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The Morning After

Optimal Greenhouse Gas Policies for Canada's Kyoto Obligations and Beyond

Mark Jaccard, Nic Rivers
and Matt Horne

In this issue...
As the fortunes of the Kyoto Protocol ebb and flow, Canada should focus on a fundamental and enduring objective, which is to implement well-designed policies that lead to a cleaner energy system by fostering long-run technological change without wreaking short-run economic havoc.

The Study in Brief

In December 2002, after months of acrimonious national debate, the Canadian government ratified the Kyoto Protocol, an international agreement that commits Canada to reducing greenhouse gas emissions (GHG) to 6 percent below their 1990 level by 2010. Many of those opposed to ratification argued that the government committed Canada to an ambitious target without knowing the economic ramifications.

Ottawa has since intensified its existing GHG policies while launching discussions with provincial governments and industry groups in an effort to develop additional programs. It is not yet possible to assess fully Canada's approach, but its emphasis on voluntary initiatives by businesses, consumers, and municipalities, supported by modest government subsidies, is similar to the dominant energy policies pursued by governments and utilities in recent decades. Unfortunately, mounting evidence indicates that this approach is environmentally ineffective and economically inefficient.

We therefore propose an alternative policy package that includes some command-and-control regulations (modest efficiency standards) and a continuation of some voluntary initiatives, but is dominated by sector-specific, market-oriented regulations. These are technology-forcing regulations that require a minimum market share for low-emission technologies (vehicle drive-trains) and energy forms (electricity generation), or a maximum level of emissions from economic sectors (major industries), while allowing time and flexibility for achieving that outcome. This type of policy stimulates privately funded research, development, and commercialization of new technologies without triggering politically unacceptable increases in production costs and energy prices in the short term, and without engaging government in the risky role of picking technological winners and losers.

Because our policies are consistent with those already implemented in major regions of the U.S., and are growing in popularity internationally, they also mitigate competitive risks to Canada from the U.S. decision not to ratify Kyoto or from the possible collapse of the entire protocol.

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In December 2002, after several months of acrimonious national debate among regions and interests, the federal government ratified the Kyoto Protocol, an international agreement that commits Canada to reducing its emissions of greenhouse gases (GHG) to 6 percent below 1990 levels by 2010.[1] Many of those opposed to ratification argued that the government was taking on overly ambitious targets and timetables without understanding what it could realistically achieve, what the cost would be, and what policies would be required. One commentator likened the sobering challenge facing the country on the day after ratification to the discomfort experienced on the morning after an evening of excessive drinking.

While most GHG policy discussions in Canada have addressed the issue of whether the country should have ratified Kyoto in the first place and should stick to that commitment, we focus in this *Commentary* on the design and implementation of an optimal package of GHG emission reduction policies for the Kyoto timeframe and beyond.

This is a critical policy juncture for Canada. In the year since ratification, the federal government developed its own GHG policies and launched negotiations with provincial governments and industry groups in expectation of developing additional collaborative policies and programs. Because we are still early in this policy development process, it is not yet possible to assess comprehensively Canada's strategy for domestic GHG reduction. But it is possible to characterize the government's approach so far as focused primarily on voluntary initiatives by businesses, consumers, municipalities and regional governments.

We believe that this emphasis on voluntarism will prove ineffective in inducing substantial long-run reductions in domestic GHG emissions, both in the Kyoto timeframe and over a longer period — and there is considerable evidence to support our position. Some of that evidence comes from recent evaluations of voluntary environmental policies in Canada and other jurisdictions. A lot more of it comes from the experiences in the 1970s and 1980s as many governments and energy utilities throughout the world tried various approaches to reducing energy use and fostering fuel switching. Because energy use is the most significant source of human-generated GHG emissions, an understanding of this field is critical in formulating policy. Fortunately, governments have considerable experience with policies to influence energy production and consumption technologies. Unfortunately, governments sometimes ignore the lessons from these experiences as political pressures drive them toward policies that, while politically acceptable, are ineffective or economically inefficient.

We seek to contribute to Canada's GHG deliberations by first presenting the special challenges facing policymaking for an environmental risk such as human-induced climate change. An understanding of these challenges provides an important basis for comparing alternative policy approaches. We then develop a

1 Under the Kyoto Protocol, developed countries and countries in transition (mostly members of the former Soviet Union) committed to reducing their aggregate GHG emissions to 5.2 percent below 1990 levels in the 2008-to-2012 period. To simplify, we use 2010 as the effective deadline date. It is important to distinguish between *signing*, which indicates that a country is willing to continue in the treaty making process, and *ratification*, which signals consent to be bound by the rules and obligations of the Protocol.

standard set of policy evaluation criteria and apply these to both conventional and newly emerging policy options for GHG emission reduction. We next turn to Canada's current GHG reduction policies and suggest reasons why these are unlikely to perform well. Finally, we present our own policy package.

While ours is not a comprehensive package, it is in sharp contrast to the approach of the federal and provincial governments so far. Our proposals include some command-and-control regulations and maintenance of voluntary initiatives where they can be proven effective, but our proposals are dominated by sector-specific, market-oriented regulations. These are regulations that stipulate an aggregate market outcome in the future by requiring a minimum market share for low-emission technologies, such as in vehicle drive trains, for forms of energy, such as in electricity generation, or for maximum aggregate emissions, as with major industrial emitters, while allowing time and flexibility among individual market participants in achieving results.

This type of policy provides a strong incentive for privately funded research, development and commercialization of new technologies, without requiring politically unacceptable levels of production cost and energy-price increases in the short-to-medium term. The specific market-oriented regulations we propose are consistent with policies already implemented in some regions of the U.S., and are growing in popularity in that country and elsewhere. That development reduces the competitive risks to Canada from the U.S. decision not to ratify the Kyoto Protocol or from the collapse of the entire protocol should that occur.[2]

As members of a university-based research team that has developed and applied policy simulation tools for almost two decades, we use our own energy-economy model to assess the performance of our policy package with respect to the evaluation criteria. The simulations show that our policy package is likely to achieve a significant reduction in GHG emissions in the Kyoto timeframe and, more importantly, stimulate substantial technological innovation and commercialization that will ensure continuing emission reductions in the post-Kyoto period, a time during which the international community expects to negotiate further commitments on global emission reduction.

This is achieved without significant short-term economic disruption, either in terms of domestic energy prices or the international competitiveness of Canadian industry. Our package falls short of achieving all of Canada's Kyoto commitments by the deadline of 2010. But this is consistent with the federal government's own climate change plans, in which a recognized shortfall in domestic reductions is compensated for by the purchase of emission credits from countries where GHG reductions exceed their Kyoto commitments, or by actions in other countries that offset Canada's emissions.[3] Most parties recognize that the timeframe is simply too short for Canada to achieve all of its ambitious Kyoto commitments through domestic reductions alone at an acceptable cost.

Finally, while we focus on GHG reduction policies from a federal government perspective, our analysis and policy suggestions are broadly applicable to GHG

2 As of the date of this *Commentary*'s release, Russia, a critical signatory, was undecided about ratification.

3 Under the Kyoto Protocol, developed countries are allowed to make use of three flexibility mechanisms designed to reduce the costs of implementation over domestic action alone — international carbon credit trading, joint implementation, and clean development mechanisms. The latter two involve GHG reduction projects in other developed and developing countries.

policies by any level of government. Given some of the jurisdictional uncertainties facing environmental policymakers in Canada, we are not suggesting that one level of government should be solely responsible for the country's GHG policy, or that one level has unconstrained authority to implement all of the policies we present. But the Kyoto Protocol is an international agreement requiring national coordination and cooperation, so the federal government will remain the primary instigator of GHG policymaking in Canada.

The Policy Dilemma

The goal of environmental sustainability presents special challenges to policy-makers, and reducing GHG emissions in order to lower the risk of climate change epitomizes some of them. For one thing, the connection between our actions as consumers and the resulting GHG emissions is not readily apparent to most people. For another, the degree to which GHG emissions can place ecosystems and people at risk is unclear and is likely to remain so for some time. As well, significant reductions in GHG emissions may be costly, although this area, too, is murky. As a result, the government finds itself in the position of possibly imposing significant near-term costs on consumers and businesses for hazy and poorly understood benefits in the future, benefits that might mostly be realized by people on the other side of the planet.

The expectation that GHG reduction will be relatively costly arises mainly from the large amount of GHG emission reductions in Canada's commitment and the relatively short period to achieve them — the 2010 deadline of the Kyoto Protocol. Although Canada's Kyoto emission target only specifies a 6-percent reduction of GHG emissions from 1990 levels, growth in population and economic activity, and to some degree changes in consumption patterns, have resulted in GHG emissions that reached 18.4 percent above 1990 levels by 2001 (Environment Canada, 2003). Under a continuation of current trends, GHG emissions are projected to climb further to 24 percent above 1990 levels by 2010. As a result, the real required reduction in GHG emissions from the business-as-usual evolution of the Canadian economy would be about 30 percent by 2010. Only six years remain for this reduction.

In its GHG reduction plans, the Canadian government appears to recognize the difficulty of achieving all of its Kyoto commitment domestically. Its allocation of reductions among domestic businesses and consumers leaves a significant gap to be bridged using international mechanisms available under the protocol. Our research suggests, however, that even the reduced level of domestic emissions abatement sought by the federal government presents a major challenge in the short time remaining.

A key cause of this difficulty is that most actions for reducing GHG emissions involve replacing existing equipment and buildings with new technologies that lead to greater energy efficiency or fuel switching.[4] This list shows the major actions required for a significant reduction of GHG emissions in Canada:

4 We distinguish between *actions* (choosing a different light bulb, driving less, installing windmills instead of a coal plant) and the *policies* (taxes, regulations, information programs) that are intended to induce these actions. They are often confused in public discussions and even in reports by experts.

- Improving energy efficiency in buildings, production processes, space-heating devices, vehicles, appliances, and electronic equipment;
- Increasing use of renewables, municipal waste, and natural gas in electricity generation;
- Switching toward low, full-cycle GHG fuels in vehicles;[5]
- Developing urban form and transportation infrastructure that encourages reduced personal vehicle use;
- Increasing the market penetration of low-GHG emitting equipment and production processes throughout industry;
- Improving and applying technologies that separate and store carbon (called carbon sequestration), and
- Changing forestry and agricultural technologies and management practices.

Attaining this kind of technological change in Kyoto's short timeframe is likely to be costly for two reasons. First, the timeframe would require premature turnover of capital stock, such as equipment, industrial processes and buildings. When equipment is retired before the end of its useful life, significant costs are often incurred. Second, businesses and individuals lack the time to become familiar with, and hopefully accepting of, emerging low-GHG technologies, including hybrid or fuel-cell cars, wind turbines and carbon sequestration. Forcing adoption of these technologies in a tight timeframe imposes less tangible, but significant consumer and business costs related to risk of failure, inappropriate design, and unreliable performance. Over a longer timeframe, policies might influence long-run technology costs and even preferences in ways that increase the willingness to adopt low-GHG technologies.

Evaluating Policy

Jaffe *et al* (2002) explore these issues in their comprehensive survey of research into the relationship between environmental policy and technological change. They find considerable empirical support for the argument that the cost of environmental improvement is sensitive to the timing and choice of policy instrument. Some policies better match the pace of technological change to the natural rate of capital stock turnover, reducing compliance costs. Others are better at inducing private research and development that leads to technological innovations that reduce the cost of environmental improvement in the long run. Some policies are better at influencing the preferences of businesses and consumers, and thus at achieving political acceptance.

Policy design for GHG reduction must trade off potentially conflicting objectives. On the one hand, it must provide strong long-run signals to motivate technological innovators, companies commercializing cleaner technologies, and consumers interested in greener lifestyles. On the other hand, those strong signals should be designed to avoid unnecessary economic cost in the short run, which also improves the prospects for political acceptance.

To address these trade-offs, policy analysts have developed policy evaluative criteria. Four common criteria that we apply here are:

5 Full-cycle means that emissions must be accounted for through the entire energy chain from primary energy production to the use of final energy by the vehicle.

- Effectiveness at achieving environmental targets;
- Administrative feasibility;
- Economic efficiency, and
- Political acceptability.

All four criteria must be considered in concert. A policy may be politically acceptable, but ineffective in achieving the intended environmental target. A policy may be effective, but not administratively feasible or economically inefficient. While no policy performs perfectly against all four criteria, some do better than others. We use these four criteria in describing and evaluating both conventional policy options and more recent innovations.[6]

Conventional Policy Options

Policy options are categorized in different ways; we focus here on where they fit along a spectrum that denotes their degree of compulsoriness. We use this uncommon term because it best expresses the extent to which certain behaviour is required by an external force, an important consideration for our policy evaluation criteria. One end of our spectrum depicts policies that are completely noncompulsory — encouraging voluntary behaviour by consumers and companies — while the other end depicts compulsory policies that mandate a specific action. The following survey of conventional policy options starts with the most compulsory

Command-and-control regulations. These mandate specific emission levels or technology characteristics, with non-compliance incurring stringent financial or legal penalties. This approach dominated environmental policy in the 1970s and is still important today, though it can be economically inefficient where it requires identical equipment choices or management practices by participants whose costs of emission reduction differ considerably (Newell and Stavins, 2003; Stavins, 2001), and regulations provide no incentive for companies to find emission reductions beyond the legal requirement (Millman and Prince, 1989; Parry, 2003). While corporate leaders and economists have convinced politicians and even some environmentalists that a strict regulatory approach inflicts a burden on the economy, people nonetheless argue that for many environmental concerns well-designed regulations can be effective, fair and not too economically onerous (Cole and Grossman, 1999).

Financial disincentives. These are charges on emissions, such as GHG taxes. This approach is not as compulsory because it does not specify a particular action; the business or consumer chooses between taking no action to reduce emissions or reducing emissions in order to pay less tax. This flexibility can reduce the cost of

6 Some policy analysts prefer other criteria, or would characterize these four differently. For example, equity could replace political acceptability. But in terms of GHG policy, we find equity difficult to define. Are equal per-capita policy costs equitable? Are equal regional costs equitable? Are costs that reflect each person's contribution to GHG emissions equitable? We prefer political acceptability, which we define as a characteristic ensuring that politicians can find sufficient support to implement a policy. Thus, one can envision situations where a policy, such as GHG taxes, might pass the first three criteria while failing the test of political acceptability, or where a policy, such as voluntary action, might fail two or three criteria but pass the test of political acceptability.

achieving an environmental improvement and maintains an incentive for innovating lower-cost ways of reducing emissions. However, recent efforts to impose or increase financial disincentives, especially in North America, have not attained political acceptance, with opponents successfully portraying these as poorly disguised attempts to replenish government coffers (Svendsen, 1998). Financial incentives. Grants, low-interest loans and tax credits improve the financial returns to businesses and consumers who take specified actions to reduce emissions. While this approach appears non-compulsory, governments generally acquire their funds from various types of compulsory taxes. As a result, while subsidies to new technologies can influence the long-run costs of GHG emission reduction — especially when directed to new product commercialization — governments generally lack the financial resources to drive technological change with this method alone. Also, it is difficult to design subsidy programs to exclude free riders — participants who qualify for the subsidy even though they would have undertaken the action anyway. When free-rider effects are calculated, some subsidy programs are a lot less effective and thus a lot more expensive than anticipated (Joskow and Marron, 1992; Sutherland, 2000; Metcalf and Hassett, 1999; Loughran and Kulick, 2004).

Voluntary approaches. These combine information and moral suasion campaigns and tend to be politically acceptable because they are at the non-compulsory end of the spectrum. Individual companies and consumers determine their level of effort for environmental protection and improvement, while government functions as information provider, facilitator, role model and award giver. Over the past decade, governments and industry have shown a growing interest in voluntary programs (Carraro and Levesque, 1999; OECD, 2003). Popular new catchphrases, such as natural capitalism, eco-efficiency, eco-effectiveness and triple bottom line, suggest that companies can increase profits by adopting technologies that are more efficient in their use of energy and materials, and hence less polluting (Hawken *et al*., 1999). However, while the growth of voluntary programs has been dramatic and participating industries offer much anecdotal evidence of voluntary actions to improve the environment, we know little about the aggregate effectiveness of such programs (Harrison, 1999). In a recent survey of voluntary approaches to environmental protection, Khanna (2001) noted that only a few empirical studies have tried to estimate the actual environmental impact of such programs, and these have not had much effect. Similarly, the OECD recently concluded that the “environmental effectiveness of voluntary approaches is still questionable.” It added: “The economic efficiency of voluntary approaches is generally low” (OECD, 2003, 14).

Recent Policy Innovations

Environmental fiscal reform, or tax shift, combines financial incentives and disincentives in an effort to increase the chances of political acceptance (Durning and Bauman, 1998; National Round Table on the Environment and the Economy, 2002). In this approach, all revenue from environmental taxes is dedicated to reducing other duties that hinder efficiency or are unpopular. Modest environmental fiscal reforms include offsetting tax adjustments on low- and high-efficiency vehicles — called a fee-bate — while more ambitious initiatives under consideration, especially in Europe, involve the application of GHG tax revenue to reduce government payroll charges, income taxes or other broad levies (Svendsen *et al.*, 2001).

Because many economists and environmentalists support environmental fiscal reform, it may yet play a dominant role in GHG policy. It must overcome, however, considerable suspicion among the public and media that, despite claims of revenue neutrality, governments tinker with the tax system only to raise revenue. Politicians are therefore reluctant to initiate large tax increases on an essential commodity like energy even if other taxes decrease as a result. For these reasons, environmental fiscal reform may play a consolidating rather than a leading role because governments would enact modest tax changes only in support of more aggressive policies that drive long-run technological change.

Emission cap and *tradable permit* (ECTP) is a fairly recent policy innovation. Government sets a maximum level of emissions (a cap), then allocates tradable emission permits to all emitters covered by the program. Usually the permits decrease in number or value over time, gradually lowering the aggregate emissions cap. The ECTP is a form of regulation in that the aggregate emissions cap cannot be exceeded, participation is compulsory, and penalties for non-compliance are severe. Unlike traditional command-and-control regulation, however, the policy allows participants to determine their emission levels and whether they will buy or sell in the emission permit market. Because of these dual characteristics, we refer to this type of policy as a *market-oriented regulation* (also called *quantity-based market instrument*). The U.S. government's amendments to its *Clean Air Act* in 1990 applied ECTP to SO_2 emissions from electricity plants with encouraging results in terms of environmental effectiveness and economic efficiency (Stavins, 1998).

Governments could apply an economy-wide ECTP for GHG abatement, allocating permits to producers or consumers. Like a GHG tax, this would increase the price of GHG-intensive energy commodities and the final goods and services that use them. To achieve identical emission reductions, the trading price of GHG permits should equal the GHG tax rate. Thus, the economy-wide ECTP shares some of the strengths and weaknesses of GHG taxes: it can be effective and economically efficient, but it will incur the same price increases as GHG taxes and the same political backlash. As suggested with taxes, governments may therefore opt to apply ECTP in a consolidating role in concert with more aggressive policies to drive long-run technological change.

The ECTP focuses on emissions, but the principles of the market-oriented regulatory approach have also been applied to sector-specific policies focused on forms of energy or groups of technologies. In the electricity sector, some jurisdictions have experimented with the *renewable portfolio standard* (RPS) — a requirement that renewable forms of energy, such as wind, biomass, hydro and solar, generate a minimum percentage of electricity. In the personal-vehicles area, California and now other jurisdictions have adopted the *vehicle emission standard* (VES) — a requirement that low- and zero-emission vehicles attain a minimum percentage of vehicle sales. The RPS and VES are like the ECTP in stipulating an aggregate market outcome while allowing flexibility among participants to minimize compliance costs. They differ by focusing on energy forms and technologies instead of emissions.

According to our policy evaluation criteria, these market-oriented policies provide a long-run signal that motivates producers to innovate and commercialize low-emission technologies but do not cause in the short-run substantial increases in the price of energy. In order to meet their minimum sales requirements, producers will either capture higher revenue from those consumers willing to pay more for lower emission electricity or vehicles, or subsidize the higher costs of these products from their sales of conventional products. Because the market-share requirement of the cleaner products is small, any cross subsidy has a minimal effect on the price of conventionally generated electricity and conventional vehicles. As a result, the policy stimulates long-run technological change, while avoiding short-run economic disruption and political resistance. The rising popularity of this approach among environmentalists and politicians over the last decade attests to its success in matching effectiveness with political acceptability. A challenge, however, is that government must negotiate targets that do not compromise economic efficiency by causing uneven compliance costs between sectors.

Table 1: ***Policy Evaluation Summary***

Policy	Effectiveness	Economic Efficiency	Administrative Feasibility	Political Acceptance
Command and Control	Good	Bad	Good	Medium
Financial Disincentive	Medium	Good	Good	Bad
Financial Incentive	Medium	Bad	Medium	Good
Voluntary and Information	Bad	Medium	Good	Good
Ecological Fiscal Reform	Medium	Good	Medium	Bad
EC TP	Good	Good	Medium	Medium
Sector-specific Market Regs	Good	Medium	Medium	Good

Table 1 summarizes our qualitative assessment of the policies against the four evaluation criteria. No approach is optimal for all criteria, but the more recent approaches perform better on average and avoid a strong negative assessment against any single criterion. The table's message is only general, however, because design can affect how a policy performs. For example, the GHG policy we propose includes energy efficiency regulations (command-and-control) where a modest level reduces the likelihood of economic inefficiency and political unacceptability.

The Canadian Policy Approach

In 1992, Canada signed the United Nations Framework Convention on Climate Change, committing to reduce its GHG emissions to their 1990 level by 2000. To this end, Canada initiated the National Action Program on Climate Change, which included information programs, voluntary challenges and modest financial incentives. Its main policy instrument for Canadian industry was the Voluntary Challenge and Registry (VCR) in which companies would submit an action plan for GHG reduction and provide regular progress reports, all on a voluntary basis. By 2000, the VCR had 757 action plans covering 75 percent of all industrial GHG emissions.[7]

7 VCR website: www.vcr-mvr.ca.

Table 2: ***Primary GHG emissions reduction policies in Action Plan 2000***

Sector	Initiative
Transportation	• Partnerships with automotive manufacturers and ethanol producers • Information provision through *EnerGuide for Vehicles* • Demonstration projects for hydrogen distribution infrastructure and efficient urban transportation
Energy Sector	• Demonstration project for carbon sequestration • Information provision and moral suasion through the *Canadian Industry Program for Energy Conservation* • Voluntary agreements with industry • Financial incentive for renewable energy • Purchase of green power by government
Industry	• Information gathering and benchmarking • Energy-efficiency audits for small and medium enterprises
Building	• Information provision to encourage retrofits in commercial sector • Information provision through *EnerGuide for Houses*

Adapted from "Action Plan 2000 on Climate Change," Government of Canada, 2000.

The impact of the emphasis on non-compulsory policies is in dispute. The Analysis and Modelling Group (1999) estimated that the VCR and related programs reduced GHG emissions by 35 megatonnes (Mt) CO_2e from what they otherwise would have been over the period 1993-to-1998 (a 5-percent decrease).[8] The method used to estimate this effect was not explained. In contrast, Bramley (2002) found that the VCR had minimal effect on emissions after examining the evolution of aggregate industrial emissions (24 percent increase in the 1990s), program coverage (less than 55 percent of industrial emissions), and case studies of the target setting and emission accounting practices of individual companies in the VCR. Takahashi *et al*. (2001) found no difference in GHG abatement between VCR participants and non-participants.

Similar criticisms have been directed at the other voluntary initiatives and information campaigns. The aggregate trend fuelled these critiques as emissions actually accelerated during the government's program. In the previous decade, Canada's GHG emissions increased 6 percent, from 572 to 607 Mt CO_2e, whereas from 1990 to 2000 emissions increased 20 percent, from 607 to 726 Mt.

After the Kyoto Protocol in 1997, the federal government launched "Action Plan 2000 on Climate Change," a set of initiatives designed to reduce domestic emissions by 49 Mt by 2010 (Government of Canada, 2000). As Table 2 shows, most of these initiatives continue the voluntary policy approach.

Then, just prior to ratifying the Kyoto Protocol in December 2002, the federal government released the "Climate Change Plan for Canada" (Government of Canada, 2002). This outlines policies for achieving a further 100 Mt of emission reductions, mostly through negotiated covenants or regulations with industry, including the electricity sector. The federal government intends to pass legislation that would allow it to set an ECTP policy for industry. Discussions with industry are underway, but with each year of negotiations and policy uncertainty, more opportunities for GHG abatement within the Kyoto timeframe are lost.

8 CO_2e stands for CO_2 *equivalents*, a unit for measuring all GHGs in terms of greenhouse-inducing effect and length of residency in the atmosphere. We use CO_2e and GHG interchangeably.

Other policies continue the focus on voluntary action with some government subsidies. Voluntary policy includes some financial support for public transit; encouraging R2000 insulation standards by commercial building developers; a voluntary target of 10 percent renewables for new electricity generation, and a voluntary target for improved vehicle efficiency. Subsidy programs in the federal budget in 2003 included $131 million for residential building shell and heating-system improvements; $250 million for research and development of energy-efficient technologies; $303 million for industrial energy-efficiency actions; $321 million for improvements to federal government buildings, vehicles and infrastructure, and financial support for a demonstration plant that would capture and sequester carbon (Department of Finance, 2003). Apart from the proposed ECTP for large industry, the emphasis is almost entirely at the non-compulsory end of the policy spectrum.

The federal government has not definitively decided how much of Canada's Kyoto commitment it will achieve by domestic actions and how much by acquiring credits from other countries. Our focus here, however, is on domestic emission abatement, and it is difficult to believe that Canada's continued emphasis on voluntary programs and modest subsidies will advance the country substantially toward its Kyoto commitment.

Still, it is easy to see why politicians would favour this approach. Voluntary and subsidy policies are much more likely to be politically acceptable, being non-compulsory policies with modest budgetary implications. Also, these programs are supported by those environmentalists who believe that GHG reduction is profitable or expect that once Canadians are better informed they will adopt low-GHG lifestyles. Finally, because the Kyoto deadline is six years away, considerable time must elapse before we have evidence that the voluntary and subsidy approach is ineffective; six years is a long time in politics, albeit not in terms of capital stock turnover and technological change.

Unfortunately, GHG abatement is more difficult than suggested by the simple financial analysis typically conducted by advocates of new low-emission technologies. There now exists a significant body of research indicating that profound technological change can be costly where low-emission technologies present extra risks for purchasers, are not perfect substitutes for the technologies they replace, or are forced to occur at a faster pace than the natural rate of turnover of capital stock (Jaccard *et al*., 2003). For example, public transit may be a less expensive means of commuting on a cost-per-kilometre basis, but most commuters attribute additional advantages to using a private automobile, a value overlooked by simple financial analysis. In several studies, some of them for the National Climate Change Process, our research group found that a GHG reduction of 180 Mt CO2e from business-as-usual by 2010 (less than the 240 Mt Kyoto requirement) would result in substantial welfare costs to Canadians.[9] In the Kyoto timeframe, these costs result from the premature retirement of buildings and capital equipment, as well as the extra risks and inconveniences associated with new technologies. These costs cast doubt on the assumption behind the voluntary approach that firms and households will adopt low-GHG technologies quickly in response to government promotion and modest subsidies.

In summary, we think that aside from the proposed ECTP policy for large industrial emitters, Canada's strategy for GHG abatement will perform poorly

9 For details of our approach and cost estimates, see Jaccard *et al*., 2002, and Bataille *et al*., 2002.

against the effectiveness criterion. Of course, the strategy can do well against the other three criteria because an ineffective, non-compulsory policy is unlikely to generate political resistance and in turn is likely to face only minor administrative feasibility issues. This is of no consolation if the approach is ineffective.

We are also concerned that this strategy misses an opportunity to lower the long-term costs of GHG emission reductions. Like many researchers in this field, we believe that the relatively high costs of GHG abatement in the short-to-medium term can be reduced in the long term — perhaps dramatically — by well-crafted policies that begin today to induce the development and adoption of low-GHG technologies. This means that Canada's strategy should be designed not just to abate emissions in the Kyoto timeframe, but also to induce the substantial technological change that will be optimal over the ensuing decades.

What We Propose

We propose an alternative policy strategy dominated by market-oriented regulations because we believe that these perform better against our policy evaluation criteria when it comes to the particular challenges of GHG policymaking. Having an aggregate regulatory requirement improves their performance against the effectiveness criterion. Involving negotiations with individual sectors of the economy, and thus being sensitive to sector-specific issues and constraints, fosters administrative feasibility. Stimulating new technology development and commercialization without increasing energy prices improves the likelihood of political acceptability, as does the flexibility offered to those affected by the policy. Indeed, this latter characteristic reduces the short-run economic impact while stimulating innovations that should lower long-run costs. After describing and simulating our policy package, we return to these policy evaluation criteria.

The components of our policy package are summarized in Table 3. We selected the targets in our policy package with the objective of roughly equating the incremental costs of GHG abatement between sectors, and we tested more and less aggressive versions of each policy. Our proposal is not intended to be comprehensive, but rather to demonstrate an alternative to Canada's current emphasis. Thus, some energy uses are omitted (freight, marine and air transport, for example, contribute about 15 percent of emissions), as are some sectors (agriculture, forestry, urban land use). Our focus is market-oriented regulations, but our proposal also has modest command-and-control regulations. We would also support some voluntary programs and a few subsidies in the form of tax credits where specific policy designs can be shown to be effective.

Large Industry Emission Cap and Tradable Permit

Our large industry ECTP is similar to that which the federal government has proposed but not yet implemented. It encompasses all non-energy industrial emitters, the oil and gas industry, and the electricity industry. We present the electricity sector separately because it is also influenced by an overlapping policy fostering renewable electricity generation.

Normally, an ECTP has a fixed cap on emissions, but we set it as a fixed requirement for emission reductions from the business-as-usual forecast. We test two levels of policy aggressiveness: The less aggressive policy requires 75 Mt of abatement and the more aggressive policy 150 Mt. One characteristic of ECTP is

Table 3: *Proposed alternative policy package*

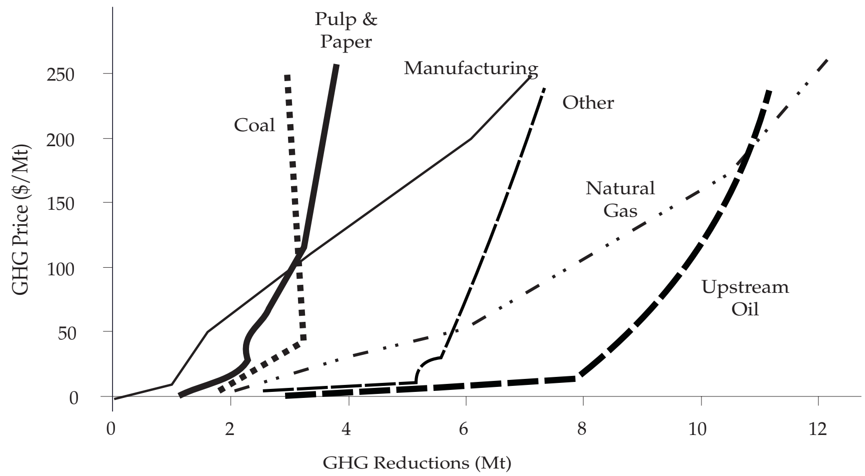
Name of Policy	Type of Policy	Sectors Affected	Actions Induced
Large Industry Emission Cap and Tradable Permit	Market-oriented regulation	Industry, Electricity Generation	Switching to lower GHG fuels and more efficient equipment Reduced demand for electricity
Renewable Portfolio Standard	Sector- specific Market-oriented Regulation	Electricity Generation	Switching to renewable sources of electricity generation
Vehicle Emissions Standard	Sector-specific Market-oriented Regulation	Personal Transportation	Switching to lower emissions vehicles
Carbon Sequestration Requirement	Sector-specific Market-oriented Regulation	Upstream Oil and Gas	Geological sequestration of carbon from fossil fuel use
Building and Equipment Standards	Command-and-control regulations	Residential and Commercial	Switching to high efficiency appliances, equipment and buildings

that the eventual trading price of emission permits depends on the costs of GHG abatement, which are uncertain until policy enactment drives industry to find the cost-minimizing balance of GHG abatement actions and GHG permit trading. The possibility of unbearably high GHG permit prices hinders the prospects for achieving political acceptability; industry leaders and regional politicians may claim that extremely high costs will affect economic well-being. To counter this concern, policy-makers can set a permit ceiling price by offering an unlimited number of permits at this price. This approach has attracted considerable interest among GHG policy analysts in recent years (Pizer, 1998) and we include it in our ECTP by setting permit ceiling prices of $10 and $50/t CO_2e for our 75 and 150 Mt requirements.[10] As a result, industry may find it cheaper to purchase additional permits at the ceiling price instead of undertaking all of the GHG abatement needed to achieve reductions of 75 and 150 Mt. We assume that government uses revenue from permit sales to purchase international permits or reimburse regions in proportion to their permit acquisition payments. This transfer will help to minimize the policy's redistribution effects.

Another attribute of our ECTP policy is that the permit ceiling prices increase in later years. The price ceiling of $10/t CO_2e increases to $20 by 2020 and continues to climb after that, while the $50/t CO_2e price ceiling follows a similar trajectory. If communicated clearly to industry at the outset, a low initial ceiling permit price prevents premature retirement of existing capital stocks, but the expectation of higher future permit prices spurs the long-term development and diffusion of low-GHG technologies on pace with the natural turnover of capital stock.

10 The $10 and $50 represent low and high price estimates for the internationally traded permits that Canada could purchase in lieu of undertaking extra domestic reductions. Based on our analysis of emission reduction cost curves for the industrial sector, we anticipate that the average domestic cost of emission reductions at these permit prices would be $4-to-$5/t CO_2e and $20/t CO_2e.

Figure 1: ***GHG reduction cost curves for Canadian industry***



Source: Bataille *et al*., 2002.

Industry

Industry has heterogeneous emission intensities and GHG abatement costs. Figure 1 shows the marginal cost of emission abatement for individual industrial sectors as calculated by our energy-economy model. In some sectors, like pulp and paper, marginal costs rise quickly as more emission reductions are required, while in others, especially oil and gas, considerable abatement is available at a relatively low marginal cost.[11]

When abatement costs are heterogeneous, ECTP should be economically efficient by ensuring that those with higher costs of reduction do less while funding the actions of those with lower costs through the purchase of their excess permits. Surveys of Canadian industry indicate that flexible policies like ECTP should be more attractive than command-and-control regulations for this and other reasons (Rivers, 2003). Also, because there are relatively few sources of GHG emissions among large industrial emitters, monitoring should be administratively feasible.

Electricity Generators

The electricity sector is dominated by non-GHG supplies: Hydro provides about 60 percent of Canada’s electricity generation, nuclear 12 percent, and renewables 2 percent. The remainder is mostly coal at 18 percent and natural gas at 6 percent, with small amounts of biomass and oil (National Energy Board, 2003). Nonetheless, fossil-fuel generation of electricity produces 100 Mt CO_2e annually and offers significant potential for abatement, although this depends on the region. Alberta and Saskatchewan are coal-based provinces with high emissions and several moderate-cost opportunities for emission reductions — primarily through fuel-switching to renewables and natural gas in the medium term, and potentially

11 The backward-bending GHG abatement curve in the coal sector portrays the interplay of various factors as GHG permit prices increase (as revealed by simulation of our integrated model). At very high GHG prices, coal use increases as coal gasification (with carbon sequestration) gains market share, thereby slightly increasing coal-based emissions while helping to reduce total emissions.

through carbon sequestration in the long term. Manitoba, Quebec and B.C. are hydro-based provinces with low emissions and much less potential for low-cost emission reductions, although medium-sized hydro facilities appear to be politically acceptable in Manitoba and Quebec, and biomass and small hydro in B.C.

This diversity in electricity generation has caused some opposition to an ECTP system by fossil fuel-based provinces fearing discrimination against their older coal plants. But this is only a problem if all ECTP permits must be obtained via auction, which would cost these provinces dearly. Policymakers can ensure instead that abatement costs are not concentrated in any particular region by allocating some permits freely — called grandfathering — to those regions with initially high emission levels (Tradable Permits Working Group, 2000). Our ECTP includes some grandfathered emission permits for Alberta, Saskatchewan and other high emission regions, and this is reflected in our estimated effects on industrial production costs and final energy prices.

Renewable Portfolio Standard

Although the electricity sector is already covered by the large industry ECTP, there is interest in designing a policy focused directly on the promotion of renewable electricity sources because they have additional social and environmental benefits that are undervalued by markets. Also, there is evidence that the costs of new renewable electricity technologies (wind, solar, biomass, small hydro) will continue to fall with economies of learning and economies of scale, but that minimum production thresholds must be reached to trigger these cost decreases (for wind, see Ibenholt, 2002).[12]

Our policy package includes therefore a renewable portfolio standard (RPS) guaranteeing a minimum market share for renewable electricity alongside actions like fuel switching from coal to natural gas and carbon sequestration in meeting the GHG abatement requirements of the ECTP. By 2010, all electricity producers (or marketers) must acquire 6 percent of their electricity from renewables in the less aggressive policy and 10 percent in the more aggressive. High penalties discourage non-compliance, but producers can trade renewable electricity certificates to reduce compliance costs.

The RPS provides a stable long-term signal to electricity generators about future requirements, yet causes a fairly small increase in the average price of electricity (Berry, 2002; Berry and Jaccard, 2001; U.S. Department of Energy, 2002). Its magnitude is set to prevent the premature retirement of electricity generation capacity.[13] The RPS is already applied in several jurisdictions in the U.S. and elsewhere, so its effect on Canadian competitiveness will be negligible. Also, while available data and recent experiences with renewables in Canada indicate that neither the 6-percent nor the 10-percent RPS would increase electricity prices by more than a few percent, the policy should nonetheless include a price ceiling for

12 Cost reduction potential varies by energy form and technology. For example, cost reductions for biomass and small hydro may not match those experienced by windpower. We use low estimates from the literature for our projections of learning curve rates with new renewables.

13 The National Energy Board (1999) projects additions totalling approximately 16 percent of our current generating capacity by 2010. Also, even at the more aggressive 10-percent share of generation, the intermittent nature of some renewables, such as wind, should not hinder the electricity system's ability to reliably meet peak load requirements.

renewable trading certificates. This would perform a function similar to the permit ceiling price with the ECTP policy, but differ in that it would be set at a high enough level where the most likely market outcome is the full achievement of the RPS target.

Vehicle Emission Standard

The transportation sector represents the single largest source of GHG emissions in Canada.[14] Research suggests that consumers are relatively insensitive to small increases in fuel prices (Espey, 1997; Hirschman et al., 1995), while strongly opposing substantial policy-driven price increases (Horne, 2003). This makes it difficult to envision policymakers applying fuel taxes as the primary driver for transforming vehicle drive-train technologies. Our package relies instead on a vehicle emission standard (VES) targeted at manufacturers of vehicles rather than directly at consumers.

The VES requires that certain types of low emission vehicles achieve a gradually increasing share of the market. Individual producers are charged per-vehicle penalties for the number of autos in non-compliance, though the policy enables producers to trade among themselves in order to achieve the required, aggregate market share at a lower cost. We classify vehicles into four types based on their tailpipe GHG emissions as shown in Table 4.[15]

In the less aggressive version of our policy package, we require that alternative vehicles (ZEV, ULEV and LEV) attain at least 40 percent of the new-automobile market by 2010, while these autos must achieve at least 64 percent of that market in the more aggressive policy package. The detailed breakdown for specific vehicle types is given in Table 5. By 2010, hybrid gasoline-electric vehicles (ULEVS) account for a significant share of the new vehicle market. These automobiles have already been on the market for a few years and manufacturers are in the process of rapidly expanding the number of models with this drive-train option. Hybrid vehicles are, in the words of market analysts, an evolutionary technology (as opposed to a revolutionary technology like hydrogen fuel cells) in that they do not require a change in design or size, and utilize the same fuel and refuelling network. The VES ensures that manufacturers will continue to push for the widespread dissemination of ULEVs, a technology resulting from the first VES in California in 1990.[16]

Like the other market-oriented regulations, the VES is attractive because it provides a signal to vehicle manufacturers about the kinds of vehicles they must make and sell without dramatically affecting average vehicle prices for consumers. Although it is difficult to quantify its impact, auto industry analysts say that the VES started in California is the primary driver behind the substantial worldwide

14 This includes personal road transportation, freight transportation and air and marine transportation. In this study, we address only the first of these.

15 The emissions ranges shown are at the tailpipe. Zero emission vehicles, like battery-electric or hydrogen, can be associated with GHG emissions in the fuel-production process; only through integrated policy modelling can policymakers be confident of the combined effect on emissions of policies affecting hydrogen and electricity production (ECTP, RPS and the carbon sequestration requirement) and policies affecting end-use technologies like automobiles. Our model simulates the combined effects of all policies.

16 The original focus of the VES in California was urban air pollution but it also affects GHG emissions; its application to GHG emissions requires the integrated policy analysis noted above.

Table 4: ***Vehicle types based on GHG emissions***

Emission Class	Example Vehicles	Emissions Range (metric tons CO_2e/vkt)*	
		Minimum	Maximum
Zero Emission Vehicle (ZEV)	Hydrogen fuel-cell	0.000000	0.000000
Ultra Low Emission Vehicle (ULEV)	Hybird	0.000001	0.000125
Low Emission Vehicle (LEV)	Efficient gasoline	0.000126	0.000200
Standard Emission Vehicle (SEV)	Inefficient gasoline	0.000201	0.000500

* vkt = vehicle-kilometre-traveled

research and development effort to innovate and commercialize ULEVs and ZEVs. To recover the extra costs of these vehicles, manufacturers may convince some consumers (early adopters, technophiles, the environmentally conscious) to pay a premium; in other cases they may have to charge slightly higher prices for conventional vehicles.[17] Because the VES already exists in California, New York and several other states, its introduction in Canada should not have competitiveness implications for Canadian automobile manufacturers and would benefit fuel-cell producers, a field in which Canadians are among the world's leaders. The VES would have a cost ceiling in the form of either a per-vehicle fine for non-compliance ($5,000 in California) or a price ceiling for ULEV and ZEV trading certificates, which manufacturers would be encouraged to develop as a flexibility mechanism for ensuring that they collectively reach the target at the lowest possible cost.

Table 5 ***Vehicle emissions standard requirements***

Emission Class	Minimum New Market Share Requirement in 2010	
	Less Aggressive	More Aggressive
ZEV	3 percent	6 percent
ULEV	15 percent	25 percent
LEV	22 percent	33 percent

Carbon Sequestration Requirement

While energy efficiency and fuel switching are seen as the conventional energy-related actions for GHG abatement, carbon sequestration is emerging as a third possibility. This involves capturing carbon from fossil fuels — usually as CO_2 — and permanently storing it in geological formations, or perhaps on the ocean floor. Geological formations are of interest because the oil and gas industry already injects CO_2 during enhanced oil recovery and more recently because of experiments to store CO_2 in deep saline aquifers. The separation of carbon from fossil fuels poses various technical challenges, but there are industry experiences to draw on. Three approaches to capturing carbon are currently emphasized.

17 The preliminary evidence from California's VES and from jurisdictions with the RPS indicates that this is how products will be priced under this type of policy. But monitoring will determine if product price changes reflect the incrementally higher costs of the low-emission technologies.

One is to capture the pure CO_2 resulting from the production of conventional fossil-fuel products. Some raw natural gas in Canada contains high CO_2 concentrations that are normally vented to the atmosphere during processing. Based on the current average concentration of 2.5 percent CO_2 in Canadian natural gas, Canada is venting about 9 Mt CO_2/yr, which will increase to 13-to-20 Mt CO_2/yr by 2010 (Keith, 2002). Oil refining and oil sands processing require the production of pure hydrogen and this process generates a stream of pure CO_2 that is ideal for sequestration. Based on projected increases in oil production from Alberta oil sands, Canada will be producing enough hydrogen to generate 13 Mt CO_2 from this source by 2010 (Keith, 2002).

A second approach is to capture carbon from the flue gases after fossil fuel combustion. In fossil-fuel electricity generating plants, CO_2 in the flue gas could be captured just as particulates and acid gases are captured today. Currently, this represents a relatively expensive way of capturing carbon because the CO_2 is of low concentration in the flue gas. But while the capture of post-combustion CO_2 from electricity plants may be feasible, its capture from small combustion sources, such as autos, is much more complicated and likely to remain expensive in the longer-term (Kreutz *et al*., 2002). AMG (2000) estimates a cost of \$38/t CO_2e for post-combustion capture and storage of carbon from coal-generated electricity in the Western Canadian Sedimentary Basin, though costs should fall with experience. Significant investment in this option, which involves retrofitting existing plants, some of which are quite new, would be challenging in the Kyoto timeframe.

A third approach is to capture carbon from fossil fuels prior to their combustion. This can occur while converting fossil fuels into zero-emission energy forms like hydrogen and electricity, with the resulting pure CO_2 shipped via pipeline to a geological storage site. A major challenge is the infrastructure required for hydrogen delivery and storage, which limits this option's impact on domestic GHG emissions in the Kyoto timeframe. But since non-electric energy represents about 70 percent of total global CO_2 emissions, this option should be pursued now in order to understand better its long-term potential (Williams, 2002). The U.S. government recently launched a \$1 billion initiative to produce hydrogen from coal with geological sequestration of the CO_2.

Carbon capture and sequestration holds the promise of continued use of fossil fuels for decades and perhaps centuries to come — especially because of the potential to convert the planet's huge coal resources into hydrogen and electricity while capturing the CO_2 byproduct. Moreover, conventional technologies and industry practices are associated with each step in the production chain: the manufacture of hydrogen; the separation of pure CO_2; the pipeline transport and geological sequestration of CO_2, and the pipeline transport of hydrogen.

Still, although the shift to non-CO_2 emitting uses of fossil fuels does not require dramatic new innovations, it nonetheless represents a profound technological transformation, especially because of the massive investment required in processing facilities, transport infrastructure and new end-use technologies like fuel cells. In our view, such a transformation calls for a similar policy approach to that which we suggest for vehicle technologies with the VES and electricity generation with the RPS. Our policy package includes, therefore, a standard requiring a small but gradually increasing amount of carbon sequestration by the Canadian energy industry.

The carbon sequestration standard is initially modest because the intent is to push the energy industry to experiment with technologies that are likely to have great value in the long term, without affecting the cost of production in the short term. While the carbon sequestration standard should be as flexible as possible in terms of technology choices, available cost information indicates that the first approach (capturing CO_2 during fossil fuel production) would achieve the most attention in the Kyoto timeframe. As a result, our policy package is initially directed at the oil and gas production and processing sector, directing that it sequester a minimum amount of CO_2 by 2010: 6.5 Mt and 12.5 Mt in the less aggressive and more aggressive scenarios.

In the decades after 2010, remaining hurdles facing carbon sequestration could be overcome and the policy would then be applied more generally to all industry, including electricity generation, in order to spur the development of the second and third approaches. CO_2 abatement through sequestration would be incorporated into the large industry ECTP, effectively merging the two policies to improve economic efficiency. As with the other market-oriented regulations, the carbon sequestration standard includes a fine for non-compliance that provides assurance of an upper cost limit for industry in case all of the three options prove to be much more costly than expected.

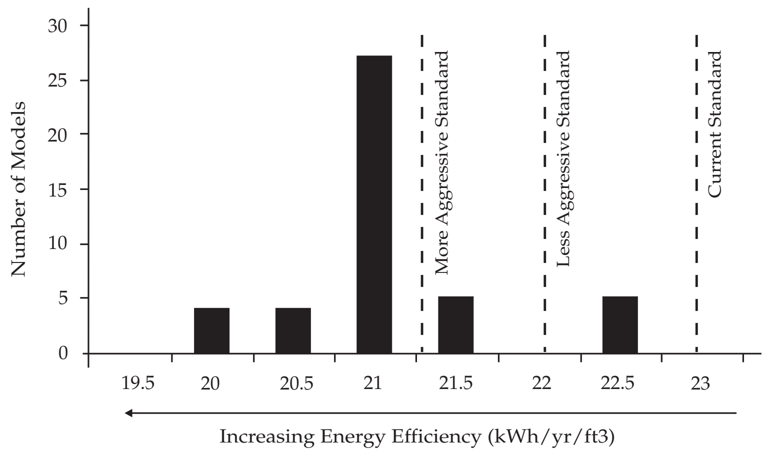
Building and Equipment Standards

Our building and equipment standards are command-and-control regulations that require products to meet specified energy efficiency requirements. They are used in many countries to regulate the efficiency of refrigerators, air conditioners, freezers, building shells (insulation levels) and other energy-using equipment. In our policy package, we set standards to phase out from new sales inefficient models of building and equipment — affecting the least efficient 10 and 30 percent in the less and more aggressive policies. These standards will not drive technological innovation as their application for this purpose would generate a strong political backlash.

Figure 2 uses refrigerators to explain our approach to building and equipment standards. The table shows the breakdown of refrigerator efficiencies for one type of refrigerator/freezer in the 20.5-to-22.4 ft^3 size class (there are 45 models in Canada of this type and size class). Our modest command-and-control regulation would eliminate the least efficient 10 or 30 percent of these refrigerators. Economic research shows that even those consumers who would ordinarily have purchased an inefficient refrigerator can experience a welfare gain from such a regulation (Moxnes, forthcoming), or at worst, a negligible loss (Stoft, 1993), usually because they were not well informed of the financial benefits from more efficient models. Other research shows that minimum standards have very little measurable effect on product price (Greening *et al*., 1997; Nadel, 2002).

Similar modest standards would be applied throughout the residential, commercial and institutional sectors — affecting building shells, heating and ventilation systems, lighting, appliances and electronic equipment. For example, standards

Figure 2: Sample building/equipment standard – Refrigerators with freezer above refigerator



Source: Data from Natural Resources Canada, 2003

will mandate a minimum level of efficiency in residential furnaces and hot water heaters, parallel to the product coverage shown in Figure 2 for refrigerators.

While we opted for a modest command-and-control approach, we believe that market-oriented regulations might also be applicable to buildings, appliances and other energy-using equipment. For example, one policy could require that a minimum market share of new residential buildings meet the R2000 efficiency standard, and include a flexible mechanism for trading among different sectors of the building construction industry. We are concerned, however, with the administrative feasibility of applying this policy approach to so many possible actions and agents, and so have excluded it from our proposal for now.

Expected Results of This Policy Package

To estimate the emission reductions and attendant costs of the proposed policy package, we used CIMS, an energy-economy model developed and applied by the Energy and Materials Research Group at Simon Fraser University (Box 1). CIMS contains a record of all energy-using technologies available for consumers and businesses in Canada. It tracks the evolution of individual equipment stocks by retiring old equipment and simulating how consumers and businesses purchase new technologies. The behavioural parameters are estimated from empirical studies of consumer and business decision making, in some cases based on past consumption patterns and in others (especially with new technologies) based on surveyed preferences for specific technology attributes.

We present our policy package's costs in terms of changes in the production costs for industry and the retail energy prices for businesses and consumers. Because the energy price increases we show are those required to induce GHG abatement by businesses and consumers, our results implicitly include all financial and intangible costs faced by consumers, what economists call welfare costs.

For some of the policies, we also conducted ancillary analyses outside of the CIMS model. In the oil- and gas-production sector, we used estimates of carbon sequestration technologies and costs from Keith (2002), Williams (2002) and Kreutz *et al*. (2002). For the equipment standards, we determined the levels of GHG emission reduction using CIMS, but have externally assumed that the intangible

Box 1: ***CIMS Model***

The CIMS model, developed by the Energy and Materials Research Group at Simon Fraser University, simulates the technological evolution of fixed capital stocks (mostly equipment and buildings) and the resulting effect on costs, energy use, emissions, and other material flows. The stock of capital is tracked in terms of energy service provided (m2 of lighting or space heating) or units of physical product (metric tons of market pulp or steel). New capital stocks are acquired as a result of time-dependent retirement of existing stocks and growth in stock demand. Market shares of technologies competing to meet new stock demands are determined by standard financial factors as well as behavioural parameters from empirical research on consumer and business technology preferences. CIMS has three modules — energy supply, energy demand, and macro-economy — which can be simulated as an integrated model or individually. A model simulation comprises the following basic steps.

1. A base-case macroeconomic forecast initiates model runs. If the forecast output is in monetary units, these must be translated into forecasts of physical product and energy services.
2. In each time period, some portion of existing capital stock is retired according to stock lifespan data. Retirement is time-dependent, but sectoral decline can also trigger retirement of some stocks before the end of their natural lifespans. The output of the remaining capital stocks is subtracted from the forecast energy service or product demand to determine the demand for new stocks in each time period.
3. Prospective technologies compete for new capital stock requirements based on financial considerations (capital cost, operating cost), technological considerations (fuel consumption, lifespan), and consumer preferences (perception of risk, status, comfort), as revealed by behavioural-preference research. Market shares are a probabilistic consequence of these various attributes.
4. A competition also occurs to determine whether technologies will be retrofitted or prematurely retired. This is based on the same type of considerations as the competition for new technologies.
5. The model iterates between the macro-economy, energy supply and energy demand modules in each time period until equilibrium is attained, meaning that energy prices, energy demand and product demand are no longer adjusting to changes in each other. Once the final stocks are determined, the model sums energy use, changes in costs, emissions, capital stocks and other relevant outputs.

The key market-share competition in CIMS can be modified by various features depending on the evidence about factors that influence technology choices. Technologies can be included or excluded at different time periods. Minimum and maximum market shares can be set. The financial costs of new technologies can decline as a function of market penetration, reflecting economies of learning and economies of scale. Intangible factors in consumer preferences for new technologies can change to reflect growing familiarity and lower risks as a function of market penetration. Output levels of technologies can be linked to reflect complementarities.

Personal mobility provides an example of CIMS' operation. The future demand for personal mobility is forecast for a simulation of, say, 30 years and provided to the energy demand module. After the first five years, existing stocks of personal vehicles are retired because of age. The difference between forecast demand for personal mobility and the remaining vehicle stocks to provide it determines the need for new stocks. Competition among alternative vehicle types (high and low efficiency gasoline, natural gas, electric, gasoline-electric hybrid, and eventually hydrogen fuel-cell) and even among alternative mobility modes (single occupancy vehicle, high occupancy vehicle, public transit, cycling and walking) determines technology market shares. The results from personal mobility and all other energy services determine the demand for fuels. Simulation of the energy supply module, in a similar manner, determines new energy prices, which are sent back to the energy demand module. The new prices may cause significant changes in the technology competitions. The models iterate until quantity and price changes are minimal, and then pass this information to the macro-economic module. A change from energy supply and demand in the cost of providing personal mobility may change the demand for personal mobility. This information will be passed back to the energy demand module, replacing the initial forecast for personal mobility demand. Only when the model has achieved minimal changes in quantities and prices does it stop iterating, and then move on to the next five-year time period.

costs to consumers of the modest regulations of our package (affecting only the 10-to-30 percent least efficient models) is close to zero, based on the findings of several researchers (Nadel, 2002; Greening *et al*., 1997; Cole and Grossman, 1999; Moxnes, forthcoming; Stoft, 1993).[18]

Table 6 presents the results for the less and more aggressive versions of our policy package. While substantial GHG abatement is available from a fairly modest policy signal, the more aggressive policy experiences incrementally rising costs of GHG abatement, at least in the Kyoto timeframe.

Less Aggressive Policy Results

The less aggressive version of our policy package achieves total GHG emission reductions of about 90 Mt CO_2e by 2010. Effects on production costs and energy prices are small.

For the large industry ECTP, the $10/t CO_2e permit ceiling price prevents industry from achieving the 75 Mt abatement requirement as industry (12.1 Mt) and electricity (45.4 Mt) combine for only 57.5 Mt of abatement. Industrial abatement occurs through actions like switching to efficient motors, conveyors, pumps and fans; energy demand reductions, and switching to high-efficiency boilers and cogeneration for steam production. The industrial sector (excluding electricity) experiences an annual cost of production increase reaching $100 million in 2010 (some of this is caused by electricity price increases). However, the costs of producing non-energy goods do not increase by more than 1 percent, which should have a negligible effect on international competitiveness.[19]

From the electricity sector, the combined effect of its inclusion in the large industrial ECTP and a RPS provides more than half of the country's GHG abatement — 51.6 Mt in 2010. Most reductions are due to switching to more efficient natural gas and coal burners, fuel switching from coal to natural gas, switching to renewable electricity, and demand reductions. The RPS causes about 6.2 Mt of reduction in addition to the 2.4 Mt triggered by the large industry ECTP. Together, these actions increase the average price of electricity by 3 percent.[20]

The carbon sequestration requirement in the oil and gas production sector reduces GHG emissions by 6.5 Mt by 2010, increasing the production cost of oil and natural gas by less than 1 percent each.

The building and equipment standards cause GHG reduction of 6 Mt by 2010 by forcing equipment manufacturers and building developers to phase out sales of the least efficient 10 percent of new buildings and equipment throughout the residential and commercial sectors.

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18 But we caution that some researchers, such as Sutherland (1991), argue that even modest-efficiency regulations can cause welfare losses, especially for low-income consumers who might be prevented from acquiring efficient technologies by their higher up-front costs. We do not believe that this will be the case with our policy package, however, based on the capital-cost comparison of the technologies excluded by our command-and-control efficiency regulations.

19 This is consistent with analysis for the "Climate Change Plan for Canada" showing that a $10/t CO2e tax would not increase the production cost of basic commodities like steel and aluminum by more than 1 percent (Government of Canada, 2002).

20 The electricity price increase is relatively homogeneous across the country because of the grandfathered permits to provinces with fossil fuel-intensive electricity generation. Without this mechanism, increases are especially higher in Alberta and Saskatchewan, as shown in Bataille *et al.* (2002).

Table 6: ***Expected results of proposed policy packages in 2010***

Policy Name	Less Aggressive Requirements	Less Aggressive Reductions	Less Aggressive Financial Effect	More Aggressive Requirements	More Aggressive Reductions	More Aggressive Financial Effect
Industry Carbon Trading System[a]	$10/t CO_2e permit price	12.1 Mt	- Cost to industry of $100M in 2010 -Non-energy commodity production costs increase by much less than 1 percent - Retail price of gasoline increases by 3 percent natural gas by 4 percent	$50/t CO_2e permit price	15.4 Mt	- Cost to industry of $380M in 2010 -Non-energy commodity production costs increase by 1-2 percent -Retail price of gasoline increases by 15 percent, natural gas by 20 percent
Electricity Carbon Trading System	$10/t CO_2e permit price	45.4 Mt	- Increase average retail electricity price by 2 percent	$50/t CO_2e permit price	71.2 Mt	- Increase average retail electricity price by 8 percent
Renewable Portfolio Standard[b]	6 percent total generation from renewable sources	6.2 Mt	- Increase average retail electricity price by 1 percent	10 percent total generation from renewable sources	14.4 Mt	- Increase average retail electricity price by 2 percent
Vehicle Emissions Standard	3 percent ZEV 15 percent ULEV 25 percent LEV	14.8 Mt	- Increase average vehicle cost by 8 percent -Decrease average fuel consumption by 12 percent	6 percent ZEV 25 percent ULEV 33 percent LEV	29.2 Mt	- Increase average vehicle cost by 14 percent -Decrease average fuel consumption by 19 percent
Sequestration Requirement	$10/t CO_2e permit price 6 percent total	6.5 Mt	- Increase retail natural gas price by 0.3 percent - Increase retail gasoline price by 0.3 percent	12.5 Mt sequestration requirement	12.5 Mt	- Increase retail natural gas price by 0.9 percent -Increased retail gasoline price by 0.5 percent
Building and Equipment Standards[c]	Phase out sales of least efficient 10 percent of new equipment and buildings	6.0 Mt		Phase out sales of least efficient 30 percent of new equipment and buildings	9.2 Mt	
Total		**91.0 Mt**		**Total**	**152.6 Mt**	

a. The GHG reductions from the industrial ECTP are in addition to the sequestration requirement. In the absence of the sequestration requirement, the reductions from the ECTP would be 21.4 and 30.7 Mt for the less and more aggressive policies, respectively.

b. The GHG reductions from the renewable portfolio standard are in addition to the development of renewables that is assumed to occur under business-as-usual and the development of renewables encouraged by the electricity sector carbon trading system — 2.4 Mt at both the $10/t and $50/t CO2e price.

c. If the equipment standards are applied in the absence of any policies in the electricity sector, the reductions are 10.0 and 19.1 Mt respectively, for the less and more aggressive policies.

In the transportation sector, the VES decreases GHG emissions by 15 Mt, while increasing the average purchase price of new vehicles by about 8 percent. Although there would be some distributional effects, with some consumers gaining and some losing, much of the extra up-front cost would be recovered through lower fuel consumption by the 43 percent of new vehicles having higher fuel-efficiency, that is, consuming about 12 percent less fuel on average.

The fossil fuel industry is affected by both the large industry ECTP and the carbon sequestration requirement, but the $10 permit ceiling price and the modest sequestration level result in negligible increases in the production costs of oil and natural gas, so retail prices in Canada for gasoline and natural gas increase only slightly.

More Aggressive Policy Results

The more aggressive policy package causes GHG emissions abatement of about 150 Mt by 2010. Production cost effects for industry are still small, though Canadian retail energy prices increase by 10-to-20 percent.

For the large industry ECTP, the permit ceiling price, this time at $50/t CO_2e, again prevents industry from achieving its emission-reduction requirement. Total emission reductions of 15.4 Mt in industry and 71.9 in electricity fall well short, at 87.3 Mt, of the 150 Mt abatement requirement. In industry (excluding electricity), the small increase in emission reductions with this substantially higher permit price suggests diminishing returns to extra abatement efforts in the Kyoto timeframe, in large part because additional reductions increasingly require the costly, premature replacement of capital stock.[21] This is reflected in an increase in the total annual cost of production of $400 million, a significant increase over the $100 million in the less aggressive policy. In spite of this increase, average costs of production increase only by 1-to-2 percent because of the small amount of abatement actually undertaken by the non-electric branches of Canadian industry.

For the electricity sector, the combined effect of its inclusion in the large industrial ECTP and its RPS again generates more than half of the country's GHG abatement — 86.3 Mt in 2010. In addition to the actions caused by the less aggressive policy, the more aggressive effort also triggers some medium-sized hydro projects (in Manitoba, Quebec and Newfoundland) and a small amount of post-combustion carbon capture and sequestration at Alberta's and, to a lesser extent, Saskatchewan's coal-based electricity plants. Cogeneration of electricity at existing heat production facilities increases across the country. The RPS causes 14.4 Mt of reduction, in addition to 2.4 Mt triggered by the large industry ECTP. Together, these actions increase the average price of electricity by 8 percent, which again is kept relatively consistent across the country by grandfathering some permits to regions with fossil fuel-intensive electricity generation.

The carbon sequestration requirement in the oil and gas production sector reduces GHG emissions by 12.5 Mt in 2010. This policy does not increase the average production costs of natural gas and oil more than 1 percent.

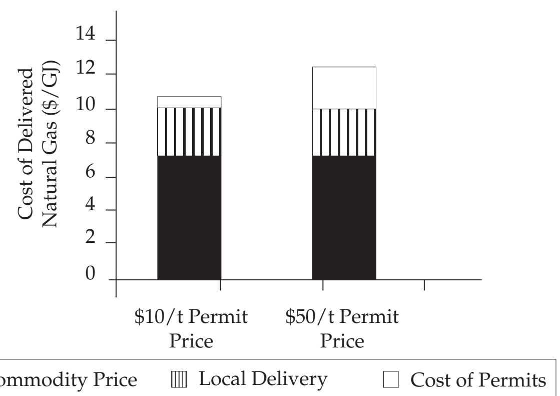
Standards aimed at phasing out sales of the least efficient 30 percent of new equipment and building designs reduce GHG emissions by 9.2 Mt in 2010.

21 Our model may be overestimating the cost of achieving the 15 Mt because while it provides a richer representation than other Canadian models of the technology options facing industry, it under-represents (as do other models) the multitude of housekeeping actions that companies facing a $50 permit price might uncover.

The VES in the transportation sector causes almost 30 Mt of GHG reductions in this scenario by requiring a 66-percent market share for new low-emission autos. This policy is projected to increase the average price of all new vehicles by 14 percent. This cost is partly offset by an improvement in average fuel efficiency for new cars of almost 20 percent, although this average masks a significant divergence between the higher fuel consumption of standard-efficiency vehicles and the much lower consumption of the new LEVs and ULEVs. Increases in the price of gasoline could cause the annual costs of operating a standard-efficiency vehicle (including the amortized up-front cost) to rise almost 20 percent, while the annual costs for the more efficient vehicles will be the same or only slightly higher than under business-as-usual. But this depends on the extent to which manufacturers are required by reluctant consumers to subsidize high-efficiency autos by increasing the prices of standard-efficiency vehicles; we assume a fairly high subsidy, which may not be the case if hybrid vehicles become commonplace and their fuel savings widely recognized.

As with electricity, the higher abatement costs of the more aggressive policy package affect domestic prices for fossil fuels. The large industry ECTP and the carbon sequestration requirement increase average retail gasoline prices by 15 percent and average residential natural gas prices by 20 percent. Figure 3 illustrates the effect of the energy price increases with respect to natural gas prices in Vancouver in 2010. Even the price increase for the more aggressive policy is within the range of recent retail price fluctuations.

Figure 3: Vancouver residential natural gas prices in 2003 and impact of permit price (commodity price includes transmission cost)



Source: www.terasen.com.

Beyond Kyoto: Longer-Term Effects on Costs and GHG Reductions

In the period to 2010, both of our proposed policy packages impose relatively small short-term costs on Canadian consumers and businesses, which contributes to the political acceptability of our approach. With their mandatory nature, the policies also provide greater confidence that significant GHG reductions will occur in the Kyoto timeframe when compared with an approach dominated by voluntary initiatives. Because our package only contains a few policies (with perhaps one or two more to be added for sectors omitted from this exercise), it should be administratively feasible.[22] Our policy package is likely to be less economically efficient than a single economy-wide program, such as GHG taxes or a single, economy wide ECTP, but our ECTP covers all industries, including oil and gas production and electricity, and it passes on energy production cost increases to consumers through energy retail prices.

As a result, a generally consistent price signal spreads throughout the economy, albeit at a low level. Politicians may decide that the modest economic efficiency cost is a reasonable trade-off for attaining political acceptability, and they should appreciate the fact that under this package there are no government subsidies to research and development or technology acquisition. Private-sector research and development is instead triggered by the sector-specific, market-oriented regulations, which provide a higher implicit price signal than the more broadly applied ECTP.

We believe that in the period after 2010 our policy package will become even more effective by promoting the kind of technological change that makes it possible to dramatically reduce GHG emissions without sacrificing economic growth. In particular, the gradual increase in severity of each of our policies provides a strong and predictable long-term signal to producers and consumers about the value of reducing GHG emissions, yet allows time for capital stocks and consumer and business preferences to adjust. Furthermore, the technology-specific nature of our policies allows us to target directions in innovations that analysts predict to have the greatest potential for long-term cost reductions, such as carbon sequestration, low- and zero-emission vehicles, and renewable electricity generation, without involving the government in the risky business of selecting preferred technologies. The policy does not choose which form of carbon capture and sequestration, it does not choose between battery and fuel cell for zero-emission vehicles, it does not favour any particular form of renewable electricity and, aside from the modest market allocation for renewables, it does not favour one low-emission form of electricity generation over another.

Although it is generally non-specific with respect to technologies, our policy package does position Canada to keep pace with fundamental technological innovations likely to emerge in the post-Kyoto period. The requirement for zero-emission vehicles ensures the development, especially after 2010, of a growing domestic market for fuel-cell drive-trains, which will benefit technologies where Canada already enjoys an edge. The carbon-sequestration requirement should foster Canadian production of hydrogen by whichever process proves superior, providing the growing supplies required by the hydrogen-driven fuel-cell vehicle market — and securing Canada's case for expanding energy production from our plentiful oilsands and coal resources.

Figure 4 shows our simulation for the evolution of GHG emissions in Canada under business-as-usual and our proposed policy package.[23] Although neither the

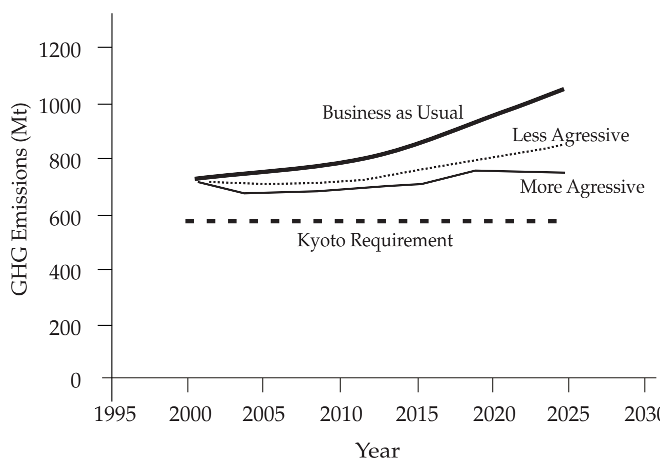
22 One reviewer commended our plan for "eliminating a lot of flotsam and jetsam — a myriad of feel-good measures which will achieve nothing more than undermine the case for a well-designed policy."

23 In the interests of brevity, we have only presented the detailed results of our policy simulation for 2010. Results for later years shown in Figure 4 are available from the authors.

less- nor the more-aggressive policy packages achieve all emission reductions required under Kyoto, both generate significant technological change that stabilize GHG emissions over the longer term, even as economic output and population grow. The more aggressive package goes even further by decoupling GHG emissions from economic output, which continues to rise throughout the forecast — portending a future, decarbonated Canadian energy system supplied by large hydro, small-scale renewables, zero- and low-emission fossil fuels.

Finally, in this longer timeframe there may be concern that a low-emission, low-cost energy source like natural gas will become expensive as consumption increases and current gas fields are exhausted. In the energy supply component of our energy-economy model, we assume that the long-run supply curve for natural gas rises only slightly in North America, even though prices may fluctuate dramatically because of cyclical market imbalances.[24] If we are wrong, and instead North America is on the verge of exhausting all means of producing natural-gas-like products at or close to current production costs, then GHG abatement policies such as ours would cause higher natural gas prices. Still, this will only occur if most other means of reducing GHG emissions, such as energy efficiency, renewable energy, coal gasification with carbon sequestration, and nuclear power, prove to be very expensive in the long run no matter how intensive our efforts to reduce their costs.

Figure 4: ***Long-term evolution of GHG emissions in Canada***



Conclusion

There is strong evidence from past efforts to influence energy-related technologies and consumer choices that the current GHG policy strategy in Canada — dominated as it is by voluntarism and modest subsidies — will fail to spur the technological change required for substantial GHG reductions. If the current

24 Natural gas and synthetic substitutes can be produced from coal-bed methane, direct coal gasification, and perhaps one day from deep, geopressurized gas.

government policy thrust does not change significantly, we forecast that future emissions will diverge little from the business-as-usual line in Figure 4. One implication is that public funds spent on information and subsidies to encourage research, development and commercialization of low-emission technologies will not achieve the expected environmental benefits. But because subsidies and voluntarism are politically acceptable, there is a risk that policymakers at the federal and other levels of government will opt for these policies even though they might perform poorly against other key criteria such as economic efficiency and effectiveness in achieving environmental targets.

In this *Commentary*, we describe our simulation of the likely effect of an alternative policy approach, one that emphasizes a melding of regulatory certainty at an aggregate level with considerable market-oriented flexibility at the level of individual companies and even consumers. Though both of the alternative policy packages that we explore fail to achieve domestically all the GHG emission reductions prescribed under Canada's Kyoto commitment, we forecast that they will move the country much further toward that target, thus requiring less outflow of Canadian capital to acquire internationally traded GHG permits or to finance foreign GHG-reducing projects. But because of the high cost of achieving all of the Kyoto reductions domestically, it makes sense for Canada to achieve some of its commitment through these international mechanisms.

Our policy package is designed to have a minimal short-term impact on the economic welfare of individual Canadians or the competitiveness of Canadian industry, which gives it excellent prospects for achieving political acceptability. Aggregate costs are minimized by flexibility mechanisms for trading among companies, and incremental costs can be further equalized among regions and sectors by a mix of allocating and auctioning GHG emission permits under the ECTP policy. Non-energy industrial costs of production would not increase by more than 1-to-2 percent, even with our more aggressive policy. The product choices available to consumers would expand for some types, while decreasing slightly for others — usually providing more options for products with under-recognized benefits of lower operating costs while reducing slightly equipment models that are more costly to operate. The more aggressive policy has electricity and fuel cost increases of as much as 20 percent, though for a growing number of consumers and companies these are offset by the lower operating costs of new, more efficient equipment and buildings.

Administrative feasibility should not be a major concern. Detailed emissions monitoring would only be required for large-point sources in the industrial and electricity generation sectors. Other sectors would be regulated with manufacturer-focused technology production standards, which are easier to enforce for small sources of emissions than are emissions regulations on installed equipment. For example, once regulators are confident that zero- and low-emission vehicles have met minimum sales requirements, annual vehicle emission testing in urban areas can be limited to older, conventional gasoline-driven automobiles.

This combination of environmental effectiveness, economic efficiency, political acceptability and administrative feasibility helps explain why the key policy approach we propose — market-oriented regulations — is rapidly gaining support and being implemented by other developed countries. Many of our major trading partners are implementing policies like the VES and the RPS. This includes the U.S., even though Washington rejected the Kyoto Protocol and does not face the same immediate pressures to reduce GHG emissions.

The Kyoto Protocol represents a tentative first step by the international community to address the global challenge of GHG accumulation in the atmosphere. But because this is not a challenge that can be dealt with to any significant degree in the 2010 timeframe, the policies we explore in our package are intended to ensure that strong incentives exist today for Canadian innovators, private investors, corporations and individual consumers to pursue opportunities within Canada to develop and adopt technological innovations that over the long run will move the country toward a low-emission path, and which should generate economic opportunities, domestically and abroad, by keeping pace with global trends in technological change. Unlike traditional policy instruments, however, our policy package can produce significant long-term innovation and lower costs of GHG reduction without hampering economic well-being in the shorter term. Then, as new technologies become available, it becomes possible to shift to more conventional market instruments, such as economy-wide GHG taxes or an economy-wide ECTP. Political acceptance of these kinds of price-based policies, with all of the economic efficiency gains they offer, is more likely when businesses and consumers see that alternative technologies work and are cost-effective. As Jaffe and Stavins (1995, 44) noted:

> "In the long run, the development and widespread adoption of new technologies can greatly ameliorate what, in the short run, sometimes appears to be overwhelming conflicts between economic well-being and environmental quality."

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