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Executive Summary

Robert N. Stavins, Todd Schatzki and Rebecca Scott[1]

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A combination of factors pose significant barriers to developing effective and efficient sets of policies to achieve long-run climate policy objectives. Political opposition to particular types of policy mechanisms (for example, GHG pricing) and the global, stock-pollutant nature of the climate problem are among the major factors posing practical policy challenges. Effective and efficient climate policy is needed in the long run to meaningfully address the climate problem, making the design of transitions to such long-run policies from the current portfolio of policies an important task for policymakers.

1. Efficient Long-Run Climate Policy Should be Grounded in GHG Pricing, with Additional Policies to Target Emissions Not Subject to GHG Pricing and Address Other Relevant Market Failures

It is widely acknowledged that the foundation of long-run effective and efficient GHG policy will be GHG pricing reflecting the social cost of GHG emissions. Effective and efficient policies, however, must address two key issues. First, because it is infeasible, impractical, or too costly to monitor some emission sources, GHG pricing will inevitably not cover all emissions. For example, agricultural sources, such as methane from cows, are typically not covered by cap-and-trade systems. Hence, policy measures targeting emissions sources not covered by GHG pricing should be undertaken (if those policies foster benefits greater than costs). Second, market failures *unrelated* to the GHG emission externality can directly or indirectly affect GHG emissions. We refer to these as "non-GHG market failures." For example, firms may invest too little in research and development (R&D) on low-GHG technology development because information about their innovations will spill over to other firms, thus preventing investing firms from capturing the full benefits of their investments. Patents reduce but do not fully prevent these information spillover effects. Other market failures affect property-owner investments in energy efficiency, development of alternative vehicle refueling infrastructure ("chicken-and-egg" problems), and many other energy-related decisions. Appropriate, well-designed policies addressing these specific market failures can improve economic outcomes, while reducing emissions.

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Long-run efficient climate policies do not include all policy options that can reduce GHG emissions. For example, performance standards aimed primarily at reducing GHG emissions are less cost-effective than GHG pricing. Moreover, when implemented alongside cap-and-trade, these policies may create perverse interactions, raising costs but creating little (or no) change in GHG emissions. Our previous analysis demonstrated that due to these interactions, California's Low Carbon Fuel Standard (LCFS) *increased* GHG emissions (given increases in out-of-state emissions) and raised costs by over $700 million from 2013 to 2017.

While political factors may make immediate adoption of GHG pricing at appropriate levels impractical, wise policy design can enable a smooth transition to such pricing over time. Making this transition will yield large social benefits, and it may be necessary in order to meaningfully reduce GHG emissions if the high costs of less-efficient approaches reduce society's willingness to pursue them.

Reducing reliance on less-efficient policies may face opposition. Once in place, firms supplying the products and technologies needed to comply with these policies have a vested interest in perpetuating the policies. For example, rooftop solar installers have an interest in maintaining policies subsidizing rooftop solar. However, gradual transition away from more costly policies can mitigate the impacts on these firms, as citizens gradually become acclimated to GHG pricing.

2. Governments Have Options to Transition from Current Policies to Efficient Long-Run Policies

The first step in the transition to efficient long-run climate policies is establishing GHG pricing. In practice, initial pricing levels will be below the socially optimal level because of political constraints, among other factors. But once adopted, GHG pricing can be gradually increased.

In tandem, dependence on complementary policies targeting GHG emissions also covered by cap-and-trade (for example, performance standards) can be reduced. This transition has several effects. *First*, reducing reliance on the less-efficient policies undoes the artificial downward pressure they put on GHG prices. Thus, the price distortion is reduced. *Second*, gradually reducing dependence on these policies lowers costs, as the less-efficient policy is scaled back. *But* this transition does not impact on total emissions when GHG pricing is created through a cap-and-trade program.

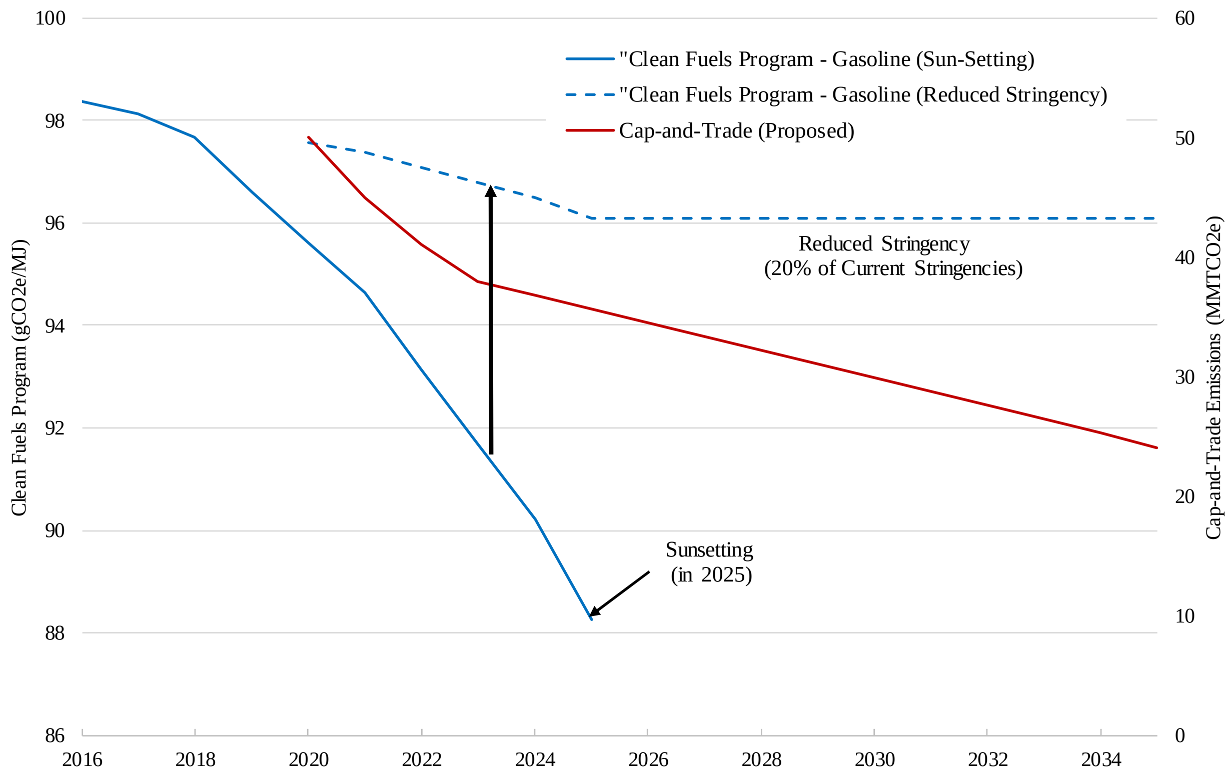
There are three options to reduce reliance on a complementary policy: (1) reducing its stringency; (2) ending the program at a future date ("sunsetting"); or (3) a combination of (1) and (2). For example, **Figure ES-1** illustrates two alternatives trajectories for Oregon's Clean Fuel Program (CFP), which reduces the carbon-intensity of transportation fuels by 10 percent by 2025. One alternative (the dashed blue line) reduces the carbon-intensity reductions by 80 percent compared to current levels. A second alternative (the solid blue line) sunsets the CFP in 2025, but otherwise keeps the CFP carbon-intensity standard unchanged; the current rule keeps the CFP carbon-intensity at the 2025 level, unless the standard is subsequently changed. By comparison, the cap-and-trade program's emission cap remains unchanged; thus, total in-state emissions are unchanged although the CFP standards are modified.

3. Governments Have Multiple Options for Efficiently Addressing Market Failures Not Directly Related to GHG Emissions

Governments have many policy options to address non-GHG market failures. A transition to more efficient climate policy can include new (or enhanced) measures that address these market failures.

Developing the best mix of policies is important to ensuring that these market failures are addressed effectively and efficiently.

Figure ES-1. Illustrative Trajectories for Alternative Clean Fuel Program Standards



One important market failure is underinvestment in R&D to bring down the costs and increase the efficiency of low-GHG technologies. Some may resist reducing reliance on less-efficient complementary policies under the belief that they create needed incentives for innovation in low-GHG technologies. Given this concern, a complementary policy can be replaced with more-targeted policies aimed at achieving these innovation benefits; moreover, this substitution can increase efficiency, producing more innovation gains at lower cost.

Performance standards uniformly target all emission reductions regardless of whether they are created by undeveloped technologies or existing technologies. Thus, such a standard creates only small or modest incentives for innovation while imposing relatively high costs. Our previous analysis of California's policy mix showed that the incremental costs of performance standards compared with cap-and-trade can be large, despite the fact that such policies may lead to only limited technology innovation. By contrast, targeted incentives better exploit society's resources to promote innovation. For example, the California Solar Initiative subsidized solar installations in the early stages of deployment, but was phased down over time to avoid subsidizing the technology once it was commercialized.

There are a number of options to support technology development at various stages of the innovation process, including investment in basic research, innovation contests (for example, prizes for the first technology to meet a pre-defined goal), government adoption of new technologies, subsidies for early-stage technologies (declining as technologies reach commercialization), and investment in infrastructure necessary for new technology deployment (for example, electric vehicle charging stations). Smaller jurisdictions (such as individual states, like Oregon) may face practical considerations that make certain options more efficient and feasible than others.

Thus, governments have sensible approaches to climate policy that increase reliance on GHG pricing over time, reduce the use of less efficient complementary policies, and expand policies that enhance innovation. Such policy evolution over time reduces costs, while preserving GHG emission goals.

Transitioning to Long-Run Effective and Efficient Climate Policies

Robert N. Stavins, Todd Schatzki and Rebecca Scott[2]

March 2019

A combination of factors pose significant barriers to developing effective and efficient portfolios of policies to achieve long-run climate policy objectives. Among these factors are political opposition to particular types of policy mechanisms; challenges converting local concern about the climate to efficient policies, given the global-commons, stock-pollutant nature of the climate problem; technical challenges in designing low-GHG energy systems; and coordination challenges among nations given free-rider incentives. Given these factors, the design of current climate policies ought to consider the sequence of policy design, with the aim of transitioning over time to more effective and efficient climate policies.

This paper evaluates factors affecting the potential to transition over time to more efficient long-run climate policies, including the sequence of policies to be adopted. By considering these factors, policymakers can increase the likelihood that more efficient policies emerge from the current suite of less-efficient measures being pursued by some national and sub-national governments.[3]

To make these concepts tangible, we focus on the state of Oregon, which is currently contemplating the adoption of a GHG cap-and-trade system.[4] Policies that create GHG pricing, such as a cap-and-trade system, are the foundation of an economically efficient climate policy. But the immediate transition to GHG pricing at efficient price levels is politically tenuous. Thus, in the interim, many jurisdictions pursue less efficient (and less effective) policies that pass political muster. We consider how governments, such as the State of Oregon, might transition from these less-efficient policies to more efficient GHG pricing policies over time.

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[3] This paper builds upon our previous paper, "GHG Cap-and-Trade: Implications for Effective and Efficient Climate Policy In Oregon". In that paper, we evaluated Oregon's proposed GHG cap-and-trade system and considered its implications for other climate policies Oregon had already adopted. In this paper, we focus on how governments, such as Oregon, can shift toward more efficient long-run climate policies.

[4] For example, Senate Bill 1507, also known as Oregon's Clean Energy Jobs bill, would create a GHG cap-and-trade system for major sources of GHG emissions. 79th Oregon Legislative Assembly, Senate Bill 1507, Ordered February 16, 2018.

In Section I, we start by defining the principles of long-run effective and efficient climate policies. We also discuss various barriers to immediate adoption of more efficient policies and consider how the sequence of policies adopted can affect a government's ability to transition to more efficient policies in the long run. Sections II and III consider particular transitions through which governments can improve the long-run efficiency of climate policies. In Section II, we consider the transition from less-efficient complementary policies aimed at reducing GHG emissions to GHG pricing. In Section III, we consider policy transitions aimed at addressing market failures that indirectly affect GHG emissions, focusing on policies to increase the pace of development of low-GHG technologies without resorting to sector- or technology-specific standards.

I. LONG-RUN EFFECTIVE AND EFFICIENT CLIMATE POLICIES

The fundamentals of economically efficient or cost-effective (least-cost) climate policies are well understood, but political and technical impediments can lead to the adoption of climate policies that fall short in various regards. As a result, governments often take a "belts and suspenders" approach that pursues GHG abatement through broad suites of policy measures that separately target each category of emission source. While an efficient climate policy will likely include multiple measures, those measures will look different from a set of policy measures which focus on individual sources.

A. Economic Principles for Long-Run Effective and Efficient Climate Policies

From an economic perspective, efficient climate policy will aim to reduce GHG emissions through a set of policies that maximize net benefits (that is, the difference between benefits and costs). This set of policies will include three components to address three respective market failures as directly as possible:[5]

1. **GHG pricing.** GHG pricing internalizes the environmental impacts of energy-use decisions of households, businesses, and industry through either a GHG cap-and-trade system or a GHG tax. In principle, the price placed on GHG emissions should reflect the true costs (damages) of GHG emissions, often referred to as the "social cost of carbon". An important numerical benchmark for the social cost of carbon are estimates developed by the United States Government's Interagency Working Group (IWG) on the Social Cost of Greenhouse Gases.[6, 7] The IWG's most

[5] Bennear, Lori and Robert N. Stavins, "Second-best theory and the use of multiple policy instruments," *Environmental and Resource Economics* 37(1): 111-129, 2007.

[6] These social costs of carbon estimates represent the global damages to various sectors, including agriculture and energy dependent sectors, climate driven human health impacts, damages from sea-level rise, and impacts to ecosystem services. Peace, Janet and Robert N. Stavins, "In Brief: Meaningful and Cost Effective Climate Policy: The Case for Cap and Trade," Pew Center on Global Climate Change, June 2010; Stavins, Robert N., "A U.S. Cap-and-Trade System to Address Global Climate Change," The Hamilton Project, October 30, 2007.

[7] The IWG developed these estimates to provide United States' regulatory bodies with a consistent estimate of the social cost of carbon for use in regulatory analyses. *See* Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12688, Interagency Working Group on Social Cost of Carbon, United States Government, February 2010 ("TSD 2010"). For other estimates, *see for example* National Research

recent estimates indicate that the social cost of carbon from emissions occurring in 2030 would range from $25 to $115 per metric ton (in nominal dollars), depending upon the choice of discount rate used to convert the future damages created by those emissions into present value terms.[8]

2. **Complementary policies targeting sources not covered by GHG pricing.** Because it is infeasible, impractical, or too costly to monitor some emission sources, GHG pricing will inevitably not cover all emissions. For example, agricultural sources, such as methane from cows, are typically not covered by cap-and-trade systems. Hence, policy measures targeting emissions sources not covered by GHG pricing should be included (if those policies foster benefits greater than costs).

3. **Complementary policies targeting "non-GHG market failures."** Some economic decisions that directly or indirectly affect GHG emissions are plagued by market failures *unrelated* to the GHG emission externality. We refer to these as "non-GHG market failures." Such market failures arise from innovation spillovers, network externalities, information problems, behavioral phenomena, congestion externalities, and other factors.[9] Policies directly aligned with the underlying market failure will typically address the problem most efficiently and effectively. For example, network externalities associated with refilling/recharging stations may suggest directly subsidizing refilling/recharging networks, rather than subsidizing all forms of low-GHG transportation (for example, LCFS).[10]

Long-run efficient climate policies by no means include all potential complementary policies that (directly or indirectly) reduce GHG emissions. In particular, various types of standards may be less cost-effective than GHG pricing in achieving emission reductions. Examples of such standards include low carbon fuel standards that mandate reductions in the average carbon-intensity of transport fuels and renewable portfolio standards that mandate increases in the share of electricity generated by so-defined renewable technologies.

Council, 2009, *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*, Washington, DC: The National Academies Press at 216-219 for a brief review.

[8] For example, the social cost of carbon in 2030 reflects present and future damages from 1 metric ton of emissions in 2030 discounted back to 2030 at a 3 percent discount rate. See TSD 2016 at 4. The IWG reports the social cost of carbon in $2007. We convert $2007 to $2030 using historical annual average CPI values for all urban consumers provided by the BLS (https://www.bls.gov/cpi/tables/supplemental-files/home.htm) and forecasted CPI values that we derive from forecasted year to year (specifically Q4 to Q4) percent changes in the CPI presented by the 2018 Economic Report of the President, (https://www.whitehouse.gov/wp-content/uploads/2018/.../ERP_2018_Final-FINAL.pdf, Table 8-1, column 4).

[9] Schatzki and Stavins (2018) provide a discussion of these market failures. For a related discussion, focusing on renewable energy technologies, *see* Gillingham, Kenneth and James Sweeney, "Market Failure and the Structure of Externalities", In: Harnessing Renewable Energy, Boaz Moselle, Jorge Padilla, Richard Schmalensee (eds). RFF Press, 2019.

[10] Of course, this approach is not without challenges. Uncertainty over which new technology will be the most cost-effective inevitably creates risk that the wrong technology is subsidized.

When implemented with efficient GHG pricing, such overlapping complementary policies may provide limited environmental benefit, while having significant unintended consequences.[11] When implemented with GHG cap-and-trade, a complementary policy aimed at reducing GHG emissions generally causes little (or no) additional GHG emissions reductions, as it simply shifts emissions among sources covered by the cap, without effecting the cap's stringency.[12] However, while leaving emissions unaffected, such a complementary policy generally raises costs by shifting emission reduction efforts to more costly actions proscribed by the complementary policy.[13] Moreover, such a policy will tend to depress cap-and-trade allowance prices,[14] thus diluting the magnitude of the GHG price signal,[15] which is particularly problematic for inducing technological change. Schatzki and Stavins (2018) analyze California's GHG cap-and-trade and Low Carbon Fuel Standard policies, finding that, relative to cap-and-trade alone, the LCFS actually *increased* GHG emissions (because of induced increases in out-of-state emissions) and raised costs by over $700 million from 2013 to 2017.

In practice, it may be difficult to distinguish between complementary policies addressing non-GHG market failures and those simply seeking emission reductions from sources already covered by GHG pricing. All GHG measures, including GHG pricing and standards aimed at reducing emissions, such as RPS and LCFS, create financial incentives for private firms (entrepreneurs) to increase investment in energy research and development (R&D). Thus, advocates of sector- or technology-specific standards often argue that they are intended to achieve technology change needed to reduce emissions.[16] In these cases, the relevant question becomes whether these measures address

[11] For a general discussion of policy interactions, *see* Schatzki, Todd and Robert N. Stavins, "Implications of Policy Interactions for California's Climate Policy" (with Robert N. Stavins), Regulatory Policy Program, Mossavar-Rahmani Center for Business and Government, Harvard Kennedy School, August 27, 2012.

[12] As we show in Schatzki and Stavins (2018), emissions can increase or decrease when complementary policies overlap partially with the cap-and-trade system. For example, California's LFCS covers lifecycle emissions that include sources under California's cap-and-trade system and also some outside the system. In fact, the LCFS has *increased* emissions because of induced change in emissions outside the state.

[13] A complementary policy may be non-binding, in which case it has no effect on costs.

[14] Cap-and-trade design can incorporate mechanisms to mitigate the downward impact of complementary policies on GHG price levels. However, these designs do not mitigate the other inefficiencies associated with inefficient complementary policies. Burtraw, Dallas, et al., "Quantities with Prices," Resources for the Future Working Paper 18-08, March 2018.

[15] Interactions between complementary policies and a GHG tax differ from those between complementary policies and cap-and-trade. When implemented with GHG taxes, complementary policies aimed at reducing GHG emissions may achieve additional emission reductions, although these reductions occur at (marginal) costs greater than the GHG tax. If the GHG tax is set at the efficient level, additional emission reductions would achieve negative net benefits (that is, benefits less than costs).

[16] For example, the California Air Resources Board (CARB) has stated: "Since 2011, the LCFS has been a cornerstone of California's effort to reduce greenhouse gas (GHGs) emissions and has spurred innovation in low-carbon transportation fuels such as hydrogen, electricity and biodiesel" (CARB, "CARB amends Low Carbon Fuel Standard for wider impact," September 27, 2018); "The LCFS is an important tool in California's efforts to reduce the impacts of climate change by spurring innovation in an array of cleaner fuels" (CARB, "Air Resources Board readopts Low Carbon Fuel Standard," July 19, 2017). Other researchers have similarly focused on the LCFS as a policy to induce technological innovation and investment in new technologies, including Farrell, Alexander E. and

underinvestment in technology development in the most efficient way, or whether alternatives would more effectively direct society's resources toward advanced technology development.

B. Current Policy Mixes

National and sub-national governments have taken multiple paths in developing climate policies. Within the United States, faced with less federal leadership on climate policy, some states have sought to develop their own policies, often in coordination with other states (and Canadian provinces). These state climate initiatives often seem to take a "belt and suspenders" approach that includes a suite of policies targeting different activities that generate GHG emissions. These measures include GHG pricing through taxes and/or cap-and trade; prohibitions on certain technologies (for example, coal-fired generation); sector-specific and technology-specific performance standards, such as Renewable Portfolio Standards (RPS) and Low Carbon Fuel Standards (LCFS); technology subsidies; low-GHG resource procurements (for example, multi-year contracts for wind resources); and various means to support R&D.

The set of policies adopted by Oregon provides one example of a mix of measures a given state may take to reduce GHG emissions:

- ***Clean Fuels Program (CFP)***. The Clean Fuels Program is a version of an LCFS, that is, a standard designed to lower the carbon-intensity of transportation fuels. The CFP requires reductions in the average fuel carbon-intensity below a baseline level. As regulated by the program, carbon-intensity reflects "life-cycle" emissions including tail pipe emissions, emissions sequestered in the process of growing fuel crops (for renewable fuels), and emissions created during fuel production. Fuel suppliers can comply with the standard by selling a mix of fuels with an average carbon-intensity below the cap (that is, by "over-complying"), or by purchasing credits generated by suppliers that have over-complied with the standard. The program was implemented in 2016.
- ***Renewable Portfolio Standard (RPS)***. Oregon's RPS requires that 50 percent of electric power used in the state be generated from renewable sources of electricity by 2040. Renewable energy sources include technologies such as wind power, solar power, geothermal power, small hydropower, certain biomass products, and power generated with landfill gas.
- ***Oregon Renewable Fuel Standards.*** Oregon's Renewable Fuel Standards require that fuels sold in the state include 10 percent ethanol in gasoline and 5 percent biodiesel in diesel fuel.[17]
- ***Sustainable Transportation Initiative***.[18] This is an integrated statewide effort to reduce GHG emissions from the transportation sector, and it includes several components: a Statewide Transportation Strategy, GHG emission reduction targets for metropolitan areas, land use and

Daniel Sperling, "A Low-Carbon Fuel Standard for California Part 1: Technical Analysis", Institute of Transportation Studies, UC Berkeley, May 29, 2007, and Parson, Edward et al., "Controlling Greenhouse Gas Emissions from Transport Fuels: The Performance and Prospect of California's Low Carbon Fuel Standard," Pritzker Brief No. 10, June 2018.

[17] Oregon Department of Environmental Quality, Clean Fuels Programs, Policies and Partnerships: https://www.oregon.gov/deq/aq/programs/Pages/Clean-Fuels-More.aspx.

[18] https://www.oregon.gov/ODOT/Programs/Pages/OSTI.aspx.

transportation-scenario planning guidelines, and tools that support local governments in reaching their emissions-reduction goals.

- ***Coal-to-Clean Law***. This law requires the state's electric utilities to eliminate coal-fired electricity from their mix of energy generation by 2030.
- ***Energy Trust of Oregon***. The Energy Trust of Oregon provides information, cash incentives, and technical assistance to help Oregon utility customers invest in energy-saving or renewable energy projects. Its services and support are available to both residential and commercial customers. The Trust is funded by charges included in electric and natural gas utility customer bills.

The State is now contemplating the adoption of a GHG cap-and-trade program, which would provide a foundation for more effective and efficient long-run climate policy. As it does so, the State can also consider whether adjustments to existing policies or the introduction of new policies might better position the State to transition to more effective and efficient policies in the long run. Such benefits may spill over to other governments (national or sub-national), which may draw lessons from Oregon's experiences with the evolution of its climate policy.

C. Barriers to Efficient Long-Run Climate Policies

If we know which initiatives provide for a long-run efficient climate change policy, *why wait to implement those policies*? The simple answer is politics, while a more nuanced answer acknowledges that over time we continue to learn about policies' effectiveness in addressing many aspects of the climate problem, particularly barriers to developing low-GHG technologies.

Political realities may not support the immediate adoption of climate policies that rely on sufficiently high (efficient) GHG pricing.[19] Some may oppose climate policies, *per se*, which is a barrier to *any* climate policy. To the extent that more efficient policies can lower costs, such opposition may be diminished by adopting these more efficient policies. Others oppose GHG pricing policies because of their apparent cost or association with "taxes" and government actions. Such opposition reflects many factors, including misperceptions of the underlying economics, concern about the incidence of the policy (that is, *who pays*), and concern about how GHG pricing revenues will be used.

Thus, when GHG pricing is adopted, the resulting price levels are often well below the social cost of carbon or price levels that would be needed to achieve the emission targets sought by legislators. Instead, states (and other local governments) often pursue the "belts and suspenders" approach through a "suite" of policies targeting many of the activities that cause GHG emissions. This approach is often

[19] Other factors may contribute, such as emission and economic leakage if there are large differences in GHG prices between jurisdictions. More generally, on climate policy "sequencing", *see*: Meckling, Jonas, Thomas Sterner and Gernot Wagner, "Policy sequencing toward decarbonization," *Nature Energy*, November 2017; Pahle, Michael, et al., "What Stands in the Way Becomes the Way, Sequencing in Climate Policy to Ratchet Up Stringency Over Time," Resources for the Future Report, June 2017.

more politically expedient, as it offers the possibility of addressing climate change while at least partially hiding the costs.[20]

However, as state climate policy targets become increasing ambitious, this approach may become less effective at achieving desired emission reductions, and the costs associated with inefficient complementary policies may become greater, further undermining political viability. Moreover, measures that establish preferences for particular technologies create financial incentives for the private suppliers of these technologies to advocate for perpetuation of the policies, even if they are no longer warranted.[21] Such "rent-seeking" is particularly evident in current policies targeting development of specific technologies.[22] For example, rooftop solar companies advocate for perpetuation of net metering policies and other subsidies that lower the costs of rooftop solar, while ethanol producers advocate for perpetuation of the federal Renewable Fuel Standard, which subsidizes the production of eligible fuels.[23] As we discuss in Section II.C, appropriate policy design can reduce these incentives. For example, subsidies for rooftop solar in the California Solar Initiative gradually declined according to pre-set schedules, thus providing an initial incentive to help early deployment of rooftop solar in California, while eliminating the incentives after the technology had crossed hurdles to commercialization.

Decisions about the use of revenues from GHG pricing policies (tax revenues or auction revenues in cap-and-trade systems) are also key to political willingness to adopt GHG pricing. The implications of revenue use for political viability are complex, as political constituencies differ in their view about the best use of GHG pricing revenues. Some constituencies are generally opposed to any new policies that enlarge government coffers; for these groups, transparent mechanisms that return revenues directly to citizens, such as rebate checks, may reduce their opposition to GHG pricing. Other constituencies supportive of more direct regulation may wish to direct GHG revenues to efforts to reduce GHG emissions. Such spending can be beneficial *if* targeted at emissions not covered by GHG pricing and at

[20] Some argue that this approach may provide other political benefits, such as building constituencies to support subsequent, more stringency policies.

[21] Meckling, Jonas, Thomas Sterner and Gernot Wagner, "Policy sequencing toward decarbonization," Nature Energy, November 2017; Pahle, Michael, et al., "What Stands in the Way Becomes the Way, Sequencing in Climate Policy to Ratchet Up Stringency Over Time," Resources for the Future Report, June 2017.

[22] The value of investments made by firms in supplying technologies used to comply with an inefficient complementary policy may diminish if reliance is reduced on that policy. A gradual transition can diminish potential reduction in value, if any. However, any loss in value may also be diminished if the technology is induced by GHG pricing or other policies. For example, certain fuels used to comply with Oregon's CFP may also be induced by Oregon's existing renewable fuels standards or GHG cap-and-trade. Moreover, if Oregon were to exclude certain biofuels from GHG cap-and-trade compliance, as is the case in California, this would also induce increased consumption.

[23] State regulators often allow residential households to "sell back" electricity generated through rooftop solar, an approach characterized as "net metering." This subsidizes households installing rooftop solar at the expense of other customers, because customers without rooftop solar must bear a disproportionate share of the utility's fixed costs of operation. However, altering rate structures to account for these cross-subsidies has led to large public battles with well-capitalized interests supporting indefinite continuation of net metering policies. Moot, John, "Subsidies, Climate Changes, Electric Markets and the FERC," *Energy Law Journal* 35:345-374, 2014.

non-GHG market failures, such as underinvestment in low-GHG R&D. If spent simply to reduce emissions covered by GHG pricing, then such spending will likely create distortions.

While decisions about revenue use have significant impacts on the costs of achieving climate goals, these decisions may also lower political barriers to GHG cap-and-trade systems if revenue uses can defuse arguments grounded in opposition to new taxes. For example, making a GHG cap-and-trade system revenue-neutral through transparent return of revenues to citizens may address concerns that the policy is, in effect, a new tax, while directing some funds to R&D efforts may mitigate underinvestment in efforts to develop advanced low-GHG technology.

II. OPTIONS FOR TRANSITIONING TO MORE EFFICIENT LONG-RUN CLIMATE POLICIES

Given typical political circumstances, policymakers seeking to develop efficient long-run climate policies must consider the evolution of climate policies over time. This evolution may include a sequential process that adds new (and possibly subtracts existing) policies over time, and that adjusts the relative stringency of policies to achieve a more effective policy portfolio.

At present, climate policies typically rely too little on GHG pricing, too much on standards aimed at technology adoption in particular sectors, and too little on addressing certain non-GHG market failures, particularly underinvestment in R&D of advanced low-GHG technologies.[24] While immediate adoption of high GHG prices may not be politically feasible, policy design can facilitate the transition to greater reliance on GHG pricing over time and greater attention to non-GHG market failures, as appropriate. Transitioning to more efficient long-run climate policies potentially will involve several steps:

1. ***Develop (or enhance) market-based GHG prices.*** Policies must first be developed that establish GHG pricing. Initially, price levels may be relatively low to acclimate individuals and firms to the use of GHG pricing. Thus, initial prices may be below the economically efficient level (for example, below the social cost of carbon).

   Over time, reliance on GHG pricing can be increased by setting more ambitious emission reductions targets and/or reducing the stringency of complementary policies that tend to depress GHG prices.

   GHG pricing policies need to determine how revenues from GHG taxes or allowance auctions are used. Revenues can be used to lower economic costs, while also addressing political realities. Opposition to GHG pricing may reflect both direct resistance from particularly affected industries or individuals and broad opposition to new sources of government revenue (that is, opposition to “taxes”). Options that “rebate” revenues transparently may mitigate perceptions about government use of GHG revenues. However,

[24] For example, American Energy Innovation Council, Restoring American Energy Innovation Leadership, Report Card, Challenges, and Opportunities, February 2015; National Academy of Sciences, The Power of Change: Innovation for Development and Deployment of Increasingly Clean Electric Power Technologies, Washington, DC: National Academies Press, 2016, available at http://nap.edu/21712 (“NAS 2016”).

other options, such as reducing other distortionary taxes (e.g., income taxes), may reduce climate policy costs.[25]

2. ***Eliminate or phase out complementary policies designed largely (if not exclusively) to achieve GHG emission reductions***. These so-called complementary policies generally raise the cost of emission reductions and depress cap-and-trade prices. Over time, tapering off (and eventually eliminating) these policies shifts the burden of achieving emission reductions to GHG pricing, while also raising allowance prices to create broader incentives to achieve emission reductions.

3. ***Develop or strengthen efficient and effective complementary policies to target emissions not covered by GHG pricing and address non-GHG market failures***. With cap-and-trade in place, some complementary policies can continue to support environmental goals while enhancing economic efficiency. These policies include measures that target emissions outside the cap of the cap-and-trade system and measures that address non-GHG market failures. Given the need for advanced, low-GHG technologies to address climate change, policies that address underinvestment in R&D due to innovation spillovers are essential for long-run efficient climate policy. Policies that address other market failures (for example, information, incentive, and behavioral problems) can also be important additions to efficient policy portfolios.

These transitions should account for characteristics of and interactions between these policies that affect economic and political outcomes. Some policies can compete with one another for government funding, while others can create revenues sources to potentially support new initiatives. Some policies can draw attention to government efforts to mitigate GHG emissions, while others are more hidden. Some policies create a small group of beneficiaries that may lobby for their perpetuation, while others create more diffuse beneficiaries.

To illustrate the various aspects of such transitions, we consider two important cases. First, we consider the transition between a cap-and-trade program and a complementary policy that targets reductions in emissions under the cap. Through stylized analysis, we illustrate the tradeoffs between a newly proposed cap-and-trade system in Oregon and the state's current Clean Fuel Program, which provides incentives to reduce the carbon-intensity of transportation fuels. Second, we consider developing (or enhancing) policies to address non-GHG market failures. Specifically, we consider policy options to develop or expand R&D for low-GHG technologies.

[25] *See*, Stavins, Robert N. and Todd Schatzki, "Using the Value of Allowances from California's GHG Cap-and-Trade System" (with Robert N. Stavins), Regulatory Policy Program, Mossavar-Rahmani Center for Business and Government, Harvard Kennedy School, August 27, 2012.

A. Transition from Complementary Policy to GHG Pricing: Illustration with Oregon's GHG Cap-and-Trade and Clean Fuel Program

Faced with a gap between current policies and a long-run efficient policy, governments have several options.

First, gradually reduce the stringency of complementary policies targeting GHG emission reductions. Under this approach, the stringency of the complementary policy is reduced, while GHG pricing is enacted or remains in place. While the complementary policy remains partially in place, complying with it becomes less costly, until the policy itself is no longer binding. At this point, actions needed to comply with the complementary policy are being taken due to incentives from GHG pricing.

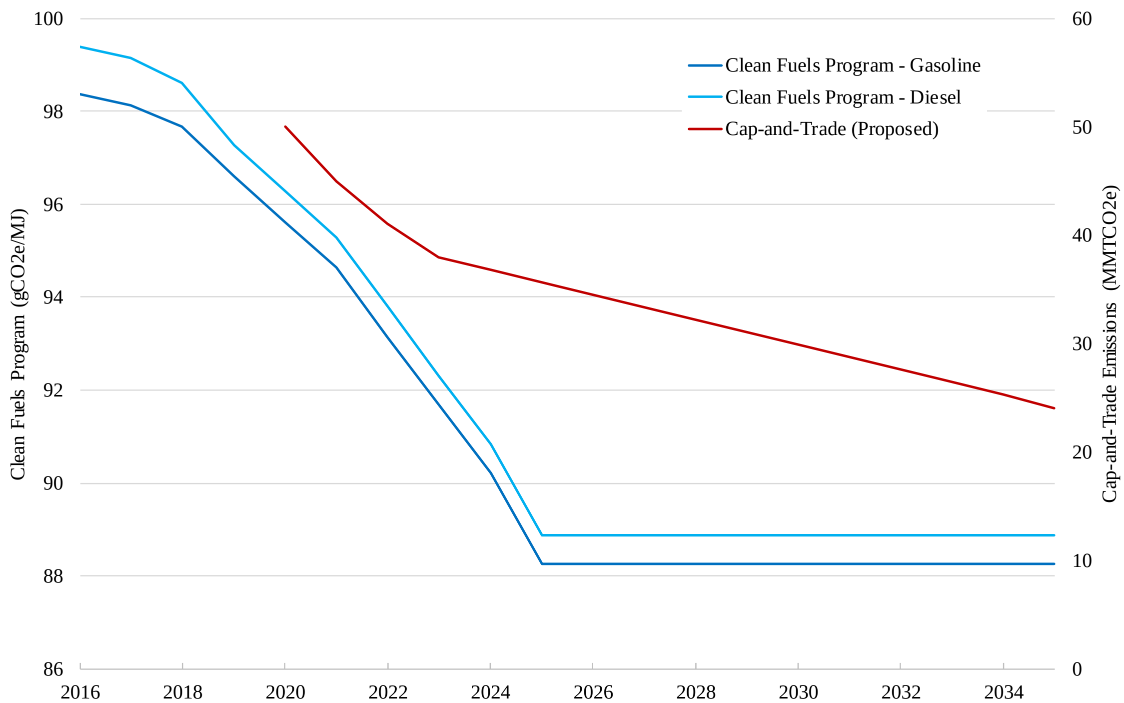
Second, sunset complementary policies targeting GHG emission reductions. Under this approach, the complementary policy is set to be terminated at a pre-determined future date. In the interim period, the policy remains in effect as currently designed, or under modified scope or stringency. Of course, reduced stringency and sun-setting can be combined to arrive at an alternative transition that combines both effects.

Third, immediately eliminate complementary policies seeking incremental emission reductions. This approach is the most economically efficient approach to transitioning policies, although it may entail greater political challenges.

We consider the options in the context of Oregon climate policy to illustrate the tradeoffs. Specifically, we consider a potential policy transition that creates new reliance on cap-and-trade policy and decreases reliance on Oregon's Clean Fuels Policy (CFP). Our illustration reflects quantitative analysis of the actual requirements under the current CFP and the targets included in recent GHG cap-and-trade proposals (for example, SB 1507). **Figure 1** shows the trajectory for the emission cap under current cap-and-trade proposals and the GHG emission-intensity fuel requirements under the CFP.[26] These regulatory requirements represent the status quo.

Figure 1. Trajectories of Oregon Climate Policy Regulatory Requirements

[26] Because both programs allow banking, actual emissions may exceed the standard in any given year, as long as cumulative emissions remain below the multi-year cumulative target.



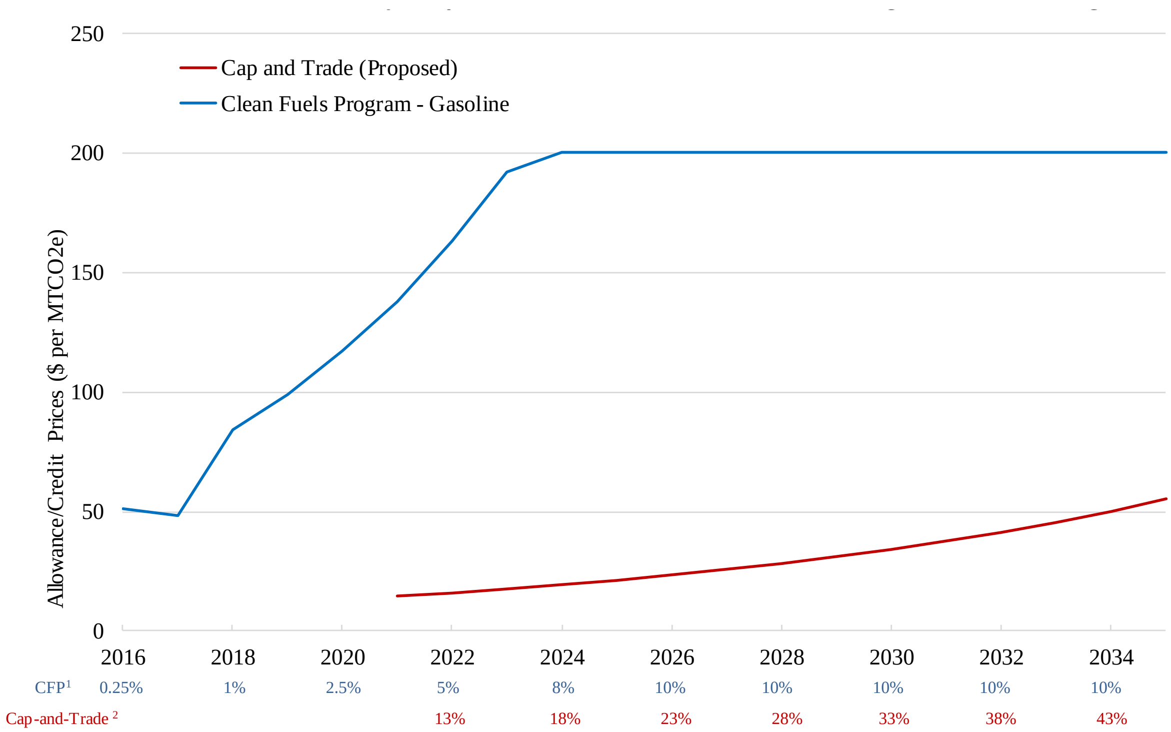
For both cap-and-trade and the CFP, compliance costs reflect the policy's stringency and the costs of actions needed to comply with these requirements. For each, required abatement reflects the difference between the targets shown in **Figure 1** and business-as-usual emissions (for cap-and-trade) or carbon-intensity (for the CFP) absent the policy. Developing reliable estimates of the economic costs of environmental policy requires careful and detailed analysis. In considering market outcomes (prices), we rely on a combination of market data and prior analysis to arrive at approximations that are intended to illustrate how market outcomes change with different transitions between policies. However, we do not seek to provide precise estimates of the economic impacts of the various policy options, and caution should be used in citing specific allowance prices from the figures.[27]

Figure 2 shows potential CFP credit price and cap-and-trade allowance price trajectories before considering any policy transitions. Under both policies, prices are represented per one metric ton of carbon dioxide equivalent ($MTCO_2e$) emissions, and they reflect the (marginal) costs of reductions at contemporaneous levels of abatement. Because both policies allow allowance/credit banking, contemporaneous emissions may be at or below policy targets. When actual annual emissions are below the annual policy target, the market in effect "over-complies" to create banked credits or allowances. When banking occurs, year-to-year price changes reflect a risk-adjusted discount rate, given the

[27] In future work, we may supplement the analysis we provide here with quantitative modeling of market outcomes.

opportunity for inter-temporal arbitrage. The price trajectories shown in **Figure 2** are consistent with such banking.[28]

Figure 2. Illustrative Cap-and-Trade and Clean Fuel Program Price Trajectories



Notes:
[1] CFP percentages refer to the percent reduction in carbon-intensity (gCO2e/MJ) for gasoline and gasoline substitutes relative to the baseline.
[2] Cap-and-Trade percentages refer to percentage reductions in carbon emissions relative to 1990 levels.

Oregon's CFP credit prices are currently approximately $80 per ton, although the mandated reduction in carbon-intensity (from baseline levels) was only 1 percent in 2018. These relatively high prices reflect many factors, including current high abatement costs, competition for low-GHG fuels with entities complying with California's LCFS, and banking driven by concerns about higher abatement costs in the future as stringency increases.[29] Experience from California's LCFS suggests there is a meaningful risk that prices could rise substantially in future years, as LCFS credit prices are currently at or near the $200 per MTCO$_2$e cap on prices in the Credit Clearance Market.[30] Cap-and-trade prices reflect estimates

[28] For example, for CFP prices, we assume a risk-adjusted discount rate of 18 percent, reflecting both an opportunity cost of capital and regulatory risk. In practice, actual allowance prices over time do not follow such smooth paths given on-going changes in abatement costs, required abatement, and other changes in market expectations.

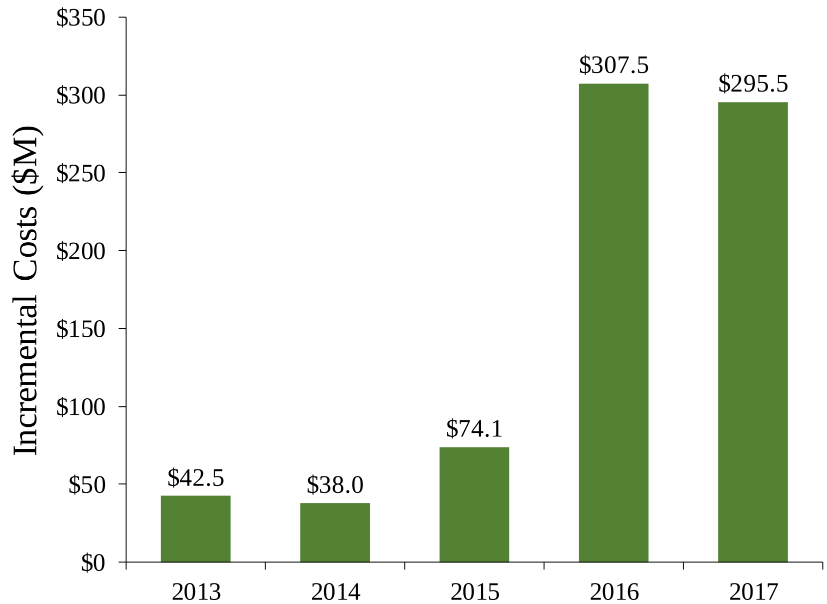
[29] In fact, the CFP program bank of credits fell in the fourth quarter of 2018.

[30] Firms subject to the LCFS can defer compliance for up to 5 years if they cannot procure credits through the Credit Clearance Market.

of emission reduction costs from recent third-party modeling efforts, adjusted to account for opportunities to bank allowances. These estimates are developed to illustrate the impacts of changes in policy trajectories, and are not intended to forecast the prices of the market instruments developed by each program.

As shown in **Figure 2**, there is a substantial gap between the price of CFP credits and cap-and-trade allowances. The gap is indicative of the large difference in (marginal) emission reduction costs under each program, and is indicative of the potential cost savings from transitioning from CFP to greater reliance on cap-and-trade. Our analysis of California's LCFS suggests that these cost savings could be very substantial. For example, **Figure 3** shows estimates of annual total incremental costs of California's LCFS relative to costs with only cap-and-trade.[31] For example, in 2017, LCFS costs of compliance were $295.5 million greater than they would have been had emission reductions been achieved by the cap-and-trade program alone.

Figure 3. Annual Incremental Costs, California's LCFS



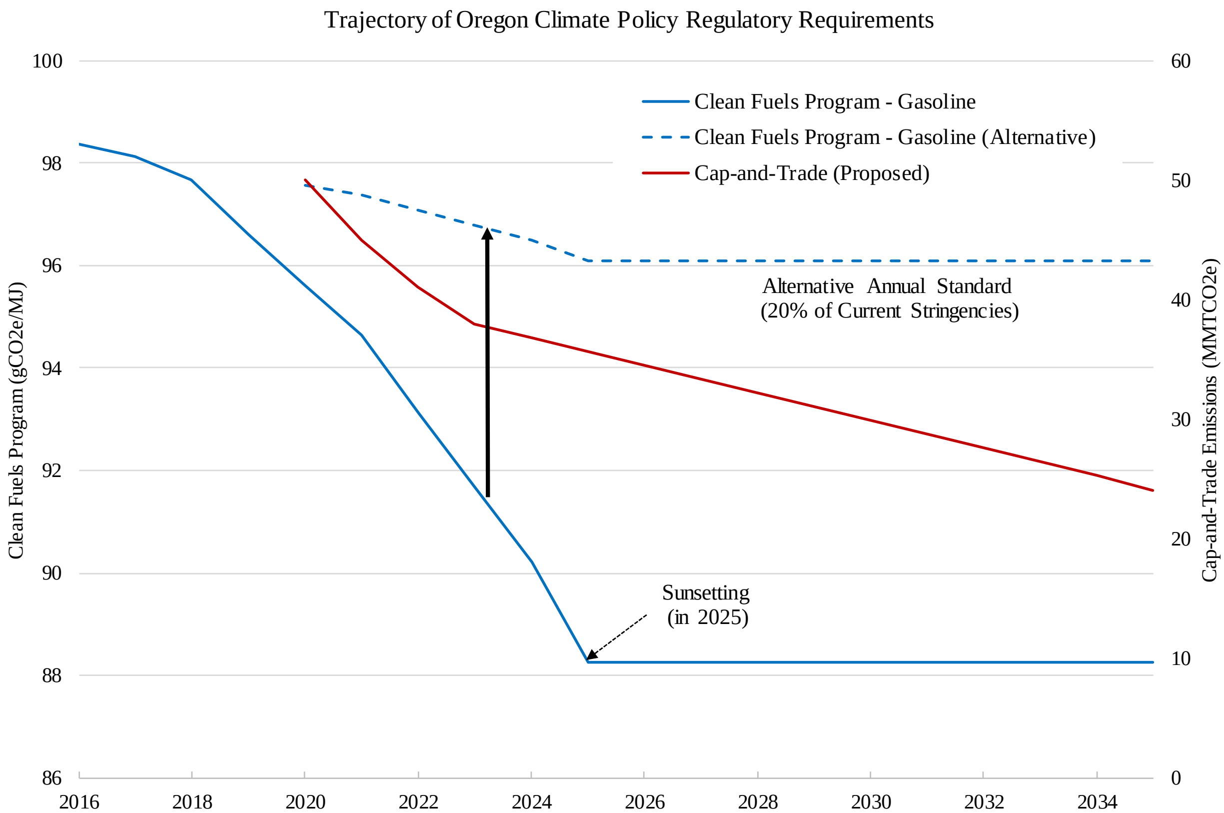
Source: Schatzki and Stavins (2018)

Figure 4 illustrates a policy that reduces the stringency of the CFP. This is the reduced stringency approach described above. In this example, the CFP achieves a 2 percent reduction in the carbon-intensity of fuels by 2025 rather than the 10 percent reduction in carbon-intensity targeted under the current rule. This modification would have several consequences. First, the less-stringent CFP standard would reduce the quantity of reductions achieved through the CFP, which in turn would reduce market prices for CFP credits. Second, while the CFP would achieve fewer emission reductions, the cap-and-trade program's cap on emissions remains unchanged. Thus, while in-state transportation sector emissions would increase, these increases would be fully offset by reductions in other sectors through the

[31] Schatzki and Stavins (2018).

cap-and-trade program.[32] As a result, in-state emissions are unchanged. **Figure 5** shows transportation sector emissions with the change in the CFP stringency;[33] as shown, emissions from the non-transportation sectors increase as the CFP stringency decreases. Finally, given the shift in emission reductions from the CFP to the cap-and-trade program, cap-and-trade allowance prices would increase.

Figure 4. Illustrative Trajectories for Alternative Clean Fuel Program Standards



[32] In principle, reducing CFP stringency could either increase *or* decrease emissions covered by the cap-and-trade program. The ambiguity of this impact occurs because carbon-intensity reflects lifecycle emissions, which includes emissions under and outside the cap-and-trade program. In practice, most fuel substitutions used to comply with the CFP reduce emission reductions necessary to comply with the cap-and-trade system. Therefore, reducing CFP stringency has the practical effect of increasing cap-and-trade stringency.

[33] Transportation sector emissions shown reflect emissions from motor vehicle sources, excluding other transport sources and non-motor emissions (e.g., potential emissions from air-conditioning systems).

Figure 5. Transportation Sector Emissions Under the Cap with Alternative CFP Standards

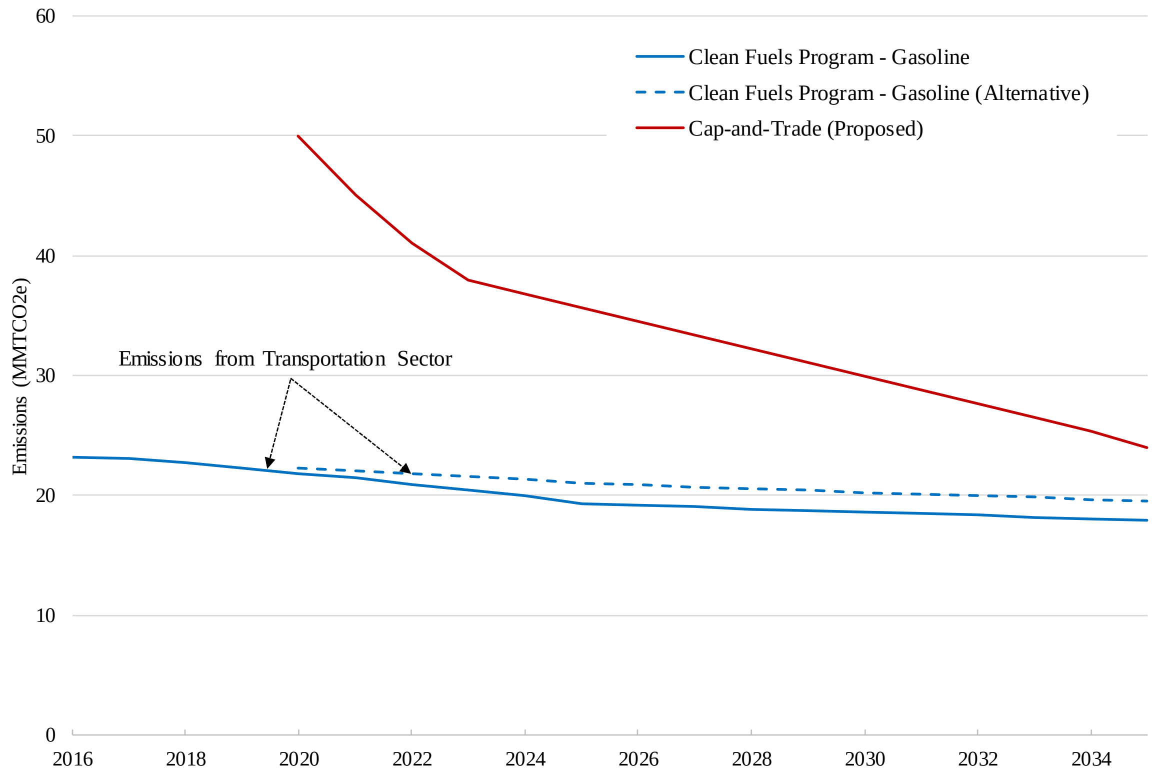
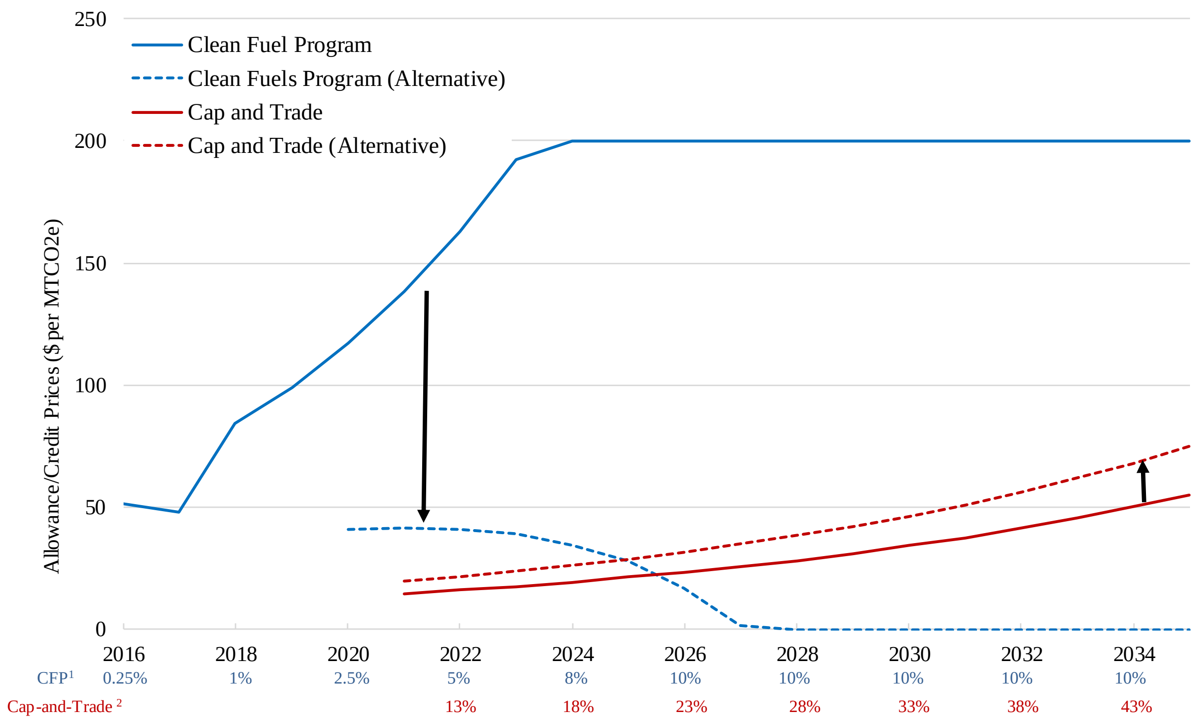


Figure 6 illustrates potential changes in prices from the reduction in CFP stringency. First, CFP credit prices decline due to the reduced CFP stringency. The magnitude (and trajectory) of this price change will depend upon many factors, including the relative costs of abatement under the CFP and cap-and-trade programs. Figure 6 illustrates a situation in which marginal CFP abatement costs fall relative to the marginal abatement costs under cap-and-trade, so that CFP allowance prices decline over time.[34] Eventually, all abatement needed to comply with the CFP is achieved by cap-and-trade, at which point CFP credit prices fall to zero. In effect, changes in fuel use from cap-and-trade incentives create sufficient CFP credits to comply with the reduced CFP carbon-intensity standard.

Second, while CFP credit prices decrease, cap-and-trade allowance prices increase. Because the CFP achieves fewer emission reductions, the quantity of emission reductions needed to comply with the allowance cap increases, which thereby increases allowance prices. As with the changes in CFP credit prices, the change in allowance prices depends upon many factors, such as the specific changes in the CFP, the cap-and-trade abatement cost curve, and the extent of banking, given future cap stringency.

[34] With the overlap between the CFP and GHG cap-and-trade programs, CFP allowances prices reflect the incremental abatement cost needed to achieve abatement required to comply with the CFP given other regulations, including cap-and-trade.

Figure 6. Illustrative Price Trajectories with CFP Standards at 20 Percent of Current Stringency

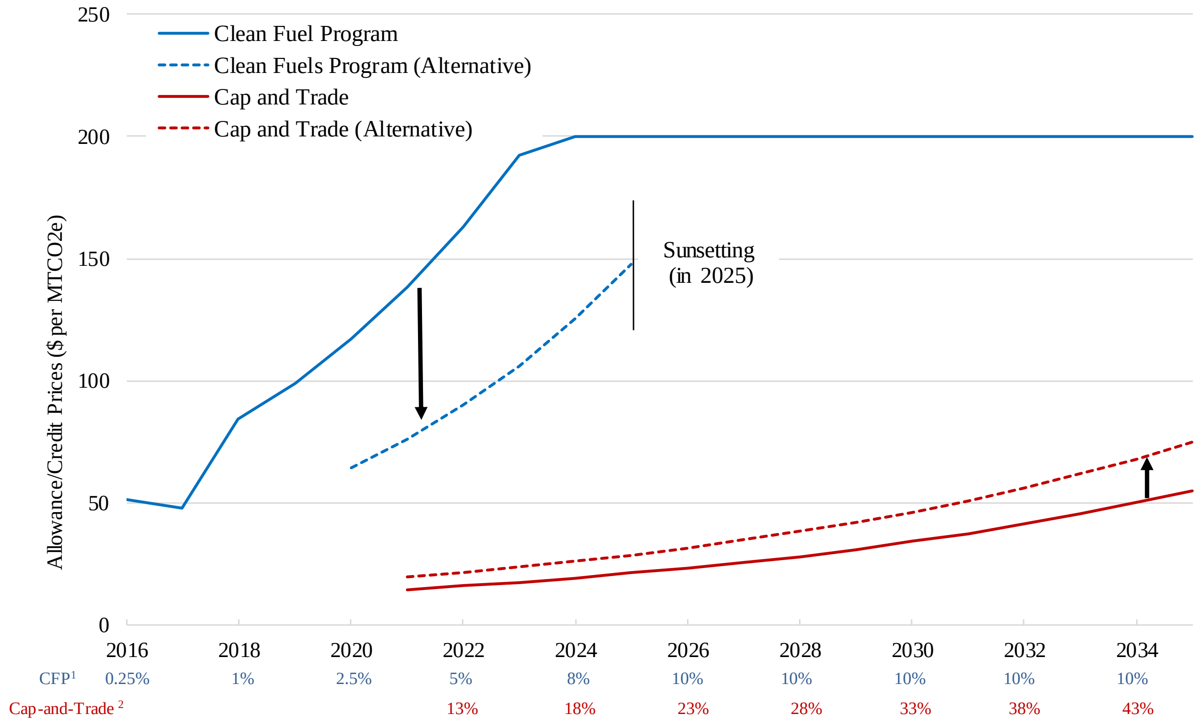


Under the sunsetting approach, the CFP remains in effect until termination at a pre-determined future date. As shown in **Figure 4**, we assume the CFP carbon-intensity standard remains in effect at current levels through 2025, but that the standard is rescinded in 2026. While the annual stringency does not change while the CFP remains in effect, cumulative CFP reductions are reduced because there is no carbon-intensity standard after 2025.

Figure 7 illustrates the potential impact of sunsetting on prices. In this case, CFP credit prices initially drop due to the reduction in cumulative abatement under the CFP; in effect, the policy's cumulative stringency is reduced, requiring less costly abatement over the policy's lifetime. However, in the interim years before the regulation sunsets in 2025, credit prices increase as the program's stringency continues to increase from year to year while in effect.[35]

[35] In effect, we assume that the marginal costs of compliance (to meet the mandated carbon-intensity) grows from year-to-year at a faster rate than the discount rate, implying that credits are banked from the present until 2025.

Figure 7. Illustrative Price Trajectories with CFP Sunsetting in 2025



An important factor affecting the economic outcomes of the transition from the CFP to cap-and-trade is the reduction in cumulative CFP stringency over time. The reduction in stringency differs for the reduced stringency and sunsetting approaches. **Table 1** compares cumulative abatement and annual abatement under alternative CFP policies. Cumulative abatement is estimated through 2035, while annual abatement reflects the number of years the CFP is assumed to be in effect, lower for the sunsetting cases. Under the sunsetting approach, cumulative and annual abatement increase for sunset years further in the future. Similarly, cumulative and annual abatement increase with an alternative CFP stringency set at a higher percentage of the current stringency. For any given level of cumulative abatement, annual abatement is greater under the sunsetting approach, because the cumulative abatement is required to be achieved in a smaller number of years.

Table 1. Reduction in Cumulative and Annual Abatement from Alternative CFP Designs, $MTCO_2e$

Sun-Setting Approach			Reduced Stringency Approach		
Sunset Year	Cumulative Abatement 2019 to Sun-Set-Yr (MMTCO2e)	Annual Abatement (MMTCO2e)	Alternative Stringency (Percent of Current Stringency)	Cumulative Abatement 2019 to 2035 (MMTCO2e)	Annual Abatement (MMTCO2e)
2021	1.49	0.75	10%	2.56	0.15
2022	2.48	0.83	20%	5.11	0.30
2023	3.74	0.94	30%	7.67	0.45
2024	5.29	1.06	40%	10.23	0.60
2025	7.20	1.20	50%	12.78	0.75
2026	9.10	1.30	60%	15.34	0.90
2027	10.99	1.37	70%	17.90	1.05
2028	12.86	1.43	80%	20.45	1.20
2029	14.71	1.47	90%	23.01	1.35
2030	16.55	1.50	100%	25.57	1.50

Sources:
[1] Clean Fuel Programs data from Oregon DEQ available at https://www.oregon.gov/deq/aq/programs/Pages/Clean-Fuels.aspx.

In practice, many factors affect the market outcomes under alternatives approaches to transitioning from complementary policies to greater reliance on GHG pricing:

- Changes in GHG prices will depend on both the current degree of price suppression from the complementary policy and the reduction in out-of-market abatement as the complementary policy stringency is relaxed.

- Changes in economic costs will reflect the difference in the cost of abatement between the complementary policy and cap-and-trade. Thus, cost savings will be greater when transitioning away from complementary policies that require relatively high-cost abatement. As the stringency of the complementary policy is reduced, the gap in marginal abatement costs between the complementary policy and cap-and-trade will diminish until eventually the complementary policy is no longer binding and its market instrument price (for example, the CFP credit price) falls to zero.

- Changes in emissions are expected to be zero when transitioning from a complementary policy to cap-and-trade, as reduced stringency of the complementary policy has no effect on the overall cap on emissions under cap-and-trade.

The magnitude of these individual effects is an empirical issue, specific to the particular policies being evaluated and the opportunities for sequencing and transition.

B. Transitions to Address Non-GHG Market Failures: Example of Under-Investment in Low-GHG Technology Development

Effective and efficient long-run climate policy will include mitigation of non-GHG market failures (affecting GHG emissions) through efficient policy measures. Developing such measures requires careful assessment of the non-GHG market failures affecting GHG emissions, identification of potential policy measures to mitigate those market failures, and assessment of which options provide the greatest net benefits. We consider one particularly important market failure, underinvestment in research and development into advanced low-GHG technologies. This market failure is important for several reasons.

First, research that lowers the cost of reducing GHG emissions can help other jurisdictions, including other countries that face more severe economic constraints, to pursue GHG reductions to meet more ambitious goals. The benefits of such positive technology spillovers may far exceed the benefits any given country can produce by reducing its own emissions.[36]

Second, there is general agreement that there is under-investment in research and development into advanced low-GHG technologies, particularly given the need for such advanced technologies to achieve meaningful reductions in GHG emissions at reasonable costs.

Third, the transition away from sector- or technology-specific complementary policies toward greater reliance on GHG pricing may reduce incentives for advanced technology development in the sectors in which complementary policies are being relaxed. Creating or enhancing measures that focus directly on low-GHG technologies may offset any decreases in incentives for advanced technology development.

Performance standards typically provide uniform incentives for GHG reductions irrespective of the state of development of the technologies used to reduce emissions. Thus, these policies may promote substantial technological innovation or simply lead to widespread deployment of existing technologies. Other policy mechanisms better target financial incentives toward technology development. For example, while California's LCFS may promote technology development, as is argued by CARB, the overall program cost is very high, on par with total federal spending on low-GHG energy technologies.[37] Thus, a reallocation of resources from California's LCFS or Oregon's CFP to measures that directly target R&D incentives may create substantial efficiency gains.

Given our focus on Oregon's CFP, we direct attention to market failures affecting the development of advanced technologies in the transportation sector. Below, we discuss the market failures that limit the development of low-GHG technologies, and then examine policy measures to address these market failures.

[36] Fischer, Carolyn, "The Role of Technology Policies in Climate Mitigation," Resources for the Future Issue Brief #09-08, July 2009 ("Fischer 2009"), p. 7.

[37] Schatzki and Stavins (2018).

1. R&D Market Failures in the Transportation Sector

All GHG policies create incentives for private-sector investment in clean energy and energy efficiency, with GHG taxes and cap-and-trade doing so by raising the effective price of GHGs.[38] Indeed, the lack of appropriate GHG prices—and the correspondingly low reward for reducing emissions—has been the most important reason for underinvestment in this area. A number of additional market failures, however, may slow investment in R&D and the deployment of new technologies. Because such technologies can lower the overall cost of reducing GHG emissions, policies to address energy R&D market failures should be part of an efficient portfolio of climate policies.[39]

Market failures affecting development of low-GHG technologies arise at different points in the R&D process, which begins with basic research and continues with applied research, development and practical demonstration, and ultimately adoption and diffusion of new technology.[40] Below we provide an overview of market failures that can affect transportation R&D at various stages.

a) Knowledge Spillovers

One of the major impediments to efficient levels of R&D is that investors are unable to capture the full value of their innovations. One innovation may spur further innovations; new knowledge may "spill over" to other firms. As a result, individual incentives to invest in R&D are lower than the societal rewards.

These mismatched incentives are the rationale for patents, which allow investors to capture a greater portion of their innovations' value. However, knowledge spillovers often create value beyond what patents are able to protect, and thus private incentives for R&D may still be less than socially optimal levels.

While knowledge spillovers occur throughout the R&D process, they are most acute at the basic research stage, leading to the greatest gap between private and social returns on investment.[41] As the rewards to basic research typically are far in the future, the incentives to conduct such research are less likely to be preserved by limited-lifetime patents.[42]

[38] Jaffe, Adam B., Richard G. Newell, and Robert N. Stavins, "Technology Policy for Energy and the Environment," *Innovation Policy and the Economy*, Vol. 4, 2004 ("JNS 2004"), pp. 43-45, 49-50.

[39] See Fischer, Carolyn, and Richard G. Newell, "Environmental and technology policies for climate mitigation," *Journal of Environmental Economics and Management*, Vol. 55, 2008, pp. 142-162; Newell, Richard G., "The Role of Energy Technology Policy Alongside Carbon Pricing," in *Implementing a U.S. Carbon Tax: Challenges and Debates*, 2015 ("Newell 2015"), p. 180; and Aldy, Joseph E., et al., "Designing Climate Mitigation Policy," *Journal of Economic Literature* 48:4, 2010 ("Aldy et al. 2010"), p. 924.

[40] See, for example, the NAS 2016, pp. 51-53; Newell 2015; Jaffe, Adam B., Richard G. Newell, and Robert N. Stavins, "Energy-Efficient Technologies and Climate Change Policies: Issues and Evidence," Resources for the Future Climate Issue Brief No. 19, Dec. 1999 "Jaffe, Newell, and Stavins 1999"), pp. 8-10.

[41] Aldy et al. 2010, p. 925.

[42] Fischer 2009, p. 3.

b) Incomplete Information[43]

Another factor that may discourage investment in R&D is asymmetry between the information available to investors and the information available to those actually performing the R&D. If investors' ability to forecast a new technology's potential profitability is poorer than that of scientists, engineers, and firms undertaking R&D, then this lack of information creates an additional risk for investors. As compensation for this risk, investors require a risk premium, which effectively pushes up the cost of R&D and leads to underinvestment.[44]

c) Network Effects and Other Adoption Externalities

At the adoption phase, several factors may discourage the diffusion of new technologies. As mentioned above, knowledge spillovers may continue beyond the research stage of the innovation process. If firms can benefits from others' learning-by-doing, then they will have an incentive to avoid some of the costs and risks of introducing a technology by waiting for others to go first. The same phenomenon can occur on the consumer side, with consumers putting off adoption of a new technology until others have tried it and generated know-how through learning-by-using.[45] Both learning-by-doing and learning-by-using may slow the diffusion of a new technology.

Network externalities can also pose barriers to technology diffusion. Positive network externalities arise when a technology's value to consumers increases with its market penetration. A single telephone, for example, is basically useless; the phone's value arises from its ability to connect with a network of other telephone users.

Network externalities can be a particularly significant barrier to the rollout of new transportation technologies, as the usefulness of such technology to consumers can depend on an infrastructure network. Gasoline-fueled cars, for example, derive much of their usefulness from the availability of filling stations that sell gasoline.

Network effects can lock society into existing technologies compatible with infrastructure that is already available. Where network externalities exist, alternatives to the existing technology face a "chicken-and-egg" problem: the alternative is only useful to consumers if there is an infrastructure network to support that technology, but the infrastructure network does not exist because consumers do not demand the technology in the absence of the network.[46]

[43] Low-GHG technologies also face substantial regulatory risk. Regulatory risks are particularly high for low-GHG technologies because, in effect, demand for these technologies depends on policies created by legislators and regulators. Without these policies, the low-GHG attribute of these technologies may have little value, absent independent demand from individual consumers or corporations.

[44] Jaffe, Adam B., Richard G. Newell, and Robert N. Stavins, "A tale of two market failures: Technology and environmental policy," *Ecological Economics* 54, 2005, pp. 167-168.

[45] JNS 2004, p. 40. There is some evidence of learning-by-using in the adoption of hybrid vehicles. See Heutel, Garth, and Erich Muehlegger, "Consumer Learning and Hybrid Vehicle Adoption," *Environmental and Resource Economics* 62:1, 2015, pp. 125-161.

[46] See, for example, JNS 2004, pp. 41-42.

A barrier to the diffusion of electric vehicles, for example, is the lack of an extensive network of charging stations for drivers to rely on. Without a large fleet of electric vehicles that need charging stations, however, there is insufficient incentive to construct charging stations. Similarly, there is little incentive for filling stations to offer lower-GHG fuel blends if drivers do not demand them, but if those fuel blends are not easily available, then consumers will shy away from purchasing the specially-designed engines required to use many lower-GHG fuel blends.[47]

d) Behavioral Biases

Adoption and diffusion of new technologies may also be discouraged by consumer behavioral biases and bounded rationality. Many energy-efficient technologies, for example, require an upfront investment in exchange for lower energy costs in the following years. However, consumers may fail to appropriately balance these future savings against up-front technology costs. For example, consumers may place too much weight on the extra up-front cost of more efficient vehicles (that also emit fewer GHGs), such as hybrids or electric vehicles, and too little weight on the subsequent fuel savings. Consequently, some consumers who would be better off with a hybrid may instead opt for standard gas-powered cars.[48] The existence of such behavioral biases among some consumers could also lower the overall demand for energy-efficient technology and therefore reduce incentives to invest in clean-technology R&D.

2. Policies to Remedy R&D Market Failures in the Transportation Sector

Multiple policy instruments are available to address R&D market failures in the transportation sector. Below, we assess the tradeoffs among some of the options available to policymakers.

a) Support for Basic and Applied Research, Development, and Practical Demonstration

Government financial support has the potential to bring about socially-beneficial research that would not otherwise take place. This support can come in a number of forms, including:

[47] See, for example, U.S. Energy Information Administration, “Biofuels: Ethanol and Biodiesel Explained,” August 8, 2018, *available at* https://www.eia.gov/energyexplained/index.php?page=biofuel_home; Gent, Edd, “New Biofuels Could Work in Regular Diesel Engines,” *Scientific American*, June 20, 2017, available at https://www.scientificamerican.com/article/new-biofuel-could-work-in-regular-diesel-engines.

[48] The evidence is mixed as to whether such myopia affects vehicle purchase decisions. Some studies find that consumers undervalue the savings associated with better fuel efficiency, but this finding is sensitive to discount rate assumptions. *See* Allcott, Hunt, and Nathan Wozny, “Gasoline Prices, Fuel Economy, and the Energy Paradox,” *Review of Economics and Statistics* 96(5), 2014, pp. 779-195; Dreyfus, Mark K., and W. Kip Viscusi, “Rates of Time Preference and Consumer Valuations of Automobile Safety and Fuel Efficiency,” *Journal of Law and Economics* 39(1), 1995, pp. 79-105; discussion in Parry, Ian W., Margaret Wells, and Winston Harrington, “Automobile Externalities and Policies,” *Journal of Economic Literature* 45, 2007; and Gerarden, Todd D., Richard G. Newell, and Robert N. Stavins, “Assessing the Energy-Efficiency Gap,” *Journal of Economic Literature* 55(4), 2017, p. 1509.

- ***Direct funding of research in the public sector and research grants to non-profit, educational, and private institutions.*** Governments can, and do, finance research directly. Direct funding may take the form of support for research within public institutions. The federal government, for example, supports 17 national laboratories within the Department of Energy (DOE), which undertake basic and applied research in a large number of areas related to clean energy (among other topics).[49] Funding may also take the form of grants to institutions, such as universities and other non-profit entities. For example, DOE administers an extensive portfolio of research grants open to applications from a variety of institution types.[50] One of its grant programs is the Advanced Research Projects Agency-Energy (ARPA-E), which provides short-term funding for projects that parlay research into practical technology.[51] State and local governments also fund some scientific research, but such funding is currently small: as of 2015, nonfederal government spending comprised only 0.1 percent of total U.S. spending on basic research and 0.3 percent of total U.S. spending on applied research.[52]

- ***Tax breaks for research outside the public sector***. Governments may use tax incentives to lower the effective cost of research. In the U.S., for example, the federal government introduced a "Research and Experimentation" tax credit in 1981, which allows businesses to claim a portion of their R&D expenditures as credits against their tax bills.[53]

- ***Inducement prizes that offer a monetary reward for achieving a particular innovation.*** Whereas direct funding and tax incentives provide support for R&D inputs, inducement prizes reward R&D outcomes.[54] Typically, an inducement prize specifies a goal and offers a monetary reward either to the first entity that meets that goal ("first-past-the-post") or the entity that meets that goal in the best way in a pre-specified time period ("best-in-class" or "contest").[55]

[49] U.S. Department of Energy, Office of Science, "Laboratories," *available at* https://science.energy.gov/laboratories.

[50] See, for example, U.S. Department of Energy, Office of Science, "Funding Opportunity Announcements," *available at* https://science.energy.gov/grants/foas/open.

[51] See, for example, National Academies of Sciences, Engineering, and Medicine, *An Assessment of ARPA-E*, Washington, DC: National Academies Press, 2017, *available at* https://www.nap.edu/download/24778#, p. ix.

[52] These figures reflect all U.S. R&D, not just clean-technology R&D. See National Science Board, "Science & Engineering Indicators 2018," Tables 4-7 and 4-8, *available at* https://www.nsf.gov/statistics/2018/nsb20181/data/appendix.

[53] Until 2015, this tax credit was nominally temporary, but repeatedly extended; in 2015, it was made permanent. *See*, for example, U.S. Department of the Treasury, Office of Tax Analysis, "Research and Experimentation (R&E) Credit," October 12, 2016, *available at* https://www.treasury.gov/resource-center/tax-policy/tax-analysis/Documents/RE-Credit.pdf.

[54] Newell, Richard G., and Nathan E. Wilson, "Technology Prizes for Climate Change Mitigation," Resources for the Future Discussion Paper 05-33, 2005, available at https://media.rff.org/documents/RFF-DP-05-33.pdf?_ga=2.235491459.36518121.1550503193-1451887737.1549321608 ("Newell and Wilson 2005"), p. 3.

[55] Newell and Wilson 2005, pp. 33-34; National Research Council, Innovation Inducement Prizes at the National Science Foundation, Washington, DC: National Academies Press, 2007, available at https://www.nap.edu/download/11816, p. 5.

> Inducement prizes may therefore be able to steer researchers' efforts toward a particularly socially desirable scientific or technological advancement.
>
> Inducement prizes have a lengthy history in the transportation sector. One of the earliest known uses, by the British government in the early 1700s, was to improve ship navigation via better measurement of longitude.[56] The use of inducement prizes has continued to encourage transportation innovations since then, with privately-funded prizes offered for the first airplane flight between New York and France[57] and for the first private, reusable, manned vehicle capable of reaching space;[58] and with publicly-funded prizes offered for autonomous vehicle technology (the famous DARPA Grand Challenge) and for certain innovations that could facilitate space travel (the NASA Centennial Challenges).[59] Inducement prizes have also been used to encourage improvements in energy efficiency,[60] and DOE has recently offered a number of clean-energy prizes, such as the H2 Refuel H-Prize Competition for "small-scale hydrogen fueling"[61] and the L Prize for an LED bulb with the qualities of a 60-watt incandescent bulb.[62]

When contemplating support for clean-energy research, policymakers should compare the advantages and disadvantages of funding R&D directly in the public and non-profit sectors versus subsidizing R&D in the private sector. Direct funding allows policymakers to target advancements that yield large social payoffs, such as technologies that supply public goods. Direct funding may also allow policymakers to ensure continued work on socially beneficial research that might otherwise be difficult to induce in the private sector, whether because knowledge spillovers are large, the timeline for profitability is far off, or private investors' institutional features (such as business models averse to capital-intensive projects) discourage projects.[63] In this sense, the ability to select projects to support may be desirable. However, this responsibility also comes with disadvantages, as the private sector may have better knowledge about the potential profitability of different technologies and may therefore be in a better

[56] Newell and Wilson 2005, p. 14.

[57] The $25,000 Orteig Prize was announced in 1919, and won by Charles Lindbergh in 1927. See Morgan, Jaison G., "Inducing Innovation Through Prizes," *Innovations*, Fall 2008, *available at* https://www.mitpressjournals.org/doi/pdf/10.1162/itgg.2008.3.4.105, pp. 105-106 and note 2.

[58] In particular, the Ansari X-Prize offered $10 million to the first "privately financed […] spaceship capable of: [c]arrying 3 people [t]o 1000 Km about the Earth's surface [t]wice within 2 weeks." (Ansari X-Prize, "Launching a New Space Industry," *available at* https://ansari.xprize.org/prizes/ansari.)

[59] Newell and Wilson 2005, pp. 18-20.

[60] Newell and Wilson 2005, p. 16.

[61] U.S. Department of Energy, Hydrogen & Fuel Cells Program, "About the H-Prize," *available at* https://www.hydrogen.energy.gov/hprize.html.

[62] See, for example, Whyte, Chelsea, "Philips Win L Prize, but the Race is Still on for a Better Bulb," *National Geographic News*, August 5, 2011, *available at* https://news.nationalgeographic.com/news/energy/2011/08/110803-philips-led-light-bulb-wins-l-prize/.

[63] See, for example, JNS 2004, p. 56.

position to allocate R&D efforts efficiently.[64] Given these tradeoffs, the preferred strategy may involve a mix of direct funding and tax incentives.

When policymakers have a clear sense of the particular innovation they wish to support, both direct research funding and inducement prizes may be sensible options. Inducement prizes come with several advantages. While they require policymakers to lay out a clear goal, they are agnostic about the means of achieving it, meaning that policymakers do not have to bet on a particular technology, and innovators with diverse ideas may cast their hats into the ring.[65] As the prize is only awarded if the goal is achieved, the government does not bear the risk associated with creative approaches.[66] In some cases, incentive prizes may therefore be able to bring about a particular level of innovation at a lower cost than research grants.[67] On the downside, however, such prizes are not appropriate to all R&D challenges. They are workable only for challenges that can be distilled cleanly into a goal that can be objectively judged.[68]

Long-term credibility is also important for the effectiveness of R&D tax incentives. As R&D may only pay off on a relatively distant horizon, investors may not be particularly influenced by short-run tax breaks or tax incentives whose long-run existence is uncertain.[69] Such considerations should be taken into account when devising tax policy to encourage innovation. Similar concerns apply to the creation of inducement prizes, because without a credible guarantee that it will be paid out on the publicized terms, a prize will be less effective in spurring investment in R&D. To protect a prize's credibility against future budget shortfalls or changes in political sentiment, policymakers may want to consider putting the prize money in escrow or purchasing an insurance policy up-front to pay the prize money when it comes due.[70]

b) Interventions to Address Barriers to Adoption and Diffusion

At the adoption and diffusion stages of technological innovation, policy intervention may be useful in addressing adoption externalities (such as network effects and knowledge spillovers from learning-by-doing and learning-by-using), possible behavioral phenomena, and other impediments. Appropriate intervention may help overcome, or hasten the overcoming of "chicken-and-egg" problems that discourage transitions to cleaner technologies. Among the tools that policymakers might consider are:

- ***Loans and loan guarantees to support clean-energy firms.*** As discussed above, information asymmetries may increase the cost of borrowing to invest in innovative new technologies. More generally, it may be difficult and expensive to secure funding to deploy new low-GHG technologies: such technologies often lack a financial track record that banks use to evaluate

[64] See, for example, JNS 2004, p. 57; Schatzki and Stavins 2015, p. 16.

[65] Newell 2015, p. 185.

[66] NAS 2016, p. 64.

[67] Newell and Wilson 2005, p. 7.

[68] Newell 2015, p. 185.

[69] Newell 2015, p. 182.

[70] Newell and Wilson 2005, pp. 22-23.

risk,[71] and often they also require a high capital intensity that conflicts with venture capital business models.[72] Given these challenges to securing funding, governments may consider subsidized loans or loan guarantees for firms deploying new low-GHG technologies.

At the federal level, DOE's Loans Program Office does precisely that. It provides loans and loan guarantees to bridge the "commercial deployment funding gap" for emerging clean-energy and clean-transportation technologies.[73] Its Advanced Technology Vehicles Manufacturing (ATVM) program, for example, provides loans to support the building and revamping of U.S. factories to produce fuel-efficient, alternative-fuel, and electric vehicles, and associated infrastructure.[74] The ATVM program has provided loans to Tesla to support its Model S and Nissan to support its Leaf.[75]

There is a history of loan programs at the state level as well. In fact, Oregon has a State Energy Loan Program (SELP) to provide low-interest loans for energy-efficiency, alternative-energy, and alternative-fuel projects.[76]

- ***Grants to support late-stage development, deployment, and adoption.*** Monetary grants are another potential instrument to encourage desired deployment and adoption of clean-transportation technologies. The Federal Transit Administration (FTA), for example, administers a Public Transportation Innovation Program that offers grants for demonstration and deployment projects,[77] and a Low or No Emission Vehicle Program that provides state and local governments

[71] U.S. Department of Energy, Loan Programs Office (LPO), "LPO Financial Performance," November 2014, *available at* https://www.energy.gov/sites/prod/files/2014/11/f19/DOE-LPO-MiniReport_Final%2011%2013%2014_0.pdf ("LPO 2014"), p. 2.

[72] See, for example, Ghosh, Shikhar, and Ramana Nanda, "Venture Capital Investment in the Clean Energy Sector," Harvard Business School Working Paper 11-020, 2010, *available at* https://www.hbs.edu/faculty/Publication%20Files/11-020_0a1b5d16-c966-4403-888f-96d03bbab461.pdf.

[73] LPO 2014, p. 2.

[74] U.S. Department of Energy, Loan Programs Office, "ATVM," *available at* https://www.energy.gov/lpo/atvm (LPO, "ATVM"); U.S. Department of Energy, Loan Programs Office, "Eligibility for the Deployment and Manufacturing of Infrastructure for Alternative Fuel Vehicles and Electric Vehicles," January 9, 2017, *available at* https://www.energy.gov/sites/prod/files/2017/01/f34/FactSheet_Vehicle_Announcements_01_9_17.pdf.

[75] LPO, "ATVM."

[76] SELP is not accepting applications at present. See Oregon Department of Energy, "Energy Loan Program," *available at* https://www.oregon.gov/energy/incentives/pages/energy-loan-program.aspx; U.S. Department of Energy (DOE), Alternative Fuels Data Center, "Electricity Laws and Incentives in Oregon," *available at* https://afdc.energy.gov/fuels/laws/ELEC?state=or (DOE, "Electricity Laws and Incentives in Oregon").

[77] Federal Transit Administration (FTA), "Public Transportation Innovation – 5312," *available at* https://www.transit.dot.gov/funding/grants/public-transportation-innovation-5312.

with funding for low-GHG buses.[78] At the state level, Oregon provides grants to support the purchase of cleaner school busses.[79]

- ***Inducement prizes.*** With appropriate tweaks to their design, inducement prizes can also be used at the adoption and diffusion stages of the innovation process. For example, a policymaker could design an inducement prize in which the reward is a government purchasing contract.[80] Alternatively, the policymaker could set an inducement prize in which the reward depends on the extent of deployment. For example, the early 1990s, a consortium of energy utilities, with help from the U.S. EPA and the Washington State Energy Office, created an inducement prize called the Super Efficient Refrigeration Program (SERP). Under SERP, the firm that produced the best energy-efficient, CFC-free refrigerator was awarded a rebate for each such unit sold (up to a predetermined limit).[81] Potentially, a similar inducement-prize design could be used to encourage the deployment of new transportation technology, such as vehicles compatible with low-GHG fuel blends.
- ***Tax breaks, rebates, and other subsidies.*** Barriers to the diffusion of new technologies may also be targeted with policies that lower the perceived costs of deployment and adoption. Tax breaks are one such policy. The federal government provides multiple tax credits for low-GHG technologies, including a corporate tax credit for electricity production using wind, geothermal, and solar technologies;[82] a personal tax credit for home installation of renewable-energy systems (for example, solar, small wind, and heat pumps);[83] and tax credits of $2,500 to $7,500 for the purchase of plug-in electric vehicles.[84] These tax credits reduce the effective cost to consumers of adopting new technologies, and may therefore help encourage faster diffusion. Rebates are another way in which investment in new energy-efficient technologies can be subsidized. The California Solar Initiative, for example, provided consumers and businesses that install solar-power systems with rebates based on the system's expected or actual electricity production.[85]

[78] Federal Transit Administration (FTA), "Low or No Emission Vehicle Program – 5339(c)," *available at* https://www.transit.dot.gov/funding/grants/lowno.

[79] DOE, "Electricity Laws and Incentives in Oregon."

[80] Newell and Wilson 2005, p. 32.

[81] Gillingham, Kenneth, Richard Newell, and Karen Palmer, "Retrospective Examination of Demand-Side Energy Efficiency Policies," Resources for the Future Discussion Paper 04-19 rev, September 2004, *available at* https://ageconsearch.umn.edu/record/10477/files/dp040019.pdf, pp. 17-20.

[82] U.S. Department of Energy (DOE), "Renewable Electricity Production Tax Credit (PTC)," *available at* https://www.energy.gov/savings/renewable-electricity-production-tax-credit-ptc.

[83] U.S. Department of Energy, "Residential Renewable Energy Tax Credit," *available at* https://www.energy.gov/savings/residential-renewable-energy-tax-credit.

[84] U.S. Internal Revenue Service (IRS), "Plug-In Electric Drive Vehicle Credit," January 29, 2019, *available at* https://www.irs.gov/businesses/plug-in-electric-vehicle-credit-irc-30-and-irc-30d.

[85] State of California, California Energy Commission & California Public Utilities Commission, "Step 3: Apply for Incentives," *available at* https://www.gosolarcalifornia.ca.gov/csi/step3.php.

Design of subsidies should consider many factors. One factor is the "salience" of different forms of incentives to individuals and businesses. Evidence shows that consumers respond differently to various forms of subsidization (for example, tax credits, rebates, or preferential benefits, such as high occupancy vehicle access), even when the monetary value of incentives is similar. Another factor is permanence.[86] Tapering off the size of the subsidy can reduce the risk that technology suppliers are incentivized to lobby for perpetuation of the subsidy, even after the technology becomes fully commercialized. Both the federal plug-in vehicle tax credits and the California Solar Initiative reduced the subsidy value as the number of individuals taking advantage of the subsidy hit certain milestones.

- ***Government adoption of new technologies.*** In addition to policies that seek to encourage diffusion of new technologies by nudging the behavior of consumers and businesses, governments can influence adoption through their own purchasing decisions. By selecting advanced technologies, governments can absorb some of the learning-by-using costs and help to support development of needed infrastructure networks.

  At the federal level, regulations already require that some vehicle-purchase decisions reflect efficiency and emissions criteria. Department of Defense rules require it to choose hybrid or electric over traditional vehicles for non-combat purposes when costs are similar,[87] and federal statutes require that a proportion of federal (and even some state) vehicle fleet additions be comprised of certain advanced fuel vehicles (including hybrids).[88] At the state and municipal levels, governments have the opportunity to choose emerging clean-transportation technologies for the use of employees and the provision of public services. Portland, Oregon, for example, recently announced plans to transition its bus fleet gradually from diesel to electric.[89]

- ***Utility and construction regulations to advance infrastructure availability.*** One way to expand the network infrastructure necessary to fuel certain low-GHG vehicles is to support development of a network of refueling stations. Options include: public funding of a large, integrated network, developed by private contractors or regulated utilities; subsidies for new refueling station development or expansion of refueling capabilities at existing stations; or development and zoning requirements. In Oregon, a 2017 executive order mandates that the state building code be updated to require that new parking structures are compatible with the installation of two or more electric-vehicle charging stations.[90]

[86] Gallagher, Kelly Sims and Eric Muehlegger, "Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology," *Journal of Environmental Economics and Management* 61(1): 1-15, 2011.

[87] U.S. Department of Energy (DOE), Alternative Fuels Data Center, "Electricity Laws and Incentives in Federal," *available at* https://afdc.energy.gov/fuels/laws/ELEC?state=US (DOE, "Electricity Laws and Incentives in Federal").

[88] DOE, "Electricity Laws and Incentives in Federal."

[89] Theen, Andrew, "TriMet debuts $500 million plan to ditch diesel buses, go electric," OregonLive.com, 2018, *available at* https://www.oregonlive.com/commuting/2018/09/trimet_debuts_500_million_plan.html.

[90] DOE, "Electricity Laws and Incentives in Oregon"; State of Oregon Office of the Governor, Executive Order No. 17-21, "Accelerating Zero Emission Vehicle Adoption in Oregon to Reduce Greenhouse Gas Emissions and

Policy decisions to address adoption externalities should reflect multiple considerations. In selecting among the many measures available, policymakers should aim to create the greatest net benefits given the potential for targeted technologies to lower the aggregate cost of reducing GHG emissions. These benefits will reflect many factors, including the nature and severity of adoption externalities, the scope of use for targeted technologies, and the potential for reductions in technology costs.

Policies to counteract adoption externalities come with risks that should be considered from the outset. Providing incentives for technology deployment may require that policymakers choose particular technologies to support. With this choice comes the risk of backing the "wrong" technology, that is, a technology that proves to be less cost-effective than alternatives.[91] If there are network externalities, government support could perversely lead to lock-in on a more costly technology. For example, government incentives or requirements for flex-fuel vehicles could lead to lock-in on that technology, which may prove more costly in the long-run than alternatives, such as electricity or hydrogen-fueled vehicles; but, of course, the same is true for each of these alternatives. Given uncertainty in costs, approaches that allow the market flexibility to innovate can reduce these risks.

Government subsidies also create incentives for suppliers to exert effort through lobbying to maintain these subsidies (that is, rent-seeking behavior).[92] One way to mitigate such rent-seeking is to taper subsidies over time through predetermined schedules.[93] The California Solar Initiative provides rebates to consumers and businesses that install solar panels, with the size of the rebate declining as more solar panels are installed.[94] Similarly, the federal tax credit for plug-in electric vehicles is being phased out as manufacturer sales of these vehicles increase.[95]

In addition to the considerations and risks outlined above, policymakers should keep in mind that market failures at the adoption and diffusion stages, and the potential effect of policy responses directed at those market failures, vary from sector to sector and from technology to technology. Markets and technologies should be analyzed individually when considering policy intervention.[96]

3. Special Considerations for Policymakers at the State Level

States contemplating measures to address R&D market failures may face different tradeoffs than policymakers acting at the federal level. Effective implementation of many R&D measures involves

Address Climate Change," November 6, 2017, *available at* https://www.oregon.gov/gov/Documents/executive_orders/eo_17-21.pdf.

[91] See, for example, JNS 2004, p. 42.

[92] Newell 2015, p. 187.

[93] See, for example, Schatzki, Todd, and Robert N. Stavins, "Beyond AB 32: Post-2020 Climate Policy for California," January 2014, available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2378669, p. 41.

[94] California Energy Commission & California Public Utilities Commission, "California Solar Initiative Rebate," *available at* https://www.gosolarcalifornia.ca.gov/csi/rebates.php.

[95] U.S. Department of Energy (DOE), "Renewable Electricity Production Tax Credit (PTC)," *available at* https://www.energy.gov/savings/renewable-electricity-production-tax-credit-ptc.

[96] See, for example, Aldy et al. 2010, p. 925.

fixed costs, implying that federal programs may be more efficient than individual state programs. For example, evaluation of proposals to fund basic research requires highly technical staff to evaluate research proposals, assess each project's potential, and understand promising areas for technological development. Given these factors, among others, most basic research funding occurs at the federal level.

Lacking federal action, individual states could coordinate with like-minded states and provinces to pool research funding, coordinate research priorities, and share resources to administer funding programs. Such pooling would avoid duplication of effort in learning about the technological landscape and maximize use of skilled resources to analyze options and reach decisions about funding and measures to pursue. In addition, pooling would allow states to diversify the risks associated with their research investments, particularly if those investments involve financial commitments, such as loans or loan guarantees.[97]

These pooling benefits would need to be weighed against the local economic benefits of directing funding to researchers at in-state universities or firms, although multi-state initiatives could include procedures for ensuring that the economic benefits of research activities are spread among states contributing to the initiatives. However, directing funding to local institutions may come at a cost if these resources are less effective at achieving the underlying technology development that is the objective of the measures. Moreover, research that eventually lowers the cost of reducing GHG emissions may have the greatest net benefits of the actions an individual state can take, as reductions in technology costs can spill over across the globe, thus leading to broader emission reductions. Hence, catering to local economic interests may reduce the efficacy of policies aimed at advancing low-GHG technology more than is immediately apparent.[98]

Naturally, a concern among smaller-scale policy jurisdictions, such as states, may be that their own investments crowd out investment that otherwise would have been undertaken by larger bodies, such as the federal government. If the federal government targeted an overall level of basic research funding for the country as a whole, for example, then investments by Oregon might simply shift a portion of the investment burden to Oregon without increasing overall investment. Potentially, coordination with the federal government — particularly on the use of matching funds, with the state offering funding on the condition of federal matching, or vice versa — might help alleviate this concern.

[97] States may also potentially increase the impact of their policies by coordinating with policymakers at the federal level. The National Academy of Sciences (NAS) has suggested a network of "Regional Energy Innovation and Development Institutes" (REIDIs) to coordinate and cooperate with federal energy-innovation programs. Such a system could be useful in directing state efforts where they are most effective. NAS 2016, p. 68.

[98] Fischer 2009, p. 7.