RESOURCES
for the FUTURE

RFF Climate Policy Toolkit

Explainers, Experts, and Other Useful Climate Policy Information from Resources for the Future

Contents

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Social Cost of Carbon 101

A review of the social cost of carbon, from a basic definition to the history of its use in policy analysis.

Explainer by Kevin Rennert and Cora Kingdon — August 1, 2019

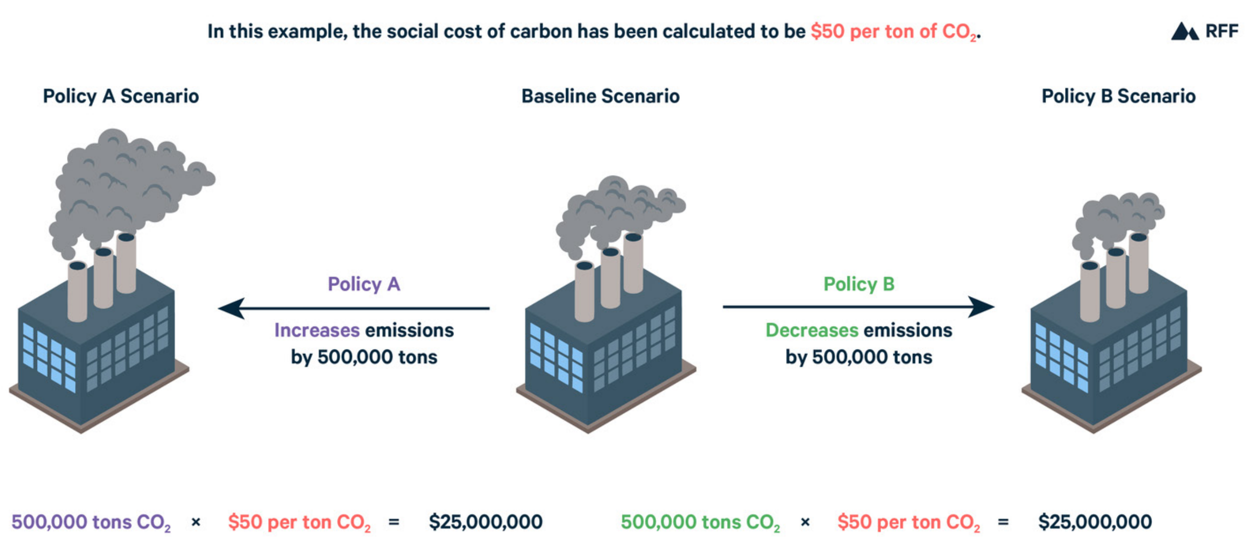
The **social cost of carbon** (SCC) is an estimate, in dollars, of the economic damages that would result from emitting one additional ton of greenhouse gases into the atmosphere. The SCC puts the effects of climate change into economic terms to help policymakers and other decisionmakers understand the economic impacts of decisions that would increase or decrease emissions. The SCC is currently used by local, state, and federal governments to inform billions of dollars of policy and investment decisions in the United States and abroad. This explainer reviews how the SCC is used in policy analysis, how it is calculated, and how it came to be.

How is the SCC Used in Policy Analysis?

One of the primary ways the SCC is used in policy design and evaluation is through benefit-cost analysis. A **benefit-cost analysis** compares the total economic benefits of a proposed policy to its total economic costs. Take, for example, a regulation that limits air pollution: its total benefits—including those from improvements to public health and the environment due to better air quality—would be compared against the implementation costs, such as the purchasing and installation of equipment to control air pollution. Benefit-cost analysis has been a **required part** of federal regulatory analysis since it was implemented by the Reagan administration in 1981.

The SCC is used in benefit-cost analysis to quantify the dollar-value of a policy's effect on climate change due to changes in greenhouse gas emissions. For policies that increase emissions, the expected increase in emissions (in tons) is multiplied by the SCC, and the result is included as part of the total estimated **costs** of the policy. For policies that decrease emissions, the change in emissions is multiplied by the SCC, and the result is added to the expected benefits of the policy.

Using the SCC to Calculate Costs and Benefits of Changing Emissions



How is the SCC Calculated?

Estimates of the SCC are calculated in four steps using specialized computer models.

- Step 1: Predict future emissions based on population, economic growth, and other factors.
- Step 2: Model future climate responses, such as temperature increase and sea level rise.
- Step 3: Assess the economic impact that these climatic changes will have on agriculture, health, energy use, and other aspects of the economy.
- Step 4: Convert future damages into their present-day value and add them up to determine total damages.
-

These four steps are completed to obtain a baseline value for the damages of emissions. Then, the modeling process is repeated with a small additional amount of emissions to see how much it changes the total cost of damages. The increase in damages from the additional emissions provides an estimate of the SCC. The model is then run hundreds of thousands of times to evaluate the uncertainty of the estimates.

Where Is the SCC Used Now?

The SCC is used across the entirety of the US federal government as part of required benefit-cost analysis of significant regulations and other actions (as described above). It is also used in **several states** and in a range of other decisionmaking contexts:

- In New York and Illinois, the SCC serves as the basis for the value of "zero-emission credits" paid to electric utilities under state clean energy legislation.
- In Colorado, Minnesota, and Washington, electric utilities are now required to use the federal SCC in their resource planning.
- In California, recent state legislation requires regulators to incorporate the SCC in policy analysis.
- The Canadian government has **adopted the estimation methodology**.
- The Mexican government is considering incorporating the SCC **into its policy analysis**.
- Several proposals for a federal carbon tax introduced by members of Congress suggest a starting tax level equal to the 2016 central case SCC.

SCC Calculation Considerations

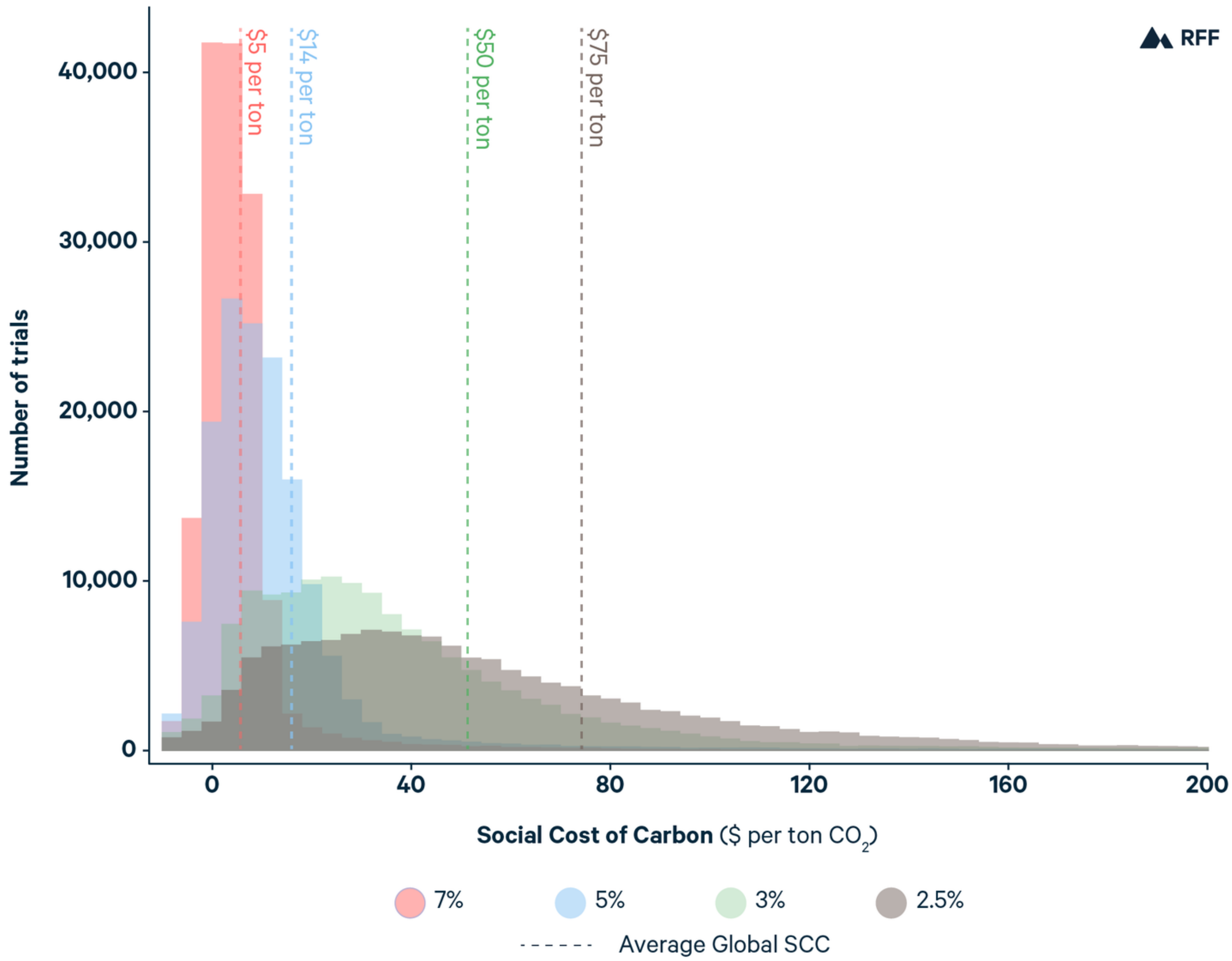
There are many modeling choices that affect the value of the SCC. The models are based on research and expertise from many different fields, such as climate science, demography, and economics. While these disciplines inform the scientific and research-based modeling decisions that are necessary for calculating the SCC, some parts of the calculation also require researchers to make assumptions that contain value judgements. Additionally, the modeling must incorporate information that is inherently uncertain, such as projections of future economic growth.

Discount Rate

The **discount rate** used in estimating the SCC incorporates both empirical evidence and value judgements. In Step 4 of the SCC modeling process described above, future damages are converted into present-day value by using a discount rate to determine how much weight is placed on impacts that occur in the future. Future costs and benefits are generally considered less significant than present costs and benefits, and the discount rate reflects this level of relative significance. A high discount rate means that future effects are considered much less significant than present effects, whereas a low discount rate means that they are closer to equally significant. The effects of different discount rates on estimates of the SCC

Discount Rate	Global SCC ($ per ton CO_2)	Domestic (US) SCC ($ per ton CO_2)
2.5%	75	10
3%	50	7
5%	14	2
7%	5	1

The Range of Values of the SCC



can be seen in the table below. (Estimates of the SCC in 2020 published in the Affordable Clean Energy Rule Regulatory Impact Analysis. Units are 2019$ per ton of CO_2)

Global vs. Domestic

Another assumption made in SCC modeling is the geographic scope of the calculation; how SCC estimates with different geographic scopes are used in decisions also reflects value and policy judgements. In Step 3 of the SCC modeling process, the economic impacts can be calculated based on global damages (the total effects of emissions felt all around the world) or they can be limited to domestic damages (e.g., those felt within the United States). This choice significantly affects the outcome of SCC estimation, as shown in the table above.

Uncertainty

In calculating the SCC, it is necessary to make some assumptions that introduce uncertainty. For example, there is a range of plausible values for certain inputs to the SCC models, such as future economic growth rates and the magnitude of climate system responses. In order to account for this uncertainty, the models are run hundreds of thousands of times with different values for the uncertain variables and parameters. Given the range of uncertainty involved in this calculation, the SCC is best represented not as a single number, but as a range of possible values. For practical applications, however, a **central case value** is chosen, which is usually the average of all of the estimates for a given discount rate. Government analyses have also previously reported a "high impact scenario" in order to represent an upper-end indication of uncertainty in the estimates.

Policy Evolution of the SCC

While benefit-cost analyses have been required to assess the implications of economically significant regulations since the Reagan administration, the effects of greenhouse gases on climate change were not considered in these analyses until more recently. In 2008, the Center for Biological Diversity (CBD) **took the US government to court** over new fuel economy standards, arguing that by not accounting for future costs from climate change, policymakers had implicitly valued the costs of damages from climate change to be zero. The courts ruled in favor of the CBD, setting the legal requirement for the US government Revenue Use to account for the costs and benefits of changes in greenhouse gas emissions in its economic analysis. The federal government employs the SCC to satisfy this requirement.

In the federal government's initial implementation of the SCC, government agencies and departments each developed and applied their own estimates. During the Obama administration, the Office of Management and Budget convened an Interagency Working Group on the Social Cost of Carbon (IWG) to develop a harmonized set of estimates to be applied consistently across the federal government. The group consolidated multiple models drawn from the academic literature and ran them over a range of standardized input scenarios in order to arrive at the federal government's estimates of the SCC. In 2016, the IWG turned to the National Academy of Science (NAS) for guidance on how best to improve, refine, and update their modeling process. In 2017, NAS published a **comprehensive report** laying out ongoing research priorities to ensure the SCC remains grounded in the best available science. The report's findings helped inform the development of Resources for the Future's **Social Cost of Carbon initiative**, which is stewarding a global team of distinguished scientists and economists working to advance the NAS's recommendations.

In 2017, President Trump signed **Executive Order 13783** which, among other actions, disbanded the Interagency Working Group on the Social Cost of Carbon and stated that the estimates generated by the Interagency Working Group were not representative of government policy. This executive order removed the requirement for individual government agencies to employ a harmonized set of SCC estimates in their regulatory analyses. In practice, rules proposed by a number of agencies after the issuance of Executive Order 13783 have relied on a set of interim estimates based on the same methodology and infrastructure as used by the Interagency Working Group, but with two modifications: calculating only damages occurring within the United States and employing discount rates of 3 percent and 7 percent for use in the primary analysis of regulations. Interagency Working Group estimates had previously reported global damage numbers and had employed discount rates of 2.5 percent, 3 percent, and 5 percent. These changes significantly alter SCC estimates, as depicted in the table of values above. For instance, the SCC for domestic economic impacts at a 7 percent discount rate would be $2.20 in the year 2050, while the SCC for global economic impacts at a 2.5 percent discount rate would be $100.62. These changes reflect both conceptual economic and policy judgements and have prompted substantial discussion. For example, RFF researchers have written **blogs** and **public comments** on the topic.

Resources for the Future (RFF) is an independent, nonprofit research institution in Washington, DC. Its mission is to improve environmental, energy, and natural resource decisions through impartial economic research and policy engagement.

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Carbon Pricing 101

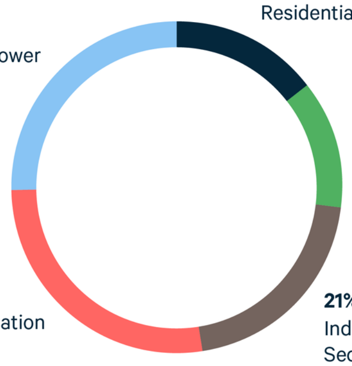
An introduction to carbon pricing, including carbon taxes and cap-and-trade programs, the benefits and design of pricing policies, and applications around the globe.

Explainer by Marc Hafstead — March 5, 2019

What Is Carbon Pricing?

Carbon pricing is a climate policy approach used in a number of countries and subnational jurisdictions (regions, states, provinces, cities) around the world. Carbon pricing works by charging emitters for the tons of emissions of carbon dioxide (CO_2) for which they are responsible. CO_2 is emitted largely through the combustion of fossil fuels used for electricity generation, industrial production, transportation, and use of energy in residential and commercial buildings.

2018 United States Carbon Dioxide Emissions from Energy Consumption by Sector



Data source: US Energy Information Administration, May 2019 Monthly Energy Review

Comparing Carbon Taxes and Cap-And-Trade Programs

Carbon pricing policies traditionally take two forms: carbon taxes and cap-and-trade programs.

A **carbon tax** is a price set per ton of carbon or, more commonly, per ton of CO_2 emitted. Because CO_2 emissions from the combustion of fossil fuels are proportional to the carbon content of the fuel, a carbon tax is, in effect, a tax on CO_2. A \$1 tax per ton of CO_2 is equal to a \$3.7 tax per ton of carbon, because carbon constitutes roughly 3/11 of the weight of CO_2.

A **cap-and-trade** program limits the total amount of CO_2 that can be emitted by certain facilities. In a cap-and-trade program, the government issues a limited number of **emissions allowances** (also known as permits), each of which grants the holder the right to emit one ton of CO_2. Allowances can be distributed in a number of ways: they can be directly allocated to firms or facilities (a concept called **free allocation of allowances**) or sold through auction markets. The limited, government-controlled supply of allowances "caps" the total amount of emissions. Allowances can be traded, and the sales and purchases (supply and demand) of allowances yield a **market price** for allowances—essentially the price of one ton of CO_2 emissions.

Some cap-and-trade programs include provisions for the **banking and borrowing** of allowances over time: permits issued in one year can be submitted to account for emissions in later years (banking), and permits for future years can be issued and used in the current year (borrowing). When banking and borrowing take place, emissions during a specific year may be greater or less than the number of allowances issued in that year, but over time, the emissions and allowances are balanced. Banking and borrowing gives firms more flexibility in methods of compliance and reduce the costs of meeting a cumulative emissions target.

Carbon taxes and cap-and-trade programs primarily differ by the type of certainty they provide. Carbon taxes provide **price certainty**, as entities subject to the tax know how much they'll have to pay per ton emitted—but simply setting a tax rate doesn't guarantee any particular level of emissions reductions. Cap-and-trade programs, on the other hand, set a cap on emissions and therefore provide **quantity certainty**—but price fluctuations under the trading market structure can provide a less solid basis for business planning decisions. Hybrid systems, however, can be used to reduce price or emissions uncertainty. Under cap-and-trade programs, price floors and ceilings have been **proposed** and **utilized** to prevent prices from being "too low" or "too high." Carbon taxes can also be **designed** to automatically adjust if actual emissions miss some predetermined emissions path.

Benefits of Carbon Pricing

Carbon pricing policies—carbon taxes and cap-and-trade programs alike—have several attributes that make them generally more efficient, or less costly, than other potential policies to reduce carbon dioxide emissions (such as technology mandates, direct regulations, subsidies to zero-carbon energy sources, and others). A few of these key attributes are discussed below.

Flexibility

Carbon pricing allows firms to choose the most efficient method to reduce (or not to reduce) emissions in response to the carbon price. Under other policies, such as technology mandates, a regulator chooses a single method for a wide set of firms. Such one-size-fits-all approaches may lead to unnecessarily costly reductions for some firms if cheaper methods to reduce emissions exist.

Equal Marginal Costs of Abatement

An economy-wide carbon price applies a uniform price on CO_2 emissions regardless of the source. As a result, the **marginal abatement costs (the costs to firms of decreasing their emissions by one unit)** are equalized across firms and sectors. This is a necessary condition for minimizing the overall costs of emissions reductions. Regulations often imply different marginal abatement costs across firms and sectors: if one sector has a regulation with very high marginal abatement costs, it may be more cost-effective to remove that regulation and impose more stringent regulations in sectors with lower abatement costs. In practice, it would be very difficult for regulators to accomplish this, but it is an inherent quality of carbon pricing.

Encouraging Conservation

A carbon price encourages individuals and businesses to reduce their carbon emissions more than conventional regulations. A conventional regulation (such as a performance standard) sets a strict limit on emissions per unit of output, but does not provide incentives to reduce overall demand. In contrast, carbon pricing provides incentives to reduce emissions per unit of output, but also charges a price for every additional ton of CO_2 that is not reduced through increased efficiency. Therefore, the price of carbon-intensive goods (i.e., electricity or gasoline) will likely be higher under a carbon price than under conventional regulations, which encourages individuals and businesses to reduce their demand (to the extent possible). Thus, a carbon price encourages more conservation than conventional regulations.

Revenue

A carbon price creates a new revenue stream that can be used in a number of ways. Revenue use can significantly affect the economic costs and political feasibility of a carbon pricing policy. This is discussed in more depth below.

The price of carbon-intensive goods, such as gasoline, will likely be higher under a carbon price than under conventional regulations, encouraging more conservation. Photo: k_samurkas/Shutterstock

Options for Carbon Pricing Design

Beyond the choice between a tax and a cap, there are many policy options for how a carbon price would be applied in the economy, all of which have different impacts on overall cost, emissions reductions, revenues raised, and so on.

Price

According to economic theory, emissions pricing produces the highest net benefits (environmental, health, and other benefits minus economic costs) when the carbon price is equal to the **marginal damage** of carbon emissions, or the damage caused by adding one additional ton of carbon dioxide into the atmosphere. This would be accomplished either by setting the carbon tax equal to the marginal damage or, under a cap-and-trade program, by capping emissions at a level that leads to an emissions allowance price equal to the marginal damage. This marginal damage is often called the social cost of carbon (SCC).

Stringency

Policy **stringency** is determined by the level of the tax rate (under a carbon tax) or the level of the emissions cap (under cap and trade) and how they change over time. A $50 carbon tax is more stringent than a $10 carbon tax: it will lead to lower emissions and higher costs. In determining stringency, policymakers face a tradeoff between environmental goals and the costs of meeting those goals. In the United States, policy stringency is often framed relative to international agreements or temperature goals: policy A will meet the 2025 Paris targets or policy B will limit warming to 2 degrees.

Coverage

The **coverage** of a carbon pricing policy determines which sectors of the economy and which emission types are covered by the carbon price. For example, the European Union Emissions Trading System cap-and-trade program covers CO_2, nitrous oxide (N_2O), and perfluorocarbons (PFCs) emitted by 11,000 energy-intensive plants in the electric power and manufacturing sectors across 31 European countries. Overall, the policy covers **about 45 percent** of the EU's greenhouse gases. In comparison, British Columbia's carbon tax applies to the purchase and use of fossil fuels regardless of end-use sector, covering **about 70 percent** of provincial greenhouse gas emissions.

Negative Externalities

When private decision makers cause harm to an unrelated third party, that harm is called a negative externality. For example, if a power plant generates electricity and sells it to its customers, the pollution it emits in the process may affect the health of neighboring communities. The health effects of this pollution would be a negative externality of the power plant's electricity generation and sale.

Arthur Pigou's seminal 1920 book, ***The Economics of Welfare***, introduced the idea of taxing negative externalities. In his book, Pigou showed that taxing a negative externality at a price equal to the marginal damage internalizes the externality and maximizes overall welfare.

Point of Regulation

The **point of regulation** of a carbon price determines exactly who is required to submit permits or pay the tax to the government. An **upstream** carbon tax would tax fossil fuel producers for the carbon content (and hence ultimate CO_2 emissions) of their products. A **midstream** tax would tax the first purchaser of fossil fuels in the supply chain. For example, a midstream tax would require a refinery to pay for the carbon content of all the crude oil it purchases. A **downstream** tax applies to the emitter: for example, coal-fired generators, industrial users, or households and businesses that use gasoline in their vehicles or natural gas in their homes and businesses. The administrative cost of a carbon price can vary widely by the point of regulation, but ultimately a carbon price is passed on to consumers regardless of the point of regulation. To learn more about the economics of the point of regulation, see **this report** by economist Gilbert Metcalf.

Revenue Use

With the exception of cap-and-trade programs that freely allocate allowances to firms, carbon pricing policies raise **revenue**. Both the overall economic costs and the distribution of those costs across segments of society are significantly determined by how the revenues are used. In this explainer, we take an in-depth look at the question of what to do with the revenues.

Other

Carbon pricing policies may include other design elements aimed at **mitigating cost uncertainty under a cap-and-trade program** or **emissions uncertainty under a carbon tax**, or reducing potential competitiveness issues under **cap-and-trade programs** or **carbon taxes**.

Carbon Pricing Programs around the Globe

As of March 2019, the World Bank's **Carbon Pricing Dashboard** highlights 52 carbon pricing initiatives implemented or scheduled for implementation, with 46 national jurisdictions and 24 subnational jurisdictions covered by those initiatives. In 2018, these initiatives would cover 11 gigatons of CO_2 equivalent, representing 20% of global greenhouse gas emissions.

At the moment, the majority of global carbon prices take the form of cap-and-trade programs, the largest of which can be found in the European Union and the state of California. Carbon taxes are growing in popularity, however, and are now in place in the United Kingdom, several Canadian provinces, Sweden, and more.

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Carbon Pricing 102: Revenue Use Options

An overview of how different carbon pricing policies generate revenue, the options for revenue use, and the implications of each option.

Explainer by Marc Hafstead — September 26, 2019

Carbon Pricing Revenue

Carbon pricing revenue consists of the funds generated by **carbon pricing policies** (carbon taxes and cap-and-trade programs). Carbon pricing policies are implemented to limit the amount of carbon dioxide (CO2) emitted into the atmosphere. The socioeconomic effects of a carbon pricing policy vary substantially depending on how the revenue from the policy is used. As such, revenue use is a significant aspect of policy design. This explainer will outline how different carbon pricing policies generate revenue, the options for revenue use, and the implications of each option.

Overview

There are two types of carbon pricing policies: carbon taxes and cap-and-trade programs. The way revenue is generated and the amount of revenue generated depend on the type of policy.

A carbon tax is a price set per ton of carbon or, more commonly, per ton of CO_2 emitted. The amount of revenue generated is determined by the fixed price per ton of emissions and how responsive demand for fossil fuels is to the price: revenue generation will be higher if demand for fossil fuels that emit CO_2 are not very responsive to the tax.

A cap-and-trade program limits the total amount of CO_2 that can be emitted by covered entities. (See the **Carbon Pricing 101** explainer for more details on cap-and-trade programs.) Covered entities are required to submit allowances equal to their emissions each year; the total number of allowances determines the cap on emissions. How allowances are allocated determines the amount of revenue generated by the policy; free allocation of allowances to firms generates zero revenue for the government whereas auctioning generates similar revenues as a carbon tax. For cap-and-trade programs with auctions, the amount of revenue generated is determined by the price of the allowances sold and the number of allowances sold each year.

There are several options for revenue use, and these options can be used individually or in a hybrid combination with other options. The options—and the ways they affect a policy's overall impacts—are described below.

Progressive Policy vs. Regressive Policy

Many public policies affect households differently; these differences are described as the **distributional effects** of a policy. When considering the distributional effects on households with different levels of income, policies are often described as **progressive**, **proportional**, or **regressive**. A policy is progressive if the costs constitute a larger proportion of income for high-income households than for low-income households and regressive if the costs constitute a larger proportion of income for low-income households than for high-income households. It is proportional if the policy's costs constitute the same proportion of income for households with different income levels.

Carbon Dividends

A carbon dividend distributes the revenue from a carbon price back to households, typically in the form of a check, a tax credit (annually or through adjustments to employer tax withholding), supplements to existing payments from federally administered benefit programs like Social Security, or through payments using the electronic benefit transfer system (used to deliver food stamp benefits). In its simplest form, a carbon dividend would divide the amount of revenue generated by a carbon price over the course of a year evenly among all households. However, a carbon dividend does not need to be divided in equal amounts (it can be divided based on one's income, tax returns, or other factors), and the details of a carbon dividend vary among policies. A carbon dividend has been used to redistribute revenues in a number of climate policy proposals, including the **Energy Innovation and Carbon Dividend Act**, **the Healthy Climate and Family Security Act**, **the Climate Action Rebate Act**, and **Climate Leadership Council's Carbon Dividend Plan**.

Carbon dividends are an especially progressive, or equitable, use of the revenue, as the dollar amount of a carbon dividend **will likely** exceed the increased costs incurred by the average low- and middle-income household. A study by the **US Treasury** predicted that approximately 70 percent of households would be better off with an equal per capita dividend.

Tax Swaps

A tax swap uses the revenue from a carbon price to reduce taxes deemed "distortionary"—taxes that can result in a decrease of economic output, because they tax labor or capital. **Distortionary taxes** may unintentionally encourage individuals to work fewer hours by taxing their income (labor), or they may encourage businesses to produce less output by taxing the equipment they use to create products (capital). These types of taxes can include payroll, individual income, or corporate income taxes.

The costs of distortionary taxes can be partially (or even fully) offset if the revenue generated from these taxes can be "swapped" with the revenue generated from a carbon price. This swap can allow distortionary taxes to be reduced, which can produce economic gains. For example, **Chen and Hafstead** estimate that a carbon tax of $43.40 (in 2019 dollars) would decrease real GDP by 0.59 percent in 2025. However, if the revenues are used to reduce distortionary taxes, then GDP loss **could be lowered to as little as 0.35 percent**. So, a tax swap can reduce the economic costs of a carbon price by reducing other economic distortions.

These economic effects from a tax swap are called the **revenue-recycling effect**, and the size of the effect depends on which particular tax is reduced. If revenues are not used to reduce preexisting tax rates, or if revenues are used to finance new spending, then there is no beneficial revenue-recycling effect.

Green Spending

Carbon pricing revenue can be used to finance "green spending" programs aimed at reducing emissions through non-pricing methods. For example, it can be used to subsidize electric vehicles or clean energy generation, fund **weatherization programs**, invest in energy efficiency improvements, and more. Using the revenue for green spending may not be as beneficial as one might think, however. First, most evidence suggests that green spending programs would increase total carbon pricing policy costs and exacerbate distributional issues (making the policy more regressive). For example, **Borenstein and Davis (2016)** find that US tax credits for clean energy investments have gone disproportionately to higher-income households. Second, there is increasing **evidence** that green spending programs may deliver smaller environmental benefits than projected. Further, the foregone use of revenues to either increase economic efficiency (through tax swaps) or address distributional issues (carbon dividends) is an additional cost of green spending.

General Spending

Apart from spending specifically intended to reduce emissions, carbon pricing revenue can also be spent in other ways. Policymakers could choose to spend the revenue on programs aimed to make the overall policy effects more progressive; for example, universal healthcare, student debt relief, and free college are spending programs that would benefit lower-income groups more than higher-income groups. Policymakers also may choose to spend revenue in other ways, unrelated to the environment or progressive policies; for example, spending on infrastructure improvements. General spending may make the policy more or less regressive, depending on how the money is spent. Again, using all of the carbon revenues on general spending eliminates the opportunity to use the revenues to increase efficiency or address distributional issues.

Deficit Reduction

The **federal deficit** is the amount of money the federal government has spent above and beyond the revenue generated within a given time period. For example, if the federal government generates $3 trillion in revenue in one year and spends a total of $4 trillion that year, the deficit would be $1 trillion. Policymakers may decide to use carbon pricing revenue to decrease the deficit and reduce future interest payments on that debt.

Why Revenue Use Matters

As discussed above, there is an inherent equity-efficiency trade-off when it comes to revenue use. In terms of dividends versus tax swaps, dividends make the policy more progressive and more expensive, and tax cuts make the policy less progressive and less expensive. This trade-off between equity and efficiency requires policymakers to strike a balance between competing goals. And there may be a further trade-off between equity, efficiency, and political popularity: green spending, perhaps more regressive and more expensive than dividends or tax swaps, **polls well** among the general public.

Economics aside, the political feasibility of a carbon price may ultimately depend on whether or not the revenue use addresses the concerns of key stakeholders.

In The Weeds: Is Carbon Pricing Progressive?

A **common argument** against carbon pricing is that a price on carbon is regressive because, compared to high-income households, low-income households spend a larger share of their incomes on carbon-intensive goods, such as electricity and motor vehicle fuels (source: **consumer expenditure survey**). However, **recent research** has shown that the impact of carbon pricing on household income is actually progressive and that the overall impact of carbon pricing, in the absence of revenue use, is progressive as well. Two mechanisms drive this result. First, low-income households receive a greater share of their income from government transfer payments. Because most of these payments (such as Social Security benefits) are linked to inflation, any policy-induced increase in the price of carbon-intensive goods is accompanied by higher transfer payments, which directly offsets higher energy costs for households that receive these payments. Second, carbon-intensive industries are also capital-intensive industries, and capital income—received primarily by richer households—is more adversely affected by carbon pricing than labor income.

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Comparing Carbon Pricing Proposals in the 116th Congress

Source: "The Year of the Carbon Pricing Proposal" by Marc Hafstead, August 2019

Bill (Sponsor and Cosponsors)	**Energy Innovation and Carbon Dividend Act** (Ted Deutch and 58 cosponsors)	**American Opportunity Carbon Fee Act** (Sheldon Whitehouse, Brian Schatz, Martin Heinrich, Kirsten Gillibrand)	**Stemming Warming and Augmenting Pay Act** (Francis Rooney, Dan Lipinski)	**Climate Action Rebate Act** (Chris Coons)	**Raise Wages, Cut Carbon Act** (Dan Lipinski, Francis Rooney)	**America Wins Act** (John Larson)
Initial Tax Rate (per metric ton)	$15	$52	$30 ($2021)	$15	$44	$52
Annual Adjustments	$10 + inflation	6% + inflation	5% + inflation	$15 + inflation	2.5% + inflation	6% + inflation
Starting Year	2020	2020	2021	2020	2020	2020
Revenue Use	Taxable Carbon Dividends	Tax Credits, Social Security Beneficiary Payments, State Block Grants ($10 billion)	**70%:** Payroll Tax Cuts **10%:** Social Security Beneficiary Payments **10%:** Block Grants for Low-Income Assistance **10%:** Adaptation, energy efficiency and advanced research and development	**70%:** Taxable Carbon Dividends to single filers (income <$100k, phase out from $80k to $100k), joint filers (income <$150k, phase out from $130k to $150k) **20%:** Infrastructure **5%:** Research and Development **5%:** Transitional Assistance	**94%:** Payroll Tax Cuts and Increases to Social Security Benefits **5%:** Low-Income Home Energy **1%:** Weatherization Assistance	**54%:** Infrastructure Spending **43%:** Consumer Tax Refunds to Low-Income Households **3%:** Transitional Assistance
Automatic Adjustment Mechanism	Yes: Additional $5 price increase	No	Yes: Additional $3 price increase every other year	Yes: Additional $15 price increase	No	No
Covered Gases	All Greenhouse Gases	All Greenhouse Gases	All Greenhouse Gases	All Greenhouse Gases	Energy-Related Carbon Dioxide Emissions	Energy-Related Carbon Dioxide Emissions
Exemptions	Farms, Armed Forces	None	Ozone-depleting substances (if Kigali Amendment has been ratified)	None	None	None
Fluorinated GHG Fee	10%	10% to 100% (10% adjustment from 2022 to 2031)	100%	20%	10%	N/A
CCS Refunds	Yes	Yes	Yes	Yes (with restrictions)	Yes	Yes
Border Adjustments	Emissions-Intensive and Trade Exposed; i.e., Iron, Steel, Steel Mill Products, Aluminum, Cement, Glass, Pulp, Paper, Chemicals, Industrial Ceramics	Energy-Intensive Manufactured Goods; Energy costs greater than 5% of total cost	All Manufacturing Sectors (and metal ore, soda ash, and phosphate processors) with 5%+ GHG intensity and 15%+ trade intensity	Emissions-Intensive and Trade Exposed; i.e., Iron, Steel, Steel Mill Products, Aluminum, Cement, Glass, Pulp, Paper, Chemicals, Industrial Ceramics	Rebates/credits for fossil fuel exports; taxes applied to "imported taxable products"	Rebates/credits for fossil fuel exports; carbon equivalency fee applied to imports of "carbon-intensive goods"
Regulatory Action	Suspends GHG related	Not specified	Moratorium on most GHG	Not specified	Suspends GHG related	Not specified
State Law Preemption	No	Not specified	No, but declining credits for carbon price payments to states	No	Not specified	Not specified

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Electrification 101

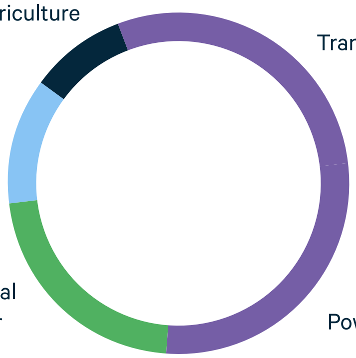
An overview of how electrification can reduce emissions, from the feasibility of electrifying different technologies to the policy options for encouraging economy-wide electrification.

Explainer by Kathryne Cleary — December 5, 2019

What is Electrification?

Electrification refers to the process of replacing technologies that use fossil fuels (coal, oil, and natural gas) with technologies that use electricity as a source of energy. Depending on the resources used to generate electricity, electrification can potentially reduce carbon dioxide (CO_2) emissions from the transportation, building, and industrial sectors, which account for **63 percent** of all US greenhouse gas emissions. Addressing emissions from these sectors is critical to decarbonizing the economy and, ultimately, mitigating the impacts of climate change. This explainer reviews how electrification can reduce emissions; possibilities and potential challenges of electrification in the transportation, building, and industrial sectors; and policy options for encouraging electrification.

2017 US GREENHOUSE GAS EMISSIONS BY SECTOR



Data from EPA "Inventory of US Greenhouse Gas Emissions and Sinks" (2017)

How Can Electrification Reduce Emissions?

In the United States, over **70 percent** of electricity is currently generated using zero- or low-carbon fuels (36 percent is from nuclear energy and renewables, and 35 percent is from natural gas, which emits the **least carbon dioxide** of any fossil fuel when burned). Consequently, technologies that use electricity as a fuel source result in lower carbon dioxide emissions on average than those that use fossil fuels directly. Additionally, the electricity grid is expected to become even cleaner over time as many state policies (such as **Renewable Portfolio Standards**) aim to increase the amount of electricity generated by renewable sources. Thus, the benefits associated with electrification will likely grow in the future as electricity generation becomes less carbon-intensive.

If policymakers seek to decarbonize the transportation, building, and industrial sectors, replacing fossil fuels with electricity may also be one of the only technologically viable options. Several methods are available for decarbonizing the electricity sector, but other sectors have far fewer options available for significantly reducing emissions (read about different options for reducing emissions in each sector **here**). For example, many alternative transportation fuels (such as biodiesel and ethanol) are cleaner than gasoline, but they still emit carbon dioxide and other conventional air pollutants when burned. **Hydrogen**, another alternative fuel, does not produce emissions but is very expensive and requires electricity to make. Transitioning from fossil-fuel technologies to electric technologies in non-power sectors would allow policymakers to focus on decarbonizing the electrical grid—a task that may be far more feasible than attempting to decarbonize each sector separately.

Notably, the benefits of electrification today vary depending on the resources used to generate electricity. Within the United States, emissions from electricity generation vary significantly. Some areas have a higher proportion of zero-carbon resources in their electricity generation portfolios and are much cleaner than regions that rely more on fossil fuels like coal. For example, the state of **Washington** relies on hydropower for a majority of electricity generation and stands to benefit greatly from electrification. **Wyoming**, on the other hand, has a resource mix comprised almost entirely of coal with a small amount of renewables and natural gas. Consequently, the benefits from electrification in Wyoming today could be negligible, or even negative for some technologies if generating the electricity to run them creates more emissions than using fossil fuel technologies would. However, these benefits could change in the future as the grid resource mix evolves.

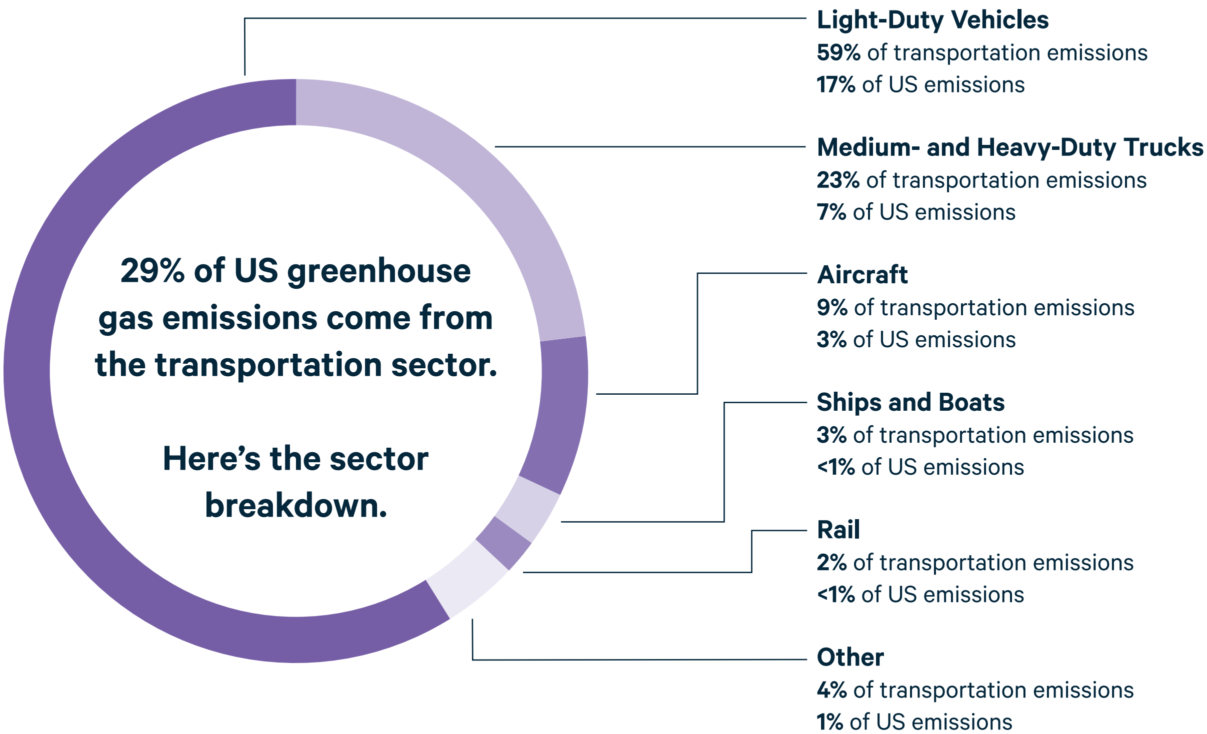
Potential for electrification varies greatly across and within sectors. While some sectors already have commercially-ready technologies, others do not and could struggle both technologically and economically to electrify.

Electrification of the Transportation Sector

Overview

The transportation sector accounts for 29 percent of US greenhouse gas **emissions** (2017 data). Within the sector, nearly 60 percent of **emissions** come from light-duty vehicles, 23 percent from medium- and heavy-duty vehicles, and the remaining 18 percent from aircraft, ships, rail, and other sources. Given the limited electrification potential of aircraft and ships, and the small share of rail in the sector, this section will focus exclusively on electrification of light-, medium-, and heavy-duty vehicles.

2017 US Greenhouse Gas Emissions
TRANSPORTATION SECTOR



Data from EPA "Inventory of US Greenhouse Gas Emissions and Sinks" (2017)

Benefits of Electrification

Most light-duty vehicles (like cars, SUVs, and small trucks) run on gasoline while heavy-duty vehicles (like buses or large trucks) typically run on diesel fuel. The Corporate Average Fuel Economy (CAFE) **Standards have required these vehicles to become more fuel-efficient over time**, but substantially reducing emissions from vehicles will ultimately require fuel switching away from carbon-emitting gasoline or diesel to a cleaner fuel like electricity. In addition to decreasing greenhouse gas emissions, transitioning to electric vehicles can benefit the electric grid and improve air quality.

As noted above, the range of benefits of vehicle electrification heavily depends on the types of fuels used for electricity generation. For example, a car that is charged in Washington state primarily with hydroelectric power will have a lower carbon footprint than a car charged in Wyoming using power from coal plants. However, even with these considerations, driving an electric car **currently produces** fewer carbon dioxide emissions than a gasoline car when charged anywhere in the United States. The reason is that in addition to not producing tailpipe emissions, electric vehicles are also more **fuel-efficient** relative to gasoline and diesel vehicles.

Electrification of transportation can also improve air quality. Switching to electric cars and trucks can reduce air pollution where the vehicles are operating, since they do not produce tailpipe emissions. Electrification of municipal buses could also be particularly beneficial for improving local air quality. While municipal buses account for a small portion of overall transportation CO_2 emissions, they typically run on diesel fuel or compressed natural gas (CNG) and produce tailpipe emissions containing other air pollutants (like nitrogen oxides and sulfur dioxide) that contribute to poor local air quality, while **electric buses do not**. Switching to electric buses could improve air quality, particularly in low-income neighborhoods that rely heavily on bus lines, and therefore provide health benefits for those communities.

In addition to environmental benefits, electric vehicles could also provide **benefits** to the electric grid by charging when electricity is abundant and demand is low and discharging to the grid when demand for electricity is high. This capability could be particularly useful for accommodating variations in electricity production from variable renewables.

Challenges and Barriers

Widespread electrification of light- and heavy-duty vehicles faces many economic and technological challenges. Many car manufacturers already sell electric cars, but these vehicles face barriers to widespread adoption, mainly due to limited charging infrastructure and the high price tag (largely attributable to battery costs). As the number of electric vehicles grow, they could also put **pressure** on the local power lines by substantially increasing the amount of electricity being used.

Heavy-duty vehicles face even more obstacles to electrification relative to light-duty vehicles. Heavy-duty trucks require large batteries that take up a lot of space, limiting the space available for carrying goods. Also, trucks often travel very long distances and may require frequent charging, which adds to travel time and makes limited charging infrastructure a significant barrier. These features could limit the ability for electric trucks to substitute for fossil fuel-burning trucks unless other measures are taken to reduce charging times, such as advances in fast charging technology or battery exchange (see **ICCT** for more).

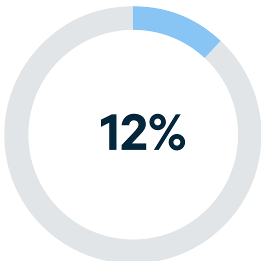
Electrification of Buildings

Overview

Residential and commercial buildings contribute about **12 percent** of all US greenhouse gas emissions. A **majority** of commercial and residential buildings rely on fossil fuels—such as natural gas or oil—for space heating, water heating, and cooking.

2017 US Greenhouse Gas Emissions

COMMERCIAL AND RESIDENTIAL SECTORS



12% of US greenhouse gas emissions come from commercial and residential buildings.

They mostly come from energy used for space heating, water heating, and cooking.

Data from EPA "Inventory of US Greenhouse Gas Emissions and Sinks" (2017)

Benefits of Electrification

As with vehicles, carbon emissions from buildings can be **reduced** through fuel switching from fossil fuels to electricity for residential or commercial building energy needs. Additionally, switching to electric heating and cooking technologies can have substantial air quality benefits. Some electric appliances can be better for indoor air quality than their fossil fuel-based counterparts—natural gas cooking stoves, for example, **release** carbon monoxide, nitrogen dioxide, and other harmful pollutants when in use.

Challenges and Barriers

Electrification of buildings is quite feasible from a technological standpoint. Commercially available electric technologies for heating and cooking currently exist, including electric heat pumps, electric hot water heaters, and electric stoves. A recent **study** done by the Lawrence Berkeley National Laboratory (LBNL) estimates that nearly the entire sector could be electrified using existing technologies; however, electrification faces economic constraints.

Economic feasibility varies geographically and by building type. For example, electric heaters (for heating both space and water) are **economically competitive** with existing fossil-fuel technologies in some areas of the US (particularly the South and California). However, they struggle to achieve economic parity in other areas. LBNL **claims** that electric heat pumps make the most sense economically in areas with mild climates and low electricity prices. Additionally, they are also more economically competitive when installed in new buildings than when they replace existing technologies in older buildings.

Electrification of the Industrial Sector

Overview

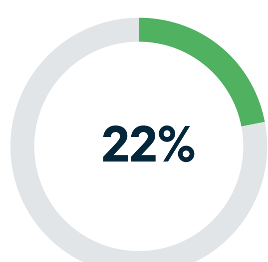
Industrial CO_2 emissions account for about **22 percent** of total US greenhouse gas emissions and are predominantly from the production of materials, such as steel, cement, glass, and petrochemicals. Most of these production processes use fossil fuels for heating and as feedstock (raw material) in their processes. When heated to very high temperatures, these materials emit carbon dioxide.

Benefits of Electrification

Electricity can theoretically **substitute** for fossil fuels as an energy source in processes for the production of some materials, such as **heating** required in the production of glass, paper, steel, and cement. For example, replacing natural gas furnaces with electrolytic

2017 US Greenhouse Gas Emissions

INDUSTRIAL SECTOR



22% of US greenhouse gas emissions come from the industrial sector.

They mostly come from the production of materials, including steel, cement, and petroleum.

Data from EPA "Inventory of US Greenhouse Gas Emissions and Sinks" (2017) reduction technology has the **potential** to significantly reduce CO_2 emissions in several industries, including textile, wood, paper, and chemicals.

Challenges and Barriers

Electrification of industrial processes faces more technological challenges than other sectors. Electrification **could** alter many existing processes, which could create complications, especially if the processes are intricate. Additionally, reducing emissions by replacing feedstock with non-fossil alternatives is challenging for many industries (particularly steel and cement production). **Alternative feedstocks** in these industries are still in early-stage research and development without commercial application.

In addition to technological challenges, electrification of industry faces economic challenges. Electrified industrial processes are currently more **expensive** than existing technologies to operate, as electricity is more expensive than natural gas per unit of energy.

Given these technical and economic barriers, the industrial sector may be the most difficult sector to fully electrify. In some cases, other alternatives for decarbonization might be more feasible and less expensive (such as implementing **carbon capture and storage** for existing processes).

Implications for Policy

Electrification is technologically feasible in many sectors, but it faces implementation challenges due to the high costs for replacing existing technologies and processes. If policymakers and electric utilities wish to reduce greenhouse gas emissions by encouraging electrification, policies and incentives that will help overcome these barriers may be needed.

Some policy **incentives** already exist to promote electrification, such as **tax credits** and rebates for the purchase of electric cars and heat pumps. While these policies can encourage a transition to electric technologies, a more economically efficient approach would be an economy-wide **carbon pricing policy**, such as a carbon tax or emissions cap-and-trade program, that affects all sectors rather than addressing each sector individually. If carbon dioxide emissions were priced across the entire economy, then fossil-fuel based technologies would become more expensive to operate, thus encouraging electrification of these technologies. A carbon price would also encourage fuel switching to cleaner energy sources within the electric sector, further improving the overall benefits of electrification.

If electric utilities wish to encourage electrification, they can also offer price incentives for the use of new electric technologies like cars or water heaters. For example, San Diego Gas & Electric (SDG&E) offers customers a **low electricity rate** specific for electric vehicle charging during off-peak hours.

Policymakers or utilities may also have to intervene to prevent potentially negative consequences from electrification. As more sectors become electrified, electric utilities may face challenges in meeting higher electricity demand, which might require upgrades to infrastructure in order to accommodate the additional load. Alternatively, these impacts could be mitigated through other methods, such as managed charging of **cars** or **water heating**. Similarly, as the economy becomes more dependent on the electricity system rather than fossil fuel-burning technologies, policymakers and grid operators may need to take precautions to ensure that the power grid is able to maintain reliability and resilience in the face of possible power disruptions. Despite these challenges, electrification could be an effective tool for reducing carbon emissions, especially if it is encouraged through efficient policy design.

Resources for the Future (RFF) is an independent, nonprofit research institution in Washington, DC. Its mission is to improve environmental, energy, and natural resource decisions through impartial economic research and policy engagement.

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RESOURCES for the FUTURE

Clean Energy Standards

Issue Brief 19-01 by Kathryne Cleary, Karen Palmer, and Kevin Rennert — January 2019

The Difficulty of Pricing Carbon

Pricing carbon—imposing a direct cost on each ton of greenhouse gas emissions emitted—is a policy tool favored by economists for its cost-efficiency in reducing emissions. In practice, policies to price carbon directly have proven difficult to put in place in the United States and elsewhere. Except for the Regional Greenhouse Gas Initiative, which caps emissions from electricity generators in nine northeastern states, and the AB32 cap-and-trade program in California, carbon pricing in the United States has yet to materialize. In the 2018 midterm elections, voters in Washington State rejected Ballot Initiative 1631, which would have established the nation's first carbon fee. This failure represents the second time in the past two years that Washington voters have rejected a carbon tax, highlighting the challenging politics of imposing a direct price on carbon even in one of the most progressive states in the nation.

In contrast, policies that promote renewable energy have been popular and widely implemented in states across the political spectrum. Nearly **three-quarters of US states** have adopted either a mandatory or a voluntary renewable portfolio standard (RPS), a traditional approach that requires (or encourages, in the case of voluntary programs) that a certain percentage of a utility's sales come from eligible renewable energy technologies (including wind, solar, and geothermal). Although the percentage requirements or targets vary substantially across states, the overall goals of such RPS policies are typically to deploy zero-carbon renewable resources, reduce emissions, diversify the energy mix, and provide an incentive to induce market entry of technologies with the potential to create new jobs.

By allowing renewable energy production to generate renewable energy credits (RECs) that can be traded, an RPS provides a market-based solution to meeting renewable energy deployment goals. However, the narrow technological focus of an RPS, combined with generally low renewable targets that limit their ability to displace emitting generation, can curb the effectiveness of the RPS as a tool to reduce greenhouse gas emissions. One way to enhance the ability of this more traditional approach to reduce emissions is to expand an RPS into a more inclusive clean energy standard.

What is a Clean Energy Standard?

A clean energy standard (CES), while lacking a universally accepted definition, typically refers to a technology-neutral portfolio standard that requires that a certain percentage of utility sales be met through "clean" zero- or low-carbon resources, such as renewables, nuclear energy, coal or natural gas fitted with carbon capture, and other technologies. As with an RPS, eligible technologies are awarded credits per MWh of generation that can be traded, which provides an efficient, market-based solution to meet a standard.

A CES offers the potential to achieve an equivalent level of emissions reductions as an RPS at lower cost. Having a greater number of technologies in competition to reduce emissions can increase market efficiency and lower overall compliance costs for a given level of emissions reduction. In addition, the inclusion of a broad range of zero- and low-emitting technologies as compliance options for a clean energy standard can also increase ambition with respect to emissions reductions. A technology-neutral CES coupled with a more stringent target could therefore result in both higher emissions reductions and lower costs relative to a traditional RPS.

Previous research done by **RFF** suggests that further efficiency gains are possible by using a credit system based on emissions rates rather than technology type. This credit system would encourage emissions reductions through changes in dispatch or investments at a facility, consequently further reducing emissions and lowering costs by allowing low-carbon technologies to participate. Under this construct, technologies would be compared on an emissions rate basis with a reference type of emitting generator, either a new coal plant or some type of natural gas plant, and would receive credits accordingly.[1] Plants that emit at an equivalent or higher rate than the baseline plant would receive zero credits, while those with an emissions rate less than the baseline can earn partial credit. This structure would bring a CES one step closer to providing incentives similar to those created by pricing carbon directly.

Economists generally agree that in theory, pricing carbon directly is a more cost-effective approach than a CES for reducing emissions. However, previous RFF **analysis** suggests that a CES can be a relatively more cost-effective approach when the labor and capital market effects of preexisting taxes on those inputs to production are taken into account and when the emissions reduction target is low. The reason is that other policies (carbon tax, cap-and-trade) can interact with existing taxes on labor and capital and raise the policy's cost, while a CES has no such interactions.

The changes that a CES will drive in power generation can be expected to affect electricity costs at both wholesale and retail levels. The magnitude of the effects will depend, among other factors, on the stringency of the policy target. The provision of credits to clean resources will likely create an incentive to expand energy supply and consequently lead to lower wholesale market prices. This effect notably differs from that of a carbon price, which would likely raise wholesale prices. The extent to which decreased wholesale market prices will lead to lower retail prices could vary with the policy target but would be especially likely when customers are served by a vertically integrated utility that generates more clean energy credits than it needs to comply with the standard. Conversely, as the target becomes more stringent and credit prices increase commensurately, retail prices would likely increase for electric utilities that are net purchasers of credits.

Previous Efforts on Clean Energy Standards

Past Federal Attempts

The idea of a national clean energy standard is not new, and the concept has received bipartisan support. In 2010, Senator Lindsey Graham (R-SC) sponsored the **Clean Energy Standard Act of 2010** which would have set a clean energy standard to 50 percent of electricity sales by 2050. Two years later, Senator Jeff Bingaman (D-NM) introduced the **Clean Energy Standard Act of 2012** (CESA 2012) to the Senate Committee on Energy and Natural Resources which would have set a federal clean energy standard at 24 percent of electric generation in 2015, rising 3 percent per year until reaching 84 percent in 2035. Similar to Sen. Graham's bill, the list of eligible technologies included all non-emitting sources (renewables and nuclear) and several low-emitting sources (e.g., natural gas, waste-to-energy, and fossil fuel generation with carbon capture and storage) placed in service after 1991. Unlike the Graham bill, CESA 2012 used emissions-based crediting for low-emitting sources relative to a baseline with an emissions rate of less than 0.82 metric tons of carbon dioxide (CO_2) per MWh.

Previous RFF **analysis** and congressional **testimony** provided at the time of the Bingaman bill's introduction found that it would have substantially reduced cumulative CO_2 emissions to 21 percent below 2005 levels by 2035 but also raised average electricity prices by 18 percent in 2035 relative to a baseline scenario. That analysis emphasized the emissions reduction potential from implementing a federal CES as well as the associated policy trade-offs of various design options with respect to overall costs and the distribution of those costs across the country.

Since 2012, the US energy market has undergone substantive changes that would likely reduce the compliance costs of implementing a CES structured similarly to CESA 2012 today. Costs for renewable energy and natural gas have dropped significantly in the past few years, and consequently these technologies have displaced higher-emissions coal plants based on market forces alone, even in the absence of a large-scale federal policy intervention. Given that the cost of compliance has decreased and the generation fleet has become much cleaner since 2012, a federal CES today would likely require a much higher initial target to provide meaningful emissions reductions.

State Clean Energy Standards

Motivated by concerns about carbon emissions and nuclear plant retirements, several states have already implemented programs to promote multiple types of zero- or low-emitting generation in a spirit similar to the technology-neutral CES outlined above. Each of these state approaches differs from a comprehensive CES, however, in its tailoring of incentives to specific technologies, as well as in other important ways.

In New York, for example, policymakers established a zero emission credit (ZEC) program in 2016 alongside the state RPS to keep existing nuclear plants online. The program compensates nuclear plants at a fixed price[2] per MWh under a long-term contract until it expires in 2029. Illinois and New Jersey subsequently adopted similar approaches. New York named this new broader clean energy program (consisting of the RPS and ZEC programs) the "Clean Energy Standard" despite the lack of tradable credits or an established percentage target standard for nuclear generation. Compared with a technology-neutral CES that encourages competition, ZEC payments may result in higher payments to nuclear generators than would otherwise be seen in a tradable credit market.

Pennsylvania's Alternative Energy Portfolio Standard, originally enacted in 2004 and modified several times since, encourages both renewable resources, such as wind and solar, and nonrenewable resources, such as useful thermal energy and integrated gasification combined-cycle coal. However, unlike a comprehensive CES, the incentives for each of these categories are kept distinct: the standard has one tier for renewable energy and a second tier for "alternative" energy, with separate corresponding targets and associated credit markets. Compared with a technology-neutral CES, the separate incentives for different technology categories could limit the gains from efficiency provided by a single credit market. Also, Pennsylvania's definition of alternative technologies eligible for credit in tier two is broad and not limited to low-emitting sources: for example, it includes waste coal—a polluting and previously discarded form of low-energy coal. The Pennsylvania targets are set to a modest 8 percent and 10 percent of sales by 2020–21 for tiers one and two, respectively, and are therefore limited in their emissions reductions potential.

California has come closest to embracing a CES, albeit with a long implementation lag. In September 2018, the state passed **SB 100**, which requires that 100 percent of retail sales come from zero-carbon sources by 2045. Though SB 100 has been interpreted in popular media as requiring that California transition to 100 percent renewable energy, the new law more specifically states that 100 percent of electricity sales must come from "eligible renewable energy resources *and* zero-carbon resources," of which 60 percent of sales must be from renewable energy sources by 2030. The legislation itself does not define the zero-carbon sources that can be used to comply with the standard, as they will be defined in subsequent regulation to be developed by the state's public utilities commission. The 60 percent renewable target represents a substantial increase relative to the **29 percent of sales** that renewables represent currently. The requirement that such a high percentage of the overall goal come from renewables could potentially limit the cost-effectiveness of the policy relative to a technology-neutral CES without such a restriction.

If the sole goal of these state policies is to reduce carbon emissions, that goal could be achieved more efficiently by implementing a technology-neutral CES. To do so, a state would need to expand the list of technologies eligible to meet the standard and adjust the standard commensurately to ensure the same level of emissions reduction.

In practice, a policy's economic efficiency will depend on a host of design decisions, including technology coverage, treatment of existing generators, and cost constraints. All of these factors can influence the policy outcome in terms of emissions abatement, cost, and resource mix.

Policy Design Considerations

When designing a CES, policymakers encounter several tradeoffs and must consider the most appropriate option. Many of the considerations are relevant at both state and federal levels. Reports from **RFF** and the **Center for Climate and Energy Solutions** (C2ES) provide a thorough review of the design options available for a CES. Significant decisions involve which technologies to include, how high to set the target (given the current level of renewable energy and other non-emitting generation), how to treat existing resources, and whether the standard should be technology or emissions-based, among others. We briefly describe various considerations and policy trade-offs below.

Technology-neutral vs. technology-specific. In designing a CES, policymakers must choose between minimizing costs by adopting a technology-neutral approach to crediting, based on a metric such as emissions intensity, and encouraging certain technologies. For example, some existing RPS targets include "carve-outs" or separate requirements for certain technologies to ensure that the standard is not met exclusively by the lowest-cost renewable energy. As a consequence, including carve-outs tends to raise the costs of the policy in the near term, but a carve-out may also help promote technological learning and thereby lower future costs for nascent technologies needed to comply with later years of the policy. A potentially lower-cost option would be to assign higher credits to nascent and therefore more expensive technologies (e.g., solar coupled with energy storage could receive twice the MWh credit provided to wind) that policymakers specifically want to encourage until the technology matures. However, assigning higher credits for particular technologies can reduce the stringency of the policy.

Crediting existing generators. A related consideration is how to address the crediting of existing zero-carbon generators. A reason to exclude existing technologies is that credit revenue may not affect their decision to operate in the future. This is likely the case for hydroelectric plants but not necessarily for nuclear plants that may be struggling to remain online. A recent **report** by the Union of Concerned Scientists reveals that more than one-third of the US nuclear fleet is either unprofitable or already scheduled for early retirement. The retirement of these nuclear generators could lead to an increase in carbon emissions, since they would likely be replaced with carbon-emitting natural gas plants. Under these economic conditions, policymakers could find that crediting existing generation could be necessary to keep zero-carbon generation online and prevent increases in emissions.

However, many other nuclear plants continue to operate without subsidies, and therefore crediting them unnecessarily could increase compliance costs and place an additional burden on consumers.

Cost containment. Policymakers must decide whether an alternative compliance payment (ACP), a payment that electricity retailers can make in lieu of having to surrender clean energy credits, is needed as a safety precaution to contain costs. Including an ACP could limit the emissions reduction potential of the policy.

Interaction with other policies. When designing a CES at the federal or state level, policymakers should consider possible interactions between existing policies. One potential interaction could be an existing state RPS (or CES if such a policy were implemented) with a federal CES. Since a CES is typically implemented at the utility level like an RPS, a federal policy will likely either override an existing state policy or allow the state policy to dominate (if it is stricter). The interaction of policies could also potentially lower allowance prices in the existing policy's territory.

Crediting for resources outside of the compliance region. Another important CES design choice is whether to credit clean generators located out of state or out of the country. Allowing resources from outside the compliance region to earn credits could help lower the costs of compliance but may also run counter to the desire of policymakers to drive economic development domestically or within a given state. However, excluding entities outside the compliance regions, particularly those that might sell power to load-serving entities with compliance obligations under the policy, may run afoul of the interstate commerce clause or trade agreements. This issue has led to legal battles in a few states over whether excluding out-of-state resources has violated the clause (see **here** for details). To avoid this issue, some states have chosen to allow resources from within their regional transmission jurisdiction to be eligible for compliance.

Additional Considerations for a Federal Standard

The above-mentioned considerations apply to the design of any CES, but even more trade-offs must be taken into account when constructing a national policy. A federal CES offers significant emissions reduction potential and could lower compliance costs relative to a collection of state policies by allowing trading among a greater number of resources over a much larger geographic area. However, this larger area comes with more extreme regional differences in existing energy fleets, available resources, and existing policies, all of which will need to be accounted for to create the political coalition necessary to support a national policy. The following considerations will likely be more consequential at the federal level.

Addressing regional "fairness." A particular challenge for federal CES legislation is concerns about the fairness of the policy. Some regions of the country have already aggressively pursued clean energy and boast abundant renewable resources while others have consistently relied on their own fossil fuels. Setting a single nationwide standard that some utilities can easily meet and others struggle to achieve could result in a wealth transfer from fossil fuel–rich states to cleaner states with an excess of clean energy above the standard. One proposed method to address such fairness concerns has been to require all regions to increase their clean generation by a certain percentage, rather than requiring a percentage of sales; however, this approach could limit the economic efficiency of the policy.

Treatment of small utilities. Another important policy consideration is the treatment of small utilities. Previously proposed federal RPS and CES legislation often exempted small utilities from compliance obligations. RFF **analysis** of Senator Bingaman's bill found that exempting small utilities in this manner had significant consequences: it caused retail electricity prices to differ by as much as 50 percent between exempt and nonexempt utilities by the year 2035, with exempt utilities having lower prices. The exemption offered the potential policy benefit of reducing regulatory burdens for small utilities that might not have the resources to alter their existing energy fleets, but the resulting imbalance in prices created inequity among electricity customers in different areas in the model runs. Such an exemption could also create an incentive for a proliferation of small utilities to qualify for it. Although this trade-off could also occur at the state level, the consequences are likely more pronounced on a national scale.

The Path Forward

Policymakers interested in reducing carbon emissions from the electricity sector in a cost-effective way could find that a CES is a viable alternative to putting a price on carbon. Though not a perfect instrument, it likely holds more political appeal than a carbon tax and could be tacked on to existing RPS programs. Implementation of a CES at either the state or federal level could have enormous potential to transform the electricity sector.

Consideration of a CES may be particularly relevant for some states with RPS policies that are phasing out over the next few years. Maryland, Missouri, Colorado, New Mexico, and South Carolina, for example, all have final RPS target years of 2021 or before. The approaching final target dates may prompt state lawmakers to revisit these policies and therefore could provide an opportunity to implement a clean energy standard instead of expanding an existing RPS.

Hawaii, on the other hand, is kicking its RPS into high gear with aggressive future targets, and more states may follow suit. The idea of "100 percent renewable energy" has political appeal for states with green agendas. But if the goal is zero-carbon generation, a technology-neutral CES is likely more economically efficient and could also help avoid the grid-related risks that come with relying exclusively on intermittent power (see **NREL** study).

At the federal level, despite notable and even bipartisan introductions of economy-wide climate policies over the past several years, the US Congress has not acted. However, the updated and stark predictions in reports by the **Intergovernmental Panel on Climate Change** (IPCC) and the **National Climate Assessment** have given climate change a new wave of national attention. Many new and incumbent Democrats have promised action on climate as they regain control of the House of Representatives for the first time in eight years. These circumstances suggest that the 116th Congress is likely to provide a window of opportunity for developing and evaluating various approaches to climate legislation.

The technologies for and economics of power generation have changed significantly since the last time a CES was an active part of the policy conversation at the federal and state levels. Over the intervening years, economists' understanding of market-based policy mechanisms to reduce emissions has also continued to increase, aided in part by advances in the modeling tools available to evaluate such policies. In light of the windows of opportunity for policymakers at both the federal and state level to explore a CES policy, RFF experts are currently using a pair of RFF's state-of-the art, highly detailed power sector models to evaluate a comprehensive set of policy options for a CES. Results from this analysis will be available in the coming weeks and months.

Notes

1 E* is the baseline plant emissions rate and E' is the emissions rate of the plant in question. The credit is determined by the following equation: the maximum of zero or C = (E* – E') / E*. Plants that emit no carbon would receive a full credit ((E* – 0) / E* = 1). Those that have an emissions rate greater than E* earn zero credits while those with an emissions rate less than E* earn partial credit.

2 The ZEC value is based on the social cost of avoided carbon and changes in expected wholesale electricity prices and is adjusted every two years.

3 They might no longer qualify for full credits once lifecycle emissions are counted, as called for in the Act.

4 The formula for awarding clean energy credits is: Generator credit = 1 – ((generator emissions rate) / (0.4 Metric Tons per MWh)).

5 Some readers may be interested in comparisons with the US power sector's greenhouse gas emissions in 2005, since that is a standard comparison year. Our modeling projects that that the power-sector greenhouse gas emissions in 2035 under the Policy would be 76% lower than the estimated US power sector greenhouse gas emissions in 2005. This counts CO_2 and methane.

6 This $106 billion cost is the reduction in what economists call "consumer surplus." In this case, it could instead be called "end-user surplus" because it is the total across all users of electricity, both residential and non-residential.

7 Thirty-two is the estimated 100-year global warming potential of methane and is also the approximate ratio of the estimated damage per ton of methane versus of CO_2.

Resources for the Future (RFF) is an independent, nonprofit research institution in Washington, DC. Its mission is to improve environmental, energy, and natural resource decisions through impartial economic research and policy engagement.

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RESOURCES for the FUTURE

Projected Effects of the Clean Energy Standard Act of 2019

Issue Brief 19-03 by Paul Picciano, Kevin Rennert, and Daniel Shawhan — May 2019

This analysis was conducted as part of RFF's Future of Power Initiative: **www.rff.org/fop**

Summary of Modeling Results

Relative to a "no additional policy" baseline, the proposed Clean Energy Standard Act of 2019 is projected to:

- Reduce power sector greenhouse gas emissions in 2035 by 61%, with cumulative emission reductions between 2020 and 2035 of approximately 10 billion metric tons of carbon dioxide (CO_2) equivalent;
- Increase generation by renewables from 30% to 56% of total generation in 2035;
- Avoid retirement of 43 GW of nuclear generation capacity as of 2035. This would increase nuclear generation from 10% to 18% of total generation in 2035;
- Reduce generation from fossil sources from 60% to 26% of total generation in 2035;
- Provide net benefits of $579 billion over the 2020–2035 time period;
- Prevent 30,000 premature deaths from air pollution in the US over the 2020–2035 time period; and
- Increase nationally averaged retail electricity rates by 4% in 2035.

Introduction

On May 8, 2019, Senator Tina Smith (D-MN) and Rep. Ben Ray Luján (D-NM) introduced the "Clean Energy Standard Act of 2019" (hereafter referred to as "the Act" or "the Policy"). Under the Act, suppliers of retail electricity would be required to account for a percentage of their retail sales as coming from sources that are "clean," measured according to the amount of greenhouse gas emissions per unit of electricity generated. Under the Act, the nationally averaged percentage requirement for clean electricity increases from approximately 51% of retail sales in 2021 to approximately 77% in 2035 and approximately 96% in 2050.

The full legislative text is available **here**, and a summary from the sponsors is available **here**. For an overview of clean energy standards at both the federal and state levels, see this **RFF Issue Brief**.

Structure of the Clean Energy Standard Act of 2019

Under the Act, generators of clean electricity would be awarded full or partial "clean energy credits," which may be sold or traded, for each clean megawatt-hour (MWh) generated. To demonstrate compliance with their annual obligation, Retail Electricity Suppliers would surrender sufficient clean energy credits, obtained either from their own clean generation or purchased from others. In addition to being able to trade credits, compliance entities may also hold or "bank" credits, thereby allowing for overcompliance in the early years of the Policy and undercompliance in the later years. The increasing clean energy requirement and associated demand for clean energy credits would provide a continued incentive for adding clean generation to the grid until the power sector is almost entirely decarbonized after 2050.

The Act defines one clean energy credit as representing one megawatt-hour of electricity generated with zero greenhouse gas emissions. Emission sources that would qualify for full credits under the Act include wind, solar, hydropower, and nuclear.[3] Partial credits are awarded on a sliding scale based on the net greenhouse gas emissions of a generator relative to a benchmark emissions intensity of 0.4 metric tons of CO_2 per megawatt-hour (MWh)[4], thereby providing incentives for fossil-fuel generation equipped with carbon capture and storage as well as biomass, and waste-to-energy generation. Emissions intensity calculations for the purpose of crediting generators would account for lifecycle greenhouse gas emissions, including those associated with the extraction and production of the fuels combusted, among other factors. The Policy would also award credits for qualified combined heat and power, and would give extra credit to a limited amount of low- or zero-emission, innovative, dispatchable technologies.

Rather than set a nationally uniform compliance target for all suppliers of retail electricity, the compliance obligation for each individual Retail Electricity Supplier is set based upon its own historical percentage of clean generation —specifically, its clean energy percentage for the calendar year of enactment of the legislation. The rate of annual escalation of such targets is further delineated between large and small Retail Electricity Suppliers as follows: The clean energy compliance requirement for a given Retail Electricity Supplier with annual retail sales above 2 million MWh escalates by 2.75% per year until it reaches 60%, then by 1.75% per year until the compliance target reaches 90%. Beginning in 2040, for such Retail Electricity Suppliers that have reached targets of 90%, the percentage requirement increases by 1% annually until it reaches 100%. Retail electricity suppliers with initial annual retail sales less than 2 million MWh have a compliance obligation that escalates by 1.5% per year to a maximum of 90%. After 2040, small Retail Electricity Suppliers that had reached a 90% obligation would have their percentage requirement increased by 1% annually.

The Act provides cost containment measures in the form of an Alternative Compliance Payment (ACP) that Retail Electricity Suppliers may make in lieu of surrendering clean energy credits. The ACP is set to start at 3 cents per kilowatt-hour and escalate at 3% annually until the end of 2029, then 5% annually thereafter. The Act also contains provisions to reduce the annual escalation rate of the compliance obligations in response to sustained and significant usage of the ACP for compliance, as well as to increase their annual rate of escalation in response to sustained low credit prices.

Modeling the Policy with E4ST

We utilized a detailed model of the US power sector, the *Engineering, Economic, and Environmental Electricity Simulation Tool* (E4ST), to assess changes in power sector greenhouse gas emissions, composition of the fleet of generators, and societal welfare, including effects on premature mortality and retail electricity prices, resulting from the Act.

In interpreting the results presented below, it is important to note that all models provide an imperfect approximation of the real world. See page 5 for further detail on the model and modeled policy specifications including ways in which they differ from the Act.

Changes to Generation and Emission Reductions

As shown in Figure 1, compliance with the clean energy requirements posed by the Policy is projected to drive significant changes in the composition of the generation fleet compared to a baseline without additional policy. These changes include substantial increases in zero-emission sources, the avoidance of expected retirements in the existing nuclear fleet, and decreased generation from fossil sources. Specifically, compared with a policy baseline that assumes no additional policy, in 2035 the legislation is projected to increase wind generation by 16%, solar generation by 9%, and nuclear generation by 8%, while decreasing coal and natural gas generation by 10% and 24%, respectively.

The shift of the power sector to lower-carbon sources yields associated emission reductions compared with the no additional policy baseline (Figure 2). Specifically, nationwide CO_2 equivalent emissions from the power sector decrease by 967 million metric tons, or 61%, in 2035, relative to the baseline 2035 value.[5] This reduction is attributed to

Figure 1: US Electricity Generation under the Clean Energy Standard Act of 2019

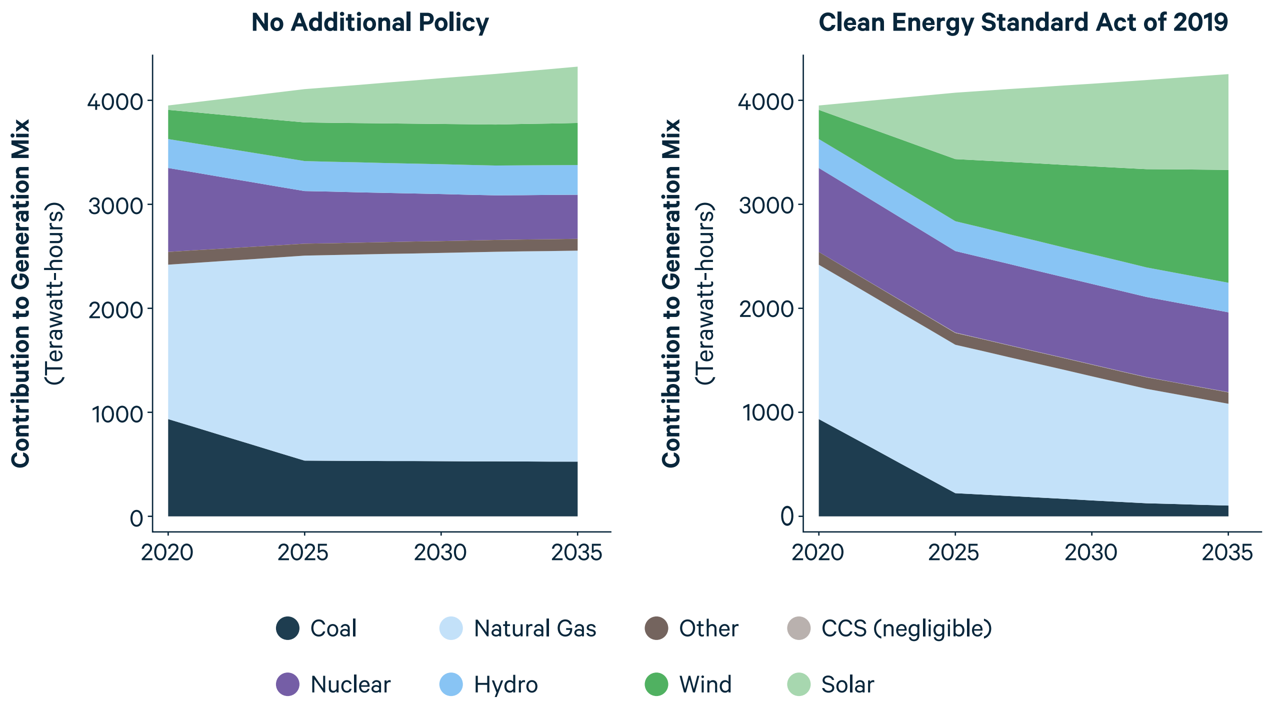
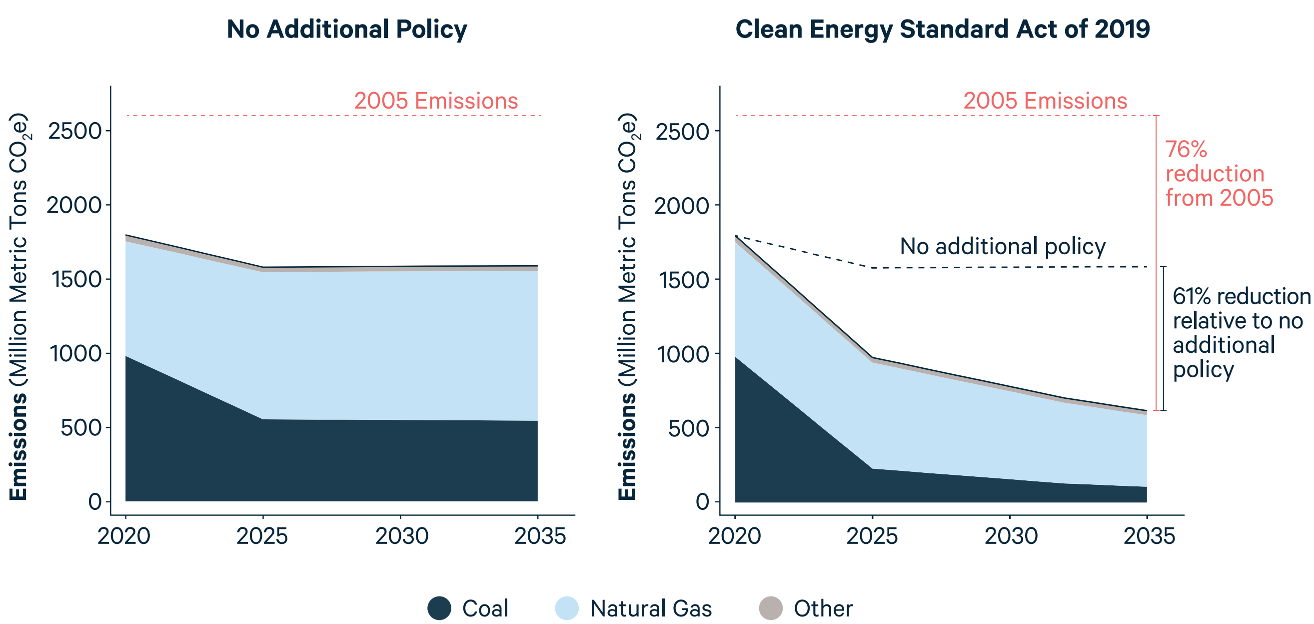


Figure 2: Electric Sector Emissions under the Clean Energy Standard Act of 2019



80% lower emissions from coal (45% of the total reduction) and 52% lower emissions from natural gas (55% of the total reduction). Cumulatively, from 2020 to 2035, emissions decrease by 9.9 billion metric tons, or 38%.

Projected Effects on Welfare

The net benefits of the Policy over the 2020–2035 time period have an estimated value of $579 billion. All dollar values in this section are net present values from the perspective of 2021, assuming a 3% continuous discount rate. All dollar values in this brief are reported in 2013 dollars. A breakdown of the welfare benefits is shown in Figure 3. The Act is projected to:

- Reduce cumulative greenhouse gas emissions by approximately 10 billion metric tons between 2020 and 2035. This is estimated to reduce $470 billion worth of net harm to society that would otherwise be caused by climate change.
- Prevent 30,000 premature deaths from air pollution in the US over the 2020–2035 time period by reducing sulfur dioxide and nitrogen oxide emissions from power plants. The estimated value of this is $226 billion.
- Increase the net profits of the power generation industry by $19 billion.
- Increase retail electricity rates between 2020 and 2035 (Figure 4) by an average of 2.7%, with a projected increase in 2035 of 3.9%. The estimated total cost from higher electricity rates is $106 billion.[6]
- Increase US government expenditures by $29 billion, primarily due to increased expenditures in the form of the 10% investment tax credit for the increased amounts of solar energy capacity built under the Policy.

Discussion and Future Work

In our assessment of the legislation, an aspect that particularly merits further consideration is the application of different clean energy percentage requirements to different Retail Electricity Suppliers in the same market. Given the strong competitive advantage that could be realized by Retail Electricity Suppliers that started from a low clean energy requirement, structuring the Policy in this manner could potentially incentivize a rapid shift towards such Retail Electricity Suppliers, which would reduce the intended effectiveness of the bill at increasing clean energy use, and also raise equity concerns for

Figure 3: US Welfare Effects of Clean Energy Standard Act of 2019 (Net Present Value, 2020–2035)

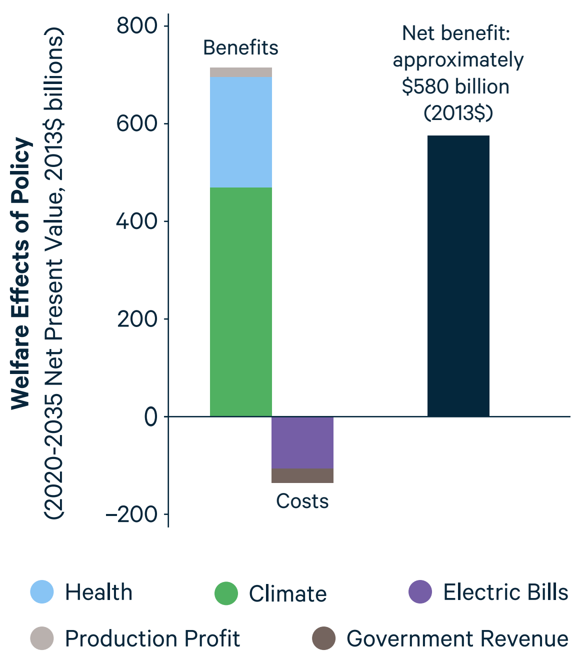
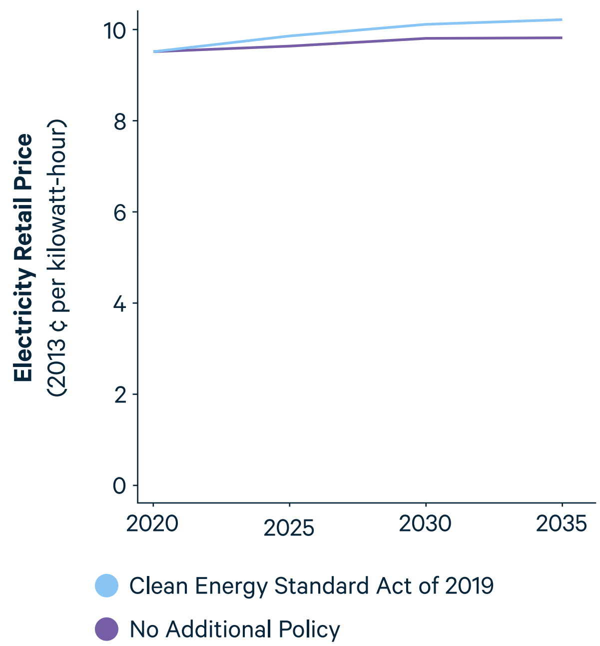


Figure 4: US Average Retail Electricity Price under the Clean Energy Standard Act of 2019



disadvantaged suppliers and their customers. The use of a slower requirement growth rate for suppliers that are initially small exacerbates this issue.

Two additional modeled effects of the Act that are not discussed in this brief are the projected effects of the Policy on wholesale market prices as well as on state-level electricity prices. The Act is projected to decrease clearing prices in wholesale electricity markets, though such decreased clearing prices are projected to be more than offset for eligible clean energy generators through revenues from CES credit sales. Preliminary state-level analysis of the Act shows that the effects on electricity bills would vary geographically, with increases tending to be lowest in regions that are cost-effective places for wind energy development, and even lower if such regions currently derive a large portion of their generation from coal.

Further in-depth analysis of the Act that will evaluate its effects on wholesale power markets, provide state-level results for electricity prices, incorporate an expanded set of buildable clean energy technologies, and compare its effects to other potential CES policy designs and other types of carbon pricing is forthcoming.

Model Characteristics

The **Engineering, Economic, and Environmental Electricity Simulation Tool** (E4ST) is software built for benefit-cost analysis of policies, regulations, power infrastructure additions, and more. E4ST simulates in detail how the power sector will respond to such changes. It models successive multi-year periods, predicting hourly system operation along with generator construction and retirement, and various other outcomes. E4ST's advantages over other models include its high spatial detail, its realistic representation of power flows and system operation, its integration of an air pollution and health effects model, its uniquely comprehensive benefit-cost analysis capabilities, its high-quality generator data, its inclusion of Canada, and its unique adaptability, transparency, and shareable nature. E4ST has been used to analyze various policies and investments, including in projects for the US Department of Energy and the US Department of the Interior. E4ST has been developed by researchers at Resources for the Future and Cornell and Arizona State Universities, with funding, input, and review by the Department of Energy, the National Science Foundation, the New York Independent System Operator, and the Power Systems Engineering Research Center. More information is available at **e4st.com**.

Modeling Set-Up and Assumptions

To represent the Policy, the modeling included the following elements:

- For the purpose of calculating and applying the clean energy percentage requirements in each year, we aggregated all of the Retail Electricity Suppliers in each state up to the state level.
- To calculate the starting renewable energy requirement in each state in 2020, we calculated the proportion of each state's 2017 in-state generation that met the bill's definition of clean, then scaled it up using the pre-2040 requirement scale-up rates in the bill.
- The national average clean energy requirements modeled were 51% in 2021, 60% in 2025, 69% in 2030, and 77% in 2035. The market shares of clean energy differed somewhat from these requirements because of banking of Clean Energy Credits and because we report the percentages as percentages of total generation, which is approximately 6% higher than retail sales due to transmission and distribution losses.
- We simulated 2025, 2032, and 2037 both with and without the Act. We linearly interpolated to calculate results in years between and before these years.
- Buildable technologies in the model included natural gas combined cycle with and without 90% carbon capture and sequestration, natural gas turbines, nuclear, onshore wind, offshore wind (9 sites), solar, and coal with 90% carbon capture and sequestration.
- We assumed a demand elasticity of -0.4.
- Our assumed methane leakage rates are 0.000434375 short tons per million British thermal units for natural gas and 0.000175 for coal (Lenox et al. 2013).
- Our assumed damage per ton values for CO_2 and methane come from IWG (2015) and Marten et al. (2014).

- For mortality, we use the COBRA air pollution fate-and-transport model (EPA 2018) and the midpoint between the mortality estimates produced using the Krewski et al. (2009) and LePeule et al. (2012) exposure-mortality functions.
- Our assumed generator costs are medium ("mid") values from the National Renewable Energy Laboratory (Vimmerstedt et al. 2018). Wind costs assume type-5 turbines.
- Our assumed demand growth and fuel prices come from the 2019 Annual Energy Outlook high oil and gas resource and technology case. We repeated the simulations with lower natural gas prices based on NYMEX futures prices. It changed the effects of the Policy little.
- The greenhouse gas emissions we include in this analysis are CO_2 and methane, which are the main two from the power sector. We combine them into "CO_2 equivalent" by multiplying the tons of methane by 32 and adding them to the tons of CO_2.[7]

Differences between the Model Set-Up and the Act

The model set-up described above differs from the proposed legislation in a number of ways. For example, though the model represents all technologies in the existing generator fleet, it does not represent *new* builds of biomass, combined heat and power, battery energy storage, or geothermal, all of which are technologies eligible for crediting under the Act. Additionally, the model represents new builds of fossil generation with carbon capture and storage, but does not provide for retrofitting carbon capture to existing generation. The model also does not provide extra credit for dispatchable low- or zero-emitting generation technologies, or credit for imported clean generation in Canada or Mexico. Implementation of some of these aspects of the Policy and these technologies as buildable in the model is currently underway and the results from the simulations presented here will be updated upon completion. Given that the model finds the least-cost solution for complying with the Policy, the inclusion of additional sources of credits, either from outside the United States or from additional technologies as compliance tools can be expected only to lower the projected costs of the Policy relative to the current results.

In addition to the above assumptions that increase the estimated cost of the Policy, this analysis also makes two assumptions which decrease the estimated cost. First, the responsiveness of hourly load to electricity prices is based entirely on the electricity price within the same hour, rather than, say, partly on the electricity price in the preceding months. Furthermore, we assume that this load response is consistent with recovery of generation and transmission capacity costs in hours of peak scarcity, rather than through a time-invariant per-kWh charge. Second, we assume that the only emissions counted other than generators' own smokestack emissions are upstream methane releases from the natural gas and coal fuel cycles. If additional emissions were to be counted, such as those associated with building, decommissioning, and maintaining generators, as called for in the legislation, the cost of compliance would be higher, though the Policy would also result in greater emissions reductions.

In addition, the bill bases the clean energy percentage requirement of each Retail Electricity Supplier on the clean energy percentage of that supplier in the year the bill passes. Our analysis instead assumes that the bill would be changed to apply the same percentage requirement to all Retail Electricity Suppliers in a given state.

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Notes

1 They might no longer qualify for full credits once lifecycle emissions are counted, as called for in the Act.

2 The formula for awarding clean energy credits is: Generator credit = 1 – ((generator emissions rate) / (0.4 Metric Tons per MWh)).

3 Some readers may be interested in comparisons with the US power sector's greenhouse gas emissions in 2005, since that is a standard comparison year. Our modeling projects that that the power-sector greenhouse gas emissions in 2035 under the Policy would be 76% lower than the estimated US power sector greenhouse gas emissions in 2005. This counts CO_2 and methane.

4 This $106 billion cost is the reduction in what economists call "consumer surplus." In this case, it could instead be called "end-user surplus" because it is the total across all users of electricity, both residential and non-residential.

5 Thirty-two is the estimated 100-year global warming potential of methane and is also the approximate ratio of the estimated damage per ton of methane versus of CO_2.

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Paul Picciano (**picciano@rff.org**) is a Senior Research Assistant at RFF. His research focuses on energy and climate policies in the electricity sector. At RFF, he primarily develops and applies the Engineering, Economic, and Environmental Electricity Simulation Tool (E4ST), a software package used for power system planning, policy analysis, and projections. Previously, he evaluated energy and environmental regulations at NERA Economic Consulting, and researched wind and solar energy integration as an Ernest F. Hollings Scholar with the National Oceanic and Atmospheric Administration.

Dr. **Kevin Rennert** (**rennert@rff.org**) is a Fellow and Director of the Social Cost of Carbon Initiative at RFF. Rennert previously served as Deputy Associate Administrator for the Office of Policy at the US Environmental Protection Agency and as Senior Advisor on Energy for the Senate Finance Committee. From 2008 to 2014, he worked on energy and climate legislation as Senior Professional Staff for the Senate Energy Committee. In that capacity, Rennert led the development of the Clean Energy Standard Act of 2012 (S. 2146), a presidential priority that would use market mechanisms to double the amount of electricity generated in the United States from low or zero carbon sources by 2035.

Dr. **Daniel Shawhan** (**shawhan@rff.org**) is a Fellow at RFF. Much of his research focuses on predicting and estimating the effects of electricity policies, including environmental ones. Over the last thirteen years, he has played a leading role in developing a new set of capabilities for simulating how power grids, power plants, and pollution levels will respond to potential changes in policy. He also works on electricity market design and environmental policy design. He advised five US states on the successful restructuring of their electricity markets, and has also advised on the design of environmental policies. Dr. Shawhan has a PhD in Applied Economics and Management from Cornell University.

RESOURCES *for the* FUTURE

Comments on Key Considerations for United States Climate Policy

Submitted to the Committee on Energy and Commerce

Ann Bartuska, Dallas Burtraw, Brian Flannery, Kristin Hayes, Alan Krupnick, Jan Mares, Joshua Linn, Karen Palmer, Brian Prest, Kevin Rennert, and Daniel Shawhan

Public Comments
September 2019

RESOURCES *for the* FUTURE

Richard G. Newell
President & CEO

September 13, 2019

Committee on Energy and Commerce, Democratic Staff
2125 Rayburn House Office Building
Washington, DC 20515

Dear Members of the Committee on Energy and Commerce:

On behalf of Resources for the Future (RFF), I am pleased to share the attached information related to your recent request for input on key considerations for US climate policy.

Our long-standing history of working on federal climate policy issues makes us uniquely qualified to provide expert insight on both the economic and environmental considerations of such policy decisions. As you may know, RFF's mission is to improve environmental, energy, and natural resource decisions through impartial economic research and policy engagement. As an independent, nonprofit research institution, RFF is committed to being the most widely trusted source of research insights and policy solutions leading to a healthy environment and a thriving economy.

Our input is organized into two main sections. The first outlines criteria for evaluating climate policy options, while the second discusses specific policy strategies to address to reduce emissions. This information represents the contributions of nearly a dozen researchers but should not be considered an institutional or consensus view. While RFF researchers are encouraged to offer their expertise to inform policy decisions, the views expressed here are those of the individual authors and may differ from those of other RFF experts, its officers, or its directors. Furthermore, RFF does not take positions on specific legislative proposals.

We chose largely to focus on areas where RFF has considerable and recent bodies of research expertise. While we have attempted to provide a robust set of thoughts and resources to the Committee, we recognize our limitations in covering the full spectrum of climate policy considerations in a limited timeframe.

Finally, we would welcome the opportunity to speak in more detail with the Committee members about any of the ideas, issues, or publications included in this input. If you have any questions or would like additional information, please contact RFF Fellow Kevin Rennert at **rennert@rff.org**.

Sincerely,

Richard Newell

Thank you for the opportunity to contribute to the conversation around climate policy development in the United States. This response to the House Energy & Commerce Committee's request for information is organized into two main sections: the first outlines criteria for evaluating climate policy options, while the second discusses a number of specific policy strategies to address to reduce emissions and contribute to meeting Committee members' stated goal of reducing emissions to net-zero in the US economy by 2050.

Criteria for Evaluating Climate Policy Alternatives

The criteria for evaluating climate policy choices are economic, political, and human. While the list below does not address every possible criterion a policymaker might want to consider, it is useful to keep in mind these crucial measures:

The level and pace of emissions reductions is at the heart of climate policy design, given the primary rationale of reducing US greenhouse gas emissions.

The cost of the policy is important not only for the strength of the economy, but also because achieving reductions at less cost can allow for more ambitious policies.

Increasingly, and for good reason, concerns about **equity and environmental justice** assume a central place in climate policy conversations. Disadvantaged communities are most vulnerable to the potential costs of policy and to the effects of a changing climate. Many in these communities feel they have not enjoyed the benefits or environmental improvements that have accrued elsewhere. Fortunately, there are important opportunities for joint reductions in greenhouse gases and conventional air pollutants.

Economic modeling can help project who bears the cost of various policy options across populations and sectors, providing decisionmakers with critical information to help mitigate these distributional impacts. A focus on equity also includes planning for a just transition for workers affected by a transforming, decarbonizing energy system.

A number of **international concerns** should also be kept in mind when designing climate policy. First, maintaining or even improving international competitiveness is crucial. Second, domestic policy can be designed to leverage actions in other nations, which is critical in the face of a global challenge like climate change.

Technological innovation is a crucial policy outcome, not only to reduce US emissions but also to support reductions internationally. In an ideal world, US companies can benefit strongly in world markets from domestic policy actions taken to reduce carbon emissions.

Finally, it is valuable to consider lessons from previously enacted, large-scale environmental policies, as RFF Senior Fellow Dallas Burtraw, along with co-editor Ann Carlson (UCLA) and a range of contributing authors, recently did in their book ***Lessons from the Clean Air Act***. Their primary finding was the importance of building both **durability and adaptability** into policy design, to help ensure that future policies can withstand changing economic circumstances and political winds.

Policy Approaches and Considerations

As an independent, non-partisan, non-advocacy organization, RFF does not take institutional positions on specific policies to pursue. That being said, our researchers have a wealth of experience in climate policy options available to consider at the federal level. A number of those are described below.

Economy-Wide Policy Strategies

Economy-wide policy strategies are favored from an economic perspective because they have the potential to be cost effective. RFF's research focus on economy-wide policies has been on carbon pricing, in the forms of either a carbon tax or cap and trade, and we focus our comments on these approaches in this document.

Carbon Pricing

Economists often favor policy solutions that introduce a direct price on carbon emissions, which escalates over time. A price on carbon changes the relative cost of fuels by making fuels that have relatively greater emissions relatively more expensive.

A carbon price is viewed favorably because:

- It percolates through the entire economy, providing an incentive for all decision makers in the economy to look for ways to reduce emissions, for example, by improving the boiler in a factory or buying a more efficient air conditioner at home.
- It provides firms with the flexibility to make decisions that make sense based on their own information.
- Existing product markets can seamlessly incorporate changes in relative prices of goods and services.

For a further, high-level overview of carbon pricing, please see RFF's **Carbon Pricing 101** explainer.

RFF has also developed an interactive, exploratory "carbon pricing calculator," based upon output from RFF's economy-wide modeling, that allows users to compare the environmental and economic impacts of both current legislative proposals that place a price on carbon and a custom user-specified carbon tax path. Users can see the impacts of each policy on annual emissions, annual revenues, cumulative emissions, consumer prices, gross domestic product, and the distribution of impacts across income groups. The tool includes the projected impacts of the following policies:

- The American Opportunity Carbon Fee Act (Whitehouse-Schatz, 2019 version)
- The Climate Action Rebate Act (Coons-Feinstein)
- The Energy Innovation and Carbon Dividend Act (Deutch et al.)
- The Healthy Climate and Family Security Act (Van Hollen-Beyer)
- The MARKET CHOICE Act (Curbelo)
- The Stemming Warming and Augmenting Pay Act (Rooney)
- The Raise Wages, Cut Carbon Act (Lipinski).

The carbon pricing calculator (originally published as the E3 Carbon Tax Calculator) can be found at **www.rff.org/cpc**; an updated version of the calculator will be launched on September 20 at the same URL.

Carbon taxes and cap-and-trade programs primarily differ by the type of certainty they provide. Carbon taxes provide price certainty, as entities subject to the tax know how much they'll have to pay per ton emitted—but simply setting a tax rate doesn't guarantee any particular level of emissions reductions. Cap-and-trade programs, on the other hand, set a cap on emissions and therefore provide quantity certainty—but price fluctuations under the trading market structure can provide a less solid basis for business planning decisions. Hybrid systems, however, can be used to reduce price or emissions uncertainty. Under cap-and-trade programs, price floors, ceilings, and steps have been **proposed** and **utilized** to prevent prices from being "too low" or "too high." Carbon taxes can also be **designed** to automatically adjust if actual emissions miss some predetermined emissions path.

Carbon Tax

A carbon tax is perhaps the most straightforward way to introduce a price on carbon, and setting the price path is an important component of carbon tax policy design. There is significant economic evidence that a carbon price will affect short-run behavior and long-run investments and will reduce emissions.

RFF has developed extensive modeling and other analytic tools for evaluating the effects of a carbon tax. These tools allow for the assessment of the effects of carbon tax policies across a number of key metrics, including annual emissions, annual revenues, cumulative emissions, consumer prices, economic growth, and the distribution of economic impacts. RFF researchers have used these tools directly to inform policymakers in carbon tax policy design and provide publicly accessible research that:

- Analyzes a number of policy proposals including the **2015**, **2017**, and **2019** versions of the American Opportunity Carbon Fee Act (Whitehouse-Schatz); the **MARKET CHOICE Act** (Curbelo); and the Climate Leadership Council **Carbon Dividends Plan**.
- Assesses the level of tax required to meet the **US obligation under the Paris Agreement**.
- Evaluates the **distributional effects** of various approaches to carbon taxes and recycling the generated revenues.
- Assesses the **effects of a carbon tax on employment**.

An additional consideration in the implementation of a carbon tax is the level of uncertainty in emissions reductions resulting from a given price path of a carbon tax. RFF researchers have recently described in detail how a **carbon tax might adjust automatically** to achieve an emissions target.

Cap and Trade

An alternate way to introduce a carbon price is through cap and trade, such as was implemented in the successful acid rain sulfur dioxide program. A carbon price is embodied in a trading program as the price of a tradable emissions allowance. Under cap and trade, the emissions goal is identified by the cap, but, in the absence of other policy constraints, the carbon price is set by the market as it adjusts to meet the annual limit on emissions.

To date, cap and trade has been the dominant approach to putting a price on carbon in the United States and abroad. For example, in the United States, eleven states have enacted a carbon cap for all or some portion of their economies. This has allowed for considerable experience and evolution of the policy mechanism. Lessons learned from these experiences as well as further considerations for policy design are highlighted in the following resources:

- **This Resources magazine article** and **this article** from the Review of Environmental Economics and Policy provide historical context for cap-and-trade programs, including specific policy design and implementation lessons and some political considerations that affect cap-and-trade policy design. It also provides guidance to assist with implementation of future policies and notes on the implications for climate change policy.

- One of the longest running carbon cap-and-trade programs in the United States is the Regional Greenhouse Gas Initiative (RGGI). This **Resources article**, written on the occasion of RGGI's 10th anniversary, describes some of the more innovative features, including auctioning of allowances and the use of cost containment mechanisms.
- Cap and trade programs have moved away from free allocation of emissions allowances because of concern that windfall profits could result when firms receive allowances for free that have substantial economic value in the market. However, in some cases the introduction of an auction for allowances is politically or economically difficult to achieve. RFF's work described a consignment auction approach that was used in the sulfur dioxide trading program and elsewhere, in which allowances are conditionally allocated, but they must be sold in auction with revenue coming back to the original recipients. This design adds considerable transparency and stronger incentives for efficient outcomes. The approach suggested was adopted by Virginia, and an RFF **article** described how this could work.
- Recently, in response to cost considerations, cap and trade programs have begun to adjust the size of their emissions caps. For example, RFF researchers worked with RGGI states to develop an "**emissions containment reserve**" (ECR) that would provide several important benefits to help improve the functioning of the market for emissions allowances. The ECR has **now been adopted**.
- Markets are increasingly watching government policy to inform their investment plans. This fact alters the relative strengths of alternative policy approaches, like cap and trade versus carbon taxes. Cap and trade policies have a feature that carbon taxes don't, which under certain conditions can encourage more cost-effective emissions reductions. Under a cap, the market price of permits reflects traders' expectations about future policy changes, such as tightening the cap as was done recently in Europe. Market participants then closely watch for potential changes in the cap when determining their emission reductions, whereas under a carbon tax, this determination is simply driven by the statutory tax rate. Current and former RFF researchers have explored these concepts in this **article**.

Uses of Revenues Generated under Carbon Pricing Proposals

Carbon pricing proposals are also often touted for the revenue they generate that can be used for other purposes. Though they impose their price on carbon in distinct ways, a carbon tax and cap and trade both convey a value on emissions that is evident in tax revenue or cap and trade allowance value. Past modeling along with analysis of recent US federal proposals has shown that such value can total more than **$1 trillion over a decade**. How such value is allocated provides a substantial opportunity in policy design and largely determines distributional outcomes.

At a high level, there are three main types of proposals:

- Imposing a tax swap; for example, using carbon pricing revenue to reduce other corporate or payroll taxes.
- Rebating dividends back to households.
- Spending on programs to accelerate emissions reductions or adapt to a changing climate ("green investment" strategies).

RFF and other organizations have conducted **research** on the trade-offs related to various tax swaps, as well as with lump-sum rebates back to households across various income quintiles. In comparison, at the current time there is not the same depth of research on the efficiency and effectiveness of proposed green investment strategies. Given that, in a number of policy proposals, such investment strategies are put forward as critical elements for achieving target emissions reductions, understanding more about their utility moving forward will be vital for informing the design of such policies.

Assessing the Benefits of Action to Reduce Greenhouse Gases

In the development of climate legislation, an important policy tool to evaluate the benefits of action to reduce emissions is the social cost of carbon: an estimate, in dollars, of the economic damages that would result from emitting one additional ton of greenhouse gases into the atmosphere. Economic theory additionally suggests that optimal carbon policy would price each GHG at its estimated social cost of carbon.

RFF researchers, as part of **RFF's Social Cost of Carbon Initiative**, are leading a team of distinguished economists and scientists to improve the science behind estimates of the social cost of carbon through a process that ensures the highest levels of scientific quality and transparency and builds the scientific foundation for future estimates.

In addition to the bottom-up calculation of the SCC based on evaluating projected damages across multiple economic sectors, there are also numerous studies in the literature which project damages from future climate change by evaluating the effects of historical fluctuations in climate on GDP. This **paper** improves our understanding of the uncertainty around estimates of the impacts of climate change on GDP.

International Trade and Competitiveness Considerations

A key policy consideration in any potential climate legislation is the potential effects on trade and competitive positioning of US firms. From the standpoint of building support for such legislation, unions, communities, and companies of energy-intensive trade-exposed (EITE) industries are likely

to oppose climate legislation that does not accommodate their concerns with regard to international trade and competitiveness for both imports and exports. In addition, major developing nations will react to US greenhouse gas legislation that they regard as imposing arbitrary restrictions on international trade with consequences for trade immediately and for climate and trade negotiations.

RFF research has explored the potential for a border adjustment to be implemented as a part of a carbon tax that will address competitiveness concerns while also maintaining compliance with World Trade Organization (WTO) requirements.

Key insights from such research include the following:

- WTO acceptable export rebates/import charges for EITE products can be created if there is upstream tax on greenhouse gases, but not with cap-and-trade or other regulatory approaches.
- In a cap-and-trade program, the competitiveness of domestic businesses can be **addressed** through output-based free allocation of emissions allowances.
- Essential greenhouse gas emission data and information on products produced in the United States at factories is available and can be used to determine export rebates based on carbon content, greenhouse gas emissions at factory site, and greenhouse gas emissions for purchased energy-intensive raw materials like electricity.
- For nations that export to the United States, import charges can be determined in a similar fashion, based on regulatory guidelines to measure and report GHG emissions in many nations or, absent approved regulatory guidelines, based on available, industry-endorsed voluntary guidelines that exist in most EITE sectors.
- To be compatible with US WTO obligations, border adjustment for imported products cannot give credit to EITE firms for the price or "effective price" paid for their domestic greenhouse gas policies.

Further details are contained in the following RFF publications:

- **Framework Proposal for a US Upstream Greenhouse Gas Tax with WTO-Compliant Border Adjustments**
- **A Compendium: WTO-Compatible Methodologies to Determine Export Rebates and Import Charges for Products of Energy-Intensive, Trade-Exposed Industries, if There Is an Upstream Tax on Greenhouse Gases**
- **Solution to a Vexing Climate Policy Problem: WTO-Compliant Border Adjustments**

Price Responsiveness and the Shale Boom

An additional consideration for any type of carbon pricing proposal is that, at the moment, US oil and gas production is more sensitive to price changes due to the shale boom. This suggests that carbon pricing could have bigger impacts on US oil and gas production now, compared to what previous studies have calculated using data and estimates that pre-date the shale boom.

Related resources:

- **The Unconventional Oil Supply Boom: Aggregate Price Response from Microdata**: An analysis of the price responsiveness of US conventional and unconventional oil supply across three key stages of oil production: drilling, completion, and production.
- **Trophy Hunting versus Manufacturing Energy: The Price Responsiveness of Shale Gas**: An analysis of the relative price responsiveness of unconventional versus conventional natural gas extraction and of three key stages of gas production: drilling wells, completing wells, and producing natural gas from the completed wells.

Sectoral Climate Policies

In contrast to an economy-wide approach, other climate policy options would address emissions from a given sector of the economy, such as the electricity sector, transportation sector, buildings, industry, etc. From an economic perspective, sectoral approaches are often considered less efficient than carbon pricing. However, such policies may be especially useful to promote technological innovation and may be necessary, for example, if a politically achievable carbon price is not sufficient to promote changes in the transportation or industrial sectors.

RFF research has considered a number of sectoral policies and the price effects of key enabling technologies for a transition to zero emissions within a given sector.

Power Sector

- When pricing carbon directly is not possible, an alternative approach that makes use of economic incentives and can be designed to be clean technology neutral is a tradeable clean energy standard. This **issue brief** describes how clean energy standards work and this **issue brief** provides projected effects of the federal Clean Energy Standard Act of 2019, introduced by Sen. Tina Smith and Rep. Ben Ray Luján.
- **Modeling** by several groups of researchers outside and inside RFF indicates that emissions pricing in the power sector would produce very large net benefits (i.e. benefits greatly exceed the costs), largely attributable to significant benefits to health from reductions in SO_2 and NOx emissions. In addition, the net benefits of replacing coal generation with gas generation as a result of less expensive gas or as a result of a CO_2 emission price or cap are significant even when accounting for the increased estimates of the leakage rate of methane from wells and pipelines suggested by recent literature.

- The research literature features differing views on the role of storage in reducing emissions. In this **paper**, RFF researchers find that although storage can reduce the costs of reducing power sector emissions to zero, in the medium term storage could increase emissions. Using a stylized model, the effect of storage costs on emissions is shown to depend on the supply responsiveness of both fossil and renewable generators.
- Reforms to the transmission planning and siting processes to enable nationwide and cross-border planning based on minimizing the cost of decarbonization would provide significant benefit in decarbonizing the power sector. Cross-border aspects of such transmission planning are discussed in this **report**.

Transportation Sector

Decarbonizing the transportation sector is particularly complex from a policy standpoint, and absent major policy changes, RFF research has shown that vehicle miles traveled are **likely to continue increasing** in the short/medium term. A number of policies have been put in place to try to reduce emissions from the transportation sector, including tightened fuel efficiency standards, zero- or partial-zero emissions vehicles mandates, subsidies for more fuel-efficient vehicles, and more. RFF research has highlighted a number of important considerations that bear upon policy design in this area:

- Federal fuel economy/GHG standards **may be regressive**, at least in the short term.
- Tightening fuel economy/GHG standards reduces demand for new vehicles, **raising the costs** of meeting the standards.
- There is **little evidence** on the economically efficient level of subsidy for plug-in vehicles. There are complex interactions among state and federal vehicle policies, making it difficult to effectively promote plug-in vehicles.

Industrial Sector

RFF experts are currently building a research program to further explore and evaluate viable and cost-effective solutions for reducing both process and electricity consumption-related emissions from industrial sources. To date, RFF's **research** in this area has focused on opportunities to reduce emissions in the industrial sector by promoting carbon capture storage and utilization (CCUS) in the existing tax code through section 45Q.

Agriculture and Forestry

Agricultural lands and forests have enormous potential for climate mitigation through biological carbon capture and sequestration as well as **sustainable biomass energy development**, which can have economic, societal and ecological co-benefits. Policy options to reduce emissions from forestry include:

- Support for active forest management on public and private lands that incentivizes reducing emissions (i.e., reduce large scale wildfires) and encouraging forest growth and restoration.
- Through USDA conservation programs, provide incentives for farmers to use carbon sequestration practices (e.g. cover crop rotations) as well as other practices that improve soil health and reduce nitrous oxide emissions. For further background, see this **article**.

RFF experts are currently building a research program to further evaluate and explore these areas and the broader role of agriculture and forest lands to contribute to climate change policy solutions.

Considerations for Overlapping Economy-Wide and Sector-Specific Policies

In practice, carbon pricing policies such as cap and trade, domestically and abroad, almost always coexist with other policies to encourage clean energy investment. RFF research has explored policy interactions between such policy tools.

- Allowing for emissions caps to **adjust automatically** in response to changes in market prices can preserve the integrity of other policies that lead to emissions reductions.
- This **analysis of the NY carbon pricing policy** illustrates how one jurisdiction's decision to impose a higher price on carbon emissions within the electricity sector interacts with price responsive emissions supply, in the form of the RGGI Emissions containment reserve, to yield CO_2 emissions reductions within NY State and beyond.
- Results from **this article** as well as **this one** suggest that the optimal set of policies for reducing emissions is a combination of policies that includes emission pricing and funding of research and development.
- Tax incentives have commonly been used alongside other policies to reduce emissions to promote particular technology solutions. Care must be taken in the design of such incentives to ensure that they are delivering the intended or expected level of reductions. This **study** provides a case study of the "refined coal" tax credit, now being claimed at $1 billion annually, which was intended to reduce conventional air pollutants, but instead is failing to achieve its goals and actually hindering reductions in CO_2 emissions by increasing coal use by power plants.

Conclusion

We include two closing observations about how to make progress. First, policy outcomes are certain to involve a portfolio of these options and to involve measures at the federal, state and local level. This policy mix may be desirable for various reasons, such as to promote innovation, achieve ancillary benefits for example from improved air quality, or to achieve distributional outcomes. It is important that policies be designed in anticipation of overlapping influence to maximize the effectiveness of the entire portfolio.

The greenhouse gas emissions reduction goals identified by Committee leaders are ambitious, so too were the targets under the Clean Air Act in 1970, which addressed multiple pollutants across the economy and for which technologies to achieve emissions reductions did not exist at the time. The achievements under the Clean Air Act were monumental. As noted above, a recent book sponsored by the American Academy of Arts and Sciences **identified crucial features** that enabled the Clean Air Act to be durable, adaptable and flexible in achieving its goals. A key element of that success was the unusually formalized role of process in achieving scientific and citizen engagement. We can expect such attention to process to be important in addressing the ongoing and evolving challenges of climate change.

RFF Climate Policy Experts

This is a selection of RFF scholars with climate policy expertise. For additional information about our researchers, visit rff.org/people.

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Joe Aldy is a professor of the practice of public policy at the John F. Kennedy School of Government at Harvard University, a university fellow at Resources for the Future, a faculty research fellow at the National Bureau of Economic Research, and a senior adviser at the Center for Strategic and International Studies. He is also the faculty chair for the Regulatory Policy Program at the Mossavar-Rahmani Center for Business and Government. His research focuses on climate change policy, energy policy, and regulatory policy. In 2009-2010, Aldy served as the special assistant to the President for Energy and Environment. He also served as the co-director of the Harvard Project on International Climate Agreements, co-director of the International Energy Workshop, and treasurer for the Association of Environmental and Resource Economists before joining the Obama Administration.

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Jay Bartlett joined RFF as a senior research associate in 2018 to work on financial, economic and policy analysis for the Future of Power Initiative. Previously, he worked in the Office of Energy Efficiency and Renewable Energy and the Solar Energy Technologies Office at the US Department of Energy. Bartlett had earlier positions in alternative energy equity research at UBS, mergers and acquisitions at a boutique advisory firm in New York and in biophysics research at Princeton.

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Ann M. Bartuska is a senior advisor at RFF focusing on natural resources and forestry, especially a consideration of natural climate solutions through forests and agricultural lands. She also does outreach in support of the valuation of information (VALUABLES) obtained through satellite imagery. Bartuska joined RFF in 2017 after serving as the US Department of Agriculture's (USDA's) deputy under secretary for research, education, and economics as well as chief scientist. Prior to USDA, Bartuska held a host of leadership positions, including deputy chief for research and development of the US Forest Service. She also has served on the advisory board of the National Science Foundation, as executive director of The Nature Conservancy's Invasive Species Initiative, and as president of the Ecological Society of America.

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Robert Bonnie is a research scholar at Duke University's Nicholas Institute for Environmental Policy Solutions, working on conservation and environmental issues in rural America. Prior to joining Duke, during the second term of the Obama Administration, Bonnie was the under secretary for natural resources and environment at the US Department of Agriculture. In this role, he oversaw the US Forest Service and the Natural Resources Conservation Service on a variety of natural resource issues. During President Obama's first term, Robert served as Senior Advisor to Secretary of Agriculture Tom Vilsack for environment and climate change. Prior to joining USDA, Robert was vice president for land conservation for the Environmental Defense Fund where he focused on developing incentives to reward farmers, ranchers and forest owners for stewardship activities on private lands.

RFF Climate Policy Experts

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Tim Brennan, a professor of public policy and economics at the University of Maryland, Baltimore County (UMBC), has been with RFF since 1995. His work at RFF examines electricity market design, state and federal regulation, and more recently energy efficiency policy. Brennan began his career as a staff economist at the Antitrust Division of the US Department of Justice, where his work included the monopolization cases against AT&T and Microsoft. He has been the senior economist for industrial organization and regulation for the White House Council of Economic Advisers, held the T.D. MacDonald Chair in Industrial Economics at the Canadian Competition Bureau. In 2014 he served as chief economist at the Federal Communications Commission.

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Dallas Burtraw has worked to promote efficient control of air pollution and written extensively on electricity industry regulation and environmental outcomes. Burtraw's current research includes analysis of the distributional and regional consequences of climate policy, the evolution of electricity markets including renewable integration, and the interaction of climate policy with electricity markets. He has provided technical support in the design of carbon dioxide emissions trading programs in the Northeast states, California, and the European Union. He also has studied regulation of nitrogen oxides and sulfur dioxide under the Clean Air Act and conducted integrated assessment of costs, and modeled health and ecosystem effects and valuation, including ecosystem improvement in the Adirondack Park and the southern Appalachian region. Burtraw currently serves as chair of California's Independent Emissions Market Advisory Committee.

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Roger Cooke's research has widely influenced risk assessment methodology, particularly in the areas of expert judgment and uncertainty analysis. He is recognized as one of the world's leading authorities on mathematical modeling of risk and uncertainty. His current research includes structured expert judgment methodologies and uncertainty analysis, and his work focuses on the implementation of uncertainty analysis in policy-related decisionmaking. Prior to joining RFF, Cooke was professor of applied decision theory at the Department of Mathematics at Delft University of Technology, where he launched a Risk and Environmental Modeling master's program. Cooke has served as a consultant to the Japanese government, the Swedish Nuclear Inspectorate, the Dutch National Aeronautics Laboratory, the US Nuclear Regulatory Commission, and several other jurisdictions. Cooke is a lead author on the chapter addressing risk and uncertainty in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

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Maureen Cropper is a senior fellow at RFF, a professor of economics at the University of Maryland, and a former lead economist at the World Bank. She has made major contributions to environmental policy through her research, teaching, and public service. Her research has focused on valuing environmental amenities, estimating consumer preferences for health and longevity improvements, and the tradeoffs implicit in environmental regulations. At the World Bank, her work focused on improving policy choices in developing countries through studies of deforestation, road safety, urban slums, and health valuation. Cropper is currently studying the externalities associated with pandemic flu control, the impact of reforms in the electric power sector in India and the demand for fuel economy in the Indian car market. Cropper has served as president of the Association of Environmental and Resource Economists and on the US Environmental Protection Agency's Science Advisory Board. She is a research associate of the National Bureau of Economic Research and a member of the National Academy of Sciences.

RFF Climate Policy Experts

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Rebecca Epanchin-Niell's research focuses on ecosystem management, particularly understanding how human behavior affects ecological resources and identifying strategies to improve management. Much of her work has focused on invasive species, including strategies to control established invaders, improvement of monitoring strategies, and cooperative management. Epanchin-Niell's work often draws on econometric and bioeconomic modeling approaches and incorporates spatial aspects of resource movement and use.

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Carolyn Fischer is a senior fellow with Resources for the Future and holds joint appointments as a professor of environmental economics at the Vrije Universiteit—Amsterdam and as a Canada 150 research chair in climate economics, innovation and policy at the University of Ottawa. She is a Tinbergen Institute affiliate, a fellow of the CESifo Research Network, a member of Environment Canada's Economics and Environmental Policy Research Network, and vice president and council member for the European Association of Environmental and Resource Economists. She is co-editor of *Environmental and Resource Economics* and serves on the editorial board of multiple other academic journals. Fischer's research explores questions of environmental policy instrument design. She applies microeconomic theory and other modeling techniques to a variety of environmental and resource management issues, including climate and renewable energy policies, carbon leakage, technological innovation, eco-certification, and wildlife conservation.

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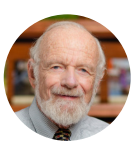
Brian Flannery joined Resources for the Future as a visiting fellow in 2012. At RFF, he continues involvement on climate and energy issues that began in 1980 when he joined Exxon's Corporate Research Laboratory. In 2011 he retired from Exxon Mobil Corporation as Science, Strategy and Programs Manager. At Exxon, he conducted research, organized international workshops and symposia dealing with climate-related science, technology, economics, and policy, and worked with others across the organization on a variety of activities involving research, operations, projects and issues where climate change was a factor. Flannery is coauthor of the reference *Numerical Recipes: the Art of Scientific Computing*. The series of books and software is widely used by scientists, engineers, economists and others who create or utilize technical computing in their research. Flannery's current interests center on developments in the Paris Agreement and challenges of reconciling obligations under the WTO and UNFCCC—in particular, border tax adjustments.



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Arthur Fraas is a visiting fellow at Resources for the Future. At RFF, Fraas works on a variety of issues related to energy and the environment, including projects looking at issues and tradeoffs with energy efficiency regulations, the development of retrospective analyses of major environmental rules, the treatment of uncertainty in regulatory analysis, and the potential regulation of greenhouse gases under the Clean Air Act. Before joining the OMB, Fraas was a senior economist at the Council on Wage and Price Stability, a staff member of the Senate Judiciary Subcommittee on Antitrust and Monopoly, an assistant professor of economics at the US Naval Academy, and a staff economist with the Federal Reserve System.

RFF Climate Policy Experts

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Lawrence Goulder is the Shuzo Nishihara professor in environmental and resource economics at Stanford University and director of the Stanford Center for Environmental and Energy Policy Analysis. He is also a research associate at the National Bureau of Economic Research; and a university fellow at RFF. Goulder's research covers a range of environmental issues, including green tax reform, the design of cap-and-trade systems, climate change policy, and comprehensive wealth measurement ("green" accounting). His work often employs a general equilibrium analytical framework that integrates the economy and the environment and links the activities of government, industry, and households. The research considers both the aggregate benefits and costs of various policies as well as the distribution of policy impacts across industries, income groups, and generations.

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Marc Hafstead joined RFF in 2013 from Stanford University. He is a leading researcher on the evaluation and design of climate and energy policies. With Stanford Professor and RFF University Fellow Lawrence H. Goulder, he wrote *Confronting the Climate Challenge: US Policy Options* (Columbia University Press) to evaluate the environmental and economic impacts of carbon taxes, cap-and-trade programs, clean energy standards, and gasoline taxes using a sophisticated multi-sector model of the United States. He is also a leading expert on the employment impacts of carbon pricing and the design of tax adjustment mechanisms to reduce the emissions uncertainty of carbon tax policies. His work has been featured in the popular press, including the *Wall Street Journal*, the *Washington Post*, Axios, and CNNMoney.

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Raymond Kopp has held a variety of management positions within RFF. Kopp's interest in environmental policy began in the late 1970s, when he developed techniques to measure the effect of pollution control regulations on the economic efficiency of steam electric power generation. He then led the first examination of the cost of major US environmental regulations in a full, general equilibrium, dynamic context by using an approach that is now widely accepted as state-of-the-art in cost-benefit analysis. During his career Kopp has specialized in the analysis of environmental and natural resource issues with a focus on Federal regulatory activity. He is an expert in techniques of assigning value to environmental and natural resources that do not have market prices, which is fundamental to cost-benefit analysis and the assessment of damages to natural resources. Kopp's current research interests focus on the design of domestic and international policies to combat climate change.

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Alan Krupnick's research focuses on analyzing environmental and energy issues, in particular, the benefits, costs and design of pollution and energy policies, both in the United States and abroad. He leads RFF's research on the risks, regulation, and economics associated with shale gas development and has developed a portfolio of research on issues surrounding this newly plentiful fuel. Krupnick served as senior economist on the President's Council of Economic Advisers, advising the Clinton administration on environmental and natural resource policy issues. He co-chaired a federal advisory committee counseling the US EPA on the implementation of new ozone and particulate standards. He is a regular member of expert committees from the National Academy of Sciences, the US EPA, and various Canadian government and non-governmental institutions. Krupnick consults with state governments, federal agencies, private corporations, the Canadian government, the European Union, the Asian Development Bank, the World Health Organization, and the World Bank.

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Benjamin Leard is a Fellow at Resources for the Future. He is an environmental economist who focuses his work on transportation policy, climate change, and discrete choice modeling. His recent work involves estimating household preferences for vehicle attributes and evaluating the costs and benefits of fuel economy and greenhouse gas standards for light duty vehicles. His work has been published in *Science* magazine, and he has been cited in the *Washington Post* for his research on consumer demand for autonomous vehicles.

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Joshua Linn is an associate professor in the Department of Agricultural and Resource Economics at the University of Maryland and a senior fellow at RFF. His research centers on the effects of environmental policies and economic incentives for new technologies in the transportation, electricity, and industrial sectors. His transportation research assesses passenger vehicle taxation and fuel economy standards in the United States and Europe. His work on the electricity sector has compared the effectiveness of cap and trade and alternative policy instruments in promoting new technology and reducing emissions of carbon dioxide and local air pollutants.

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Wesley Look joined RFF as a senior research associate in 2017. Previously, Look served as advisor on energy and environment to the US Senate Finance Committee and ranking member Senator Ron Wyden (D-OR). Look advised Senator Wyden on a range of clean energy and climate policies, including the senator's energy policy portfolio on the Senate Energy Committee. From 2007 to 2010, Look advised US cities on climate and energy policy as Program Officer with the International Council for Local Environmental Initiatives (ICLEI). Look is an expert on carbon pricing policy design.

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Jan Mares is a senior advisor with Resources for the Future, where he is involved with work on energy and environmental issues. Previously, he was a business liaison director and then a deputy director with the Private Sector Office of the Department of Homeland Security (DHS) from 2003 until 2009. During the second term of the Reagan administration, Mares was an assistant secretary of commerce for Import Administration and a senior policy analyst at the White House, where he was involved with environment, energy, trade, and technology issues. From 1981 to 1985, Mares also served as assistant secretary of energy for international affairs and energy emergencies, assistant secretary of energy for policy, safety, and environment, and assistant secretary of energy for fossil energy. For six months, he was the acting under secretary of energy. Before entering federal service, Mares was with Union Carbide Corporation.

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Gilbert E. Metcalf is the John DiBiaggio Professor of Citizenship and Public Service and Professor of Economics at Tufts University. In addition, he is a research associate at the National Bureau of Economic Research and a university fellow at RFF. Metcalf's primary research area is applied public finance with particular interests in taxation, energy, and environmental economics. His current research focuses on policy evaluation and design in the area of energy and climate change. He has frequently testified before Congress, served on expert panels for the National Academies of Sciences and the US Environmental Protection Agency, and served as a consultant to numerous other organizations. During 2011 and 2012, he served as the Deputy Assistant Secretary for Environment and Energy at the US Department of Treasury, where he was the founding US Board Member for the UN based Green Climate Fund.

RFF Climate Policy Experts

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Richard Morgenstern's research focuses on the economic analysis of environmental issues, with an emphasis on the costs, benefits, evaluation, and design of environmental policies, especially economic incentive measures. His analysis also focuses on climate change, including the design of cost-effective policies to reduce emissions in the United States and abroad. Immediately prior to joining RFF, Morgenstern was senior economic counselor to the under secretary for global affairs at the US Department of State, where he participated in negotiations for the Kyoto Protocol. Previously, he served at the US Environmental Protection Agency, where he acted as deputy administrator (1993); assistant administrator for policy, planning, and evaluation (1991–93); and director of the Office of Policy Analysis (1983–95). He has served on expert committees of the National Academy of Sciences and as a consultant to various organizations.

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Dr. Richard G. Newell is the President and CEO of RFF and an adjunct professor at Duke University, where he was previously the Gendell Professor of Energy and Environmental Economics and founding director of its Energy Initiative and Energy Data Analytics Lab. From 2009 to 2011, he served as the administrator of the US Energy Information Administration, the agency responsible for official US government energy statistics and analysis. He has served as the senior economist for energy and environment on the President's Council of Economic Advisers and was a senior fellow, and later a board member, at RFF. Dr. Newell has published widely on the economics of markets and policies for energy and the environment, including issues surrounding global climate change, energy efficiency, and energy innovation. He has provided expert advice to many institutions, such as the National Academy of Sciences, the Intergovernmental Panel on Climate Change, and the International Energy Forum, and is a member of the National Petroleum Council.

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Karen Palmer specializes in the economics of environmental regulation and public utility regulation, particularly on issues at the intersection of climate policy and the electricity sector. Her work seeks to improve the design of incentive-based environmental and technology regulations that influence the electric utility sector and to help inform the ongoing transition of the electricity sector. To these ends, she explores new designs for policies targeting carbon emissions; analyzes efficient ways to promote the use of renewable sources of electricity and energy efficiency; and investigates market and regulatory reforms to pave the way for long-term decarbonization of electricity supply and electrification of the energy economy. She is coauthor of the book, *Alternating Currents: Electricity Markets and Public Policy*, published by RFF Press.

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William Pizer is the Susan B. King Professor and Associate Dean for Academic Programs at the Sanford School of Public Policy and Faculty Fellow at the Nicholas Institute for Environmental Policy Solutions, both at Duke University, and an RFF fellow. His current research examines how we value the future benefits of climate change mitigation, how environmental regulation and climate policy can affect production costs and competitiveness, and how the design of market-based environmental policies can address the needs of different stakeholders. He has been actively involved in creation of an environmental program at Duke Kunshan University in China, a collaborative venture between Duke University, Wuhan University, and the city of Kunshan. From 2008 until 2011, he was deputy assistant secretary for Environment and Energy at the US Department of the Treasury, overseeing Treasury's role in the domestic and international environment and energy agenda of the United States.

RFF Climate Policy Experts

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Brian Prest specializes in climate change, oil and gas, and electricity markets. Prest uses economic theory and econometric models to understand energy supply dynamics and improve the design of environmental policies. In his current work, he is assessing the impacts of poor incentive structures in electricity markets on plant emissions and negative prices. He is also working to establish an empirical basis for determining discount rates used in the social cost of carbon. His past work includes econometric analysis of the US oil and gas industry, modeling the intertemporal dynamics of climate change policy under policy uncertainty, and assessing household responses to dynamic electricity pricing.

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Daniel Raimi is a senior research associate at RFF and a lecturer at the Gerald R. Ford School of Public Policy. He works on a range of energy policy issues, with a focus on oil and gas regulation and taxation and climate change policy. He has published in academic journals and popular outlets, and he has presented his research around the United States and internationally. *The Fracking Debate*, his first book, combines stories from his travels to dozens of oil and gas producing regions with a detailed examination of key policy issues. Raimi's current research examines the future of oil and gas development in the United States, focusing on how producing communities are managing near-term impacts while planning for the future. Raimi also hosts *Resources Radio*, RFF's weekly podcast.

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Kevin Rennert leads RFF's initiative to improve estimates of the social cost of carbon—a means by which policymakers account for climate change in their actions. Prior to joining RFF, Rennert served as the deputy associate administrator for the Office of Policy at the US EPA. Leading up to his appointment in the Office of Policy, he worked as senior advisor on energy for the Senate Finance Committee. In that role, Rennert advised the committee's chairman, Senator Ron Wyden, on a wide range of topics related to clean energy, efficiency, and policies to reduce greenhouse gas emissions. From 2008 to 2014, he worked on energy and climate legislation as senior professional staff for the Senate Energy Committee, leading the development of the Clean Energy Standard Act of 2012, a presidential priority that would use market mechanisms to double the amount of electricity generated in the US from low- or zero-carbon sources by 2035.

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Jhih-Shyang Shih's research interests lie in integrated system analysis of environmental and resource policy and decisionmaking. Shih has extensive experience with modeling to study energy and environmental issues, such as air quality, risk, and surface water and solid waste management, and he has studied the costs of environmental protection, technology adoption, and renewable energy. Shih's recent research has focused on electric and thermal energy storage; sustainable infrastructure; integration of renewable and energy storage; bioenergy; water resources and water quality management; energy-water nexus; and integrated assessment of climate change, land use, air and water quality.

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Daniel Shawhan's research focuses on predicting and estimating the effects of electricity policies. He has played a leading role in developing a new set of capabilities for simulating how power grids, power plants, and pollution levels will respond to potential changes in policy. He also works on electricity market design and environmental policy design. Shawhan has helped state governments craft electricity market reforms and first-in-the-nation policies for hybrid vehicles, energy efficiency, green buildings, and renewable energy.

RFF Climate Policy Experts

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Robert N. Stavins is the A.J. Meyer Professor of Energy & Economic Development, John F. Kennedy School of Government, Harvard University, Director of the Harvard Environmental Economics Program, Director of Graduate Studies for the Doctoral Program in Public Policy and the Doctoral Program in Political Economy and Government, Co-Chair of the Harvard Business School-Kennedy School Joint Degree Programs, and Director of the Harvard Project on Climate Agreements.

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Margaret Walls's research focuses on resilience and adaptation to extreme events; ecosystem services; and conservation, parks, and public lands. Walls's work on resilience assesses the factors that affect household location decisions in coastal areas, how individuals perceive flood risks, and how risk perceptions affect adaptation decisions. She has estimated the value of natural lands—such as wetlands—in providing protection from hurricanes and flooding, and is assessing the extent to which hurricanes affect US migration patterns. In 2008 and 2009, she was the study director for the Outdoor Resources Review Group, a bipartisan commission of experts assessing status and trends in conservation, public lands, and outdoor recreation resources. She is currently analyzing the local economic impacts of national monuments. Walls currently serves on the board of the Association of Environmental and Resource Economists.

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Matthew Wibbenmeyer's research seeks to understand important factors that influence administration of environmental management and to use this understanding to inform improved policy. With a focus on forest and land management, he is interested in how actions and interactions among government and individuals determine management outcomes. His current work includes an analysis of outcomes of wildfire suppression in the western United States, as well as research linking economic models of individual and government behavior with biophysical forest ecology models to study implications of behavioral biases for forest management. Wibbenmeyer's past work has used stated preference methods to study wildfire manager attitudes toward risk.

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Rob Williams studies both environmental policy and tax policy, with a particular focus on interactions between the two. In addition to his role at RFF, he is a professor at the University of Maryland, College Park and a research associate of the National Bureau of Economic Research. He was previously an associate professor at the University of Texas, Austin; a visiting research scholar at the Stanford Institute for Economic Policy Research; and an Andrew W. Mellon Fellow at the Brookings Institution. Williams has served as a coeditor of both the Journal of Public Economics and the Journal of Environmental Economics and Management.