DESIGNING THE NEXT GENERATION OF FEDERAL TAX CREDITS FOR LOW-CARBON TECHNOLOGIES

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EXECUTIVE SUMMARY

Highlights

- Achieving emissions reductions to reach economy-wide net-zero emissions by 2050 will require sustained technological innovations and widespread deployment of emerging low-carbon technologies that are not yet commercially deployed on a mass-market scale.
- Tax credits are an important policy tool for supporting the early-stage deployment of emerging technologies as well as more mature technologies that have not yet reached widespread deployment.
- This paper proposes six considerations for designing the next generation of federal tax credits that can support deployment of clean energy and low-carbon technologies in the U.S. power, transportation, industrial, and buildings sectors: technology-neutral design, performance-based incentives, producer and consumer tax credits, phaseout criteria, refundability, and equity.
- Within each consideration, the paper lays out different approaches and discusses the trade-offs between them.
- While acknowledging their significant role, federal tax credits should be seen as one tool. Deep decarbonization will require a combination of different policy tools—including tax credits, grants, loans, rebates, mandates, certifications, public procurement programs, and policies such as carbon pricing and clean energy standards—to address the harmful effects of carbon pollution.

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Introduction

Decarbonizing the U.S. economy to achieve 50–52 percent emissions reductions by 2030 and net-zero emissions by 2050 will require substantial deployment of available and emerging alternatives to fossil fuel–based technologies. Tax credits are an important policy tool that can encourage innovation and help emerging and available low-carbon technologies progress from the early stages of development and deployment towards widespread adoption. However, limitations in existing U.S. federal tax credits have generated interest in evaluating design options to make the next generation of federal tax credits more efficient and effective at spurring innovation, increasing the adoption of clean technologies, and achieving emissions reductions across different sectors of the U.S. economy.

About This Working Paper

This working paper evaluates key considerations for the next generation of federal tax credits that can incentivize innovation and accelerate the deployment of low-carbon and clean energy technologies across the U.S. power, transportation, industrial, and buildings sectors. It provides an overview of innovations and technologies that are needed to support deep decarbonization of these sectors, assesses the existing federal tax credit structure for low-carbon technologies, and explains the role tax credits can play as a decarbonization policy tool. Based on research findings and feedback from experts and thought leaders on issues around the proper design of tax credit policies, the paper outlines different approaches for designing the next generation of federal tax credits, discussing their strengths and trade-offs. Forthcoming working papers will present analyses demonstrating the emissions reductions and economic benefits of a suite of tax credits that incentivize the deployment of various low-carbon technologies.

Limitations of the Current Federal Tax Credits

During fiscal year (FY) 2019 and FY2020, the federal government provided approximately \$24.7 billion in tax credits to support various low-carbon technologies (JCT 2019). Federal tax credits have helped drive the deployment of several low-carbon technologies, including wind, solar, and electric vehicles. Renewable energy capacity, for instance, has seen significant growth during the last decade; policy support, such

as federal renewable energy tax credits and declining costs, has enabled wind and solar energy, in particular, to become cost competitive with fossil fuel generation.

At the same time, existing tax credits suffer from critical design deficiencies that make them less effective:

- Federal tax credits have been caught in an endless cycle of expirations and extensions, sometimes retroactively. These short-term tax credits create uncertainty and discourage long-term planning by the private sector.
- Most clean energy tax credits are nonrefundable, meaning they can only be used by taxpayers with positive tax liability or through the tax equity market. A refundable tax credit allows the taxpayer to receive the full tax credit in the form of a payment or other compensation regardless of how much tax is owed. A direct-pay option specifically refers to the option of receiving a payment for the full amount of the tax credit.
- Once tax credits are in place, they need to be periodically reviewed to ensure that eligibility and duration keep pace with rapidly changing technologies and markets. Without review, tax credits have, in many cases, failed to sustain innovation.
- Existing federal tax credits do not apply to many low-carbon technologies that are essential for decarbonizing different sectors of the U.S. economy, including energy storage, transmission, medium- and heavy-duty zero-emissions vehicles, commercial and industrial heat pumps, transformative industrial technologies, and hydrogen production. In other cases, existing tax credits, such as the Section 45Q credit, are inadequate and can be further improved to deploy emerging technologies such as direct air capture.

Tax credits can be most effective when accompanied by complementary policies that work in tandem to move clean technologies from the emergence phase to the diffusion phase and finally to widespread adoption. During the initial research, design, and development phase, ensuring federal funding is available to all sizes and types of organizations—through grants, loans, and tax incentives—can spur innovation and foster the development of low-carbon

technologies. Once low-carbon technologies have been demonstrated successfully and are ready to enter markets, federal financial incentives in the form of carbon pricing, supply- and demand-side tax credits for low-carbon technologies, and direct-pay programs, along with nonfinancial incentives such as standards and mandates, can spur rapid deployment.

Since a major role of tax credits is to induce technological improvements and help emerging technologies reach cost parity, tax credits should be phased out once a technology has reached a sufficient level of market penetration. However, without policies such as carbon pricing that address the harmful effects of carbon pollution, market forces may prolong the use of high-carbon technologies due to the low cost of using existing fossil fuel-based equipment and infrastructure. As a result, tax credit advocates have proposed keeping them in place until they achieve intended outcomes, such as achieving an emissions reduction goal.

Recommendations

This paper proposes six design considerations that should guide federal policymakers in designing a new generation of tax credits. Whereas the first five are geared towards ensuring that federal tax credits contribute to technological innovation and accelerated deployment of low-carbon technologies, the sixth consideration aims to make tax credits widely accessible to more Americans.

- **Technology-neutral design**, where possible, with technology-specific tax credits used to target technologies that are deemed crucial to deep decarbonization
- **Performance-based incentives**, where possible, rather than tying incentives to monetary investment
- **Producer and consumer tax credits** for low-carbon technologies
- **Long-term credits with clear phaseout criteria**
- **Refundability and a direct-pay** option to increase availability and impact
- **Equity** to enable the adoption of low-carbon technologies by low- and middle-income Americans

In this working paper, we discuss each of these design considerations in detail as well as the key limitations and trade-offs associated with each.

1. INTRODUCTION

The United States can and must take significant action over the coming years to deploy existing clean technologies and reduce greenhouse gas emissions. However, a growing literature suggests that achieving deep decarbonization of the U.S. economy cannot be done with existing, economically mature technologies alone and will require sustained innovation across a number of key areas (Hart and Noll 2019). The International Energy Agency (IEA) has concluded that in order for the world to get to net-zero emissions, roughly half of emissions reductions in the coming decades must come from low-carbon technologies that are not yet commercially deployed on a mass-market scale (IEA 2020).

Recognition of this need for innovation has helped fuel discussion about scaling up the nation's investment in research and development related to low-carbon technologies. Although vitally important, such efforts will fall short of their goals if they are not backed by a robust set of policies designed to support the entrance of new technologies into the marketplace.

Tax credits have been discussed as a method of fostering a supportive environment for early-stage deployment of cutting-edge technologies, including advanced modular nuclear reactors; direct air capture (DAC); long-duration energy storage; carbon capture, utilization, and storage (CCUS); hydrogen made from renewable energy (green hydrogen) or from natural gas combined with carbon capture (blue hydrogen); and low-carbon steel and cement, as well as technologies that are commercially available but have not reached widespread deployment, such as electric vehicles (EVs) and heat pumps (Bartlett and Krupnick 2020b; Hart and Noll 2019).

Previous research has highlighted the need to reform the current architecture of low-carbon technology tax credits and the adoption of a technology-neutral tax credit structure that can accelerate innovation and deployment of these technologies, enabling the United States to decarbonize the entire economy (Hart and Noll 2019; Sivaram and Kaufman 2019). Two separate federal technology-neutral tax credit bills—the Energy Sector Innovation Credit bill, introduced by Representative Tom Reed (R-NY; henceforth called “the Reed bill”) in 2020, and the Clean Energy for America Act, introduced by Senator Ron Wyden (D-OR; henceforth called “the Wyden bill”) in 2021—have been proposed as a way to simplify the current system of incentives.

The analysis in this paper is drawn mainly from a review of available literature and five expert roundtable discussions. The literature review included industrial reports, academic literature, government documents and research, and reports and briefs from environmental stakeholders. The expert roundtable discussions included thought leaders from industry, environmental groups, nonprofits, and academic researchers and focused on issues related to effective tax credit design in the U.S. power, transportation, industrial, and buildings sectors. Roundtable participants provided insights on how to improve existing tax credits and how to design new ones, and these insights influenced the findings presented in this report. Data related to assessing the technology readiness levels of various low-carbon technologies to meet decarbonization needs, as well as insights on tax credit design considerations for these technologies, are based on expert consultations, academic literature, and publicly available U.S. decarbonization studies and energy outlook reports.

2. KEY TECHNOLOGICAL INNOVATIONS NEEDED FOR DEEP DECARBONIZATION

Since 2005, U.S. emissions reductions have been driven primarily by the transition of power generation from coal to natural gas and the shift towards a larger share of renewables in electricity generation (IEA 2019). Far less progress has been made in decarbonizing other sectors of the economy. Reducing emissions 50–52 percent below the 2005 level by 2030, a target set by the Biden administration, requires an immediate mobilization of low-carbon technologies that are commercially available or close to commercial deployment (Hultman et al. 2021; Williams et al. 2021). Achieving net-zero emissions by 2050 requires a broad array of technological solutions, many of which are not yet commercially available, to address other hard-to-abate sectors of the U.S. economy, such as medium- and heavy-duty transportation, aviation, shipping, and carbon- and energy-intensive manufacturing. Without accelerated, widespread adoption of low-carbon technologies, energy-related carbon dioxide (CO₂) emissions are expected to rise or stay the same in four of the five major sectors, with only emissions from the power sector slightly decreasing (Figure 1).

Under IEA's Faster Innovation Case 2020 (which brings the global energy system to net-zero emissions by 2050), almost half of cumulative emissions reductions stem from technologies that are not fully commercial today, with emerging clean technologies such as hydrogen-based

steel production; CCUS in cement and steel production; and hydrogen-fueled fuel cell vehicles for long-distance transportation entering markets after 2030 (IEA 2020). Such low-carbon technologies are currently in different phases (emergence, diffusion, and widespread adoption) of the S curve, which graphically depicts how technologies develop (Figure 2). The slope of the S curve varies significantly for different technologies and drivers of technological progress and adoption changes along the curve (Hart and Noll 2019).

In the following sections, we describe key decarbonization challenges across key sectors and technologies that would be needed to enable the United States to achieve net-zero emissions by 2050. These technologies are in various stages of development and will need policy support to reach widespread adoption. See Appendix A for an illustrative list of low-carbon technologies needed by each sector.

2.1 Power

Between 2005 and 2019, energy-related CO₂ emissions from the power sector dropped by 33 percent—despite an increase in electricity generation during this period—due to a shift from coal to gas, increasing shares of renewable energy, and energy efficiency improvements (EIA 2020). Faster adoption of power sector decarbonization options will be critical because this can enable faster decarbonization of other sectors of the U.S. economy, such as home heating and cooking, transportation, and industry through electrification. Fully decarbonizing the U.S. power sector by 2035, the target set by the Biden administration to make electricity carbon free, will require a rapid expansion in transmission capacity, deployment of sufficient energy storage, and adoption of technologies that can meet requirements of firm capacity, especially during times when renewable energy output is low. Currently, lithium-ion batteries and pumped storage hydropower are relatively mature economically, but they are not good options for long-duration electricity storage, defined as systems that can discharge for 10 hours or more at their rated power. Other energy storage technologies, such as flow batteries, compressed air energy storage, and electro-thermal batteries, as well as other emerging technologies, including small modular reactors, advanced geothermal, natural gas with CCUS, and hydrogen, are promising options to provide clean firm capacity. However, these technologies are still in pilot stages and need policy support to reach commercial deployment.

Figure 1 | Historic and projected energy-related CO₂ emissions and U.S. CO₂ emissions by sector

Source: EIA 2021.

Figure 2 | S-curve phases of low-carbon technology development and adoption

Notes: BEV = battery-electric vehicle; FCEV = fuel cell electric vehicle.

Source: ETC 2020.

2.2 Transportation

Energy-related CO₂ emissions from the U.S. transportation sector were 5 percent lower in 2019 compared to 2005 and now account for the largest share (37 percent) of total U.S. energy-related CO₂ emissions (EIA 2020). Decarbonizing transportation by 2050 requires phasing out sales of new internal combustion engine (ICE) vehicles between 2030 and 2035 (Larson et al. 2020) and the simultaneous aggressive adoption of zero-emissions vehicles (ZEVs), such as battery EVs (BEVs) and hydrogen fuel cell EVs (FCEVs), and low-emissions vehicles, including plug-in hybrid EVs (PHEVs).

A rapid build-out of EV charging and hydrogen refueling infrastructure will be necessary to accelerate EV and FCEV adoption across different vehicle classes. By one estimate, at least 2.3 million public chargers (compared to the 103,000 public charging points available in May 2021) will be needed to accommodate 82 million passenger EVs on U.S. roads by 2040, which is equivalent to 42 percent of the U.S. passenger vehicle fleet in 2040 (BNEF 2020a).

Aviation and shipping are widely viewed as more challenging to decarbonize than road transport. In addition to electrification of short-haul flights, it is expected that decarbonizing aviation will require increased adoption of a combination of sustainable biofuels, hydrogen, and synfuels derived from hydrogen and captured CO₂. Decarbonizing shipping will require a technology mix of batteries and uptake of zero-emissions fuels such as liquefied green hydrogen for short-haul shipping and liquefied green ammonia for longer distances (IEA 2020).

2.3 Industry

In 2019, industrial energy-related CO₂ emissions were 1 percent higher relative to 2005 and comprised more than 20 percent of total U.S. energy-related emissions (EIA 2020). Industrial energy-related CO₂ emissions are expected to be 30 percent higher in 2050 than they were in 2018, with increases in energy demand driven by economic growth outpacing efficiency improvements (EIA 2020). The lifetime of existing infrastructure or equipment, the low cost of incumbent production routes, trade-exposed products, and low profit margins for manufacturers also present challenges for decarbonizing the industrial sector.

Electrification offers the potential to decrease industrial emissions by 50 percent (Steinberg et al. 2017), but it will depend on the ability of utilities and power suppliers to

provide adequate amounts of affordable, low-carbon electricity to industrial facilities (ETC 2018). Decarbonizing the industrial sector will also require increased use of low-carbon substitutes such as hydrogen for high-temperature heating and CCUS technologies for capturing emissions resulting from chemical transformations in hard-to-abate industrial processes such as iron smelting and lime calcination. In IEA's Faster Innovation Case 2020, more than half of the cumulative emissions reductions in global steel, cement, and chemical production resulted from hydrogen and CCUS applications (IEA 2020). Currently, 95 percent of U.S. hydrogen supply is gray hydrogen, which is produced from steam methane reforming (SMR; Bartlett and Krupnick 2020a). Blue hydrogen (produced from SMR with CCUS) and green hydrogen (produced from electrolysis of water using renewable energy) are the two main pathways for producing clean hydrogen. Figure 3 shows the cost barriers to the production of low-emissions hydrogen.

2.4 Buildings

Direct CO₂ emissions from buildings accounted for 12 percent of total U.S. energy-related CO₂ emissions in 2019, with emissions 5 percent higher that year relative to 2005 (EIA 2020). Building emissions are expected to grow steadily through 2050, assuming current trends and policies (EIA 2020). Energy efficiency improvements, expansion in distributed electricity generation, and regional population shifts partially offset the impacts of population and building stock growth (Mahajan 2019).

Deep decarbonization of buildings will require electrification of building processes that currently use fossil fuels, such as natural gas, propane, and heating oil, along with further energy efficiency improvements. Electric heat pumps, especially when powered with zero-carbon electricity, offer significant potential to decarbonize space and water heating, which accounted for 65 percent of U.S. residential energy use in 2019 (EIA 2020). The market share of heat pumps needs to increase rapidly to at least 50 percent of residential heating, ventilating, and air-conditioning (HVAC) unit sales by 2030 (compared with 10 percent in 2019) to decarbonize the U.S. economy by 2050 (Larson et al. 2020; Williams et al. 2021). However, their high up-front costs can make heat pumps uneconomical for homeowners, especially compared to gas (Figure 4).

Figure 3 | Costs of hydrogen by production route, 2020

Notes: CCUS = carbon capture, utilization, and storage; SMR = steam methane reforming. Electrolyzer costs for both solar and wind electrolysis are assumed to be \$840 per kilowatt. For solar electrolysis, the capacity factor is 26 percent, and the electricity cost ranges from \$17.50 per megawatt-hour (MWh) to \$85/MWh; for wind electrolysis, the capacity factor is 48 percent, and the electricity cost ranges from \$23/MWh to \$55/MWh.

Source: Bartlett and Krupnick 2020a.

Figure 4 | Total cost of ownership for air-source heat pumps versus gas heating units in residential buildings, 2020

Note: Accumulated cost of heating includes heating unit up-front cost and fuel costs for an average single-family home (140 square meters) over a lifetime of 20 years. Up-front costs for air-source heat pumps range from \$5,824 to \$7,634, whereas up-front costs for gas and oil heating units are assumed to be \$4,123 and \$6,873, respectively. Assumed fuel costs average \$0.12–\$0.17 per kilowatt-hour (kWh), \$0.03–\$0.05/kWh, and \$0.07–\$0.11/kWh for air-source heat pumps, gas, and oil heating units, respectively. The different fuel costs have been converted to a common energy unit to aid comparison. If heat pumps are purchased instead of central air conditioners when central air conditioners will be replaced, heat pumps are closer in total cost than shown here.

Source: BloombergNEF 2020b.

3. THE CURRENT LANDSCAPE OF FEDERAL TAX CREDITS

Tax credits, combined with other federal policies, represent a crucial opportunity to accelerate technology deployment and emissions reductions. During fiscal year (FY) 2019 and FY2020, the federal government provided approximately \$24.7 billion in tax credits to support low-carbon technologies through a number of targeted tax credits that support the production of electricity from renewable energy, alternative transportation fuels and vehicles, energy efficiency in homes and commercial buildings, and CO₂ sequestration (JCT 2019) (see Figure 5). The two largest are the production tax credit (PTC) and the investment tax credit (ITC), followed by incentives for residential energy efficiency and EVs. See Appendix B for an overview of existing tax credits in the power, transportation, industrial, and buildings sectors.

3.1 Current Tax Credit Effectiveness

Federal tax credits are intended to help drive deployment of low-carbon technologies and can also serve as a tool to spur innovation (Hart and Noll 2019). Evidence to date

indicates that although tax credits have helped technologies move up the adoption curve, their impact on advancing innovation has been harder to discern.

A more effective tax policy must create opportunities to drive down costs, advance technological learning, and, crucially, enable wider deployment of new and emerging technologies. A number of design deficiencies, however, are leading to suboptimal impacts:

- **“On-again, off-again” cycle creates uncertainty.** Existing tax credits for renewable energy technologies have been allowed to lapse several times and have led to a boom-and-bust cycle of development (Hart and Noll 2019). The repeated expiration and short-term renewal of the PTC was particularly harmful for wind turbine manufacturing as it was working to gain a foothold in the United States (see Figure 6). Tax credits should, therefore, be in place for a reasonable period of time, assuring market players that it is worth making the investment.

Figure 5 | Total cost of federal tax incentives for low-carbon technologies, FY2019 and FY2020

Notes: ITC = investment tax credit; PTC = production tax credit. Figure shows cost of federal tax incentives for fiscal year (FY) 2019 and FY2020 according to estimates of the Joint Committee on Taxation (JCT). Estimates include both personal income and corporate income tax expenditure amounts. Alternative technology vehicles include tax credits for plug-in electric vehicles and alternative technology vehicles. “Other” includes credits for carbon dioxide sequestration, investment in advanced nonbusiness energy property, and holders of clean energy renewable bonds and qualified energy conservation bonds.

Source: JCT 2019.

Figure 6 | Wind capacity additions and PTC expirations and extensions, 1990–2020

Sources: EIA 2020; Frazier et al. 2019.

- Most tax credits are nonrefundable, meaning they can only be used by taxpayers with significant tax liability.** Residential energy efficiency tax incentives, for instance, have been claimed by higher-income taxpayers, which can undermine one of the policy goals of using tax credits—to advance energy efficiency among low-income households (Crandall-Hollick and Sherlock 2018; see Figure 7). EV tax credits have also been found to be disproportionately claimed by higher-income taxpayers, especially those with adjusted gross income of \$100,000 or more (Sherlock 2019). Making these credits refundable, and in some cases replacing them entirely with grants and rebates, can increase equity and participation in these programs.
- The inability to keep pace with new developments and trends depresses innovation.** Once tax credits are in place, they should be periodically revised or contain provisions to ensure that eligibility and duration keep pace with rapidly changing technologies and markets. For example, Section 45L, which provides an incentive for energy-efficient new homes, has stuck to the 2006 International Energy Conservation Code even though revisions are made to this code every three years. Although the numbers of new homes qualifying for the credit have increased, home builders have focused on building-envelope improvements using outdated technologies, inhibiting the adoption of newer, more efficient options (Hart and Noll 2019).

Figure 7 | **Distribution of the residential energy tax credit claimants and total amount of credit by adjusted gross income, 2018**

Source: WRI calculations based on 2018 U.S. Internal Revenue Service Statistics of Income data.

■ **There is an absence of tax credits for emerging low-carbon technologies.** Currently, federal tax credits do not apply to many low-carbon technologies that need to be part of the decarbonization toolbox across different sectors, including energy storage, transmission, medium- and heavy-duty ZEVs, commercial and industrial electric heat pumps, and hydrogen production. Energy storage technologies qualify for tax credits only when they are paired with energy generation sources that otherwise qualify for tax credits. Including these technologies within the federal tax credit scheme would enable faster market penetration and more widespread decarbonization impacts.

A significant rethinking of the federal tax credit structure is needed. Fortunately, a smarter tax credit approach for low-carbon technologies is fertile ground for bipartisan support. Both Democrats and Republicans support tax reforms to incentivize deployment of clean technologies,

as demonstrated by the Reed and Wyden bills; the Growing Renewable Energy and Efficiency Now (GREEN) Act of 2021, introduced by Democrats on the House Ways and Means Committee; and numerous proposals to eliminate fossil fuel subsidies. Congress should build upon this momentum to implement the next generation of federal tax credits, which can align with the urgent need to decarbonize the U.S. economy.

4. THE ROLE OF COMPLEMENTARY POLICIES IN DECARBONIZATION

Although tax credits can play a role in increasing deployment of low-carbon technologies, they are most effective when accompanied by complementary policies that work in conjunction to move critical technologies towards deployment and widespread adoption. Each phase of the S curve is characterized by unique barriers to low-carbon technologies that require targeted policy solutions.

Policymakers possess many tools that can be used to decarbonize the economy. Financial incentives include grants, low-interest loans, and loan guarantees; tax tools such as excise taxes, consumption taxes, and emissions taxes; and tax credits, exemptions, and exclusions. Product and process efficiency standards drive innovation by providing market opportunities for low-carbon technologies, and mandates, such as a ZEV mandate, are important tools for increasing adoption of proven low-carbon technologies. Each of these policy tools entails different roles for the government, the program recipient, and the potential business partners of the recipient, and each tool has design options that can be used to adjust the program's accessibility and expenditure levels. These tools are most effective in driving decarbonization when they are used in tandem to encourage the development of low-carbon technologies through all stages of the S curve (Figure 8).

4.1 Emergence Phase

Low-carbon technologies must be researched, designed, and developed, and each of these stages requires substantial investment to spur innovation and foster the development of low-carbon technologies. Public sources of funding that are most effective in the emergence phase include grants, tax credits, and loans. Grants and loans provide critical funds for entities that may not have significant tax liability, and tax credits can also be designed to avoid the need for taxable revenue. The key in this phase is to provide funding options for all sizes and types of organizations, from large corporations to small start-ups. Smaller firms are more dependent on external sources of funding than large companies, though the latter may underinvest in private research and development because knowledge spillovers prevent companies from appropriating full returns on their investment.

Figure 8 | **Complementary policies to increase the development and adoption of low-carbon technologies**

Source: WRI authors.

4.2 Diffusion Phase

Once decarbonization technologies have been demonstrated successfully at the pilot level, federal subsidies and incentives are needed for rapid deployment. These subsidies can take the form of excise taxes on high-carbon technologies, tax credits for low-carbon technology producers, consumer tax credits for purchases of low-carbon technologies, and direct-pay programs such as grants and loans, among others. During this stage, tax credits for low-carbon technologies that offer flexibility regarding who can claim the credit and how it can be claimed are more effective because taxable revenue for early-stage technologies is generally limited relative to more established technologies.

Nonfinancial (often called “unfunded”) policies can include low-emissions mandates and standards, and these policies can force the adoption of low-carbon technologies in the diffusion stage, thus providing market opportunities that otherwise might not materialize until cost parity with incumbent technologies is reached. This early market share helps to foster cost-cutting opportunities related to scale and infrastructure that can otherwise remain significant barriers over long timescales. For instance, renewable portfolio standards in many states have helped renewable energy deployment, and state-level ZEV mandates have forced automakers to provide low-emissions vehicle options for consumers.

4.3 Widespread Phase

Once a low-carbon technology is well established, policies that promote its competitiveness are essential to reaching full decarbonization in a timely manner. Without policy incentives for this last phase of the S curve, market forces will dominate production and consumption, which could result in prolonged use of high-carbon technologies because using existing equipment and infrastructure until it reaches its natural end of life is the lower-cost option. Pricing carbon to address the harmful effects of carbon pollution can be a key strategy to encourage the market to move from dirty to cleaner technologies. Federal standards, such as a clean electricity standard and a ZEV mandate, can also play an important role in completing the transition to 100 percent clean energy technologies.

Policies should support low-carbon technologies in all stages of the S curve, aiming for a continual process of innovation and technology replacement and an ever-decreasing carbon intensity. The role of tax credits, in particular, is to induce technological improvements and

drive down costs for emerging technologies. Other policy tools discussed above should be used to complement, and in some cases address the deficiencies of, tax credits. Collectively, these policy tools can help build a market for low-carbon technologies.

5. DESIGN CONSIDERATIONS FOR FEDERAL TAX CREDITS FOR LOW-CARBON TECHNOLOGIES

This section outlines design considerations for federal tax credits for low-carbon technologies in the power, transportation, industrial, and buildings sectors.

- **Technology-neutral design**, where possible, with technology-specific tax credits used to target technologies that are deemed crucial to deep decarbonization
- **Performance-based incentives**, where possible, rather than tying incentives to monetary investment
- **Producer and consumer tax credits** for low-carbon technologies
- **Long-term credits with clear phaseout criteria**
- **Refundability and a direct-pay** option to increase availability and impact
- **Equity** to enable the adoption of low-carbon technologies by low- and middle-income Americans

These design criteria—and their inherent trade-offs—are discussed below.

5.1 Technology-Neutral Design

To the extent that technology-neutral tax credit design is possible, market forces can be relied upon to develop the most cost-effective technologies. In contrast, technology-specific policies can entrench a few technologies in the marketplace, resulting in economic inefficiencies and suboptimization (Hart and Noll 2019; Sivaram and Kaufman 2019). Current proposals for tax reforms, therefore, have called for changes that would make the federal tax code more technology neutral.

One approach would be to assign a dollar amount per metric ton of emissions reduction, where the level of the tax credit could be based on the social cost of carbon. Other metrics could be used, such as energy savings. This approach, however, is subject to various challenges.

By prioritizing only the lowest cost-abatement options, it could delay the replacement of long-lived equipment with clean technologies, thus slowing emissions reductions in hard-to-abate sectors. This approach is also likely to be administratively challenging, which would reduce economic efficiency and could allow for gaming. Overall, this approach would enable tax credits to mitigate the cost impacts of scaling and diffusing mature clean technologies but might not be effective in advancing innovation.

A second approach would be to establish tax credits that target specific functions within each sector while remaining agnostic about which technology will decarbonize those functions (Table 1). In the power sector, for instance, the functions can be thought of as generating electricity from zero-carbon sources, transmitting electricity from one location to another, and storing energy for long durations.

Finally, a third approach could allow for technology-specific tax credits for low-carbon technologies that are expected to play a crucial role in decarbonization across multiple sectors, such as clean hydrogen and CCUS. By building up market share in one or more sectors, costs can be brought down across all sectors, increasing the potential for decarbonization across sectors.

In reality, federal tax credits are likely to be a combination of sector-specific technology-neutral tax credits and technology-specific credits. A mixed approach would achieve a certain level of economic efficiency while acknowledging that information, though incomplete and imperfect, exists regarding the set of technologies that will play a key role in decarbonization. In the case of technology-specific policies, phaseout criteria should be carefully designed to allow for project planning while guarding against technology entrenchment to the extent possible (Section 5.4).

5.2 Performance-Based Incentives

Perhaps the most crucial tax credit design elements for maximizing efficiency and impacting decarbonization are the credit's target and the metric for awarding the credit. ITCs that attach incentives to project costs or other nonperformance-based metrics risk spending public dollars inefficiently. Performance-based metrics, in contrast, align with technology-neutral objectives and reward projects that actively progress towards climate goals while also being efficient with spending. In the following sections, we offer tax credit design options for performance-based incentives in the power, transportation, industry, and buildings sectors.

5.2.1 Power

The three main functions associated with power supply are electricity generation, storage, and transmission, and each of these functions could be targeted with a separate tax credit. Similar to the PTC for wind, the performance basis for tax credits would be kilowatt-hours (kWh) of electricity generated by zero-carbon technologies. However, this approach does not distinguish between firm and variable generation, which play different roles on the grid. One possible solution proposed by the Reed bill ties the credit to the value of electricity in the wholesale market. For technologies accounting for less than 1 percent of national electricity generation, the incentive is set at 60 percent of the value of energy when it is sold. If the market values electricity at \$10 per megawatt-hour (MWh) at a given time and the clean generation source is able to meet that demand, the incentive would pay \$6 for that MWh. The Reed bill would phase out incentives as a technology's market share grows (Box 1). This approach can reward flexible and firm generation, including advanced nuclear, geothermal, advanced hydro, and facilities with CCUS, which can be ramped up or down in response to market signals (Powell and Kersey 2020).

Table 1 | **Tailoring technology-neutral tax credits to support decarbonization functions within sectors**

POWER	TRANSPORTATION	INDUSTRY	BUILDINGS
Zero-carbon generation	Electric vehicles in light- to heavy-duty segments	Low-carbon heat	Energy efficiency and demand management
Energy storage	Electric vehicle charging infrastructure	Carbon dioxide capture	Electrification
High-voltage transmission	Low-carbon fuels in hard-to-abate segments, including aviation and shipping	Process emissions	Low-carbon building materials

Source: WRI authors.

Energy storage is increasingly viewed as essential to a low-carbon electrical grid because it allows for the connection of variable renewable energy sources without needing fossil fuel plants to respond to peak demand events or stabilize the grid. A performance-based tax credit could be applied to storage by crediting clean electricity that is routed to storage. Under the Reed bill approach, storage could be included by counting “generation” at the time electricity is used (presumably at a time when it is more valuable), rather than when it is first generated. This would require tagging zero-carbon energy generation that goes into storage so that it is not double counted, but only credited when used.

An ITC approach is likely to work better for deploying high-voltage transmission lines, but it could be tied to clear performance metrics. For example, projects should be capable of transmitting electricity at a voltage of no less than 275 kilovolts and have a transmission capacity of at least 500 MW, as included in the Electric Power Infrastructure Improvement Act of 2021 introduced by Senator Martin Heinrich (D-NM). An ITC could also be designed to reward long-distance, interregional lines and projects that utilize underground power lines along existing highway and rail infrastructure with already established rights-of-way. Tax credits could specify that projects do not exceed a threshold of cumulative transmission losses as a percentage of overall transmission line capacity. This would encourage the continual development of new technology to improve efficiency.

Box 1 | Example of performance-based tax credit design for zero-carbon electricity generation

- 60 percent of the value of energy when it is used, for a technology that accounts for less than 1 percent of electricity generation
- 45 percent of the value of energy when it is used, for a technology that accounts for less than 2 percent of electricity generation
- 30 percent of the value of energy when it is used, for a technology that accounts for less than 3 percent of electricity generation

Source: Approach based on Representative Reed's Energy Sector Innovation Credit bill, 2020.

5.2.2 Transportation

Performance-based incentives could support decarbonization of the transportation sector through vehicle electrification, EV charging infrastructure deployment, and adoption of low-carbon fuels.

A consumer-facing tax credit to accelerate EV adoption could be based on vehicle range per charge. Larger incentives for EVs offering longer ranges could attract consumers who have a strong preference for ICE vehicles because of driving-range concerns. Additionally, price reductions offered by such a range-based tax credit could increase the availability of longer-range EV models by incentivizing automakers to improve battery performance and vehicle design and efficiency. Tax credits for EV purchases can be further complemented with policies that reward removing ICE vehicles from the road.

Tax credits for charging infrastructure should incentivize the construction of all important charging classification levels, which are defined by charging rate. Expanded penetration of Level 2 charging infrastructure—commonly found in homes, workplaces, public parking, and commercial settings—can help with EV uptake. However, widespread deployment of Level 3 direct-current fast chargers (DCFC), especially in highway locations, is necessary if EVs are to be used for long-distance travel. Taking the significant cost and benefits of Level 3 charging infrastructure into account, the tax credit could be designed to provide a larger incentive for investments at this level. Tax credits for Level 3 charging could vary according to power output to account for the differing charging needs of passenger car EVs and medium- and heavy-duty EVs. The power flow required to fast charge medium- and heavy-duty vehicles is very large, and tax credits could be designed to help with the full system cost, including any power system upgrades needed.

Finally, low-carbon fuels are necessary for decarbonizing existing ICE vehicles until full electrification is achieved as well as for heavy-duty vehicles, aviation, and shipping. A PTC for low-carbon fuels could be designed as a price per gallon of gasoline equivalent, with the credit amount varying according to the carbon intensity of the fuel being produced or delivered. Box 2 provides examples of performance-based tax credits in the transportation sector.

Box 2 | Example of performance-based tax credit design for the transportation sector**Tax credit proposal for electric vehicles (EVs) in the light-duty vehicle segment**

- EV tax credit level as a function of vehicle range:
 - \$7,000 tax credit for EVs with driving range of more than 300 miles
 - \$5,000 tax credit for EVs with driving range of 200–300 miles
 - \$4,000 tax credit for EVs with driving range of 100–200 miles
 - \$3,000 tax credit for EVs with driving range of 50–100 miles
- Tax credit eligibility limited to vehicles with a manufacturer suggested retail price less than \$45,000–\$50,000

Tax credit proposal for zero-emissions vehicles (ZEVs) in the medium- and heavy-duty vehicle segment

- ZEV tax credit level as a function of vehicle range:
 - Tax credit worth 70 percent of purchase price difference between ZEV and internal combustion engine (ICE) vehicles with driving range of more than 300 miles, capped at \$100,000

- Tax credit worth 60 percent of purchase price difference between ZEV and ICE vehicles with driving range of 200–300 miles, capped at \$75,000
- Tax credit worth 50 percent of purchase price difference between ZEV and ICE vehicles with driving range of 100–200 miles, capped at \$50,000

Tax credit proposal for EV charging infrastructure

- Tax credit worth 50–70 percent of cost of installing direct-current fast chargers with incentive varying according to maximum power output
- Tax credit worth 30 percent of the cost of installing Level 2 chargers

Tax credit proposal for low-carbon fuels

- Two dollars per gallon equivalent for fuels with carbon intensity at least 50 percent lower than average carbon-intensity benchmark for gasoline and diesel fuels, rising to four dollars per gallon for a zero-carbon fuel

5.2.3 Industry

The industrial sector presents significant challenges to designing performance-based tax credits, in part because it produces a wide variety of products. Many products can be substituted for others, making it hard to maintain a level playing field among technologies and products. Also, emissions performance metrics in the industrial sector need to be defined relative to a benchmark, or counterfactual, which can be uniquely defined for each process or product. However, a limited number of essential processes and commodities within the industrial sector are relatively amenable to technology neutral, performance-based tax credit designs because they are specific, well defined, or homogeneous—for example, heating, CCUS, steel, cement, ammonia, hydrogen, and glass.

Industrial heating is responsible for roughly 10 percent of global emissions and could be targeted with a technology-neutral, performance-based tax credit. Fossil fuel boilers used for low-temperature and medium-temperature heating processes can be replaced with electric boiler technologies, and high-temperature heat processes operating between 400°C and 1,000°C and very high-temperature processes operating above 1,000°C are more amenable to fuel switching to low-carbon fuels, such as hydrogen.

Performance metrics for a PTC for basic materials such as steel, cement, and glass products could be based on an emissions-intensity benchmark for each product covered. This product-specific but technology-neutral approach would incentivize retrofits and incremental improvements in the emissions intensities of manufactured products and also investment in innovative technologies. To further incentivize innovative technologies, a PTC could be paired with a complementary policy, such as an ITC, for proposed projects that have large up-front costs and could demonstrate a significant reduction in emissions intensity relative to the benchmark.

Additionally, certain products and technologies offer potential decarbonization opportunities across a variety of processes in many sectors, and their production could be encouraged with a performance-based tax credit. Hydrogen, for instance, has great potential to decarbonize industrial high-heat processes, iron ore reduction, and transportation and can provide medium- and long-term energy storage. Fuels derived from biomass waste—useful in industrial heating processes and in the transportation and power sectors—could also be targeted with a PTC. CCUS and direct air capture and storage (DACS) are cross-

cutting technologies that are critical for decarbonizing the industrial and the power sectors. The existing Section 45Q tax credit offers support for these technologies, but the incentive levels are sometimes too low to be effective. Increasing the incentive levels for CCUS and DACS would encourage the build-out of capture technologies and storage infrastructure. Box 3 offers design recommendations for low-carbon tax credits in the industrial sector for industrial heating processes and commodity manufacturing.

5.2.4 Buildings

A technology-neutral and performance-based approach to incentivizing energy efficiency in commercial buildings and new homes can be based on the percentage of energy savings or can meet the latest requirements of building standards, such as the U.S. Environmental Protection Agency's Energy Star program and the U.S. Department of Energy's Zero Energy Ready Home program.

For existing commercial buildings, energy savings could be relative either to a preretrofit base or to the most recent building standards. For new buildings in both residential and commercial markets, the percentage of energy savings should be relative to the most recent building standards

or new codes calling for net-zero emissions. Tax credits should go to developers for building energy-efficient homes and buildings. Box 4 provides examples of performance-based tax credits for incentivizing energy efficiency in new homes and commercial buildings.

For existing residential homes, a performance-based tax credit may be too weak to incentivize enough consumers to invest in whole retrofits or too slow to contribute to meaningful climate action. Residential customers typically replace appliances at the very end of their life and are motivated by point-of-sale incentives. Moreover, tax credits for this market would not reach many low- and moderate-income families because they cannot afford to pay up front and then wait for a tax refund. For all these reasons, retrofit grants and rebate programs may be better suited to advance energy efficiency for existing homes.

Technology-neutral energy efficiency tax credits should be paired with technology-specific programs and electrification tax credits, which could target key technologies such as electric heat pumps and heat pump water heaters. Tax credits for appliances can be tied to efficiency levels, leaving it to manufacturers to choose which technologies to employ to reach those levels.

Box 3 | Example of performance incentives for low-carbon tax credits in the industrial sector

Tax credit proposal for industrial heat

- Electrification of low- and medium-temperature heat (less than 400°C)
 - Production tax credit for facilities that maintain 50 percent electrification of low- and medium-temperature heat over a production year; the tax credit incentive would be equal to 75 percent of the cost difference between the low-emissions products and fossil fuel-based products
- Use of waste biomass or hydrogen for high-temperature heat (greater than 400°C)
 - Production tax credit for facilities that maintain 50 percent of high-temperature heating using waste biomass and/or hydrogen over a production year; the tax credit incentive would be equal to 75 percent of the cost difference between the low-emissions products and fossil fuel-based products

Tax credit proposal for commodity manufacturing

- Steel, cement, and ammonia
 - Production tax credit for products that have an emissions intensity at least 30 percent lower than the industrial average; the tax credit incentive would be equal to the annual production times 50 percent of the cost difference between the low-emissions products and the average industry-wide product costs
 - Production tax credit for products that have an emissions intensity at least 50 percent lower than the industrial average; the tax credit incentive would be equal to the annual production times 75 percent of the cost difference between the low-emissions products and the average industry-wide product costs
- Hydrogen
 - Production tax credit equal to two dollars per kilogram for blue hydrogen, green hydrogen, or emerald hydrogen which is hydrogen production from waste biomass gasification with CCS (with a phasedown as production volumes increase and costs decline)

Box 4 | Example of performance-based incentives for building energy efficiency

Tax credit proposal for new energy-efficient homes

- Tax credit of \$2,500 for new homes meeting the latest Energy Star requirements, which require homes to be at least 10 percent more efficient than homes built to code
- Tax credit of \$5,000 for new homes meeting Zero Energy Ready Home program, where most or all of the homes' annual energy use can be offset with on-site generation (e.g., rooftop solar)

Tax deduction proposal for new energy-efficient commercial buildings

- Tax deduction of \$2.50 per square foot for buildings that are at least 25 percent more efficient than Standard 90.1-2019 of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
- Tax deduction of \$3.50 per square foot for buildings that are at least 35 percent more efficient than ASHRAE 90.1-2019
- Tax deduction of \$5 per square foot for buildings that are at least 50 percent more efficient than ASHRAE 90.1-2019

Tax deduction proposal for existing commercial buildings

- Tax deduction of \$2.50 per square foot when buildings achieve 25 percent energy savings compared to preretrofit consumption level
- Tax deduction of \$3.50 per square foot when buildings achieve 35 percent energy savings compared to preretrofit consumption level
- Tax deduction of \$5 per square foot when buildings achieve 50 percent energy savings compared to preretrofit consumption level

capacity, scale up production, and reduce per-unit costs through economies of scale (ETC 2020; Ladislav et al. 2021). Compared to demand-side tax credits, supply-side incentives such as a manufacturer tax credit could better accelerate the adoption of emerging technologies. A manufacturer tax credit lowers prices at the time of sale, whereas a consumer tax credit requires buyers to claim the credit when filing their taxes—and it is only available to consumers with a significant tax liability. Manufacturer credits, because they generally reduce the wholesale price of products, will also often reduce markups added at subsequent stages in the supply chain. Additionally, manufacturer tax credits such as the now-expired Section 45M energy-efficient appliance tax credit could encourage development of more-efficient products. Section 45M provided credits to manufacturers according to the energy savings their appliances offered, and the credit allowed more efficient technologies to become affordable to a wider segment of consumers (Hart and Noll 2019).

Although tax credits for manufacturers or producers have different strengths, supply-side incentives that aim to support innovation, lower production costs, and scale up production may have limited impacts in the absence of effective demand-side incentives. For example, the Section 48C advanced manufacturing tax credit, offered under the 2009 American Recovery and Reinvestment Act (ARRA), provided \$2.3 billion to incentivize domestic renewable energy, nuclear, and energy equipment manufacturing, but the program did not meet its manufacturing capacity build-out goals because manufacturers lacked confidence in local market demand for clean energy equipment (Ladislav et al. 2021).

Strong demand-side incentives could also be important for accelerating the adoption of more mature clean technologies that are on the verge of reaching cost competitiveness but still have limited market penetration. For example, EVs are expected to become cost competitive with ICE vehicles as early as 2025 but are expected to account for only 42 percent of new car sales in 2040 (from about 2 percent in 2019; BNEF 2020a). Demand-side tax incentives can speed up their deployment by driving down costs and increasing customer acceptance. The implementation of demand-side incentives should ensure that those incentives are available to a greater section of consumers. Later, we discuss issues around making tax credits refundable (with a direct-pay option) and more equitable.

5.3 Producer and Consumer Tax Credits

Reaching economy-wide net-zero emissions will require substantial expansion of clean technologies. A combination of supply- and demand-side incentives will be necessary to establish industries and supply chains that can support a fully decarbonized economy and enable widespread deployment of emerging cleaner alternatives to incumbent fossil fuel–based technologies.

Emerging industries and technologies that are in the “pre-cost-competitive” phase (e.g., green hydrogen, industrial heat pumps, or advanced energy storage technologies) will require strong supply-side incentives to deploy initial

In some instances, federal tax policy may need to incentivize both demand and supply for emerging clean technologies such as green hydrogen. Hydrogen's use in decarbonizing heavy industry will require a significant increase in production of green hydrogen as well as fuel switching in industrial processes, both of which currently entail high costs. A PTC could incentivize an increased supply of green hydrogen, and an ITC could enable industrial users to switch from emissions-intensive heating or processes to green hydrogen.

5.4 Long-Term Credits with Clear Phaseout Criteria

Federal tax credits should be long term to provide predictability and certainty to the private sector and contain clear phaseout criteria, which reduce support for clean technologies as they move up the adoption curve. Below, we outline different phaseout criteria:

Market share. Tax credits are phased out as market share thresholds are reached. The Reed bill takes this approach. According to the bill, low-carbon electricity sector technologies become ineligible for tax incentives when they reach a market share of 3 percent. The emerging electricity production credit in the Reed bill also reduces as generation grows: the credit is worth 60 percent for a technology representing less than 1 percent of national generation, but 30 percent as generation share rises to 3 percent. Although this approach would enable a technology to gain a foothold in the market, determining the market share threshold might be a contentious political process. Moreover, eliminating all credits for clean power at 3 percent market share could hinder the widespread deployment of these technologies, especially in the absence of other decarbonization policies, such as clean energy standards.

Contract for difference. A tax credit can be phased out through a contract for difference mechanism that determines the amount of the tax credit according to the difference between the current production cost of a low-carbon technology or product and the current market price of a competing carbon-intensive technology or product. This approach would allow market forces to phase out a tax credit by reducing the amount of the incentive as an emerging technology becomes more cost competitive with incumbent technologies. However, this approach could encourage producers to exploit the credit by artificially increasing the apparent cost of production to receive a

higher tax credit than the amount set by actual market prices. This approach is also likely to create uncertainty in the market, leading to difficulties in financing a project's capital costs.

Emissions reduction goal. Tax credits would be phased out after emissions targets are reached. The Wyden bill takes this approach. In the electricity sector, the bill calls for phasing out incentives when the Environmental Protection Agency and the Department of Energy certify that the power sector emits 75 percent less carbon than 2021 levels. Incentives are phased out over a period of five years to avoid "cliffs," where incentives disappear suddenly. This approach has the benefit of tying tax incentives to a desired outcome (i.e., emissions reduction) but also risks supporting already mature technologies and may be unnecessarily expensive.

Time limits. Congress specifies the number of years during which technologies are eligible for incentives. This has been the preferred approach to date. However, as the history of existing tax credits shows, time limits—especially when they are shorter duration and prone to repeated expirations and extensions—have often created uncertainty about whether incentives would be extended, depressing private investment. Longer-term incentives provide policy certainty but can also lead to technology lock-in by supporting mature technologies.

Unit limits. A technology is eligible for tax credits until it reaches a specified cap on cumulative units produced. The argument for unit caps is that once manufacturers have produced a given number of products, acquired experience with the technology enables them to lower costs. However, this approach requires specifying the unit cap in a way that the incentive supports the adoption of promising technologies while screening out more mature technologies. The EV tax credit's cap of 200,000 cars per manufacturer illustrates other potential drawbacks of this approach. It can discourage first movers, penalize risk-taking, and dissuade potential investors from funding first movers (Hart and Noll 2019). As Tesla and General Motors have hit the 200,000 cap, their electric cars are now disadvantaged in the market. Options to address this could include increasing the manufacturer-specific cap, lowering but not eliminating the tax credit once a manufacturer has reached a specified production volume, and removing the manufacturer-specific cap and replacing it with an overall unit cap available for all EV models on a first-come-first-served basis.

Emissions pricing/standards. Credits are phased out when carbon emissions are taxed or regulated in a given sector. In scenarios where policymakers apply multiple decarbonization tools, tax credits are best used as a tool to incentivize the deployment of available technologies, drive down costs, and induce technological innovation, not as a permanent tool that substitutes for other deployment policies, including carbon pricing or clean energy standards that address the externality of carbon pollution (Trembath et al. 2020). In the absence of a sector- or economy-wide decarbonization policy, however, completely phasing out tax incentives for more mature technologies can put them at a disadvantage in an environment where their dirty competitors can pollute for free (Hart and Noll 2019). Clean energy technologies compete on an uneven playing field where most states do not price carbon into their markets and fossil fuel technologies continue to enjoy a range of direct and indirect subsidies (Aldy 2014; Coady et al. 2019).

If tax credits remain available even after a technology has been widely adopted, they can contribute to technology lock-in and stifle innovation and deployment of other technologies (Hart and Noll 2019; Trembath et al. 2020). The implications in terms of forgone revenue to the federal government can also be substantial to the extent that the technology is already able to compete with incumbent technologies. For that reason, phaseout criteria that are tied to market share, contract for difference, or unit limits may be desirable. On the other hand, given the decarbonization imperative and the absence of sector- or economy-wide policies, tying the phaseout criteria to certain intended outcomes, such as meeting emissions reduction goals or until emissions pricing and other standards are in place, could be preferable.

5.5 Refundability and a Direct-Pay Option

Many current tax credits offer incentives only to developers, organizations, and individuals with sufficient tax liability. For example, Section 179D for commercial building energy efficiency was not available to private building owners who did not have sufficient tax liability, even though they made up a significant share of commercial real estate owners (Goldstein et al. 2012). This has limited the uptake of the credit, as have factors such as the low value of the incentive and the complicated procedures to qualify.

Similarly, the current PTC and ITC programs require that the recipient have enough tax liability to take advantage of the tax credit in the year that it is earned. Many project owners must therefore partner with tax equity investors, which means that a percentage of the tax credit is ultimately collected by the tax equity partner rather than the project developer, decreasing the efficiency of the tax credit.

Tax credit refundability relaxes the requirement of sufficient tax liability. Although tax refundability can take many forms, the most efficient and effective form is as a direct payment to the recipient. Under a direct-pay option, the recipient can treat the credit as an estimated payment on taxes owed, which can then be refunded when taxes are filed, even if the credit exceeds total tax liability.

Other tax credit refund options include grants and rebates, which provide direct cash payments to developers and consumers. For example, Section 1603 of ARRA gave renewable energy project owners the option to apply for a 30 percent cash grant instead of claiming the tax credit. The funds for these grants were subject to the congressional appropriations process, however, and the program was discontinued in 2011.

Rebates, on the other hand, can offer a point-of-sale incentive, such as for the installation of alternative energy technologies or the purchase of ZEVs. A point-of-sale incentive, as opposed to a refund that is collected upon filing taxes, has been shown to be better at motivating consumers (Huang 2010; Saltee 2011). The State Energy-Efficient Appliance Rebate Program, under ARRA, offered a wide variety of rebate options on efficient household appliances, including the option of a point-of-sale rebate.

5.6 Equity

The primary goal of federal tax credits is to encourage innovation and deployment of low-carbon technologies. However, tax credits can also enable a more equitable deployment of technologies, especially by spurring their uptake among low- and middle-income individuals and households. There is significant evidence that, to date, available tax credits have been used mostly by wealthy Americans when purchasing EVs or investing in energy efficiency technologies. Although these early adopters have helped bring down the cost of these technologies, future consumer-facing tax credits can also be designed to make low-carbon technologies accessible to most Americans.

As discussed earlier, one way to address equity issues with existing tax credits in the transportation and buildings sectors is to convert the credits to refundable credits or point-of-sale incentives. Policymakers could also consider replacing tax credits with grants and rebate programs that provide direct cash payments to eligible consumers.

A second way to target tax credit benefits to those who need them most is to incorporate an income cap. However, careful consideration should be given to the level at which the income cap is set because it would have a direct impact on who can claim the credit. For instance, an income cap of \$100,000 per individual and \$200,000 per two or more adults would exclude 29 percent of recent EV buyers. An income cap would also make it more difficult to provide a point-of-sale credit or rebate because of the need to verify eligibility. A better approach might be to impose a cap on the vehicle manufacturer's suggested retail price, excluding expensive luxury EVs. Furthermore, creation of a used EV tax credit could improve access to EVs for low- and middle-income consumers. There is a possibility, though, that this approach could just raise used EV prices; the supply of used EVs is fixed by the pace of new EV sales, leaving the net price to buyers unchanged. Policies that can provide cash for old, gas-guzzling cars, similar to the "Cash for Clunkers" program, can also boost the ability of middle- and low-income consumers to buy used and/or new EVs.

Another approach to improving equity involves geographically driven tax credits. Recent tax credit discussions have focused on renewing the Section 48C Manufacturing Tax Credit Program, and the proposed American Jobs in Energy Manufacturing Act, introduced in 2021, would provide a credit to manufacturers to build new or expand existing facilities to produce low-carbon technologies. Half of the proposed allocation of \$8 billion would target coal communities that have been adversely impacted by the shift away from coal generation and did not benefit from the earlier implementation of the Section 48C tax credit. Tax credits that are geared towards manufacturers or producers of low-carbon technologies could also be accompanied by requirements that support domestic content and high labor standards. This can promote equity and help reduce economic inequality.

6. CONCLUSION

Properly designed federal tax credits can lead to accelerated deployment of low-carbon technologies and stimulate a virtuous cycle of innovation—both key to long-term decarbonization of the U.S. economy.

Tax credits, however, are not the only tool to address climate change. Successful decarbonization will require a policy package: federal investment in research, development, and demonstration as the backbone of clean technology innovation; financial incentives, including tax credits to bridge the cost gap between emerging low-carbon technologies and their high-carbon competitors; and policies such as carbon pricing and clean energy standards, which can address the economy-wide externalities of carbon pollution.

To date, Congress has been stuck in a repeated cycle of extending expired or expiring tax credits for low-carbon technologies, perpetuating uncertainty and discouraging long-term planning by the private sector. The current system needs to be replaced with a predictable, forward-looking tax credit regime that can lead to rapid economy-wide emissions reductions.

To address the decarbonization challenge effectively, the next generation of federal tax credits should include the following characteristics:

- **Technology-neutral design**, where possible, with technology-specific tax credits used to target technologies that are deemed crucial to deep decarbonization
- **Performance-based incentives**, where possible, rather than tying incentives to monetary investment
- **Producer and consumer tax credits** for low-carbon technologies
- **Long-term credits and clear phaseout criteria**
- **Refundability and a direct-pay** option to increase availability and impact
- **Equity** to enable the adoption of low-carbon technologies by low- and middle-income Americans

How each of the above considerations is included in the design of tax credits will have implications for their operation. Trade-offs are involved in choosing one approach over another. For instance, phasing out tax credits when a technology has reached a specified market share can prioritize innovation and minimize costs borne by taxpayers. However, if the goal is accelerating the pace of decarbonization, then making tax credits available to even mature low-carbon technologies (especially in the absence of any policy mechanism that addresses the externalities of carbon pollution) may be warranted.

In forthcoming research, the World Resources Institute (WRI) will share analysis estimating the emissions and economic benefits of adopting a suite of tax credits to incentivize the deployment of low-carbon technologies in the power, transportation, industry, and buildings sectors. The emissions modeling analysis will highlight the extent to which technology innovation, enabled by federal tax credits, can unlock pathways for cost-effective decarbonization of the U.S. energy system. Innovation around the next generation of low-carbon technologies will not only enable deep emissions reductions but can also be a major driver of economic growth and development, particularly if U.S. manufacturers are able to export those technologies around the world. WRI will leverage the results of the emissions reduction analysis to develop an assessment of the impact of tax credits on economic growth and jobs in the United States.

APPENDIX A: ILLUSTRATIVE LIST OF KEY DECARBONIZATION TECHNOLOGIES BY SECTOR

SECTOR	FUNCTION	TECHNOLOGY
Power	Zero-carbon generation	Solar, wind, geothermal, hydropower, advanced nuclear, coal and gas power plants equipped with CCUS
	Energy storage	Lithium-ion batteries, flow batteries, flywheels, compressed air energy storage, pumped storage, and hydrogen
	High-voltage transmission	High-voltage, direct-current lines
Transportation	ZEVs	BEVs, FCEVs
	Charging infrastructure	Level 1, Level 2, and DCFC chargers
	Low-carbon fuels	Biofuels, hydrogen, synfuels
Industry	CCUS	Direct air capture, pre- and post-combustion capture, oxy-fuel combustion, chemical processes and production, geologic storage
	Low-temperature heat	Electrical resistance heating, electrical inductance heating
	High-temperature heat	Hydrogen or other low-carbon gas combustion
	Low-carbon fuels	Hydrogen, ammonia, natural gas with CCUS, renewable natural gas
Buildings	Energy efficiency	Building-envelope technologies, next-generation insulation, advanced window and HVAC control systems, reflective roofing materials
	Electrification	Air-source heat pumps, electric ranges, water heaters, and dryers

APPENDIX B: EXISTING TAX CREDITS FOR LOW-CARBON TECHNOLOGIES BY SECTOR

SECTOR	EXISTING TAX CREDITS	OVERVIEW
Power	Section 45 PTC for wind (onshore and offshore) and other renewable technologies	<ul style="list-style-type: none"> PTC was first enacted in 1992 as part of the Energy Policy Act of 1992 Provides a per kWh subsidy over a 10-year period for wind, geothermal, biomass, solid waste, and hydro facilities after a qualifying facility starts service Under the Consolidated Appropriations Act of December 2020, the PTC will remain at 60% of the full credit amount (2.5 cents/kWh) for projects that commence construction by the end of 2021 and will expire in 2022
	Section 48 ITC for solar projects	<ul style="list-style-type: none"> ITC was first enacted in the Energy Tax Act of 1978 Provides a one-time credit based on initial capital expenditure in qualifying facilities Under the Consolidated Appropriations Act of December 2020, the ITC will remain at 26% for projects commencing construction in 2020–22, 22% for projects commencing construction in 2023, and reduce to 10% for commercial solar projects and 0% for residential solar projects in 2024 and beyond
	Section 48 ITC for offshore wind	<ul style="list-style-type: none"> The Consolidated Appropriations Act of December 2020 expanded the credit to include an ITC for offshore wind projects Offshore wind projects that commence construction by end of 2025 will receive 30% ITC (and tax credit rate does not phase out)
Transportation	Section 30D credit for plug-in electric vehicle	<ul style="list-style-type: none"> The credit was established by the Energy Improvement and Extension Act of 2008 Vehicles acquired after December 31, 2009, are eligible for the credit The credit ranges from \$2,500 (for EVs with at least 4 kWh of battery capacity) to \$7,500 per vehicle (with larger batteries earning an additional \$417/kWh in excess of 5kWh) The credit phases out once a vehicle manufacturer sells 200,000 qualifying vehicles
	Section 30C credit for qualifying alternative fuel vehicle refueling property	<ul style="list-style-type: none"> The credit was introduced under the Energy Policy Act of 2005 Credit offers 30% of the cost of installing refueling equipment (with a maximum amount of \$30,000 for installations at businesses and \$1,000 for installations at a taxpayer's primary residence for installations made through December 31, 2021) Eligible refueling equipment include natural gas, propane, liquefied hydrogen, electricity, E85 (ethanol-gasoline fuel blends containing 51%–83% ethanol), or diesel fuel blends (containing at least 20% biodiesel)
	Section 40A biodiesel tax credit	<ul style="list-style-type: none"> The credit was introduced under the American Jobs Creation Act of 2004 Offers a one-dollar credit per gallon of biodiesel sold or used to produce a mixture used as a fuel Fuels used or sold after December 31, 2017, are eligible for the credit Credit expires after December 31, 2022
	Section 30B alternative motor vehicle credit for FCEVs	<ul style="list-style-type: none"> The credit was enacted under the Energy Policy Act of 2005 Offers a base credit amount of \$4,000 for FCEVs weighing 8,500 pounds or less and heavier vehicles being eligible for a larger amount, with the maximum credit amount being \$40,000 for vehicles weighing more than 26,000 pounds Credit is available through December 31, 2021

APPENDIX B: EXISTING TAX CREDITS FOR LOW-CARBON TECHNOLOGIES BY SECTOR (CONT.)

SECTOR	EXISTING TAX CREDITS	OVERVIEW
Industry	Section 45Q credits for CCUS projects	<ul style="list-style-type: none"> The credit was introduced under the Energy Improvement and Extension Act of 2008 Provides a credit for the capture and sequestration of carbon emissions from the use of coal and natural gas in the power sector and carbon emissions in the industrial sector The Consolidated Appropriations Act of December 2020 amended the credit, making qualified facilities that begin construction before January 1, 2026, eligible for the credit (begin construction by date previously set before January 1, 2024)
Buildings	Section 45L new energy-efficient home credit	<ul style="list-style-type: none"> The credit was enacted under the Energy Policy Act of 2005 Offers contractors building energy-efficient homes a credit of \$2,000 per home and a credit of \$1,000 per home for producers of manufactured energy-efficient homes Under the Consolidated Appropriations Act of December 2020, homes acquired through December 31, 2021, are eligible for the credit
	Section 25C credits for nonbusiness energy property	<ul style="list-style-type: none"> The credit was reenacted under the Energy Policy Act of 2005 Offered homeowners a tax credit for investments in high-efficiency heating, cooling, and water-heating appliances and energy-efficient windows and doors Under the Consolidated Appropriations Act of December 2020, the amount of the credit is calculated as 10% of expenditures on building-envelope improvements plus the cost of each energy-efficient property capped at a specific amount (with maximum credit amount ranging from \$50 to \$300) for installations made through December 31, 2021
	Section 25D credits for residential energy-efficient property	<ul style="list-style-type: none"> The credit was enacted under the Energy Policy Act of 2005 Offers taxpayers a credit for installing renewable energy technologies, including solar electric, solar water heating, geothermal heat pumps, small wind energy, and fuel cells in their residences The amount of the credit is calculated as a share of expenditures on such technologies with the Consolidated Appropriations Act of December 2020 setting a credit rate of 26% for installations made before December 31, 2022, and 22% for installations made through December 31, 2023
	Section 179D energy-efficient commercial building deduction	<ul style="list-style-type: none"> The deduction was enacted under the Energy Policy Act of 2005 Offers a deduction for energy-saving installations made as part of interior lighting, HVAC, or water-heating systems as well as building envelopes in commercial buildings Maximum deduction offered is \$1.80 per square foot for installations that reduce a building's annual energy and power costs by 50% or more relative to the minimum requirements of Standard 90.1 of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (with a partial deduction of \$0.60 per square foot if 50% target is not met) The credit was made permanent under the Consolidated Appropriations Act of December 2020

ABBREVIATIONS

ARRA	American Recovery and Reinvestment Act	FY	fiscal year
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers	HVAC	heating, ventilating, and air-conditioning
BEV	battery-electric vehicle	ICE	internal combustion engine
CO₂	carbon dioxide	IEA	International Energy Agency
CCUS	carbon capture, utilization, and storage	ITC	investment tax credit
DAC	direct air capture	kWh	kilowatt-hour
DACS	direct air capture and storage	MWh	megawatt-hour
DCFC	direct-current fast chargers	PHEV	plug-in hybrid electric vehicle
EV	electric vehicle	PTC	production tax credit
FCEV	fuel cell electric vehicle	SMR	steam methane reforming
		ZEV	zero-emissions vehicle

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