not take the credit. The system of tax equity investment, which allows otherwise-unrelated investors who have a tax liability to benefit from the PTC and ITC, is an elaborate and expensive work-around for this problem. Varun Sivaram and Noah Kaufman characterized tax equity investing as "an especially inefficient way to deliver subsidies," doubling the cost of capital compared with debt.[64] Similarly, the EV tax credit targets buyers rather than sellers, resulting in a regressive incentive that limits the number and diversity of buyers eligible to benefit.

Use the Whole Toolbox and the Right Tool for Each Task

Policymakers have a wide array of tools to choose from as they seek to steer the global energy system to a low-carbon future. It is important they pick the right tool for each task, particularly as they seek to accelerate clean energy innovation. Applying the wrong tool to a task leads to suboptimal outcomes, measured in both time and money.

To accelerate innovations for which no realistic market exists, policymakers should rely on tools that directly support innovators, such as public funding for RD&D and (more generous) tax incentives for private R&D. Fuel cell technology, for example, was aided far more in the early 2010s by the injection of direct funding under the Recovery Act than it was by tax incentives. As innovations such as fuel cells mature, the "push" provided by RD&D and the "pull" provided by tax incentives or other market development tools, such as government procurement and clean energy standards, should work together to accelerate innovation.

Once the risks that inhibit early adopters of an innovation are reduced, and the spillover benefits to society that arise during the takeoff phase are exhausted, tax incentives should be redirected toward the next generation of opportunities. A tool better suited to address the externality of carbon emissions, such as a carbon price or clean energy standard, should remain in place permanently, however, because the negative environmental impact of each additional carbon molecule emitted never goes away.

CONCLUSION: BREAKING THE CYCLE

Tax incentives have the potential to accelerate innovation in clean energy technologies that are poised to move rapidly up their adoption curves. Their potential has sometimes been realized in the recent past, such as with c-Si solar panels and, more recently, EVs. But too often the impact of this policy has been limited by design flaws. In some areas, such as advanced nuclear power, the incentives were poorly targeted and failed to make an impact because the technology was not ready for takeoff. In others, such as fuel cells, policymakers excluded potentially promising targets from qualifying for benefits. In still others, such as wind power over the last few years, mature technologies benefited from incentives, unnecessarily subsidizing incumbent producers and impeding more-radical innovators that might have competed with them.

The uneven results of energy technology tax incentives over the past decade and a half are the product of an unfortunate policy feedback loop. Incentives that are taken up create constituencies that then argue for extensions when the deadlines draw near. Other constituencies seeking their own piece of the pie see opportunities to benefit and jump into the fray as well. Chaotic deal making has become normalized, with lapses, retroactive extensions, and seemingly random changes that reflect budget considerations exogenous to energy.

It is long past time for legislators to break this unhealthy cycle. The imperative of combating climate change, which requires rapid and sustained clean energy innovation, has drastically raised the social cost of poor targeting, missed opportunities, and unnecessary extensions. The $20 billion or so the U.S. Treasury foregoes each year because of energy technology tax incentives could achieve much more if our principles were embodied in future policy.

Tax incentives are not a panacea. They are not an adequate substitute for a carbon tax, as some on the environmental left seem to think, nor for a robust publicly funded RD&D program, as some on the free-market right suggest. But they can be and should become consistently valuable tools for accomplishing a specific and important set of tasks that will accelerate clean energy innovation.

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