The Role of Technology Policies in Climate Mitigation

Carolyn Fischer[*]

Stabilizing global greenhouse gas (GHG) concentrations at levels to avoid significant climate risks will require massive decarbonization of all the major economies, including Canada, over the next few decades. Additional activities will be required to reduce emissions from other GHGs and to promote carbon sequestration through soil management, afforestation, and avoided deforestation. Achieving the necessary scale of emissions reductions will require a multi-faceted policy effort to support a broad array of technological and behavioral changes. This paper outlines some core principles for guiding the design of clean technology policies, with a focus on energy.

Carbon pricing *is* a technology policy.

At the core of any cost-effective approach must be a strong and increasing price signal across the entire economy that carbon emissions are costly. Emissions pricing can be implemented either through a carbon tax or a broad-based cap-and-trade system. The reason for a primary reliance on carbon pricing is twofold.

First, technologies are only useful if people want to use them. While social values may influence some folks to become early adopters of hybrid cars or compact-fluorescent light bulbs, financial self-interest is the primary driver of such decisions for most participants in a market economy. Carbon pricing makes clean technologies more cost-competitive, which provides "market pull" by encouraging their adoption. Greater potential for uptake in turn encourages the private sector to innovate improvements and alternatives. Thus, carbon pricing reduces some of the need for reliance on public innovation programs targeted specifically toward clean energy, as the market has more incentive to contribute. Furthermore, carbon pricing ensures that public

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[*] Consultant. Address: 3215 Pauline Dr., Chevy Chase, MD, 20815, USA. Tel: +1-301-652-3265. Carolyn Fischer is also a Senior Fellow at Resources for the Future, 1616 P Street, Washington, DC 20036 USA. The author is grateful for helpful comments from Alex Long, Dave Sawyer, Thomas Sterner, David Popp, and Knut Einar Rosendahl.

spending on "market push" strategies of research, development, and deployment (RD&D) ultimately has greater impact, by increasing demand for these technologies.[1]

Second, many options are available for reducing emissions. Not only is there a huge array of technological solutions for electricity generation, production processes, building materials, and consumer appliances, but a variety of behavioral changes can contribute to smaller emissions footprints. No command-and-control regulation could efficiently prescribe all the appropriate activities that should be undertaken. Carbon pricing, on the other hand, creates incentives to do all these things: use less carbon-intensive fuels and products, conserve energy, and develop and deploy emissions-reducing technologies. All of these options will compete in the marketplace, allowing decisions for reducing emissions to be made on the basis of cost-effectiveness. Furthermore, when cost-effective reductions are taken in the near term with current technologies, some pressure is lifted on the speed and depth of technological change needed in the future to reach a long-term cumulative emissions goal.[2]

Technological change and turnover will be essential for deep reductions; however, a lack of emissions pricing is not the only roadblock. In the following sections we discuss a host of other impediments to a robust market for clean technology RD&D: financial, regulatory, behavioral, and network barriers; knowledge and innovation spillovers; scale economies and other challenges. Furthermore, political realities may constrain the carbon price from being sufficiently high and credible as to induce the necessary transformation and innovation.` Thus, while experts agree that a carbon price is necessary, few believe that a carbon price alone is sufficient to achieve these goals cost effectively. The carbon price should be supported by complementary policies to address barriers to technological development and deployment.

Pick winning technology *policies*.

Many studies have been conducted of the technological options for achieving deep reductions in GHG emissions. In a well-known *Science* article, Pacala and Socolow (2004),

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[1] For a broader discussion of the interaction between emissions pricing, spillovers, and public support for environmentally friendly technologies, see Fischer (2008).

[2] Fischer and Newell (2008) show that, even with knowledge spillovers, policy cost-effectiveness depends largely on the degree to which all options for reducing emissions are encouraged. While emissions pricing is the single most effective policy, an optimal portfolio also includes R&D support, achieving emission reductions at significantly lower cost than any single policy.

professors of ecology and engineering at Princeton University, introduced a now popular tool illustrating the "wedges" of potential reductions from available technologies to bring the emissions path to a stabilization target. These kinds of studies are informative, but they focus on the capacity of technologies, rather than the cost-effectiveness of reduction options, the possibilities for innovation over time, or the role of policies in getting there. Economists who model climate policies, on the other hand, tend to focus on cost-effective solutions, but often with less technological detail. All models have difficulty incorporating realistic representations of technological change, uncertainties, barriers, and non-market-based policies.

In Canada, two recent NRTEE reports address the climate technology challenge. Peters et al. (2008) provide a "roadmap" of carbon pricing and technological deployment scenario for Canada to meet a deep reduction target. This study combines a good deal of technological detail with an economic approach, improving our understanding of what is both technically and economically feasible, and of what the marginal cost of reaching such targets may be. Still, these kinds of studies are of course limited by the many assumptions, albeit informed ones, they have to make. These assumptions include the technologies available (for example, solar and hydrogen options were not emphasized), their costs, rates of change, whether there is a role for R&D (no), how they respond to learning, and how users respond to them. Energy projections are difficult for proven technologies, much less emerging ones. A particular concern is unseen roadblocks on the roadmap. Lambert et al. (2008) conduct an expert elicitation analysis of the main barriers to deploying those technologies and the likelihood of the roadmap scenario being feasible. They identify some specific barriers to specific technologies, which serve as examples in this context; however, the purpose of this paper is to draw out the larger principles for designing technology policies, to encourage innovations both on and off the roadmap.

In one word, a key challenge for meeting emissions and technology goals is "uncertainty." We are not sure what emissions reductions will ultimately be needed or what the corresponding prices will be. We do not necessarily have a good idea of the costs of large-scale deployment of currently existing technologies, much less when breakthrough technologies might arrive, or to what degree the costs and/or quality of existing technologies will be improved. These kinds of uncertainties can create a tension among policy recommendations. On the one hand, policies should be as neutral as possible, to allow a broad range of technologies to emerge and compete, and to avoid the problem of governments attempting to pick winners. On the other hand, we cannot be fully neutral, given that we are largely aware of the major technological options that will be available over the next decades and some technologies have specific barriers and specific potentials that may require targeted assistance. The next section discusses which kinds of problems are best addressed with broad support and which kinds may justify narrower policy responses.

Address barriers.

In a sense, the carbon price is addressing the primary barrier, which has been the lack of financial reward for climate-friendly behavior and technologies. However, additional barriers or market failures may require additional policy tools, and many of these need not target specific technologies.

Certain barriers lend themselves to broad and neutral policies.

Supporting research. For example, the social value of research and innovation often surpasses what the innovators themselves can appropriate. These knowledge "spillovers" represent a kind of market failure, since by receiving only a fraction of the benefits, innovators have only a fraction of the incentive to engage in the R&D. Studies of commercial innovations suggest that, on average, less than half of the gains to R&D return to the originator, although appropriation rates vary considerably over different types of innovations.[3] Basic research, in particular, is an excellent candidate for government support, as the commercial applications are often distant and unknown. Given that patent lives are finite, while carbon prices are still phasing in, clean technologies will have relatively low (but rising) appropriation rates, meaning that some extra support during the transition can help clean technology development. Even commercial innovations have spillovers—however, it is important to remember that spillovers are not the exclusive domain of clean energy technologies. With a carbon price in place, tax breaks and other public incentives for reflecting the additional social value of R&D are most efficient when they are broad-based. Else one risks crowding out useful innovation in other sectors.

Removing distortions. In addition to the carbon price, other policies can ensure that the allocation of private R&D better follows social (including environmental) values. For instance, distorting subsidies for fossil-based energy should be removed. In non-OECD countries, subsidies are primarily used to keep consumer prices artificially low, with overconsumption as a result. If major developing countries would wipe out all energy subsidies, global CO2 emissions

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[3] See, e.g., Jones and Williams (1998).

could fall by 4-5% (IEA 2002). In OECD countries, however, most of these subsidies are for fossil-fuel production; for example, in the U.S., half of energy subsidies go to fossil fuels, compared to 5% for renewables (IEA 2006). Many of these subsidies take the form of preferential tax treatment, relative to other sectors. Taylor et al. (2005) identify several important subsidies to the oil and gas sector in Canada—accelerated depreciation, the expensing of exploration and development costs, and other investment tax breaks; direct expenditures on infrastructure and R&D; and the incomplete capture of resource rents through royalties—many of which disproportionately support the development of the relatively dirty oil sands. Of course, beneficiaries of subsidies will resist reform. Therefore, removing subsidies may require a gradual phasing out (French coal subsidies were reduced in a 20-year program); transitioning to less distortionary forms of assistance (the U.S. replaced agricultural commodity price supports with a direct income support program); and educating the public about the benefits to rally support (IEA 2002).

Another kind of subsidy is the lack of policy to reflect the cost of other environmental damages, besides GHG emissions. Regulating conventional air and water pollutants with market-based mechanisms will also help improve market signals and make clean energy sources relatively more competitive to their fossil-fuel counterparts.

Inefficient regulations, on the other hand, can impede technical progress. Unnecessary legal and regulatory barriers that favor incumbents should be removed to allow for better competition. Unfortunately, some of the energy sectors most relevant for GHG reductions also involve highly concentrated, natural monopolies. For example, regulators of power generation, transmission and delivery must keep an eye on the ability of new entrants to join and compete. Licensing, regulations, and interconnection procedures must be clear, not overly burdensome, and coordinated across jurisdictions, while allowing for appropriate oversight to balance potential tradeoffs in economic and environmental costs. Often, streamlining regulations need not be technology-specific and can benefit all participants, not just new green entrants.

New technologies may also require explicit new policies to create regulatory certainty. For example, the long-term impacts of large-scale carbon capture and sequestration (CCS) remain uncertain, and relevant regulations, guidelines, and industry protocols are needed to assign liability and develop good practices.

Some barriers may be general in origin, but require more specific attention.

Information. For markets to function, they require not only good property rights and competition, but also information. Some product characteristics are easily observable, but others—like nutritional content or energy consumption rates—are not available or credible without government intervention. By improving the availability and visibility of information, product-specific labels, credible reporting standards, and educational campaigns can allow better consumer and firm decisionmaking at lower costs.

Standards. Still, perfect information may not be enough. Consumer uncertainty about energy prices and the quality and reliability of the new technologies being offered them can contribute to seemingly myopic behavior. Poor choices can also arise when those making decisions about the energy-using appliances and building features are not the same people as those using or paying for the energy, such as in landlord-tenant relationships. Coping with short payback horizons and principal-agent problems can require product-specific interventions, such as energy efficiency standards, fuel-economy standards, and building codes. While these standards are generally informed by technological options, they need not be prescriptive of particular ways to meet the standards. Indeed, they should be designed so as to allow cost-effective alternatives and ongoing incentives for improvement.

Financing. Risk and payback horizons also influence investment decisions; if the private perceptions of these factors do not align with the public ones, then policies may be needed to assist financing and manage risks for publicly desirable projects. Technologies for which capital costs are very large (such as nuclear, hydro, CCS) are more likely to need preferential financing or guarantees to reduce private investment risks. Even wind generation has high capital costs relative to operating costs; however, the capacity can be expanded more incrementally and policies to guarantee profitable production prices has typically been used to reduce investment risk, rather than finance guarantees, although investment tax credits are also common. Ultimately, greater certainty about the carbon pricing policy will also help to reduce risks and raise returns for low-carbon technologies, and financing interventions should focus on narrowing the discrepancy between private and public payback horizons.

Other barriers are specific to certain technologies.

Scale economies. Economies of scale are an issue for many new technologies. Until enough units have penetrated the market, production costs are high and support services are scarce. Policies to address this barrier can legitimately help some new technologies gain acceptance and get off the ground, but they should be careful to avoid extended support for uneconomic technologies. An example is hybrid vehicle tax credits in the U.S., which phase out after a certain number of models are sold. Portfolio standards also become easier to meet (and credit prices fall) as scale economies are met.

Networks and infrastructure. Some technological options require new infrastructure and support networks in order to function. However, private actors are reluctant to take on activities that supply public goods, and most would prefer to wait for someone else to do it. The resulting network externalities are an important cause of “path dependence” or “technological lock-in,” and public intervention may be required to change paths. Important examples lie in the distribution of fuels for transport: biofuels, hydrogen, CNG, or plug-in electric would require new fuel (or battery) distribution and storage equipment, as well as new vehicle engines. Here it may be costly to allow multiple new options and thereby difficult to avoid picking a winner, so the decision must be made deliberately. For costly network infrastructure investments, there is an option value to waiting for more information, in order to be confident in betting on the technology.

Some infrastructure investments for carbon-free generation technologies may also have network externalities. For example, real-time energy metering can allow for time-of-use pricing to better manage electricity demand. Direct current lines in buildings could allow solar cells to power many devices without inverters. Upgrades to “smart grid” transmission technologies can facilitate the incorporation of distributed generation and intermittent renewable energy sources. However, many infrastructure investments—like transmission lines for remote renewable energy sources—are better viewed as an additional cost to developing more capacity in those resources, although there may be other barriers related to siting or entry. The expansion of nuclear generation would require central infrastructure in the form of a waste storage facility—which involves its own tradeoffs.

Tradeoffs. Many technologies that reduce GHGs may instead cause other environmental damages and risks. For example, nuclear generation creates radioactive waste and security concerns. Hydropower affects aquatic ecosystems, fish spawning, and cultural resource access rights. Battery waste involves toxic chemicals; transmission lines can disturb other land uses; most generation siting raises “not in my backyard” (NIMBY) issues, and the list goes on. Public assessment of the tradeoffs is needed before allowing broad deployment. These assessments are also related to the regulatory regime for deploying technologies, and assuring that regime is appropriate but not unnecessarily long or cumbersome.

Certain kinds of technologies may deserve preferential treatment.

In addition to addressing important market failures and barriers, policymakers may want to direct extra attention and support to certain kinds of technologies that have special potential. Some examples of especially desirable technologies are those that expand options and reduce costs of reaching deep reductions, those that may have additional spillover benefits at home, and those that may have spillover benefits abroad, further reducing global emissions and improving the likelihood of more globally stringent GHG agreements.

Backstop technologies. As heavily emphasized in the Stern Review (2006), there is an important role for technology policies that focus on bringing down the costs of reducing carbon emissions. When the future emissions target is uncertain, as well as the costs of reaching potential targets, both R&D and early abatement activities can facilitate the adoption of more ambitious targets and thus help reduce the expected costs of future abatement, adaptation, and damages. However, certain kinds of R&D may also help to reduce the degree of uncertainty in these costs and thereby carry an extra value.

In the climate policy case, the national or societal marginal abatement cost curve represents a sequence of technological options, each more costly than its predecessor. “Backstop” technologies are a particular kind of option. Conceptually, a true backstop technology is free to be replicated at a large scale without scarcity constraints, meaning that marginal costs (though relatively high) do not increase much as capacity is expanded. The presence of backstop technologies helps to flatten out the upper portion of the overall marginal abatement curve, meaning that if stricter-than-expected emissions targets are necessary, carbon prices will not need to rise astronomically. In other words, if it turns out that climate change is even more serious than we think, and we need to step up emission reductions dramatically in the future, an affordable backstop that can be expanded to basically any scale would be invaluable. Therefore, given the uncertainty we face, there is an added value to bringing down the costs of technologies that help flatten the marginal abatement cost curve. Of course, another way to keep options open is by reducing emissions more aggressively in the near term. But if backstop technologies can keep costs lower in the worst-case scenarios, expected long-term costs are also lower, and that in turn reduces pressure to engage in deeper reductions in the near term.[4]

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[4] See Fischer and Sterner (2007).

In terms of true backstop technologies, the most-discussed candidates are carbon capture and storage, nuclear, and solar (and, theoretically, fusion). Each has the possibility of being utilized at large scales, though location (and risk management) could be a constraining factor. The solar energy flow to earth is particularly large in comparison to societal needs. RD&D programs that can lower costs, expand capacities, and accelerate how rapidly these capacities can be tapped have an added insurance value, beyond the gains that would be realized at the expected levels of utilization laid out in roadmaps.

Comparative advantage. Countries may have national RD&D policies, but the development of new technologies is a global effort. Consequently, there may be opportunities for coordination (or free-riding, for that matter) and for specialization. Technology oriented agreements can be aimed at knowledge sharing and coordination, research, development or demonstration, and even deployment.[5] Such commitments can increase the technological effectiveness of an agreement over emissions reductions, although they are generally weak policies in terms of environmental effectiveness on their own. (Even at the international level, technology policies are complements to mitigation policies.) International agreements over technology standards can also be attractive from a competitiveness point of view, ensuring that trading partners have similar cost burdens.

On the other hand, technologies might become a source of competitiveness. Due to different circumstances, some countries will enjoy a comparative advantage in certain technologies. In this case, not all countries will want to engage in the same RD&D portfolio, but rather wish to specialize to some extent. For example, countries with large availability of geological sequestration sites may prefer to invest more in CCS innovation.

Global spillovers. Technology spillovers do not respect borders either, and they can inform priorities for dealing with global pollutants like GHGs. In particular, technological advances that support international agreements and efforts have additional value beyond what is appropriated at home. For example, some technologies may have better potential to be adopted among emerging economies that lack direct carbon regulation. Indeed, the availability of low-cost abatement opportunities may help encourage these countries ultimately to take on hard

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[5] For a discussion of technology oriented agreements, see de Coninck et al. (2008).

emissions targets. Thus, developed countries will want to engage not only in technology transfer agreements, but also RD&D efforts that are likely to produce technologies to be transferred.[6]

Summary and options

We should recognize that not all barriers to adoption are market failures. Cost, reliability and quality issues, risk, etc., are all legitimate aspects that the market should be allowed to weigh in choosing cost-effective technologies. Furthermore, R&D market failures are not exclusive to energy technologies, and once most energy-related market failures are addressed (as through carbon pricing), then society must be wary of crowding out other legitimate innovation efforts.

As a result, the main tools for encouraging climate-friendly technologies should be those that encourage the market to make good choices more generally: pricing carbon emissions and other environmental damages, removing distorting subsidies and barriers to competition, and supporting R&D broadly.

Some technologies face particular barriers, requiring society to take a decision of whether to support them, committing to major infrastructure investments or environmental risks. Other technologies may merit extra support, because they offer insurance against the possible need for deeper reductions, or because they have greater potential for being adopted in other parts of the world.

Several policy options are available to support technological development. Broad-based policies include R&D tax credits, funding universities and research institutions, and other public support for research through competitive grant processes. Scale economies can be supported through tax breaks, subsidies, performance standards (including tradable ones), or market-share mandates. While the latter two policies also create an implicit subsidy to the targeted technology (like renewable energy sources), paid for by the non-preferred sources, they have the advantage of not only requiring no public outlays, but also naturally phasing itself out as the new technology becomes cost-competitive.

More specific policies are required to address particular market failures and barriers, including information requirements, energy efficiency standards, building codes, etc. In these cases, policies will generally be more effective, the more closely they target the specific market

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[6] See also Popp (2008) for insights into technology transfer policies.

failure, as opposed to a specific technology. Standards perform better when they are flexible rather than prescriptive in terms of how the goal must be achieved.

Finally, for those technologies identified as being particularly desirable, some narrower R&D policies are available. Traditionally, most policies subsidize inputs to research, either through specific tax credits, grants or contracts, or directed research in publicly funded laboratories. If government lacks the expertise or impartiality, allocation of these research funds can also be outsourced to independent third-party managers given specific mandates.[7] Technology prizes, on the other hand, offer financial inducement to an output, such as being the first to develop a specific advance or the contestant having made the most progress by a deadline. Newell and Wilson (2005) indicate that such methods have been successful in the past and they could play a supportive role in climate policy, although attention should be paid to the design features, including the technological target, the size and nature of the prize, and the method for selecting the winner.

International engagement is another component of technology policy. Recognizing that climate mitigation and technological advances are a global effort, countries can leverage their own R&D resources with international partnerships and agreements to encourage knowledge sharing and broaden the markets for new technologies.

Ultimately, the biggest driver of technological adoption and change will be the mitigation policy, which determines the demand for those technologies. An additional advantage of emissions pricing policies is their ability to generate revenue, which can fund help fund the complementary technology programs. However, that is not to say that all or even a particular share of those revenues needs to be explicitly earmarked for technology programs. Indeed, just as technologies should compete in the marketplace for adoption, technology policies should compete in the budget among all the worthy causes. Supporting climate-friendly RD&D is certainly one, but so are transitional assistance, adaptation, tax relief, foreign aid, and a host of other demands unrelated to climate, including other innovations. Priority should be given to policies that enhance overall economic efficiency—broad R&D support, removing distortions, addressing regulatory barriers, reducing tax burdens, improving information, supporting

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[7] An example is the Ontario Centres of Excellence, which operate somewhat like a publicly funded venture capital firm.

fundamental research. Then policymakers can turn to more targeted programs, fully considering the benefits and the tradeoffs.

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