Contracts for Difference to Spur Clean and Competitive Industry: Options for Federal Policymakers

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The **American Council for an Energy-Efficient Economy** (ACEEE), a nonprofit research organization, develops policies to reduce energy waste and combat climate change. Its independent analysis advances investments, programs, and behaviors that use energy more effectively and help build an equitable clean energy future.

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Data and licensing information

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Executive summary

A government-issued contract for difference (CfD) to support industrial decarbonization is an agreement between two parties in which one party (the government) promotes innovative, low-carbon industrial production, and the other (the producer manufacturing the product) seeks price certainty for the clean product. This report is intended to provide U.S. federal policymakers with background on CfD policy and to outline the core details for policymakers to consider when designing a CfD policy to facilitate clean industrial production.

The core feature of a clean industrial CfD is the “strike price”: the per-unit price—usually determined through auction—that a producer requires to manufacture the clean product (e.g., a ton of clean steel). If the market price for this product drops below the strike price, the government pays the difference between the market and strike prices. In a two-sided CfD, if the market price rises above the strike price, the producer pays the government the difference. In either case, there is no exchange of the underlying asset.

An industrial CfD policy has three key functions: (1) to support low-carbon production in cases where the technology is not yet proven or economically competitive; (2) to help producers manage market risks; and (3) to drive innovation and demonstrations of first-of-a-kind (FOAK) and nth-of-a-kind (NOAK) technologies.

CfDs offer three main advantages: (1) They reduce investment risk, thereby attracting (and lowering the cost of) private capital for the deployment of innovative technology. (2) They facilitate price discovery when suppliers bid for support in auctions. (3) They conserve public funds compared to other financial supports.

CfDs also have challenges: (1) Because they guarantee a price floor, they may weaken market incentives in some cases, especially for industrial commodities that can be stockpiled. (2) They focus on auction bid prices and therefore may overlook other policy concerns, such as social and local environmental benefits. (3) There is a risk of overcompensating producers for payments based on average prices. (4) Because CfDs are long-term contracts, they could reduce adaptability to market changes. (5) They may not be well suited for projects focusing on material efficiency and material substitution.

10 key elements for policymakers to consider in CfD design and implementation

1. **Core objectives**. Is the purpose of the CfD to demonstrate FOAK and NOAK facilities? To maximize near-term emissions reductions? Or both?

2. **Eligibility.** Which industries can participate, which products are covered, and what are the criteria for eligible products? Should the CfD be placed on the supply side or the demand side?

3. **The strike price index**. What is the appropriate standard market price index to compare CfD strike prices to? Should the CfD include mechanisms to adjust the strike price over time in response to changes in inflation or the costs of key inputs (such as energy)?

4. **Subsidy terms.** How will the strike price translate into a subsidy, especially as both the market price and strike price can change over time? Should the subsidy be one-sided, two-sided, or a hybrid, with early termination or capped payback amount options? What mechanisms should be put in place to manage CfD expenditures?

5**. Auction design**. How will auctions be structured? For example, should contract awards be allocated based solely on strike price, or according to the cost of reducing a unit of greenhouse gases (GHGs), which requires knowing the emission intensity of the proposed project? Effects on bidder incentives and program outcomes require additional research.

6**. Non-price factors (NPFs)**. Will the CfD consider broader social and environmental criteria (NPFs)? If so, how will these criteria be incorporated into the CfD program and auctions? Will they be minimum standards or bonus provisions?

7. **Emissions accounting, reporting, and verification**. How will the data, methods, and timelines be used in emissions reporting? Will there be requirements for third-party verification? Will emissions be limited to the product, or will they include the product's full or partial life-cycle assessment?

8. **The implementing agency.** Will a new implementing agency or agencies be created or will existing ones be utilized? Likely candidates for existing agencies are the Environmental Protection Agency (EPA) and the Department of Energy (DOE); the latter arguably has the strongest capacity in the essential roles and responsibilities of CfD implementation.

9. **Interaction with other subsidies.** To what extent should incentives be stackable? How should policies be designed to improve access to multiple incentive programs while avoiding double dipping and ensuring cost-effective support for innovative technologies?

10. **Legal considerations**. Previous papers on CfD policy have observed that U.S. federal law limits the use of CfDs in a number of circumstances. These limitations, however, are not applicable to a low-carbon industrial CfD program provided by the federal government.

Comparing CfDs to similar policy mechanisms

CfDs can be compared to similar policy mechanisms such as production or investment tax credits; green procurement; tradable performance standards, or TPSs; advance market commitments; and carbon pricing via direct taxation or cap and trade. We compare these mechanisms across three broad criteria: benefit to society, benefit to government, and benefit to industry.

Introduction

U.S. industry has become a focus for various federal policies aimed at revitalizing American manufacturing, bolstering national security by strengthening the defense industrial base, and creating high-quality American jobs. At the same time, a shifting policy landscape and market—such as the establishment of carbon border adjustment policies abroad and an increased number of companies with climate and sustainability goals—are making low-carbon production a key component of long-term economic competitiveness. The U.S. industrial sector is estimated to account for 29% of national energy-related carbon dioxide (CO_2) emissions in 2025, and this is projected to increase to 37% by 2050 (EIA, AEO 2025).[1] Reducing these emissions is complicated because many of the technologies needed to advance clean manufacturing require substantial capital outlays and are either in early stages of technological development or have yet to be widely commercialized—posing higher than average risk to investors. These trends underscore the need for innovative federal policy to promote energy-efficient, low-carbon, and economically competitive industrial production in the United States.

Government-issued contracts for difference (CfDs) have emerged as a promising policy tool for reducing industrial emissions because they can efficiently address clean production's price premium while mitigating the market risk associated with innovative technology. However, while there is a wealth of experience in Europe and the U.K. with using CfDs for renewable electricity, and an increasing amount of experience with non-electricity industrial sectors (Ason and Dal Poz 2024), the United States has little to no experience with such a policy. This report seeks to begin filling that gap and is intended to be a practical resource and guidebook for policymakers interested in CfDs. The report begins with an overview of CfDs and provides examples from other countries; it then outlines key design considerations for a U.S. industrial CfD program, and concludes with a comparison of CfDs to other prominent policy mechanisms relevant to industrial decarbonization.

Background

CfDs originated in the 1970s as a derivative instrument traded in financial markets among private parties, such as hedge fund managers (Brown et al. 2010). CfDs operate as contracts between two parties, where party A agrees to pay party B if the price of the underlying asset (e.g., a ton of steel) rises above a fixed price (often called the "strike price") and vice versa if the price declines below the strike price. The payment is usually the difference between the actual market price at the time of settlement and the strike price. Unlike futures and long-term contracts, under a CfD, there is no exchange of the underlying asset.

CfDs for renewable electricity were introduced in the early 2000s (Kristiansen 2004) and gained prominence in the U.K. in 2013 (Government of UK 2014). These CfDs are different from the CfDs traded among private parties in that they are issued by the government. The goal of these CfDs is to increase clean electricity production by providing price certainty and thereby lowering project risk (Beiter et al. 2023; OIES 2024). This price certainty is established through the strike price (price per unit of electricity—e.g., U.S. dollars/MWh), which is agreed to by the government and the electricity producer, usually through a reverse auction. Under such a CfD, if the market price for electricity falls below the

[1] These estimates include indirect scope 2 emissions from electricity consumed by industry. It is also worth noting that the increasing percentage of U.S. emissions coming from industry in 2050 is primarily a function of other sectors decarbonizing more quickly. Between 2025 and 2050, industrial emissions are projected to decline, but only by 10%, whereas, for example, electricity emissions are projected to decline by 66% and emissions from transportation are projected to decline by 31%.

strike price, the government pays the difference (providing the price floor); if the price exceeds the strike price, the electricity producer pays the difference back to the government. Again, as with financial market CfDs, there is no exchange of the underlying asset—the government does not procure electricity, it simply provides price certainty for the producer selling into the market. Today, government-issued CfDs are used throughout Europe to facilitate clean electricity deployment, and billions of dollars of investment in wind and solar projects have been incentivized using CfDs (OIES 2024).

A new kind of government-issued CfD—called carbon contracts for difference (CCfD)—has emerged in Europe with the goal of facilitating low-carbon industrial production. In this case, the CfD guarantees a carbon price (the strike price is a carbon price) in the context of the EU Emission Trading System (ETS). The guaranteed carbon price applies as a *payment* per ton of greenhouse gases (GHGs) *reduced* by the project, as compared to a conventional project that produces the same good. In cases where the ETS carbon price is below the strike price established in the CfD, the government pays the difference (per unit of carbon reduced). Again, the CCfD's primary function is to provide price certainty (and thereby mitigate risk) to facilitate the long-term capital investments needed to deploy innovative low-carbon industrial technologies. In 2020, the Netherlands established the Stimulation of Sustainable Energy Production and Climate Transition (SDE++) program, which included a CCfD component for carbon capture and storage/utilization (CCUS) technologies (Gerres and Linares 2022; IEA 2023). Germany recently followed suit, awarding 2.8 billion euros worth of CCfD contracts in October 2024 to participants from a variety of sectors, including chemical, paper, glass, and steel sectors (Amelang and Wehrmann 2024). See Appendix 1 for more examples of implemented CfDs.

Developing an industrial CfD policy in the United States

Building on the success of public CfD and CCfD programs in the U.K. and Europe, we consider in this report how such a program could take shape in the United States to facilitate investment in low-carbon and economically competitive industrial production. Similar to other CfDs, a U.S. program would fundamentally be an agreement between two parties, in which one party (the government) seeks to increase low-carbon production at the least cost to taxpayer, and the other (the producer) seeks a price guarantee for the clean product, thereby making investment in low-carbon production feasible and attractive (OIES 2024).

This price guarantee (the strike price) is the defining feature of a CfD. For a U.S. industrial CfD, the government would pay the producer the difference between the strike price and the market price if the market price drops below the strike price. For example, if a steel producer determines it can produce low GHG intensity hot-rolled coil (HRC) steel profitably for $850 per ton, it would bid this amount as the strike price (note that the strike price effectively includes the "green premium" for clean production). Under a CfD with this strike price, if the prevailing market price for HRC steel is $800 per ton for a given period, the steel producer receives $50 per ton from the government for that period—again, the difference between the strike price and the standard market price. The market price is typically a transparent price that moves independently of action by the CfD contract parties. To be clear, here we are referring to the market price for a standard ton of HRC steel, regardless of how it is produced—reflecting an open market in which clean steel must compete toe-to-toe with steel made using incumbent emissions-intensive technologies (Boyd Metals 2025). For renewable electricity CfDs, the hourly day-ahead electricity spot price on the wholesale market is typically used. Hourly day-ahead prices are a clear, stable reference point for settlement with electricity producers that usually base their production on day-ahead forecasts; however, longer-term averages have also been used.

Generally, the strike price is fixed for the duration of the contract, but it can be variable. For example, it might decline over time to lower government cost exposure, or it could be linked to another variable cost element—such as manufacturing input costs (e.g., natural gas or hydrogen)—to further mitigate risk for producers.

While the above example focuses on payments from the government, most CfDs are two-sided: The producer receives a payment from the government when the market price is below the strike price (below the line in figure 1) and pays the difference to the government when the market price exceeds the strike price (above the line in figure 1). Two-sided CfDs are similar to long-term contracts, such as power purchase agreements (or PPAs) in the electricity sector,[2] in that the producer does not capture revenues above the contracted price. With a long-term contract, the upside value accrues to the contract holder; with the two-sided CfD, this value accrues back to the government, which can offset program costs. One-sided CfDs also exist, allowing the producer to keep revenue above the strike price. There are also hybrid versions in which different strike prices trigger payments in each direction (Canestrini 2023). One-sided CfDs are similar to the financial derivative instrument called a "put option." However, a put option generally involves transfer of the underlying asset and accounts for the full strike price, whereas a one-sided CfD does not transfer the underlying asset and accounts only for the difference between the market price and the strike price. In competitive auctions, producers typically bid a higher strike price for a two-sided CfD than a one-sided CfD due to the greater financial risk.

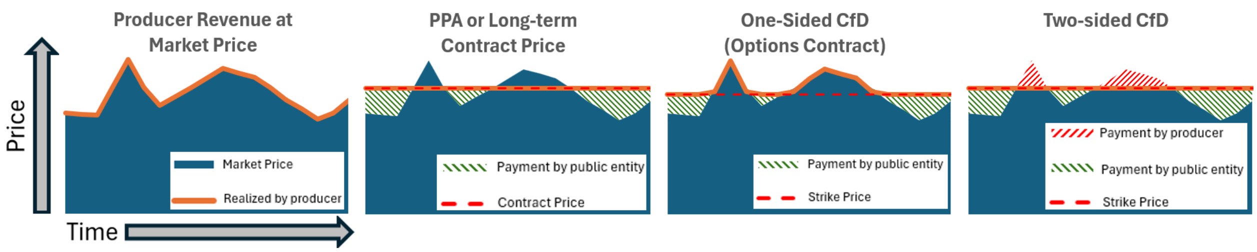

Figure 1. Payment and strike price options. Source: Beiter et al. 2023.

Most large-scale CfDs use reverse auctions, which competitively allocate a predetermined budget for eligible projects. In its role as auctioneer, the public entity would select the lowest bid amounts from all participating projects that qualify, subject to overall payments and possible price maximums.[3]

CfD duration is typically 10–20 years, providing project developers price security that matches the expected capital amortization of the assets. Alternatively, the contract's duration could be defined by a maximum production volume.

[2] CfDs differ from long-term contracts like PPAs in that CfDs do not transfer the underlying asset, whereas PPAs do.

[3] Price maximums can sometimes be overly constraining, as demonstrated by the first iteration of the recent U.K. clean electricity CfD Allocation Round 5, in which the maximum was set too low compared to a recent capital cost increase and, consequently, there were no bids (*Contracts for Difference (CfD) Allocation Round 5:Results* 2023).

What are the advantages and challenges of CfDs?

CfD advantages:

- **Mobilize private capital:** Because CfDs reduce investment risk, they can help attract private capital for innovative technology projects and may also reduce the cost of capital.
- **Enable price discovery:** Producers bid for support through reverse auctions, which enhances "price discovery" and therefore reduces the chance of over- or undersubsidization.
- **Conserve public funds:** With two-sided CfDs, if market prices are high, producers make payments back to the government, offsetting program expenditures.

CfD challenges:

- **Weaken price signals**: By guaranteeing a price floor, CfDs can reduce incentives for producers to time their sales strategically and allow them to be indifferent to market prices, which is potentially detrimental to competitors. This is particularly a concern for industrial commodities that can be stockpiled.
- **Overlook non-price benefits**: Evaluating only the bid strike price may devalue other potential benefits of projects (environmental benefits, jobs, domestic manufacturing, FOAK projects). Some CfDs have introduced "non-price factors" to incentivize projects and developers to deliver broader value to society and the environment across the supply chain.
- **Risk of overcompensation:** If CfD payments are based on average commodity prices in markets where there is a premium for low-carbon products, producers may receive larger subsidies than needed.
- **Reduce adaptability:** CfD arrangements/auctions tend to be long-term instruments and have low adaptability to changing conditions along some dimensions (e.g., new technologies, social benefits).
- **Not well suited for material efficiency or material substitution projects:** For projects that focus on more efficient material use, it can be complex to define a counterfactual reference for granting CfD payments.

Different types of CfDs relevant to industrial decarbonization

There are two primary forms of CfDs well suited to achieving industrial decarbonization:

1. **A product CfD (PCfD),** where the strike price reflects the price of the underlying product (e.g., U.S. dollars/ton of steel), which is made in a way that meets a specified level of GHG emissions performance. The PCfD thereby supports the deployment of approved low-carbon technologies and processes that meet program criteria.

2. **A carbon CfD (CCfD),** where the strike price is based on the value of a verifiable carbon emission reduction associated with the clean production. The CCfD directly incentivizes emission reductions due to the deployment of low-carbon technologies.

The key difference between a PCfD and CCfD is that their strike prices are tied to different markets. A PCfD would typically be based on a wholesale market product price for a given commodity (e.g., steel, aluminum, etc.). The advantage here is that the parties can settle on a strike price that directly hedges the cost and profitability of a specific clean commodity's production.

To date, CCfDs have been implemented only in the European Union Emissions Trading System (EU ETS), where the CCfD is based on the market value of an EU ETS emissions allowance (EUR/metric ton CO_2equivalent, or CO_2e). Using an underlying carbon price has the advantage that the effective cost per ton of carbon reduced can be easily compared across projects, regardless of the industrial product. Because the United States currently lacks a federal carbon price, a nation-wide CCfD would be difficult to establish; however, it may be possible to develop hybrid versions of a PCfD and CCfD, and CCfDs are an option at the state level where carbon pricing does exist (e.g., in California and other states).

Both PCfDs and CCfDs can be tailored to different levels of GHG-reduction performance by accepting a higher strike price for deeper emission reductions. Either type can also include indexing for inflation or the cost of key inputs, such as natural gas and hydrogen. The incremental cost of production and the potential value of emission reductions in the settled strike price are also likely to be key factors regardless of whether PCfDs or CCfDs are selected.

In the following section, we build on this general overview to explain key details associated with designing and implementing an industrial CfD program in the United States.

Design details for a U.S. industrial CfD program

In the following, we address key details of a federal CfD policy to facilitate industrial decarbonization in the United States. This section is structured to guide policymakers in making decisions about what type of CfD to design given their policy preferences. We begin by discussing key legal issues and considerations when defining a program's core objectives. We then go into detail on the structure of an industrial CfD and design features related to its implementation.

Key legal considerations

Some commentors have pointed out that current U.S. law limits the use of CfDs under certain situations (Beiter et al. 2024; Ason and Dal Poz 2024). Specifically, these authors observed that federal law preempts state CfD support for electricity generators in the wholesale electricity market, and prohibits certain retail sale of CfD instruments. However, these limitations are not applicable to a low-carbon industrial CfD program provided by the federal government. Moreover, even if these laws did apply, Congress would still have the power to enact new federal legislation authorizing such a CfD program. Please see Appendix 2 for further discussion of how current U.S. law relates to industrial CfD policy.

Existing authorities

Another legal question for policymakers to consider is whether an agency could use a CfD mechanism under existing decarbonization funding authority. It is possible to use a CfD if the existing authority includes key provisions. The language Congress uses to describe the purpose of decarbonization funding is often broad and, on its own, does not preclude a CfD. For example, the Inflation Reduction Act (IRA)

Advanced Industrial Facilities Deployment Program says that the purpose of its funds is “to provide financial assistance, on a competitive basis” for industrial decarbonization projects (42 U.S.C. §17113b). The terms “financial assistance” and "competitive basis” are broad enough to embrace a CfD approach. However, in many cases, authorizing language makes use of a CfD challenging. Continuing with the Advanced Industrial Facilities Deployment Program example, Congress indicated that the funds should be spent on specific types of capital projects and require a minimum cost-share. Both of these provisions indicate that the funds should directly apply to capital investments rather than as an incentive for production of decarbonized product, which tends to be how a CfD is structured.

A second more significant problem is that the runway for expenditure of funds may not be adequate for a CfD approach. Congress can make funds available during a single fiscal year, multiple years, or “until expended.” For funds “available until expended,” there is no timing problem. But for funds appropriated for a single year or multiple years, the funds must be obligated during the years specified and then paid out over the following five years, a period likely to be adequate for a grant but not a CfD (31 U.S.C. § 1553(a).[4] When administering a grant program, an agency can disburse funds either in advance of construction or as construction meets set milestones. In contrast, with a CfD, funds are disbursed only after all construction is complete and clean production commences and, to be effective, they generally continue for a decade or more. Even the Advanced Industrial Facilities Deployment Program, which makes funds available through 2026 and can disburse funds through 2031, would not provide a long enough period for a CfD program to be effective.

Finally, for reasons we discuss below, a department using a CfD approach would need to ensure that it did not exceed available appropriated funds, which would require it to make awards based on the highest potential payouts; this, in turn, could restrict the number or size of projects funded.

Delegation to implementing agencies

As with any legislative effort, Congress must choose what to specify in statute and which details to leave to the implementing agency. This is important both because Congress may wish to specify how a program operates or may know that certain questions require a technical assessment better suited to an agency decision-making process. And, while an agency implementing an incentive program is generally subject to fewer legal challenges than one implementing a regulatory program, legal challenges are still possible.[5] In considering the following design details, policymakers should consider whether a given detail is best addressed in statute or left to implementing agencies. Please consult Appendix 3 for suggestions on what Congress should determine in statute and what it might delegate to agencies.

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[4] For example, 31 U.S.C. § 1553 stipulates a five-year period during which funds can be used to make payments after the period of availability closes.

[5] See, for example, *XP Vehicles, Inc. v. Dep't of Energy*, 118 F. Supp. 3d 38, 80–81 (D.D.C. 2015), which holds that claims under the Administrative Procedure Act to a decision awarding a competitive grant could proceed. The law governing what decisions Congress may delegate to agencies is the subject of active litigation and has been questioned by several justices. The current standard is that Congress must provide the agency an “intelligible principle” to guide agency decisions; see *Gundy v. United States*, 588 U.S. 128, 129 (2019). The recent reversal of the *Chevron* decision means that where legislation is ambiguous, courts will no longer defer to the agency implementing the statute (*Loper Bright Enterprises v. Raimondo*, 603 U.S. 369, 412 (2024)). This reemphasizes the importance of using clear statutory text.

Defining core objectives

Generally, this report considers CfDs as a way to promote low-carbon production—which we define here as low-carbon manufacturing of industrial goods, such as steel and cement. More specifically, we see industrial CfDs as having three key functions: (1) to provide financial support to low-carbon production that is not yet economically competitive; (2) to help producers manage price risk, which typically has the additional benefit of lowering the cost of capital; and (3) to drive technology innovation and demonstration of first-of-a-kind (FOAK) and nth-of-a-kind (NOAK) facilities.

A primary question for policymakers designing an industrial CfD policy is: To what degree is the objective to demonstrate a limited set of FOAK or NOAK facilities with cutting-edge environmental performance versus to maximize near-term cumulative emissions reductions? The latter may involve the deployment of less-innovative technology, reducing facility-level carbon intensity more incrementally, but ultimately reaching a larger number of facilities and thus reducing sector-wide emissions more in the near-term.

This decision has implications for CfD policy design. For FOAK and NOAK projects, CfDs would likely need higher strike prices because FOAK and NOAK technologies are inherently less developed and therefore involve higher risk and cost. Assuming a limited CfD program budget, this means supporting fewer projects compared to a CfD program focused on simply maximizing near-term cumulative emissions reductions through the deployment of less-innovative (i.e., less risky and more economically competitive) technology. In either case, policymakers would need to define ambition levels for the program to ensure that the desired performance is achieved.

It is also possible to design a CfD program to achieve both objectives by grouping auction competitions for like projects, thereby aligning incentives with ambition (higher incentives for more ambitious projects). This approach could involve establishing a set of separate CfD auction categories based on emissions ambition (e.g., 30%, 50%, 80% below conventional facilities) or some other mechanism to increase the strike price offered for FOAK technologies and/or deep emission reductions levels. See the "Auction design" section below for further discussion of auctions differentiated by ambition.

Also, CfDs can be designed to encourage different or even multiple attributes of production. For example, in addition to spurring low-carbon production, CfDs could be designed to encourage use of domestic content in relevant supply chains, the adoption of specific technologies, and adherence to equity and labor standards. The recent inclusion of non-price factors (NPFs) in U.K. CfD policy (see below) is an example of how a CfD program can incorporate multiple policy goals, although at the risk of reducing the effectiveness of price discovery.

Structure of a U.S. industrial CfD program

The following subsection discusses the core components of an industrial CfD program, reflecting the decisions a policymaker would need to make to design such a program, including

- Eligibility
- The strike price index
- Subsidy terms
- Auction design
- Non-price factors (NPFs)
- Emissions reporting and verification

Eligibility

It is impractical to consider, at least initially, a CfD policy that covers all primary and secondary industrial products in the United States. Therefore, policymakers will need to determine which products to cover—that is, they will need to determine product eligibility.

Supply side versus demand side (offtaker) CfD contracts

Up to this point, our discussion has focused solely on CfDs between the government and an industrial producer. It is worth considering, however, whether it would be best to place the CfD on the supply side (producer) or whether there may be merits to placing it on the demand (offtaker) side of a product value chain. An example of this sort of demand-side program is the DOE demand-side support program to reduce clean hydrogen offtake uncertainty in the Regional Clean Hydrogen Hubs (H2Hubs) program.

To capture the most emissions with the least administrative complexity, it would make sense to place the subsidy on the side that has a smaller number of firms. However, assuming strike prices would be set through auction, it is important that the auction be competitive, which indicates the choice of the side that has the *larger* number of firms—recognizing, however, that even the smaller group may meet requirements for competitive auctions.

Furthermore, assuming that a primary goal of the CfD policy is to provide long-term price certainty to the producer, then it would make sense to provide the CfD to the producer. If the CfD is provided to the offtaker, the producer would be exposed to uncertainty with respect to the number of offtakers claiming the CfD (with respect to supply capacity), their level of demand, and their future preferences—including whether to continue or terminate the CfD. This indicates a significant rationale for targeting the supply side instead of the demand side. That said, there may be circumstances where policy goals will indicate either supply side or demand side, and policymakers will want to think through the pros and cons of both with respect to their policy preferences. Again, for example with hydrogen hubs, there may be cases in which producers have access to various subsidies (such as 45V and 45Q tax credits for green and blue hydrogen, respectively), but further support is needed on the demand side to bring in enough private financing to make a potential market a reality.

Where in the supply chain should the CfD be applied?

Assuming there are enough parties on the supply side to make the CfD auction competitive, the above discussion indicates that the supply side is arguably the best focal point for delivering a CfD. The question then becomes: Where in the supply chain is it best to apply the CfD?

U.S. industrial emissions are concentrated at a relatively small number of facilities. Approximately 60% of U.S. industrial product emissions[6] can be credited to a few relatively homogenous products, including iron, clinker, ammonia, key olefins (e.g., ethylene and propylene), methanol, lime, soda ash, and aluminum (U.S. EPA 2023). These materials are produced at fewer than 400 different facilities in the United States today. Applying an industrial CfD to these products—or even a subset thereof for administrative feasibility reasons—is arguably a good place to start.

Focusing CfD policy on emissions-intensive production minimizes the number of contracts needed to achieve broad coverage and impact, decreasing administrative complexity and therefore increasing programmatic efficiency. For example, primary steel mills produce a relatively small diversity of products. Secondary steel manufacturing turns these primary products into thousands of other

[6] This excludes oil and gas, mining (including coal), electricity emissions, and hydrogen production.

manufactured items, using a mixture of gas and already electrified (i.e., potentially low-emission) induction heating. Emissions-intensive reduction of iron ore using blast furnaces or direct reduction furnaces is the appropriate point of incidence because it is emissions intensive, produces relatively few standardized products, and can evolve with the growing move toward mixed primary and secondary steel making. Similarly, for cement manufacturing, the target could be the emissions-intensive clinker, rather than the vast range of cement products with different blends of additives and aggregates.

Additional criteria for determining eligible products

The success of renewable energy CfDs in the U.K. and Europe has hinged on four key characteristics common to electricity markets. These features have contributed to competitive auctions, price discovery (which increases cost effectiveness), and limited rates of contract failure. As such, the following four factors should be considered when determining which products are suitable for a U.S. industrial CfD program.

Product homogeneity. Homogeneous products are standardized with minimal variation, with little monitoring or verification necessary, for example, a kWh of electricity is indistinguishable no matter the supplier, use, or consumer.

Two products that are nonhomogeneous are more likely to have different production costs or prices, making it difficult for them to compete for the same CfD.

Liquid spot markets. Because they are standardized, homogenous products can be broadly traded on liquid spot markets. The more product specificity, the less likely it is to be sold on spot markets and the more likely it is to be sold through bespoke purchase agreements.

The higher price transparency of spot markets makes it easier to determine competitive CfDs compared to bespoke purchase agreements.

Transparent and public strike price indexing. Liquid spot markets are important for establishing transparent strike price indexes that reflect real-time production costs and profit margins. In electricity markets, day-ahead spot market prices provide this. In contrast, many industrial products can vary by market and composition, making it harder to define appropriate strike price indexes.

Independence of the index price from influence. A key requirement for an efficient and effective outcome is that bidders are unable to influence the index price against which the strike price is set.

The ability to influence a price index could result in gameable, excess profits for a bidder, lowering policy efficiency and increasing potential costs to taxpayers.

Nonhomogeneous industrial production is a significant reason why CCfD programs such as the one in Germany use a standardized carbon price—rather than product price—as the index. The carbon price has similar characteristics as renewable electricity in that it is transparent (e.g., EU ETS carbon price), directly linked to mitigation costs, and homogenous (all based on GHG emission reductions).

The strike price index

Once the set of eligible products is defined, it is necessary to determine the index for the strike price. For example, as stated above, the German industrial CCfD program sets the strike price based on the EU ETS allowance price—therefore, the EU ETS is the index. In the case of an industrial PCfD program in the United States, which currently has no such carbon price, the likely index would be the prevailing market price of the standard (not considering clean attributes) eligible product itself (e.g., $/ton of HRC steel). Given that the strike price is determined through auction, policymakers do not need to specify the strike price; again, this price-discovery element is one of the fundamental strengths of a CfD instrument. However, policymakers do need to determine what the strike price will be based on—that is, they must determine what we refer to here as the strike price index.

Furthermore, assuming a product-specific market price is used, the government could either a) rely on a nongovernmental resource for the strike price index, or b) publish the market prices, establishing its own index. For example, the U.S. Geological Survey tracks information on a range of commodities, many of which would likely be covered by an industrial CfD program (U.S. Geological Survey n.d.). Note that liquid spot price indexes tend to be more difficult for participants to distort by their own market behavior; however, it may be important to assess whether a participant has undue leverage over a market index price.

Strike price adjustments

Policymakers should also consider mechanisms to fine-tune the strike price over time. For example, most existing CfD programs adjust for inflation (Lockwood 2024) . This clearly benefits participants, as they don not have to guess at inflationary risks over the duration of the CfD when bidding strike prices.

It is also possible to adjust the strike price according to changes in key input costs, such as electricity, natural gas, and hydrogen. For example, it would be reasonable to allow the strike price to adjust with hydrogen prices for projects such as a hydrogen direct-reduced iron (DRI) facility. The German CCfD program includes this sort of adjustment—what it calls the “dynamization of energy inputs.” By removing these variables from strike price bidding considerations, firms can submit lower strike price bids (because they do not need to hedge for input cost uncertainty); this, in turn, supports better price discovery.

Subsidy terms

Policymakers will next need to specify how the strike price will translate into a subsidy. Continuing with the example from the introduction, if clean technology could produce HRC steel for $850 per ton and conventional HRC steel were being traded in the market for $800 per ton, then the project would receive a subsidy of $50 per ton (i.e., the difference between the two). If, over time, the market price changes (due to market forces) or the strike price changes (assuming the CfD allows adjustments for inflation or changes in input costs—see above), the subsidy will change accordingly. The overall subsidy would be the product of this per unit subsidy and the volume of production. In summary, the basic formulation of the CfD subsidy (in time period *t,* which is typically annual) is:

$$Subsidy_t = (Strike\ price_t - Index\ price_t) \times Production_t$$

where:

Subsidy is the payment to the company if positive and to the public entity if negative (assuming the CfD is two-sided, as we discuss further below).

Strike price is the established strike price as awarded through the auction process.

Index price is the established reference price for the product, based on the strike price index (for example, the variable market price for steel, as discussed above).

Production is the quantity of production, where the unit matches the physical unit of the strike price (e.g., tons in a $/ton strike price).

Deciding whether the CfD will be one-sided or two-sided

Policymakers must also determine whether the CfD subsidy will be one-sided or two-sided. As we mentioned in the report's introduction, in a one-sided CfD, the awardee receives only benefits from the program and is not required to make payments back to the government when the index price rises above the strike price. Conversely, the two-sided program requires that the awardee make payments in such upside scenarios.

A one-sided CfD is therefore more generous to the private party awardee, because it gets to keep the gains in upside scenarios. A two-sided program, however, provides a better deal for the government and taxpayers since upside gains accrue back to the government. However, a two-sided CfD may deter companies from participating in the program—or may induce them to bid higher strike prices—if they perceive reasonable probability of upside scenarios, and therefore lost revenues (due to government paybacks above the strike price). Furthermore, a two-sided CfD weakens the competitiveness of clean production in that conventional production can generate profits in the high price scenarios, while clean production cannot. Furthermore, a two-sided CfD has the potential to distort plant operation decisions for firms with multiple facilities—generating an incentive to increase production at facilities with no CfD payment obligation during high prices periods, which could increase emissions (given that relatively dirty facilities would not be covered by a CfD).

The German CCfD program again offers useful insights here. That program is two-sided, and the German government has cited paybacks to government as a merit of the policy. However, the program allows firms to initiate CfD cancellation after a single upside payment is made, subject to a three-year glide path—that is, once the cancellation is initiated, the firm must remain in the contract for three years, ensuring some payback to the government and tempering potential program volatility.

This early termination option represents somewhat of a hybrid approach: The policy is fundamentally two-sided, yet it offers a pathway for firms to reduce potential losses if market conditions significantly change. Another hybrid approach would be to cap the amount that firms would pay back to the government—either capped per unit of production (e.g., ton of steel) or in total over the entire contract period.

Ways of managing government CfD expenditures

The above discussion raises the broader issue of CfD policy features that affect program expenditures and revenues—for both the government and awardee. Here, we discuss additional measures policymakers may want to consider regarding governmental budgetary issues.

As we discuss later in the "Comparing CfDs to similar policy mechanisms" section, a CfD program has important differences from the grant programs and tax credits Congress has primarily used to support clean energy and clean industrial production. Federal grant programs such as the Industrial Demonstrations Program are a straightforward example of "federal spending"—that is, Congress appropriates funding for a specific purpose, the agency awards grants for qualifying activities, and the Treasury Department transfers the funds to the recipients (Driessen 2019). In contrast, a clean energy tax credit counts as a "federal tax expenditure," which taxpayers claim according to their energy investments, and the cost of which is not known in advance (allocated tax credits do cap expenditures, however; as an example, see the Section 48C Advanced Energy Project Credit).

A standard CfD is considered federal spending because it requires an appropriation from Congress and payments from the Treasury. But a CfD differs from a grant program in two key ways. First, the size of the payments under a CfD depend on market prices and thus are unknown in advance. Second, rather than being paid upfront, the CfD is paid out over time as production occurs.[7]

Most likely, the implementing agency will need to manage the unknown cost of each CfD awarded to ensure expenditures do not exceed appropriations (GAO 2004).[8] This means that when issuing awards, the agency will need to assume the maximum payment under each awarded CfD (this maximum should likely be established in CfD contracts as well). This strategy was used in the Clean Hydrogen Deployment Act of 2021 (Tonko, D-NY-20), one of the few U.S. legislative CfD proposals to date.[9] Under such an approach, a portion of the appropriated funds would likely remain unspent; policymakers may therefore want to consider provisions to repurpose unspent funds over time. An alternative approach would be to place the risk of inadequate funds on the awardees by providing for reduced payments if funds are not sufficient to fully pay all CfD contracts. Such an approach, however, would reduce the program's level of investment certainty.

Alternatively, Congress could make a CfD program a new mandatory spending program. This would allow it to function like an unallocated tax expenditure, where the program's total expenditure amount is determined by uptake from CfD recipients over time (Driessen 2019). While this would be the most functional spending structure for a CfD program, it has historically been rare and politically difficult for Congress to establish new mandatory spending programs.

Auction design

A central CfD program detail is the auction design. Given its many nuances, this policy detail is especially subject to the question of how much to specify in statute versus how much to delegate to the implementing agencies. Auctions can provide an effective mechanism for allocating limited government funds in a way that maximizes the benefits of clean industrial production (e.g., reductions in carbon intensity and increases in domestic production capacity). Auctions achieve this by placing potential bidders in a competition for these limited funds. The challenge in auction design is to give bidders incentive to bid close to their true cost of clean production—facilitating a form of price discovery. This true cost, discovered through auction, is the CfD strike price in a PCfD program (see the introduction for details on PCfD). Also, please see Appendix 4 for a brief description of price discovery nuances in an industrial CfD program context.

In designing an industrial CfD auction, policymakers must consider various goals, including maximizing the quantity of low-carbon commodity production, minimizing costs of achieving a given production target, and facilitating accurate price discovery. These goals may conflict, and the weights placed on one or another goal will shape auction design. For example, commodities with lower carbon intensity (often involving more innovative technology), tend to cost more, which places them at a disadvantage in a CfD auction based solely on commodity price bids. However, basing the auction outcome on something

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[7] In this way, a CfD is more like a production tax credit. In order to be available for a long enough period, funds appropriated to support a CfD must be designated as available until expended.

[8] General Accounting Office, *Principles of Federal Appropriations Law,* 2004 at 5-41, notes that an agency cannot rely on future appropriations and any option for contract renewal must be contingent on the availability of future funds and subject to affirmative action by the government.

[9] Other CfD programs, such as the U.K. renewables support program, avoid this problem because costs are not paid through a budgetary appropriations process but instead are recovered directly from electricity customers (Watson and Bolton 2024).

other than production cost greatly complicates both auction administration and the incentives that bidders have in fashioning their bids.

Given these complexities, our discussion of auction design focuses on auctions that allocate contract awards based solely on strike price. Alternatively, policymakers might consider an auction in which bids are evaluated according to the cost of reducing a unit of GHGs. Here, the bidder would need to specify the strike price and the emission intensity of the proposed project. The quantity of GHG reduction would be the difference between the proposal and a benchmark carbon intensity (e.g., the industry average), and the cost would be the difference between the strike price and the commodity's fair market value. Such an approach is appealing in that it directly addresses the carbon intensity of contracted production. However, the effects of such an approach on bidder incentives—and ultimately on program outcomes—are best ascertained through additional research.

Auction format

There are many types of auctions, and policymakers must identify the most appropriate type for a CfD program. Public agencies typically use sealed bid auctions for both sales and procurement. In sealed bid auctions, all bidders submit their bids prior to the close of the auction.[10] Bids are then ranked by strike price, with the lower price bids accepted in increasing order until the budget is exhausted.

Sealed bid auctions come in two basic types: uniform price and discriminatory price. In uniform price auctions, all bidders receive the strike price proposed in the first rejected bid (in the case of a reverse auction, the next bid above the highest price accepted). In discriminatory price auctions, the contract is settled at the bidder's own bid value. Uniform price auctions tend to encourage bidders to bid the true value of their product (accurate price discovery). In a discriminatory price auction, however, bidders tend to bid close to what they expect to be the closing price, potentially distorting price discovery.

The discriminatory price format is thought to be the most frequently used format in both public and private contracting. Given sufficient participation and no collusion among bidders (i.e., if there is robust auction competition), both uniform price and discriminatory price formats can have excellent properties for revenue efficiency and price discovery. The choice between these formats depends on the auction's competitiveness, which in turn is determined by factors such as the number of bidders and the dispersion of bidder characteristics. Both formats work best if accompanied by mechanisms to lower the risk of project failure (default) by winning bidders, which is why both public and private auctions are generally linked to prespecified financial default penalties in public contracting (Birulin 2020).

In addition to sealed bid auctions, there may be cases in which policymakers want to consider dynamic auctions. The English Clock auction is a dynamic auction in which the auctioneer announces a declining sequence of prices (strike price values). Bidders bid a quantity at the announced price. As the price falls, the quantity offered by bidders will fall. The auction closes when, at the announced price, the subsidy expenditure no longer exceeds the budget. All bidders receive the same price for their quantity bid.[11]

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[10] In a sealed bid auction for a CfD program, each bid would likely contain at least a strike price and an estimate of the quantity of physical units of production (e.g., tons of steel) to be covered by the CfD.

[11] In some special cases, there may be a reason to "look back" to earlier ticks of the clock and offer a marginal bidder a quantity at a higher price (Burtraw et al. 2025) .

Level of competition

Of all the CfD auction design choices, the most important are those that effect levels of participation and competition. Greater competition (itself largely based on the number of independent bidders in the auction) improves price discovery and incentives to bid truthfully, and also reduces collusion. Greater participation also likely increases the diversity of approaches represented among bidders. As important as it is, the goal of maximizing participation must be balanced against other priorities, such as the avoidance of default and the need to ensure that the program benefits multiple sectors and levels of environmental ambition (which typically requires separate auctions for different commodities and technological approaches).

One general tool for increasing participation while also maximizing the quality of bids is preauction supports such as auction and bid-preparation trainings, clear and readily accessible program communications, and even bid preparation subsidies—especially for smaller bidders. Ensuring that bidders have sufficient time after the publication of the auction rules to gather information and prepare bids is also likely to improve participation.

Avoidance of default

Achieving healthy competition in auction design requires that winning bidders perform their contractual obligations; as such, policymakers must consider mechanisms to maximize the probability of strong bidder performance. If bidders can win bids and then default at no or low cost, they have an incentive to propose unrealistic bids (with high probability of default), which discourages realistic and quality bidders from entering the auction and thereby reducing competition. Additionally, the presence of sham bidders distorts the pattern of bids for those who do participate—in the case of a reverse auction, pushing the price down below a reasonable level. The effect is to lower efficiency, harm price discovery, raise program costs, and erode the program's ability to achieve its goals. Several tools are available to address the possibility of nonperformance and associated auction distortions:

- Set eligibility criteria to exclude those most likely to underperform
- Score bids according to preannounced criteria related to likelihood of performance success
- Write contractual terms that penalize nonperformance
- Choose an auction format less likely to encourage unrealistically aggressive bidding

These tools, however, entail trade-offs for auction competitiveness. For example, establishing technical and financial eligibility criteria for participating in the auction increases the probability that winning bidders will perform. The stricter the requirements, on the other hand, the fewer potential bidders will qualify, reducing competitive participation. Similarly, strict penalties for nonperformance will discourage firms with higher risk proposals—decreasing default rates but also reducing the number of participants and potentially limiting innovation in production of the targeted commodity (or commodities). Recognizing that innovative technologies tend to have higher risk profiles and are often developed by new entrant companies—which also may have higher risk than well-established incumbents—care should be given to designing performance criteria that do not significantly disadvantage (or even outright disqualify) innovative new entrants.

Product classifications and auction categories

As mentioned above, another complicating factor regarding auction competitiveness is the fact that separate auctions may be needed by sector or product class, given heterogeneous costs of production. For example, chemical production, which relies heavily on carbon intense feedstocks, will have different economics than aluminum production, which depends heavily on electricity. Key differences also exist between primary and secondary steelmaking, which otherwise can make nearly identical products; so, in some cases, it may be important to have unique auctions by *process*, not just by product. Furthermore, while some innovative clean technologies may be shared across sectors—such as low-GHG electricity production and industrial heat pumps—innovative low-carbon technologies may vary by sector, and therefore each sector's marginal abatement costs may differ. Given all of this, it is not reasonable to assume that significantly different production processes can compete on equal footing in a single CfD auction. As a result, policymakers must define eligible product categories.

Increasing the number of distinct auctions, however, decreases the number of participants in a single auction, thereby reducing competitiveness. So, the need to reach a diversity of sectors must be balanced with the need for competitive auctions. Given high levels of initial uncertainty about costs of clean production, it may make sense to offer CfDs in narrowly defined auction categories to start—to facilitate initial price discovery—and to broaden the categories over time to include other sectors with similar cost structures. This approach is supported by the fact that it is possible to reach a large portion of industrial emissions in the United States with coverage of only a small number of products, for example, reduced primary iron for crude steel, clinker, aluminum, and the most important chemicals (e.g., ammonia, methanol, olefins) (U.S. EPA 2023).[12] Another approach—in addition to running some product-defined auctions—would be to allocate a portion of the overall CfD program budget to an openly competitive auction, which any technology or sector could participate in. At the very least, this could be an interesting experiment (to see how such a format would perform, and which technologies and sectors would participate competitively) to help inform future development of auction categories.

Specifying eligibility in terms of environmental ambition

Because the function of this initiative is to reduce industrial carbon intensity, policymakers will need to specify environmental performance requirements for eligibility. They could, for example, set a single performance floor or establish another set of auctions by level of environmental ambition within a given product class. As an example of the single floor approach, the German CCfD program requires that all eligible projects achieve at least a 60% reduction from reference facility emissions in the first three years and a 90% reduction from reference no later than the last year of the CfD.[13]

Regarding multiple auction categories by environmental performance, the same logic applies as above—significantly different levels of ambition in one product class will have different cost structures (e.g., the technology required to achieve net-zero GHG emissions in primary steel production is likely to be different than the technology required to achieve a 20% improvement over baseline for an identical product). The Section 45V Clean Hydrogen Production Tax Credit (PTC) provides an example for how higher environmental performance tracks to higher subsidization.[14] And, again, the need to facilitate fair

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[12] One avenue for this approach could be for legislators to authorize a somewhat broad set of eligible product classes and then provide criteria by which agency implementers would select among that set for the establishment of active CfD rounds. This could also include directives to the agencies to start small and expand the set of products over time, subject to program performance criteria being met.

[13] We offer more details on the German CCfD program below.

[14] The 45V credit provides four levels of incentive, with the level increasing as the carbon intensity of qualifying hydrogen decreases (with a maximum credit of $3/kg of hydrogen). The credit level also reflects whether the project meets prevailing wage and apprenticeship requirements.

competition according to environmental performance must be balanced with the need for competitive auctions.

Reserve price

Setting a reserve price is critical to auction success, especially in cases where bidders are very different or where competition is relatively thin. In an auction for CfDs, the reserve price is the maximum strike price bid that would be accepted in the auction to trigger a CfD contract. A minimum strike price (and quantity) may be specified as well to limit noncredible, "low ball" bids. The reserve and minimum prices protect against auction outcomes in which the closing strike price is either too high or too low to be consistent with the actual costs of producing low-carbon commodities; these outcomes often result from strategic bidding behavior in a noncompetitive auction. Too low a price is associated with a high potential for default on the contract, while too high a price results in an inefficient expenditure of available funds. A reserve price ensures that the price paid for the anticipated emission reductions does not exceed reasonable estimates of the value of anticipated reductions. One downside of the reserve price approach is that in some cases it may be so restrictive that no bids are offered at all. This was the case in one round of the U.K. offshore wind CfD program (Contracts for Difference (CfD) Allocation Round 5: Results 2023). That said, the straightforward solution here is to simply raise the cap in subsequent auctions.

Monitoring and verification

Government-run auctions need a system of monitoring and verification. Preannounced arrangements for monitoring, verification, and protection of private information encourage competitive bidding. It is common practice for agencies to contract with a private market monitor with expertise in assessing auction competitiveness. Before an auction, the market monitor ensures that the conditions for holding the auction are met, such as whether the participants meet their eligibility requirements or whether a minimum level of participation by independent bidders is met. After the auction, a market monitor can assess whether the bids entered are consistent with competitive behavior. Bids can be evaluated for deviating from reasonable ranges of costs, for evidence of collusive behavior, and for whether the outcome is overly concentrated compared to expectations a priori. The monitor can also evaluate the auction circumstances to determine whether the procuring agency itself acted in accordance with the auction rules. A monitoring and verification policy feeds back into the auction, giving participants confidence that the auction will be fair and will run according to the announced rules.

The process of monitoring and verification also must strike a balance between transparency and the protection of proprietary information. Accountability of public agencies requires sufficient transparency so that administrators, policymakers, and the public can determine with some fidelity that the process was fair and protected the public interest. At the other extreme, releasing too much information can interfere with the performance of the auction. Bids in auctions contain information that can allow competitors to infer valuable proprietary information of competitor costs. If potential auction participants feel that bidding in the auction would likely reveal valuable private information, they might be inclined to bid dishonestly or to not participate in the auction at all. Revealing too much information about bidders can also facilitate collusive or strategic bidding and poor auction outcomes.

Non-price factors (NPFs)

In addition to outlining the core details of how the CfD would function, policymakers may wish to incorporate NPFs. These NPFs include provisions that condition project proposals according to broader environmental or social criteria, not just the strike price (Hargreaves 2023). A good example comes from the U.K., where two NPFs have been included in Allocation Round 7 of their offshore wind CfD program. These two NPFs are called "Clean Industry Bonuses" (CIBs). The first CIB criterion is that projects invest in "more localized supply-chains." This is primarily a social/economic provision requiring projects to invest in manufacturing firms, offshore wind installation firms, or ports located in U.K. areas experiencing economic distress. The second CIB criterion requires offshore wind projects to invest in "more sustainable means of production"—as indicated by investment in either an offshore wind technology manufacturing or an installation firm that has committed to a science-based target (Department for Energy Security & Net Zero 2024).

For projects to be eligible for the U.K. offshore wind CfD, they are required to meet the CIB criteria. Compliance is evaluated prior to the CfD auction via a CIB application process. The U.K. Department for Energy Security & Net Zero (DESNZ) evaluates applications and, if compliant, it issues a "CIB statement," which is required to enter the CfD auction. In addition to meeting minimum standards, applicants can apply to receive government funds to go above the minimum standards ("CIB extra proposals"). Investments must be made by the CfD start date, and the DESNZ monitors progress during the CfD duration (Department for Energy Security & Net Zero 2024; Watson Farley & Williams 2025).

While clean energy or industrial CfDs are not yet common practice in the United States, James et al. identify four classes of NPFs at play in U.S. state-level offshore wind solicitations: "biodiversity protection or environmental impact mitigation; energy system integration; economic and workforce development; and community benefits (with a focus on disadvantaged communities)" (James et al. 2023). Additionally, many U.S. federal tax policies for clean energy, such as federal clean electricity tax credits 45Y and 48E, include something similar to NPFs: bonuses for projects meeting prevailing wage and apprenticeship standards, as well as bonuses for projects that utilize domestic content (such as steel) and that locate in communities with a history of producing energy products such as coal.

Policymakers designing an industrial CfD program may want to consider including NPFs. As the U.K. offshore wind CfD program and U.S. federal tax credits indicate, such provisions can either be articulated as minimum standards (baseline eligibility requirements) or as bonus provisions that increase the subsidy.

Emissions accounting

Emissions accounting is an important component of an industrial decarbonization CfD program as it determines the benchmark carbon intensity of eligible goods (to measure emissions reductions against) as well as the carbon intensity of goods covered by a CfD. Whether done in statute or through rulemaking, policymakers will need to specify how these carbon intensity estimates will be generated, including data and methods, timelines, and any requirements for third-party verification. Following are a few general rules:

- Use the same methods for both benchmarks and clean goods to facilitate comparison between the two.
- When possible, use publicly available data (especially for calculating benchmarks), recognizing that proprietary data will likely need to be utilized for clean goods in CfD bids, and so on.
- Establish methods that ensure harmonization between the use of publicly available and proprietary data.

- Utilize existing publicly available datasets and emissions accounting protocols, such as the Environmental Protection Agency (EPA) Greenhouse Gas Reporting Program (GHGRP) and Environmental Product Declarations.
- Require third-party verification to maximize accuracy.

Emissions accounting presents many challenges. The primary question to consider is **whether to limit** consideration to direct emissions from the project or to **consider** a full or partial life-cycle assessment (LCA). For LCA, one must further consider the type of analysis used and the scope of the analysis. Such questions lack straightforward answers, and each entails considerable administrative complexities.

Direct or life-cycle emissions?

When quantifying emissions, it is most straightforward to consider "direct" emissions—that is, the emissions occurring directly on the site of the project receiving the CfD. This includes any on-site emissions from the combustion of fossil fuels and any "process" emissions occurring through non-combustion chemical reactions (e.g., limestone calcination in cement and lime making, or iron ore reduction with coke or syngas). The advantage of using direct emissions is that they are relatively easy to measure and administer. Larger facilities may already have to report their emissions under the GHGRP, and there are well-developed methodologies to determine direct emissions in most cases.

However, direct emissions do not account for the full degree of emissions associated with a given project. For example, if process heat from combustion in an industrial process is replaced with a heat pump, direct emissions are eliminated but electricity production and consumption are increased, potentially leading to increased emissions from new generation. Considering this sort of indirect change in emissions is LCA.

While LCA is arguably a more comprehensive method for quantifying emissions changes, it may not be the best option for a policy like an industrial CfD.[15] Basing bid rankings on LCA emissions makes a project accountable for emissions that could be partially outside of its direct control, especially if it cannot select between lower and higher GHG intensity suppliers. However, in the context of a net-zero economy, those emissions will likely be targeted by other policies. For example, in the case of electricity emissions, a net-zero economy will require that electric generation produces negligible emissions, and the power sector will have its own climate policies and regulations. Thus, if a project reduces its direct emissions through electrification there may be associated electric sector emissions in the short run, but in the long run, the electrification will lead to zero emissions. However, to exclude electricity from the emissions accounting would favor technological interventions toward electrification, even if such electrification were to increase emissions in the short run elsewhere.

While electricity and other purchased energy and input emissions may be outside the control of a given industrial CfD project, the CfD project could have the ability to purchase clean energy and input attribute credits, or even build clean energy sources, so including energy and input emissions creates an incentive for the covered project to engage in such activities. Important lessons have been learned on this topic related to the 45V and 45Y/48E rulemakings, and experience with the Renewable Fuel Standard, many of which likely apply to industrial decarbonization; however, it may make sense to have

[15] Emissions from the combustion or gasification of biomass are one situation in which life-cycle analysis likely needs to be considered. The proper emissions factor for biomass is an unavoidable source of controversy, but it can be cordoned off from a full incorporation of life-cycle analysis.

different rules for energy carriers versus energy consumers, such as producers. A full discussion of this topic is beyond the scope of this paper, and further work is needed to determine the right approach to LCA for industrial decarbonization policies.

Challenges with life-cycle assessment

LCA itself presents a number of challenges. First, there are multiple types of LCA, which are generally divided into attributional LCA (ALCA) and consequential LCA (CLCA) (see Appendix 5 for details on both approaches). Second, as noted above, there are different scopes for calculating life-cycle emissions. In choosing the type of LCA, policymakers must confront the tension between accuracy of emissions quantification and administrative complexity. For example, the use of LCA in statutory text for the hydrogen (45V) and clean electricity (45Y and 48E) tax credits led to considerable controversy and delays in the issuance of guidance by the Department of Treasury due to disagreements over the type of LCA required and how it should be implemented. Some of this may have been warranted for complex technological and economic systems (sometimes good policy is complex), but it is also worth considering whether administratively simpler methodologies may be sufficient to achieve policymaker goals (Committee on Current Methods for Life Cycle Analyses of Low-Carbon Transportation Fuels in the United States et al. 2022).

Scopes

If policymakers do decide to use some form of LCA for CfD implementation, they must determine the scope of the LCA. Corporate emissions accounting is typically divided into three scopes:

- Scope 1: Direct emissions
- Scope 2: Indirect emissions from the purchase of electricity, combustion fuels, and heat
- Scope 3: All other indirect emissions

These scope decisions apply both in ALCA and CLCA frameworks. For CLCA, there are additional scope considerations—most prominently, the timeframe over which emissions are measured. Implementing scope 3 emissions accounting has been challenging in the corporate context; one way to simplify emissions accounting is to focus only on scope 1 and 2 emissions.

Issues of implementation

Below we discuss two issues pertaining to the implementation of an industrial CfD program. Because both issues would likely need to be addressed in statute, they are also part of CfD policy design. The two issues are the question of the appropriate implementing agency and the extent to which a CfD program should be stackable with other financial supports from the government.

Implementing agency

Policymakers must consider the administrative structure for implementing a CfD program. What are the key functions that such an implementing agency or agencies must fulfill? To what extent might these capacities exist in an existing agency? And, more broadly, what are the pros and cons of implementing such a program through an existing agency versus establishing a new administrative body? We begin with an illustrative example of how this is structured under the U.K. offshore wind CfD program.

The U.K. offshore wind CfD program, established by the Energy Act of 2013 (Energy Act (UK) 2013), is administered collaboratively by four independent agency bodies.[16] These agencies share the following roles:

- Overall program design, rulemaking, and management
- Program "front office," which includes implementing auctions and selecting winning bids
- CfD contracting, technical assistance, and program revenue generation
- Dispute settlement

Overall CfD program design and rulemaking is carried out by the ministerial Department of Energy Security & Net Zero (DESNZ)—the U.S. reader can think of this as similar to the Department of Energy. DESNZ authorities include establishing the CfD contracting organization, promulgating regulations regarding how to allocate CfDs, setting maximum strike price amounts, determining timeframes and budgets for CfD allocation, and establishing standard terms for the CfD itself (Department for Energy Security & Net Zero and Low Carbon Contracts Company 2023; Energy Act (UK) 2013).

The front-office of CfD implementation is handled by the U.K.'s National Energy System Operator (NESO).[17] Responsibilities here include guiding and educating applicants on program details (e.g., webinars and publication of guidance documents); managing the CfD registration and application process; determining eligibility of applicants; administering a CfD bid delivery portal; and ultimately running the auction and determining CfD allocation (National Energy System Operator n.d.; National Grid ESO 2024; Contracts for Difference Allocation Portal n.d.).

Once NESO determines CfD allocation, the Low Carbon Contracts Company (LCCC) executes and manages the contracts. The LCCC is a private, arm's length (from the government) company established and wholly owned by the DESNZ. The LCCC is governed by an independent board (which includes government representation) (Department for Energy Security & Net Zero and Low Carbon Contracts Company 2023). Additionally, funds for the U.K. CfD program have historically come from a fee (or "levy") on electricity use, and the LCCC is responsible for administering this fee. The LCCC also provides programmatic technical assistance to industry participants, as well as information and advice to the DESNZ on program development and U.K. energy and environmental policy matters (Department for Energy Security & Net Zero and Low Carbon Contracts Company 2023).

Ofgem, the U.K.'s independent regulatory body, functions as a sort of appellate body regarding disputes that may arise. In particular, if an entity disagrees with an application qualification or eligibility determination made by NESO, it can seek input from Ofgem to resolve the dispute (Ofgem 2024; Contracts for Difference Allocation Portal n.d.).

Roles and responsibilities

As the above example indicates, implementing a CfD program involves many tasks. In the U.K. example, these tasks have been assigned to a variety of entities, but it is reasonable to consider delegating to a

[16] These four entities are the ministerial Department of Energy Security & Net Zero (DESNZ), the National Energy System Operator (NESO), the Low Carbon Contracts Company (LCCC), and Ofgem—the U.K.'s independent energy regulatory body.

[17] Established in U.K.'s 2023 Energy Act and built off the traditional electricity independent system operator (ISO) model, the NESO is the independent system operator and planner for all energy systems in the U.K., including electricity, natural gas, and other forms of energy (National Energy System Operator n.d.).

smaller number of entities. Regardless of how the exact responsibilities of agency implementation are delegated, required roles include the following:

- Promulgating rules that govern program implementation
- Managing a clearinghouse of program information, including information on benchmark prices and emissions rates for covered goods
- Designing and administering auctions, including the ability to evaluate projects according to their technical and financial attributes
- Executing contracting authority, including the ability to disperse funds (and collect revenues in the case of two-sided CfDs)
- Monitoring and verification of emissions and production volumes
- Issuing penalties for failure to achieve promised levels of clean production
- Technical assistance to potential applicants and successful bidders
- Dispute settlement
- Reporting and policy advisory

Options within the federal government for consideration

Two existing U.S. federal agencies are likely candidates to run an industrial CfD program: DOE and the EPA. Between these two, DOE has the deepest technical expertise on new decarbonization technologies and greater experience providing industrial decarbonization funding. As such, we focus our comments here on DOE, which has an extensive history of facilitating technology research, development, and demonstration (RD&D), including through the use of a variety of financial and contractual instruments, such as grants and loan guarantees. DOE also has played important roles in implementing industrial-facing tax credits, such as 45V and 48C, which are arguably the closest existing U.S. policies to an industrial CfD program.

DOE has historically maintained capacity in most of the roles and responsibilities listed above, including a key one: deep expertise in executing and managing long-term contracts with energy and manufacturing firms on complex, risky, and capital-intensive projects requiring multiple points of project evaluation (“go/no-go” decision points). DOE also is the federal agency arguably most well equipped to analyze and assess the technical, economic, and environmental attributes of applicant projects, and to provide assistance to these projects as they are being built and undertake early production. DOE is also experienced in designing, assessing, and levying penalties for projects that deviate from contractual agreements or performance metrics (see the text box below for details on how the German CCfD program handles penalties).

DOE’s capabilities are well aligned with the need to assess individual projects, as well as the need to implement the overall CfD program in the context of a strategic long-term vision of U.S. industrial decarbonization and modernization, as situated in the broader energy and materials economy. And, while DOE does not have experience running auctions, because a CfD auction will require technical project evaluation and ranking, DOE experience evaluating applications for competitive programs such as the Industrial Demonstrations Program (IDP) and the 48C tax credit allocation require some of the same skills.

Examples of how compliance penalties are handled in the German CCfD program

In the German CCfD program, penalties are issued under various circumstances. For example, if in any calendar year a project is more than 10% shy of the CCfD program's emissions reduction target, it is subject to penalties.

A CCfD contract is also subject to being canceled if a project significantly deviates from emissions targets. Under these conditions, the recipient must repay 10% of the total grant award amount as a minimum penalty. Additional penalties are incrementally assessed based on how far the project falls below emission reduction targets, with limits on the maximum allowable penalty.

Penalties may also be levied under certain other conditions when the company fails to meet contractual obligations such as operational start deadlines, providing missing information, providing annual calculation data, or any willful omissions of information.

Instead of relying on an existing agency (such as DOE), the United States could establish a new separate governmental body, similar to the U.K.'s LCCC. As with the LCCC, such a body could be closely connected to DOE, but maintain independence (arm's length). This independence is a significant benefit of creating a new entity. Given that a central feature of CfD policy is to mitigate project risk (by managing market risk), insulating the contracting entity from political risk seems important. However, establishing a new entity would require a considerable effort, building from scratch the technical expertise and systems to operate such a program, whereas DOE already has much of the needed capacity.

Determining extent of stackability—interaction with other subsidies

Policymakers may also want to think about the extent to which an industrial CfD program could be combined with other federal decarbonization subsidies. For example, most existing clean energy and clean industry tax credits contain stipulations about whether a given taxpayer can take advantage of multiple incentive programs—what is often referred to as "stackability." Programs are stackable if eligible entities (e.g., companies) can take advantage of more than one of these programs simultaneously.

As an example, consider the federal 45V and 45Q tax credits. The former subsidizes any type of clean H2 fuel production; the latter subsidizes CCS, which can be used to make H2 from natural gas (blue H2). To avoid double dipping, both credits cannot be taken for clean H2 production at a single facility. However, 45Q credits could be taken at other points in the supply chain, say by electric utilities providing cleaner electricity via carbon capture at the generation plant, which then enables green H2 producers using electrolysis to qualify for a given (possibly higher) 45V tax credit.

This example illustrates that stackability is often not permitted for the same commodity at the same plant or eligible taxpayer. It is, however, permitted across the value chain, which ultimately can reduce embedded GHGs and/or costs of the downstream commodity.

From the participant's perspective, of course, the more stackability the better. From the government's perspective, however, more stackability raises outlays and could result in double dipping and overinvestment in the technologies that can take advantage of stacking. From society's perspective, particularly with a cap on total outlays, stackable technologies are given an advantage that might not be otherwise warranted, resulting in less cost-effective innovation. That said, existing credits for decarbonization of heavy industry tend to be insufficient, and so the issue of oversubsidization may be less of a concern in the case of an industrial CfD.

Economic theory suggests that if the primary goal of the industrial CfD program is to reduce GHGs as a response to climate change, then the total subsidy provided to a given project would equal the marginal damage of one ton of GHGs for every ton reduced by the project. This is applying the same logic of how carbon taxes should equal the social cost of carbon (Rennert et al. 2022) Again, theoretically—and only if optimizing around GHG reductions—stackability would be allowed up to this point for a given project.

One caveat to this simple rule is when more than one externality or more than one public policy goal is present. In the area of decarbonization, where many technologies are in early development stages, a case can be made for greater subsidies than those equal to marginal carbon damages given the need to address independent innovation externalities (due to the difficulty innovators have in appropriating the full value of their innovations, even with patent protection).

Quite apart from those conceptual considerations are practical considerations. For example, if the size of incentive for a given program is below the optimal amount, then stackability would arguably be warranted. A good example is 45V and the H2DI auction.[18] Both would subsidize the production (and either implicitly or explicitly the offtake) of clean H2, but the price differential between clean H2 and the current fuel (either fossil fuels or "gray” hydrogen) is so large and the restrictions on taking the 45V credit are so tight (although the subsidy rate is generally considered to be reasonably large), that stacking the two is arguably warranted. Also, in reality, there are or could be complex interactions with applying for various incentives, suggesting that coordination (or at least forethought) is needed in designing CfD stackability features to lower barriers to accessing multiple incentive programs.

An additional issue is perceived fairness. If some bidders in the CfD auction have access to other subsidies and other bidders did not, bidders with subsidy access would have a clear advantage because, other things being equal, they could bid lower prices. Whether the CfD auction would be considered unfair in this case might turn on why some bidders were excluded from other subsidy programs.

Comparing CfDs to similar U.S. policy mechanisms

As policymakers consider implementation of a CfD mechanism for industrial decarbonization, it is important to understand how such a mechanism compares to similar policies to ensure that it is well suited to the task. To support this understanding, we now compare CfDs to five other common policy mechanisms that can facilitate industrial decarbonization:

- Production or investment tax credits (PTC or ITC)
- Green procurement
- Tradable performance standards (TPSs)
- Advance market commitments (AMCs)
- A carbon tax

We chose tax credits, green procurement, and TPSs because they have been implemented in the North American industrial sector in recent years. We selected AMCs because they have been utilized outside of decarbonization, and literature exists on how they may be applied to the industrial sector. We chose a

[18] The H2DI auction is a mechanism designed, but not yet implemented, to support offtake of clean hydrogen within the DOE Regional Clean Hydrogen Hubs (H2Hubs) program.

carbon tax as a comparison because numerous proposals and discussions have focused on how the United States might implement such a tax.

For each instrument, we first define a representative version. Many of these instruments are flexible enough to be customized and amended to suit specific industries or fulfill certain needs. Given this wide range of potential specifications, we believe it is important to establish a baseline that we are comparing against. Appendix 6 provides an expanded description of each of these mechanisms. At the end of this section, we provide a stylized comparison between a CfD and a competitively allocated grant program.

Production and investment tax credits

PTCs and ITCs use the tax code to incentivize new clean technologies by reducing federal income tax liability. Typically, the quantity of the incentive is defined in statute, rather than through an auction or market fluctuations (as with a CfD). The PTCs and ITCs that have driven much of the deployment of clean electricity in the United States are good examples. Usually, tax credits do not have an expenditure cap, providing less certainty in government expenditure. However, some allocated credits, such as the 48C Advanced Energy Project Credit, specify a spending cap.

Green public procurement

Green procurement programs drive demand for low-emissions materials by setting emissions intensity standards for products procured by the government or government grantees. Examples include the General Services Administration (GSA) Buy Clean procurement program established under the IRA and state Buy Clean programs.

Tradable performance standards

TPSs assign industry- and sector-specific environmental performance (e.g., emissions intensity) benchmarks, which can be met through compliance, by trading credits with firms below the benchmark, or by paying a fee. TPS programs can spur innovation if the standard cannot be met by existing technologies. A prominent domestic example was California's tradable Zero Emission Vehicle (ZEV) credit system; an internationally prominent example is Canada's Output-Based Pricing System, which assigns industry-specific emissions intensity benchmarks (tons CO_2e per physical unit of output) and covers large polluters in the industrial sector.

Advance market commitments

Advance market commitments (AMCs) incentivize research and development (R&D) and capital investment in new technologies by guaranteeing a market for the product if it meets technical specifications. Sponsors make a commitment for a guaranteed price and amount of product, subject to contract provisions—such as technical requirements, a price cap, or intellectual property sharing. Key examples are in vaccine development, such as with the COVID-19 vaccine.

Carbon tax

A carbon tax sets a price on GHG emissions, incentivizing covered emitters to reduce emissions so they do not have to pay the tax. A carbon tax can either be applied upstream (at the point of refining or processing fossil fuels) or downstream (at the point of emissions). No economy-wide carbon tax currently exists for the United States, but there are 37 carbon tax programs implemented worldwide (Center for Climate and Energy Solutions 2024).

Evaluating mechanisms against our criteria

We select three overarching criteria to compare these instruments to a CfD program: benefit to society, benefit to government, and benefit to the industrial sector. These three criteria cover the key stakeholders that would be affected by a CfD or our comparison policies. For each, we also include several subcriteria that go into greater detail on specific aspects of each overarching criterion. Please see Appendix 7 for a discussion of these subcriteria, which we also highlight in the following.

Benefit to society

All of our selected policy mechanisms have moderate to high **emissions reductions potential**, depending on the stringency of the specific implementation case (e.g., a carbon tax can have low or high emissions reduction potential depending on the tax level). CfDs, TPSs, and carbon taxes all have elements that allow for discovery of the true cost of decarbonization (price discovery), which arguably maximizes GHG reductions in the context of limited subsidy budgets. All mechanisms have the potential to be tech-neutral and allow participants or covered entities to select the least-cost, highest-reduction decarbonization pathway. Carbon taxes and TPSs tend to have broader sectoral scope (frequently economy-wide), which (all things being equal regarding stringency) means greater emissions reductions. CfDs and the remaining policies tend to be sectorally focused; expanding these to an economy-wide scope would present significant administrative burden.

All mechanisms also have the potential to stimulate **technological innovation**, recognizing that AMCs and CfDs are likely best suited to be tailored to innovative technologies. CfDs can target FOAK to NOAK demonstration projects and provide price stability at the project level, reducing exposure for financing partners and improving the project's ability to attract capital. This has the ability to boost investor confidence and bridge the pathway to commercialization of the technology. Additionally, the rewards for an AMC are contingent on an innovation step.

While GHG reductions may be the primary goal of each mechanism, **co-benefits** such as environmental justice requirements, conventional air pollutant reductions, economic development in target communities (such as energy communities), and ecosystem protections can also be considered when designing the mechanism. Most mechanisms have some method of embedding co-benefits in the selection process or enforcement criteria. Arguably, tax subsidies, CfDs, and AMCs offer the most flexibility in this regard: Co-benefits are often included as requirements or bonuses in tax credits, AMCs can explicitly require co-benefits as a criterion in the technical specifications, and, while CfDs focus primarily on GHG reductions and the strike price, they can include NPFs as a requirement for bidding or as part of the selection process, as discussed above.

Benefit to government

Most mechanisms examined can specify a predictable **quantity of government outlay.** However, in many cases, this depends on whether commitments are capped; for instance, tax credits can be open ended (such as the 45V hydrogen PTC) or capped (such as the 48C Advanced Energy Project credit). Green procurement programs sometimes include total spending caps (e.g., the GSA Buy Clean program established under the IRA), but it is also possible for them to be open ended, which would introduce greater budgetary uncertainty. AMC contracts typically include a cap on the quantity of the covered material, which manages uncertainty of outlay. TPSs and a carbon tax have little to no outlay required except administrative costs. A carbon tax (depending on details such as level of pricing stringency and scope of coverage) has the potential to generate sizable revenues for the government. In certain instances, a TPS can also generate revenue (from an alternative compliance payment for noncompliers or in a standard cap-and-trade system), but these programs are often revenue neutral. CfDs can also be capped, but there is some uncertainty about how much of the total cap would be allocated, risking *under*utilization of allocated funds.

While all mechanisms are effective at reducing emissions, some tend to allocate limited government funds more **cost effectively** (measured as public dollars spent per quantity of emissions reductions). Carbon taxes and TPSs are in a category of their own, given that they do not require government expenditure to facilitate decarbonization (beyond administrative costs). The efficiency of a tax credit depends heavily on its design details—for example, tax credits tend to offer uniform subsidies per project type (e.g., clean electricity) but more tailored designs are possible (e.g., 45V). CfDs are arguably more efficient because they allow for price discovery if auctions are competitive, increasing the probability that the government provides only what is necessary to make an eligible project economical. Additionally, two-sided CfDs require firms to repay the government when the market price rises above the strike price—another feature that limits potential oversubsidization.

For many mechanisms, including a TPS and carbon tax, **administrative costs** can be high because of ongoing, annual monitoring and reporting requirements. Many also require setup costs, such as for trading markets (TPS), rulemaking and integration into the existing tax system (tax credits, carbon tax), and reverse auctions or bidding processes (CfDs, green procurement). CfDs may have relatively modest administrative costs if the number of contracts is limited. That said, executing and managing contracts entails costs, and the reverse auction process is also likely to impose costs, especially if specific requirements are necessary for many subproduct types.

Benefit to industry

CfDs, AMCs, and green procurement are effective at **reducing project uncertainty**. With CfDs, a guarantee on the price protects the investment from revenue fluctuations, allowing projects to obtain both variable- and fixed-price offtake agreements and attract private capital. AMCs also help reduce uncertainty for firms by guaranteeing a price and quantity for the green product. Similarly, green procurement helps to build a market through government purchasing, but it does not directly address risk for firms beyond providing demand. Other mechanisms do not directly address risk and uncertainty. Tax credits provide a predictable incentive that can make a technology pathway more attractive as an investment, and the incentive accounts for some market risks. For instance, the PTC adjusts based on production volume fluctuations, and the total ITC transfer adjusts as a percentage of the qualifying investment. However, tax credits do not account for price fluctuations of inputs (to the clean production process) or of the clean product itself. On the other hand, TPSs and a carbon tax provide clear guidelines and motivation for emissions reductions across all covered entities, but do not have a mechanism for reducing the uncertainty of deploying innovative technology.

CfDs also offer high **price competitiveness** with existing conventional products because producers are effectively compensated for the green premium. Tax credits also reduce the green premium, but as a flat subsidy they may not fully cover the premium in all cases (and may overcompensate in other cases). AMCs allow a product to be competitive by guaranteeing a price that is economical for the contracted producer, effectively shielding it from the incumbent producers. Emissions intensity requirements in green procurement similarly shield producers because bids will come only from producers that meet green standards. TPSs and carbon taxes are very susceptible to leakage (i.e., competition from firms outside the scope of enforcement, such as foreign producers) unless paired with something like a carbon border adjustment or output-based allocation mechanism. This risk is magnified in many industrial sectors, where products are often traded between jurisdictions.

Some mechanisms are exposed to potential **anticompetitive behavior**, especially if the pool of eligible firms is small. This is particularly an issue in the case of CfDs, where a small bidder pool can raise the risk of collusion. Another issue in many mechanisms is the risk of knowledge or intellectual property (IP) hoarding among winning firms. AMCs can mitigate this risk through long-run price caps and IP sharing agreements. Many subsectors in a CfD program may have thin markets, with only a few companies with concentrated ownership of facilities. For instance, some steel markets—including the United States, Japan, and South Korea—are more concentrated than others when measured by the Herfindahl−Hirschman Index (HHI), which determines market concentration. HHI estimates range from 1,500 to 2,400 points in these markets (Duren and Kolas 2024; Chaudhary, Trivedi, and Agrawal 2024); by comparison, the U.S. Department of Justice's merger guidance threshold is 1,800 for a "highly concentrated" market (U.S. Department of Justice and Federal Trade Commission 2023). Without IP or knowledge sharing agreements, anticompetitive behavior is possible if only one firm's projects in a subsector are selected through the auction.

Contracts for difference versus competitive clean production subsidy

A mechanism similar to a CfD (but not discussed above) is a competitively determined clean production subsidy. As with a CfD, such a subsidy would be determined through a reverse auction. But, unlike a CfD, the subsidy payment would not be integrated with a market price hedge and would—aside from inflation adjustment—not fluctuate over the contract term. The clean production bid would reflect the subsidy needed per unit of production. Selected companies would then be awarded a subsidy either "as bid" or all selected firms would receive the subsidy required by the highest selected bid. This flat subsidy would represent the additional capital and operating costs from building and operating the low-carbon project compared to a status quo project. The subsidy could be delivered as a direct cash payment or potentially as a tax credit.

This approach offers many of the same benefits as a CfD, including competitively driven subsidy price discovery, but it leaves it to the producer to manage any changes in market prices. In the United States, the risk of future price changes is generally left to investors, and managing such risks helps to ensure the productive investment of resources. A key question to consider is whether industrial firms considering decarbonization can manage the potential for price changes to their product or key inputs, or if help managing this risk is needed in addition to a decarbonization subsidy. Producers may be able to enter into long-term contracts for their products or inputs, may be able to hedge risks through other private market means, or may simply be confident about future supply and demand for their product. In such cases, a competitive clean production subsidy would provide a simpler subsidy mechanism.

Conclusion

As a major source of GHG emissions and a supplier of key construction materials such as steel, cement, and aluminum, the U.S. industrial sector is central to the transition to a low-carbon economy. Industrial decarbonization requires a high degree of technological innovation and capital investment, and additional federal policy is needed to facilitate these developments. In Europe and the U.K., government-issued CfDs have been demonstrated as a powerful tool for reducing industrial emissions while growing the economy. However, the United States has little to no experience with such a policy. With this report, we have tried to address this vacuum for policymakers by providing CfD background, describing key CfD policy design details to consider, and by comparing CfDs to similar policy mechanisms.

A key strength of a CfD is the ability to achieve price discovery for the marginal cost of abatement (achieved through a competitive auction); this enables accurate, efficient levels of subsidization, avoiding both over- and undersubsidization. This subsidy precision is augmented by two-sided CfDs, in which firms contribute funds back to the program when market conditions change (even temporarily).

CfDs are also uniquely positioned to guarantee a price for the decarbonized product and adjust for market uncertainty—both regarding the covered good as well as intermediate inputs. This risk mitigation and the ability to target the program according to the emissions reduction ambition of bidders also gives CfDs a unique ability to drive technological innovation.

However, the overall impact of a CfD depends heavily on the amount of government outlay and the program's scope. When other mechanisms—such as tax credits, TPSs, or carbon taxes—apply to all covered or eligible entities within the program scope, a CfD's emissions reduction or technology development impact is limited to the facilities with winning bids and the sectors and technologies being targeted. If CfD budgets are large, there may be many winning bidders, whereas small or narrowly targeted programs will inherently have small impacts.

Additionally, because CfDs have not yet been widely implemented in the United States or in the industrial sector, there may be some administrative challenges—not only to set up the overall program, but also to determine details such as the treatment of eligible subproduct types and auction design.

Overall, CfDs hold promise as an efficient and effective tool for reducing GHG emissions from industry, while boosting innovative U.S. manufacturing. Further work is needed to identify the right scope of coverage for such a program—balancing the need for a level playing field among auction competitors (which indicates the need to group similar products in individual auctions, thereby narrowing the field of competition) with the need for competitive auctions (which indicates the need to broaden the field of coverage to have more competitors). Further research is also needed to estimate how various program design decisions (e.g., performance requirements and noncompliance penalties) would affect auction dynamics, and how existing market characteristics (such as the extent to which producers are exposed to spot market prices versus fixed prices in long-term contracts) might impact CfD program design. Additionally, while this paper focuses on designing a federal program, it would be valuable to investigate various state CfD policy options, including the possibility of implementing a CCfD in states with carbon pricing, such as California and the RGGI states.

References

Aldy, Joseph E., Tim Brennan, Dallas Burtraw, et al. 2012. "Considering a Carbon Tax: Frequently Asked Questions." Resources for the Future, November 1. https://www.rff.org/publications/issue-briefs/considering-a-carbon-tax-frequently-asked-questions/.

Amelang, Sören, and Benjamin Wehrmann. 2024. "Germany Awards First Companies with Pioneering "Climate Contract" Scheme to Slash Industry Emissions." *Clean Energy Wire*. www.cleanenergywire.org/news/germany-awards-first-companies-pioneering-climate-contract-scheme-slash-industry-emissions. Accessed 22 Sept. 2025.

Ason, Agnieszka, and Julio Dal Poz. 2024. *Contracts for Difference: The Instrument of Choice for the Energy Transition*. OIES Paper 34. The Oxford Institute for Energy Studies.

Beiter, Philipp, Jérôme Guillet, Malte Jansen, Elizabeth Wilson, and Lena Kitzing. 2023. "The Enduring Role of Contracts for Difference in Risk Management and Market Creation for Renewables." *Nature Energy* 9 (1): 20–26. https://doi.org/10.1038/s41560-023-01401-w.

Bergman, Aaron, Alan Krupnick, Daniel Haerle, Lucie Bioret, Yuqi Zhu, and Jhih-Shyang Shih. 2023. *Demand-Pull Tools for Innovation in the Cement and Iron and Steel Sectors*. March. https://media.rff.org/documents/Report_23-01_aEmAsu3.pdf.

Bipartisan Policy Center. 2022. *Inflation Reduction Act Summary*. Bipartisan Policy Center. https://bipartisanpolicy.org/download/?file=/wp-content/uploads/2022/08/Energy-IRA-Brief_R04-9.26.22.pdf.

Boyd Metals. n.d. "Understanding the CRU Index and Steel Prices." Boyd Metals. Accessed August 15, 2025. https://blog.boydmetals.com/understanding-the-cru-index-and-steel-prices.

Brown, Christine, Jonathan Dark, and Kevin Davis. 2010. "Exchange Traded Contracts for Difference: Design, Pricing, and Effects." Journal of Futures Markets 30 (12): 1108–49. https://doi.org/10.1002/fut.20475.

Birulin, Oleksii. 2020. "Optimality of Simple Procurement Auctions." International Journal of Industrial Organization 70 (May): 102610. https://doi.org/10.1016/j.ijindorg.2020.102610.

Burtraw, Dallas, Charles Holt, Åsa Löfgren, and William Shobe. 2025. *Reverse Auctions to Procure Negative Emissions at Industrial Scale*. University of Gothenburg, School of Business, Economics and Law. https://gupea.ub.gu.se/bitstream/handle/2077/86598/854%20Reverse%20Auctions%20to%20Procure%20Negative%20Emissions%20at%20Industrial%20Scale.pdf?sequence=1&isAllowed=y.

Canestrini, Chiara. 2023. "Contracts-for-Difference (CfDs)." Florence School of Regulation, April 12. https://fsr.eui.eu/contracts-for-difference/.

Center for Climate and Energy Solutions. 2024. "Carbon Tax Basics." *Center for Climate and Energy Solutions*, May. https://www.c2es.org/content/carbon-tax-basics/.

Center for Climate and Energy Solutions. n.d. "California Cap and Trade." *Center for Climate and Energy Solutions*. Accessed May 20, 2025. https://www.c2es.org/content/california-cap-and-trade/.

Chaudhary, Isha, Charvi Trivedi, and Priyanka Agrawal. 2024. "Green Steel: Challenging the Status Quo | Wood Mackenzie." May 9. https://www.woodmac.com/news/opinion/green-steel-challenging-the-status-quo/.

Clean Air Task Force. 2024. "Designing Carbon Contracts for Difference: A Comparison of Incentives for Carbon Capture and Storage in Europe." Clean Air Task Force. https://www.catf.us/resource/designing-carbon-contracts-for-difference/.

Committee on Current Methods for Life Cycle Analyses of Low-Carbon Transportation Fuels in the United States, Board on Environmental Studies and Toxicology, Board on Agriculture and Natural Resources, et al. 2022. *Current Methods for Life Cycle Analyses of Low-Carbon Transportation Fuels in the United States*. National Academies Press. https://doi.org/10.17226/26402.

Contracts for Difference Allocation Portal. n.d. "Ofgem | Contracts for Difference CfD." Contracts for Difference (CfD) Allocation Round Resource Portal. Accessed June 25, 2025. https://www.cfdallocationround.uk/about/ofgem.

Contracts for Difference (CfD) Allocation Round 5:Results. 2023. Department of Energy Security & Net Zero. https://www.gov.uk/government/publications/contracts-for-difference-cfd-allocation-round-5-results.

Crux. 2024. "ITC vs PTC Credits: What's the Difference?" Crux, December 19. https://www.cruxclimate.com/insights/itc-vs-ptc.

Davis, Jeffrey, Michael Sykes, and Kealan Hannes. 2025. "Final Regulations for Clean Hydrogen: Making Tax Credits More Accessible." White & Case LLP, January 13. https://www.whitecase.com/insight-alert/final-regulations-clean-hydrogen-making-tax-credits-more-accessible.

Department for Energy Security & Net Zero. 2024. *Contracts for Difference Scheme for Renewable Electricity Generation Allocation Round 7: Clean Industry Bonus Allocation Framework, 2024*. Department for Energy Security & Net Zero. https://assets.publishing.service.gov.uk/media/67910467cf977e4bf9a2f17e/cfd-clean-industry-bonus-allocation-framework-corrected-22012025.pdf.

Department for Energy Security & Net Zero and Low Carbon Contracts Company. 2023. "Low Carbon Contracts Company Ltd Framework Document." February. https://aceeeorg.sharepoint.com/sites/rp/Industry/CfD/Library%20Celsius%20SP%205-8-2025/UK/LCCC_Framework_Document_published_version_Feb_2023_2.pdf?CT=1747069328264&OR=ItemsView.

Department of Energy & Climate Change UK. 2014. Contracts for Difference: Standard Terms and Conditions. Gov.UK. https://assets.publishing.service.gov.uk/media/5a7d5b1ce5274a3356f2bb87/Generic_CfD_TCs__29_August_2014_.pdf.

Driessen, Grant A. 2019. *Spending and Tax Expenditures: Distinctions and Major Programs*. Legislation. https://www.congress.gov/crs-product/R44530.

Duren, Tirzah, and Logan Kolas. 2024. *Steeling American Competitiveness: Protecting Consumers Against Bad Competition & Industrial Policy*. https://www.theamericanconsumer.org/wp-content/uploads/2024/09/Steel-Merger-2.pdf.

Energy Act (UK), c.32 (2013). https://www.legislation.gov.uk/ukpga/2013/32/contents.

Environment and Climate Change Canada. 2018. "Output-Based Pricing System." Program descriptions. October 31. https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/output-based-pricing-system.html.

Fischer, Carolyn. 2019. *Market-Based Clean Performance Standards as Building Blocks for Carbon Pricing*. The Hamilton Project. The Brookings Institution. https://www.brookings.edu/wp-content/uploads/2019/10/PP_Fischer_FINAL-1.pdf.

Gangotra, Ankita, William Carlsen, Kevin Kennedy, and Katie Lebling. 2023a. *How Advance Market Commitments and Contracts for Difference Can Help Create a Market for Green Industrial Products*. November 2. https://www.wri.org/technical-perspectives/amc-cfd-for-green-industrial-products.

Gangotra, Ankita, Katie Lebling, John Feldmann, and Kevin Kennedy. 2023b. *What Does "Green" Procurement Mean? Initiatives and Standards for Cement and Steel.* April 25. https://www.wri.org/insights/green-procurement-initiatives.

GAO (Government Accountability Office). 2004. "Principles of Federal Appropriations Law Third Edition." GAO, January. https://www.gao.gov/assets/2019-11/202437.pdf.

Gerres, Timo, and Pedro Linares. 2022. "Carbon Contracts for Differences (CCfDs) in a European Context."

Government of Canada. 2018. "Canada Gazette, Part 2, Volume 152, Number 22: Notice Establishing Criteria Respecting Facilities and Persons and Publishing Measures." Government of Canada, Public Works and Government Services Canada, Integrated Services Branch, Canada Gazette, October 31. https://gazette.gc.ca/rp-pr/p2/2018/2018-10-31/html/sor-dors213-eng.html.

Hafstead, Marc. 2019a. "Carbon Pricing 101." Resources for the Future, June 6. https://www.rff.org/publications/explainers/carbon-pricing-101/.

———. 2019b. "Carbon Pricing 102: Revenue Use Options." Resources for the Future, September 26. https://www.rff.org/publications/explainers/carbon-pricing-102/.

Hargreaves, Jessica. 2023. “UK Government Update on the Introduction of Non-Price Factors into CfD Auctions.” Linklaters, September 22. https://sustainablefutures.linklaters.com//post/102ioct/uk-government-update-on-the-introduction-of-non-price-factors-into-cfd-auctions.

Hughes v. Talen Energy Mktg., LLC, 578 U.S. 150 (Supreme Court 2016).

International Energy Agency. 2023. “Stimulation of Sustainable Energy Production and Climate Transition (SDE++) – Policies.” IEA, May 25. https://www.iea.org/policies/13639-stimulation-of-sustainable-energy-production-and-climate-transition-sde.

Internal Revenue Service. 2025a. “Clean Electricity Investment Credit | Internal Revenue Service.” May 29. https://www.irs.gov/credits-deductions/clean-electricity-investment-credit.

———. 2025b. “Clean Electricity Low-Income Communities Bonus Credit Amount Program | Internal Revenue Service.” IRS.Gov, February 11. https://www.irs.gov/credits-deductions/clean-electricity-low-income-communities-bonus-credit-amount-program.

———. 2025c. “Clean Electricity Production Credit.” IRS.Gov, May. https://www.irs.gov/credits-deductions/clean-electricity-production-credit.

———. 2025d. “Domestic Content Bonus Credit | Internal Revenue Service.” January 23. https://www.irs.gov/credits-deductions/domestic-content-bonus-credit.

———. 2025e. “Elective Pay and Transferability | Internal Revenue Service.” IRS.Gov, April 9. https://www.irs.gov/credits-deductions/elective-pay-and-transferability.

International Carbon Action Partnership. n.d. “Canada Federal Output-Based Pricing System.” International Carbon Action Partnership. Accessed May 20, 2025. https://icapcarbonaction.com/system/files/ets_pdfs/icap-etsmap-factsheet-135.pdf.

James, Mark, Kira Jannusch, Kelsey Koenig, Jack McGowan, Jon Small, and Ervin Yahr III. 2023. *Using Non-Price Criteria in State Offshore Wind Solicitations to Advance Net Positive Biodiversity Goals*. Vermont Law & Graduate School; Institute for Energy and the Environment. https://www.vermontlaw.edu/wp-content/uploads/2024/07/iee-tnc_offshore-wind-report_20230606_1644.pdf.

Kremer, Michael, Jonathan Levin, and Christopher Snyder. 2020. *Designing Advance Market Commitments for New Vaccines*. No. W28168. National Bureau of Economic Research. https://doi.org/10.3386/w28168.

Kremer, Michael, Jonathan Levin, and Christopher M. Snyder. 2020. “Advance Market Commitments: Insights from Theory and Experience.” *AEA Papers and Proceedings* 110 (May): 269–73. https://doi.org/10.1257/pandp.20201017.

Kremer, Michael, and Heidi Williams. 2010. “Incentivizing Innovation: Adding to the Tool Kit.” *Innovation Policy and the Economy* 10 (January): 1–17. https://doi.org/10.1086/605851.

Kristiansen, T. 2004. “Pricing of Contracts for Difference in the Nordic Market.” Energy Policy 32 (9): 1075–85. https://doi.org/10.1016/S0301-4215(03)00065-X.

Legal Information Institute. n.d. “31 U.S. Code § 1553 - Availability of Appropriation Accounts to Pay Obligations.” Accessed August 15, 2025. https://www.law.cornell.edu/uscode/text/31/1553.

Legal Information Institute. n.d. “42 U.S. Code § 17113b - Advanced Industrial Facilities Deployment Program.” Accessed August 15, 2025. https://www.law.cornell.edu/uscode/text/42/17113b.

Lockwood, Toby. 2024. “Designing Carbon Contracts for Difference.” Clean Air Task Force, February 12.

Metcalf, Gilbert E. 2017. “Implementing a Carbon Tax.” *Resources for the Future* Considering a US Carbon Tax: Economic Analysis and Dialogue on Carbon Pricing Options, an RFF initiative. (May). https://media.rff.org/documents/RFF-Rpt-Metcalf_carbontax.pdf.

National Energy System Operator. n.d. “Electricity Market Reform (EMR) Delivery Body | National Energy System Operator.” National Energy System Operator. Accessed May 19, 2025. https://www.neso.energy/what-we-do/energy-markets/electricity-market-reform-emr-delivery-body.

National Grid ESO. 2024. “CfD Allocation Round 6 (AR6) - Guidance.” March. https://allocation-cms-eu-west-2-files20240731180525306000000004.s3.amazonaws.com/documents/CfD-AR6-Allocation-Guidance_9sITkV2.pdf.

Ofgem. 2024. “Ofgem’s Determinations on Tier 2 Contracts for Difference Disputes - Allocation Round 6 | Ofgem.” August 30. https://www.ofgem.gov.uk/decision/ofgems-determinations-tier-2-contracts-difference-disputes-allocation-round-6.

Oxford Institute for Energy Studies. 2024. “Contracts for Difference: The Instrument of Choice for the Energy Transition.” Oxford Institute for Energy Studies. https://www.oxfordenergy.org/publications/contracts-for-difference-the-instrument-of-choice-for-the-energy-transition/.

Rennert, Kevin, Frank Errickson, Brian C. Prest, et al. 2022. “Comprehensive Evidence Implies a Higher Social Cost of CO2.” *Nature* 610 (7933): 687–92. https://doi.org/10.1038/s41586-022-05224-9.

U.S. Department of Energy. n.d. “Qualifying Advanced Energy Project Credit (48C) Program.” Energy.Gov. Accessed May 19, 2025. https://www.energy.gov/infrastructure/qualifying-advanced-energy-project-credit-48c-program.

U.S. Department of Justice and Federal Trade Commission. 2023. *Merger Guidelines*. December 18.

U.S. Energy Information Administration. 2025. “Annual Energy Outlook 2025.” U.S. Energy Information Administration. https://www.eia.gov/outlooks/aeo/.

U.S. Environmental Protection Agency and Office of Air and Radiation. 2023. "Sector Data Highlights." Overviews and Factsheets. https://www.epa.gov/ghgreporting/sector-data-highlights.

U.S. General Services Administration. 2023. "GSA Pilots Buy Clean Inflation Reduction Act Requirements for Low Embodied Carbon Construction Materials." U.S. General Services Administration, May 16. https://www.gsa.gov/about-us/newsroom/news-releases/gsa-pilots-buy-clean-inflation-reduction-act-requirements-for-low-embodied-carbon-construction-materials-05162023.

U.S. Geological Survey. n.d. "Commodity Statistics and Information | U.S. Geological Survey." Accessed May 12, 2025. https://www.usgs.gov/centers/national-minerals-information-center/commodity-statistics-and-information.

Watson Farley & Williams. 2025. "Clean Industry 'Bonus' or 'Burden'?" Watson Farley & Williams, March 3. https://www.wfw.com/articles/clean-industry-bonus-or-burden/.

Watson, Nicole, and Paul Bolton. 2024. *Contracts for Difference*. Commons LIbrary Research Briefing No. 9871. House of Commons Library. https://researchbriefings.files.parliament.uk/documents/CBP-9871/CBP-9871.pdf.

Yeh, Sonia, Dallas Burtraw, Thomas Sterner, and David Greene. 2021. "Tradable Performance Standards in the Transportation Sector." *Energy Economics* 102 (October): 105490. https://doi.org/10.1016/j.eneco.2021.105490.

Appendices

Appendix 1. Types of CfDs

Table 1. Examples of different types of CfDs

Examples of CfDs	Regions	General description
Wind and solar renewable electricity PCfD	U.K. Low Carbon Contracts Company Other examples: France, Spain, Denmark, Greece, Hungary, Ireland, Poland, Portugal, Lithuania, Romania, Belgium, Albania, Serbia, Norway, Australia	U.K. CfD scheme established in 2014 has successfully facilitated 29.4 GW of renewable energy generation (including nuclear). Index annually adjusted. In most CfD programs the last (highest) successful bid accepted sets the price for all projects in a reverse auction.
PCfD for hydrogen	U.K. Hydrogen Production Business Model (HPBM) Other examples: France, European Hydrogen Bank, Japan	HPBM provides revenue support to hydrogen producers to overcome the operating cost gap between low-carbon hydrogen and high-carbon fuels. Designed to deliver up to 10 GW of low-carbon hydrogen production capacity by 2030.
CCfD for industrial production	Germany Klimaschutzverträge Other examples: Netherlands SDE++	The Klimaschutzverträge targets net-zero transformational technologies in the heavy industry sector, with the hope of driving down costs through learning by doing. Only projects capable of a 90% emission reduction and with a high level of value chain integration are funded. The strike price index is the European ETS carbon price.
CCfD for CCUS/CCS	U.K. Department for Business, Energy & Industrial Strategy Other examples: Denmark, Danish Energy Agency	A 15-year contract pays emitter per ton of captured CO_2 to cover additional costs of deploying carbon capture. Offers additional risk protection for transmission and supply outages and legal changes if obligations are met.

Source: CATF 2024

Appendix 2. Analysis of U.S. legal constraints on CfD use

This appendix addresses any legal barriers to a U.S. federal CfD program. As stated in our report, some authors have pointed out areas in which U.S. law limits use of CfDs, raising questions about whether such an approach would be legal. These areas include regulatory limitations on use of CfDs in some commercial contexts and limits on how U.S. states may use similar mechanisms in the wholesale electricity sector. However, these limitations would not bar a new federal law authorizing the use of a CfD to subsidize low-carbon industrial production. Moreover, these limitations would not limit the federal government from using a CfD mechanism to implement an existing grant program for clean industrial production, so long as its structure did not conflict with the specific requirements of the grant program's authorizing statute.

Current U.S. law governing CfDs

U.S. law limits use of CfDs in two contexts. First, states are barred from using CfDs designed to support new generation if such generation is tied to the wholesale power markets. Second, private, commercial use of CfDs in financial instruments is subject to regulation by the Dodd−Frank Wall Street Reform and Consumer Protection Act of 2010 (Dodd−Frank), passed in the wake of the 2008 financial crisis. These limitations are mentioned in two articles discussing use of CfDs to support renewables and other clean production policies.[19]

Limits on CfDs in wholesale electricity markets

The Federal Power Act granted the Federal Energy Regulatory Commission (FERC) exclusive authority over interstate wholesale electricity sales. States retain significant authority over electricity generation and electric utilities that purchase and distribute electricity; however, this authority cannot intrude on FERC's authority over wholesale electricity markets. In 2016, Maryland discovered that this limitation included state use of a CfD mechanism to support in-state electricity generation. Maryland had established a program that set a minimum electricity price to be paid to new generators and required Maryland utilities to pay the difference when wholesale power market prices fell below that minimum. Those utilities challenged Maryland's requirement, and the Supreme Court held that this "contract for difference" policy unlawfully "invaded FERC's regulatory turf" because it "adjust[ed] an interstate wholesale rate" (*Hughes v. Talen Energy Mktg., LLC* 2016).

Importantly, the ruling is limited to the wholesale electricity sector. The conflict arose from FERC's exclusive jurisdiction over wholesale electricity rates; similar federal authority does not exist over wholesale sales of industrial products such as steel or cement. For these other sectors, either a state or a federal agency could adopt a similar policy without treading on a federal agency's exclusive jurisdiction. This ruling also does not govern the retail sale of electricity, such as the sale of electricity to an industrial electricity customer. Moreover, under the U.S. Constitution, the Federal Power Act overrides or "preempts" a state law like Maryland's but does not preempt a new *federal* law. In other

[19] The wholesale electricity market limit is mentioned in Beiter et al. (2023). The limitation on commercial sale of CfD instruments is noted in OIES (2024).

words, Congress can simply pass a new law that authorizes a federal CfD subsidy policy and amend the Federal Power Act to eliminate any conflict.[20]

Limitations on commercial financial instruments utilizing a CfD

The United States prohibits financial traders from selling financial mechanisms that utilize a CfD. Such mechanisms are permitted in a number of other countries and allow customers to bet on whether an underlying asset's value will rise or fall. Under such a mechanism, customers do not purchase the underlying asset, but they can still bet that the asset will either rise or fall in value; the broker pays the customer if the difference in asset value favors the customer and the customer pays the broker if it does not. Following the 2008 financial crisis, Congress determined that these instruments posed too much risk for most consumers, and, in Dodd−Frank, it prohibited them.

However, the prohibition on commercial, over-the-counter sales of CfD instruments does not affect the federal government's use of a CfD as part of a subsidy mechanism. First, the ban applies to contracts for difference mechanisms sold by commercial brokers to the general public, not subsidy arrangements offered by the federal government. Indeed, Section 3(c) of the Exchange Act, which was amended to limit retail sales of CfD instruments, provides that the Act does not apply to a federal government agency at all.[21] Second, Dodd−Frank regulates financial instruments sold to the general public, and the use of a CfD mechanism as part of a government subsidy offered only to industrial producers is not an "over-the-counter" sale of a financial instrument and is not offered to—and thus poses no risk to—consumers. Finally, as noted above, new federal law explicitly authorizing such a program would override Dodd−Frank even if it had created a limitation.

[20] Even if Congress did not explicitly amend the Federal Power Act, courts would seek to harmonize both statutes and, if an irreconcilable conflict existed, the more recently enacted statute would govern (see *Morton v. Mancari*, 417 U.S. 535, 550 (1974)).

[21] 15 U.S.C.A. § 78c(c): "No provision of this chapter shall apply to, or be deemed to include, any executive department or independent establishment of the United States."

Appendix 3. Discussion of CfD policy design details best established by statute

Below are some topics Congress should address in legislation authorizing a CfD program, as well as some areas where delegation may be appropriate.

- **Selection of industrial sectors.** Congress may wish to delegate the choice of sectors, but it should at least provide criteria to guide the implementing agency. For example, Congress might direct that the choice be made based on the sector's contribution to emissions, the potential emissions reductions achievable in the sector, and the potential beneficial technology spillover to other high-emitting sectors.
- **Level of emission reduction.** Congress should determine whether the program should support projects that achieve deep emission reductions—potentially requiring more expensive first-of-a-kind (FOAK) technology deployment—or is aiming for the lowest cost reductions, which may achieve a smaller degree of reduction and tend to rely on well-established technologies, or both.
- **Auction use and design.** Congress should specify the use of an auction or other competitive mechanism as this is a fundamental program element and distinguishes it from grant programs that use a more qualitative selection process. However, it is likely best that Congress delegate the establishment of the auction details so that agencies can fine-tune auctions to best meet the conditions of unique sectors and circumstances, which may change over time.
- **Minimum level of competition.** Congress should specify the cost minimization and price discovery objectives that a competitive auction process seeks to achieve and direct the administrator to ensure that the competition level is sufficient to achieve those objectives.
- **Performance requirements.** Congress should specify the minimum emissions verification requirements needed for production to qualify for payment or delegate this task to the implementing agency, with direction as to the level of quality assurance required. In addition to emissions verification, Congress should require that, in order to qualify for payment, the final product must also meet the materials performance specifications set during the competitive auction. Congress should also specify penalties for any knowing submission of false information.
- **Penalties for failure to deliver.** As described above, a successful competitive auction requires that successful bidders actually produce the product that meets all physical performance and life-cycle emissions specifications. Congress may therefore want to direct the agency to require production within a reasonable window and assess penalties for failure to produce the specified product in that window. Congress may also want to consider whether capital expenditures made in pursuit of an ultimately unsuccessful decarbonization effort may obviate the need for additional penalty.
- **Other liabilities unchanged.** Congress should specify that payment by the federal government under a CfD does not remove or alter any rights that a party may have under statute or common law with respect to the product, production process, or emissions created by the producer.
- **Cost containment.** Congress should consider setting an expenditure maximum or setting aside funds to cover potential cost increases.

- **Input indexing.** Congress should specify allowable indexing for inputs such as natural gas, hydrogen, and electricity.

Appendix 4. Price discovery and related contract specifications

The auction design for an industrial CfD program should include price discovery—that is, a good measure of the marginal value to the bidder of a unit of the auction item. Care should be taken with the price discovery interpretation of the auction price, because the contract won at auction has several elements of value to bidders. The point is not to procure tons of emission reductions or even tons of produced steel, but rather to procure, in return for a series of promised but contingent payments, a long-term contract to produce some amount of a commodity meeting a certain quality constraint (i.e., specific maximum carbon intensity). The CfD will specify a commodity market that sets the index price, a payment for each unit produced and sold, a specification of the emission intensity of production, and perhaps some type of schedule for delivery (all of which require verification from the government). The CfD will likely also contain provisions for how to handle nonperformance along specified performance criteria, including: (1) conditions under which there will be performance penalties, and what forms those will take; and (2) conditions under which nonperformance will be forgiven or options for correcting deficiencies *ex post*.

CfD program administrators may not know at the outset which CFD attributes will have the most influence over strike price bids. The risks that the producer must bear are embedded in the price, and these risks are determined by the specific terms of the CfD. While good price discovery is, in the abstract, a desirable property, how program administrators interpret the price depends on CfD characteristics, some of which have little connection to the cost of reducing a ton of GHG emissions.

Appendix 5. Consequential and attributional life-cycle assessment

There are two broad types of life-cycle assessment (LCA). The first, consequential LCA (CLCA), attempts to calculate the overall change of emissions due to an intervention. Thus, if a project demands more electricity, CLCA can calculate how that additional demand for electricity affects electric grid emissions, including any changes in the types of generation built. CLCA can also go further and examine the impacts of the change in natural gas consumption to fuel new electricity generation induced by the project, construction materials needed, and so on.

In contrast, attributional LCA (ALCA) focuses on taking the world of upstream emissions and allocating—or attributing—it to end uses. For example, emissions from electricity generation could be assigned to electricity consumers based on the average emissions rate of production. ALCA is often combined with a book-and-claim system to allow greater flexibility for consumers. In this type of system, the "attribute" of a product is separated from product delivery and sold as a distinct commodity. For example, when consumers purchase the attribute of clean energy (often called an "energy attribute certificate") along with electricity purchases from the grid, they are considered to have purchased "clean electricity," and none of the grid emissions are attributed to them for that electricity. In this way, the allocation of emissions from electricity generation are shifted around, even as it is impossible to attribute the delivery of electricity to any particular source on the grid.

Both CLCA and ALCA have been used in regulation. For example, the emissions calculation in the guidance for the Section 45V hydrogen PTC relies on energy attribute credits and is a form of ALCA. The emissions calculation to determine eligibility for the technology neutral tax credits for clean electricity, however, uses CLCA.

In a sense, CLCA is the correct approach for calculating life-cycle emissions, as there is no clear connection between the attribution in ALCA and actual changes in emissions. However, CLCA is fundamentally model driven and requires calculation of how the impacts of the intervention—for example, a project that receives a CfD—spread through the economy. So, it is impossible to objectively measure CLCA emissions, and the results often depend on the assumptions and parameters of any given model. ALCA represents an attribution of emissions rather than a calculation of change in emissions, so it has the advantage of relative administrative simplicity.[22] Even though it does not accurately quantify changes in emissions, the use of ALCA can still incentivize emissions reductions. To the extent that projects can change their purchasing patterns, either through purchasing cleaner goods or by trading of attributes in a book-and-claim system, ALCA will incentivize the purchase of clean goods over dirty goods, and that additional purchase of green goods can lead to emissions reductions.[23]

[22] However, the use of attribute credit trading led to considerable controversy in the guidance of the hydrogen production tax credit as groups lobbied for different definitions of the attributes to be used.

[23] In the electric sector, the production of clean electricity can often be cheaper than dirty electricity, leading to a supply of zero cost attribute credits. Much of the controversy over the use of ALCA for electricity emissions has been around modifying the attribute used to generate a positive price for the credit.

Appendix 6. Overview of similar policy mechanisms

Production and investment tax credits

Perhaps the best policy baselines for production tax credits (PTC) and investment tax credits (ITC) are the provisions that were modified and expanded in the Inflation Reduction Act (IRA). Tax credits incentivize new technologies by using the federal tax code to reduce a project owner's federal income tax liability. For the ITC, the project reduces its income taxes based on a percentage of the total capital investment. The PTC provides a credit based on the quantity of the covered commodity produced (such as a kilowatt-hour of electricity generated or a kilogram of clean hydrogen produced) (Crux 2024).[24] While the ITC provides a higher incentive to capital-intensive projects, the PTC incentivizes the maximum production of the green product, which may facilitate greater levels of decarbonization. The value of the tax credit is tied to legislation, rather than a market signal (such as the price of the end product, as with a CfD), which means they may be less adaptable to changing market conditions over the eligible timeline. That said, ITCs (which are based on a percentage of eligible investment) fluctuate with project capital costs; this does provide some inherent market adaptability, but only in the construction phase of a project. In many cases, tax credits can be open ended, so there is less certainty in outlay; in some cases, however, a cap can be specified—as with the IRA's 48C Advanced Energy Project Credit (U.S. Department of Energy n.d.).[25]

In both cases, eligibility under the IRA is typically determined by both the underlying technology and a benchmark for GHG intensity or emissions reductions (Bipartisan Policy Center 2022). Furthermore, some tax credits, such as the 45V hydrogen tax credit, have several tiers of credits (based on the emissions intensity of production) that determine the percentage of the full credit received. In applications such as the 45Y PTC and 48E ITC, the credits may be technology neutral (but still sector specific) and only require meeting an emissions intensity benchmark (Internal Revenue Service 2025c, 2025a). While the IRA's tax credits typically require an emissions assessment using models such as the greenhouse gases, regulated emissions, and energy use in technologies (GREET) model (Bipartisan Policy Center 2022),[26] program enforcement and accountability occur through IRS audits.

In the past, projects that were eligible for a tax credit but did not have sufficient tax liability needed a tax equity partner to monetize the credits. The IRA introduced direct pay and transferability for tax credits, which allows projects to directly receive cash in lieu of the credit in the case of direct pay or to transfer some or all of the credit to a third-party buyer in exchange for cash (Internal Revenue Service 2025e). Many tax credit programs also include additional incentives and bonuses for meeting environmental justice commitments (Internal Revenue Service 2025b), prevailing wage and apprenticeship provisions (Davis, Sykes, and Hannes 2025), and domestic manufacturing standards (Internal Revenue Service 2025d).

Green procurement

Government procurement programs can set standards for green products and create decision criteria that incorporate these standards to identify winning bids. While not often considered as a tool for stimulating major innovation, green procurement programs can drive early demand for low-emission materials for which governments are large purchasers; these materials include cement, concrete, and steel produced with existing and nearly ready technology (Gangotra et al. 2023b; Bergman et al. 2023). For instance, in the United States, the IRA provided $3.375 billion for GSA to invest in lower embodied carbon construction materials in federal buildings. (U.S. General Services Administration 2023). There are also several state green procurement programs—including in California, Washington, and Colorado.

Each of these initiatives includes a standard for the underlying emissions intensity to determine eligibility as a "clean" product. The Buy Clean Program defined clean in terms of existing carbon intensity of the "best" producers, but some solicitations defined best as the lowest 50th percentile in carbon intensity.

Bidders typically submit facility-specific and independent verification using environmental product declarations to certify their intensity, and the purchasing agency then compares those to its estimates of the distribution of carbon intensities across the market for that product. These producers are then eligible to bid for the procurement contract.

In some State Buy Clean programs, intensity standards are set and then revised to be more stringent over time. This allows producers that are currently eligible to make technological adjustments over time to reduce emissions intensity.

In general, the level of ambition of these standards can correlate with the technological readiness of the pathways that can meet those standards (Gangotra et al. 2023a). Stricter standards may map more closely to technologies that currently have lower readiness and require additional innovation to reach commercialization. As a result, green procurement initiatives are typically product and/or subproduct specific, but technology neutral for achieving the set standards.

To stimulate demand in the market, procurement programs must have a large enough procurement budget for the product. Additionally, the required share of the total budget needed to meet the green standard also must be adequately sized. For instance, while many procurement programs mandate that only a small share of total procurement be green, California's Buy Clean program requires that 100% of the state's purchased steel meet its green standards.

Tradable performance standards

Performance standards set a goal, such as a maximum amount of emissions for a unit of product in a given year, for all entities regulated under the standard. Performance standards are technology neutral, but the standard itself can motivate innovation, especially if it cannot be met by baseline or conventional technologies. Tradability is created when a producer can more than meet the standard and then sells its extra credits to another firm that does not meet the standard at a price below what it would cost that firm to meet the standard technologically.

Tradable performance standard (TPS) programs have been prominent in the U.S. transportation sector—including the nationwide Corporate Average Fuel Economy standard and California's zero-emissions vehicle standard (Yeh et al. 2021). In the electricity sector, many states have renewable portfolio standards that require states to obtain and deliver a certain percentage of renewable energy, and there have been proposals for nationwide clean energy standards in Congress. In the industrial sector, there are several cap-and-trade systems with output-based allocation, such as the California cap-and-trade and the EU ETS systems, which distribute emissions allowances to industries based on production levels (Fischer 2019). While related to a TPS, cap-and-trade programs differ by imposing a cap on total emissions and allowing trading of emissions allowances (in this case, based on output), whereas a TPS sets emissions intensity targets and allows trading based on relative performance against that target.

One representative TPS for the sector is the Canadian Output-Based Pricing System (OBPS), which covers large polluters in industrial sectors such as refining, cement, iron, and steel (Government of Canada 2018). In the OBPS, facilities are assigned an industry-specific emissions intensity benchmark (tons CO_2e per physical unit of output). Their annual compliance obligation is calculated by multiplying this benchmark by their production output. Facilities whose emissions fall below this obligation are rewarded with tradable compliance credits worth the difference; facilities that exceed this obligation must either surrender saved credits, purchase credits worth the difference, or pay a carbon fee to the government (the federally established carbon price of $80/ton in 2024) (International Carbon Action Partnership n.d.).

Environment and Climate Change Canada amended the initial proposal for OBPS to establish separate benchmarks for many subprocesses, including for the steel industry, which was separated by feedstock (e.g., scrap versus ore) and end product (e.g., cast versus rolled steel) (Environment and Climate Change Canada 2018). Covered facilities must monitor their emissions, production levels, and captured and stored emissions on an annual basis. Verification results and an annual report must then be submitted to Environment and Climate Change Canada and verified by an accredited third party (Environment and Climate Change Canada 2018).

Under OBPS, proceeds from the program are returned to provincial and territorial governments, which decide how to use them. In California's cap-and-trade system, program proceeds are deposited in the state's Greenhouse Gas Reduction Fund, which is appropriated to state agencies for programs to further reduce emissions. Additional laws have required that at least 25% of revenues are spent on programs benefiting disadvantaged communities and an additional 10% on programs for low-income households or communities (Center for Climate and Energy Solutions n.d.).

Advance market commitment

An advance market commitment (AMC) is a contract, typically offered by a sponsor such as the government or the private sector, to guarantee purchase of a new product or technology. AMCs are effective when the market cannot adequately incentivize the R&D and capital investments necessary for commercialization. Under an AMC contract, predefined technical specifications are laid out as targets for the developer. Additionally, the sponsors guarantee a price and maximum amount of product covered by the commitment if these targets are met. The sponsors may also provide a top-up payment if there is realized demand for the product, but only at a lower price. The guaranteed price ensures a return for the developer, who in exchange may agree on a long-run price cap for the product or on licensing the intellectual property to other producers (Kremer and Williams 2010).

AMCs have most commonly been used for vaccine development, where an AMC can guarantee that newly developed vaccines will be widely distributed to the broader population (Kremer, Levin, and Snyder 2020). For instance, during the COVID-19 pandemic, part of Operation Warp Speed offered contracts to producers such as Pfizer, which was promised $2 billion for 100 million doses (Kremer, Levin, and Snyder 2020). AMCs have not yet been widely used for the deployment of low-carbon technologies, but one example is Frontier, a privately administered AMC for carbon removal technologies. Nevertheless, rather than technical specifications pertaining to efficacy in the case of vaccines, a low-carbon AMC could instead use carbon reductions or low-carbon intensity as metrics for success. A key risk is that capital costs for low-carbon technologies may be significantly larger than for vaccine development (Gangotra et al. 2023a). Additionally, the sponsor (especially if it is a government entity), would need to specify how the product covered under the AMC would reach the end user. In the case of vaccine development, the government distributes doses to pharmacies and care facilities. However, there is less clarity on how to distribute commodities such as green steel.

A key benefit of an AMC is that the sponsor does not pick winning and losing technologies, only those that meet predetermined technical specifications. Additionally, setting the guaranteed price and quantity in advance gives certainty to sponsors' outlay, but the AMC must be appropriately sized to have an impact on investment decisions and the market.

AMCs for industrial commodities used in bulk for government projects (e.g., cement, concrete, and steel for infrastructure) may be particularly amenable to inclusion in green procurement programs (discussed above).

Carbon tax

A carbon tax sets a price per ton of GHGs emitted; under certain conditions, it produces identical efficiency outcomes to an ETS system, where price is variable but quantity is capped. The tax provides price certainty, as emitters know how much they will need to pay per ton of emissions. Unlike a TPS, a carbon tax alone does not set a target for emissions intensity (Hafstead 2019a). Many countries have a carbon tax (or a similar mechanism), but no economy-wide carbon tax exists in the United States. For the purposes of our comparison, we discuss design elements for a hypothetical national, economy-wide carbon tax.

A carbon tax allows for the most flexibility for covered entities to choose their decarbonization pathways. Because all covered entities are subject to the same price on emissions, the only requirement is to reduce those emissions regardless of the method or to pay the tax. Additionally, when the carbon price is equivalent to the marginal damage of emissions (the social cost of carbon), the mechanism can achieve the realized emissions reduction while maximizing welfare (Hafstead 2019a). Setting the appropriate price is a trade-off between lower emissions or higher costs. A carbon price that increases energy costs could have a greater impact on carbon-intensive industries or trade-exposed sectors, such as metals and chemicals. The overall effect depends on factors such as the carbon intensity of the producers and their ability to substitute for less carbon-intensive production processes (Aldy et al. 2012).

The administrative burden of a carbon tax depends in large part on the point of regulation. A more upstream tax could target refineries or other processing plants, while a downstream tax could target local distribution company or final consumers, such as large-scale emitting entities. A more upstream tax is commonly believed to be administratively simpler, since it applies to a smaller set of refiners and processors, while a downstream tax must cover a large set of emissions sources from transportation to power plants and industrial facilities. However, there are instances in which a downstream tax is more efficient, such as with natural gas where taxation at local distributors covers a higher share of natural gas at a lower administrative cost (Metcalf 2017).

Revenues generated from a carbon tax can be used in a number of ways. For example, they can be reinvested into further emissions reduction efforts, such as low-carbon technology development or adaptation and resilience. Other uses can alleviate some of the regressive distributional effects of the tax, especially for lower-income households who spend a larger share of income on energy. These can include a dividend that distributes revenues back to households or more general policies (Hafstead 2019b).

Appendix 7. Metrics and criteria for comparison of similar policies

As we noted in the report section, "Comparing CfDs to similar U.S. policy mechanisms," we selected three overarching criteria to compare similar policies to a CfD program: benefit to society, benefit for government, and benefit for the industrial sector. Here, we describe these criteria and their associated subcriteria.

Benefit to society

Implementing a CfD or other industrial policy would reduce emissions and their associated climate impacts. Carbon emissions have an impact across society, including on health, agriculture, and the economy. This criterion compares the effectiveness of our array of policies on maximizing and sustaining carbon emissions reductions and their associated benefits. We include several subcategories that compare not only the quantity of possible reductions, but also the speed of decarbonization and persistence of these benefits.

- **Sector emissions reductions:** The U.S. industrial sector is estimated to produce 29% of national energy-related CO_2 emissions in 2025, including emissions from electricity used by industry (EIA, AEO 2025). Policies can have varying degrees of impact on reducing these emissions.
- **Technological innovation:** Whereas the previous criterion focuses on emissions reduction potential at the sectoral level, this criterion focuses on deployment of novel technologies at the facility level. It also targets how the policy mechanism can advance progress toward commercialization of deep decarbonization technologies.
- **Equity and environmental co-benefits:** Policies may have the ability to induce co-benefits in addition to their primary objectives. Such co-benefits can include reductions in conventional air pollutants, improved health, and protection of ecosystems. This criterion also considers whether the mechanism gives the flexibility to accommodate environmental justice issues, such as benefits to workers, community, and domestic content requirements (Internal Revenue Service 2025d).

Benefit to government

Key considerations for the government concern the amount of government outlay and the cost effectiveness of that outlay. Given the sensitivity around federal spending, it is desirable to show that funding is being used efficiently to achieve the desired outcome. This includes not only the cost of the policy mechanism itself, but the associated administrative costs and the mechanism's ability to promote and advance other goals.

- **Government outlay:** This criterion includes both the amount of outlay necessary to implement the program, as well as the certainty of the outlay over the course of its intended lifetime.
- **Cost effectiveness:** This criterion emphasizes the outlay required per unit of GHG reduction to maximize the impact at the lowest possible cost to the government. It further focuses on minimizing the risk of picking winners, such as specific technologies or firms, which can narrow the potential pathways to emissions reductions and potentially reduce cost effectiveness. This criterion also includes the program's potential for price discovery—that is, the market price of the emissions reduction.

- **Administrative costs:** For each mechanism, there are costs associated with setting up the policy. This criterion also focuses on costs associated with regulation and enforcement to ensure that covered entities are operating within the boundaries of the mechanism.

Benefit to industry

Finally, we consider the effects on industry and whether the mechanisms for inducing emissions reductions will allow covered firms to continue to remain competitive as they innovate. We consider the mechanism's ability to reduce uncertainty and risk as producing firms and financial institutions invest in technological pathways. We also consider the need for the products to remain competitive with existing production pathways, as well as the need to reduce anti-competitive behavior.

- **Reduced uncertainty:** This criterion considers whether financing risks are reduced as firms conduct R&D and make investments in new technology pathways. Examples here include a firm's ability to get product offtake and financing or recoup their investment.
- **Price competitiveness:** Here, the focus is on whether the mechanism allows firms to remain competitive with existing products (both domestic and international). The goal is to ensure that a market exists for a new product without being inhibited by high costs or uncertainty.
- **Minimize anticompetitive behavior:** Depending on how consolidated an industry is, it is important to minimize the risk that only a few firms benefit from the mechanism, as well as to ensure that learnings from the policy diffuse across the industry.

Appendix 8. Summary of policy comparisons

Table 1. Comparison of benefits to society

Mechanism	Emissions reduction potential	Technological innovation	Equity and co-benefits
Contracts for difference (CfDs)	CfDs create a strong incentive for private capital investment by providing price stability. Their specific GHG impact depends on the amount of funding available, and whether they target FOAKs/NOAKs or more proven technologies with greater near-term GHG-reduction cost effectiveness.	They encourage innovation by simultaneously providing price stability and subsidization of the green premium; reducing risk and making innovative technologies economical in the market—and thereby improving the project's ability to attract capital.	The focus is primarily on GHG reductions, however non-price factors such as social equity goals (including environmental justice (EJ) and labor policy priorities) or environmental co-benefits (reductions in non-GHG pollutants, such as criteria air pollutants) can also be integrated into the auction process.
Tax subsidies (ITC and PTC)	Technology neutral credits can be applied to a broad array of technologies and drive at-scale emissions reductions.	Technology neutral credits can drive innovation for a broad group of technologies. Technology-specific credits may be less effective, as they may prioritize already commercialized technologies or pick winners.	Credits can include equity goals or co-benefits as an additional incentive or as a requirement. Many IRA tax credits include such bonuses.
Advanced market commitments (AMCs)	AMCs can drive the initial innovation by creating a market for the good, but further scaling and cost reductions may be limited without additional support.	Awards are contingent on achieving a technological innovation outlined in the contract.	Equity requirements or co-benefits can be included in the technical specifications of the contract.
Green procurement	A trade-off exists between technological readiness and size of the total purchase. Larger green purchase mandates typically set less ambitious benchmarks in the near term.	While purchases must meet a specified emissions benchmark, they do not necessarily need to fulfill an innovation step, especially if benchmarks for a clean product are less ambitious.	Existing programs typically focus on GHG benchmarks, but they could potentially include equity and/or co-benefits provisions (either requirements or bonuses).
Tradable performance standards (TPSs)	An emissions intensity mandate ensures that covered entities in aggregate meet a reduction intensity benchmark.	Covered entities can meet benchmarks through innovation, but that depends on the decarbonization options available and the stringency of the benchmark.	Benchmarks are almost always focused on GHGs. It would be difficult to incorporate other co-benefits. EJ and co-benefits could be addressed through distribution of proceeds.
Carbon tax	While no reduction is mandated, a high carbon price offers a strong incentive to shift from higher-cost, carbon-intensive activities, but risks leakage if not paired with a carbon border measure.	Covered entities are incentivized to reduce their emissions, but technological innovation depends on how high the tax is set. A low tax may incentivize only incremental emissions reductions.	The tax is focused on GHG metrics, but EJ and co-benefits could be addressed through distribution of proceeds, which can mitigate some of the regressive distributional effects.

Table 2. Comparison of benefits to government

Mechanism	Certainty and quantity of outlay	Cost effectiveness	Administrative requirements
Contracts for difference (CfDs)	A CfD requires significant but predictable outlay, but quantity of outlay is mitigated by reverse auction, which minimizes probability of oversubsidization.	Market price discovery through a competitive auction increases cost effectiveness. Two-sided CfDs are even more cost effective, as firms may be required to repay the administrator under certain conditions.	The number of contracts is typically limited, and auction setup is the main administrative requirement. The program may need to specify requirements for many subproduct types.
Tax subsidies (ITC and PTC)	Because they tend to be open-ended commitments available to all eligible projects (unless capped like 48C) and are also not tied to the market, tax credits can have relatively high and uncertain costs.	Credit amounts do not reflect market conditions, creating the risk of over- or undersubsidization. Cost effectiveness depends on whether they are technology neutral or eligible to only a narrow set of technologies.	Rulemaking can be a complex process, but enforcement is conducted via tax audits.
Advanced market commitments (AMCs)	A predictable upfront commitment incentivizes demand, but full costs can depend on the eventual price of the output in the market.	AMCs can be cost effective if they stimulate commercialization at scale, but there are risks if more investment is needed for the wider market.	Some costs are required to set up the mechanism, define the goals, and evaluate performance.
Green procurement	The contract bidding process can help lower costs, and firm upfront purchase commitment can help reduce outlay and provide some certainty.	While cost effective in reaching a targeted reduction, extension to the wider market is more uncertain.	The main requirements here include changes to purchasing guidelines, evaluation of emissions assessments, and compliance monitoring.
Tradable performance standards (TPSs)	Does not require direct funding, only outlay for reporting and enforcement as well as administration of the trading market.	Covered entities determine their own least-cost compliance with minimal government outlay.	Ongoing, annual monitoring is required, along with setup costs to create a registry and trading system. Products often need to be separated into subproducts with unique characteristics.
Carbon tax	Carbon taxes generate revenue rather than cost to the government; the outlay is almost entirely administrative.	A well-designed tax incentivizes economy-wide emissions reductions and does not pick winners.	Requirements here include ongoing, annual monitoring and reporting, and integration into the tax system.

Table 3. Comparison of benefits to industry

Mechanism	Reduces uncertainty	Price-competitive with existing product	Induces no anticompetitive behavior
Contracts for difference (CfDs)	CfDs fully guarantee the price and can protect the project (and its investors) against revenue fluctuations.	They guarantee a price for the product that is comparable to or the same as the market price, depending on implementation. On the other hand, the market price may also be above the strike price. In a two-sided CfD, the producer would pay the administrator this difference.	This mechanism may favor larger companies that can absorb upfront costs and concentrate benefits to those firms if there is not adequate knowledge sharing beyond the selected firms.
Tax subsidies (ITC and PTC)	These subsidies provide some certainty through a predictable incentive. However, the incentive does not adjust to market conditions or firm performance.	The subsidies lower the cost of the subsidized product but may not fully offset higher costs compared to the market, as the mechanism gives only a flat subsidy.	Tax subsidies may overly favor large firms that can absorb upfront costs. However, all firms in the market can be eligible for the credit.
Advanced market commitments (AMCs)	AMCs reduce investment risk by guaranteeing a market for the product. Some R&D investment risks remain, however, including the risk of failing to meet contract goals.	AMCs establish predictable demand for new clean products, but further mechanisms may be needed to make such products truly price-competitive outside of the AMC.	Only a few firms may be able to meet targets, leading to a market advantage. Long-run price caps or IP licenses can allow for wider learning.
Green procurement	This approach provides certainty over the course of the procurement contract but the risks of selling into the broader market are not mitigated.	Typically, this mechanism is not directly price competitive with the existing market; it depends heavily on the cost- and market-readiness of the product in the broader market.	Contracting terms can ensure a diverse set of suppliers rather than a concentration among top firms.
Tradable performance standards (TPSs)	A TPS provides a clear goal for firms and predictable decarbonization requirements. The trading mechanism gives firms greater flexibility, although large price fluctuations can occur. No financing or price support is provided.	There can be risks from firms outside the scope of the mechanism, such as foreign producers or smaller entities not covered by the standard.	Firms with more resources have a competitive advantage. Smaller firms may need to rely on the credit market to remain in compliance.
Carbon tax	A carbon tax provides a stable price signal for emissions and flexibility in determining decarbonization pathways. However, no additional support is provided and firms downstream of the tax may simply pass the costs directly to consumers.	This mechanism does not directly support price competitiveness, as the market as a whole determines the technology pathways. However, there can be risks from firms outside the scope of the mechanism (e.g., foreign producers).	This tax applies uniformly to all firms but both upstream and downstream implementations could penalize small firms that lack capital or scale.