How to Cut Greenhouse Gas Emissions:
A guide for policy-makers, in Canada and elsewhere. Part 1: National Policies.

Edward A. Parson
Professor of Law and Natural Resources & Environment, University of Michigan
Senior Research Associate, Centre for Global Studies, University of Victoria
parson@umich.edu, 250-472-4531

DRAFT – May 24, 2007 (main text 6,804 words; complete, 6,979 words)

Summary: After briefly summarizing the reasons for an urgent effort to limit and reduce greenhouse-gas emissions, this note outlines how to design policies to achieve such a reduction. Effective and practical mitigation policies need three components: economy-wide measures such as emission fees or tradable-permit systems that put a price on emissions and so reorient incentives for private investment and innovation across the economy; targeted sectoral regulations in areas that are insensitive to the economy-wide incentives; and government support for climate-safe energy R&D. In addition to increasing overall effectiveness, the sectoral measures and R&D support can be designed to support technological areas of national advantage, and to manage the distribution of the policy's costs across regions and sectors to help craft feasible political deals.

1, The Science of Climate Change: We know enough to know we need to act.

Scientific debate about climate change is not "over". No scientific debate ever is, if being over means eliminating all uncertainty. But basic points about climate change are now known with great confidence. The earth is warming and the climate is changing, at rates that are rapid relative to prior human experience. The recent changes are predominantly caused by human emissions of greenhouse gases, most importantly carbon dioxide (CO_2) from burning fossil fuels. The climate changes already occurring will continue, probably at an increased rate. The impacts of these changes are already starkly evident in some places – particularly in Arctic regions – and are likely to grow strongly through this century and beyond. Although there remains substantial uncertainty about how fast the climate will change and precisely what its impacts will be, there appear to be non-negligible risks of severe changes – changes that would at least be seriously disruptive to even rich societies, and would overwhelm all development efforts in poor societies. For all competent and impartial observers, the time for arguing about the scientific evidence for whether climate change is real, human caused, and serious, is past. We know enough to make a compelling case for action. The urgent question now is: what action?

2. What to do about it: why reducing emissions is the major early requirement.

Actions available to deal with climate change fall into two major categories – usually called **mitigation** and **adaptation** – plus a third approach, **geoengineering**, to be held in reserve. **Adaptation** measures try to adjust human society to climate change to reduce its harmful impacts, e.g., by building dikes to deal with increased flood risk from higher sea level or river flooding, or planting drought-resistant crops to deal with drier summers.

We will have to do a lot of adaptation, because we have long missed the chance to keep climate changes small. But with a few important exceptions – e.g., building long-lived, climate-sensitive infrastructure such as water-management and flood-control systems, and places like the Arctic where major impacts are already occurring – the need for adaptation is not immediate, but spread over the time horizon of expected impacts, a few decades or longer. Adaptation is an essential part of the response to climate change, which has been neglected in prior debates, but not the most urgent part.

Geoengineering measures would actively manipulate the global climate to offset the effects of greenhouse gases, e.g., by injecting reflective aerosols into the stratosphere or positioning shields in space to shade a little of the sun's disk. While there are no serious near-term geoengineering proposals, it is increasingly clear that these options must be studied for their effectiveness, cost, and especially their potential risks. Because these measures can probably be implemented faster than other responses, they can provide a safety net in case we badly fail to limit climate change or are unlucky in how harmful it turns out to be. If things are looking dire in 2030 or 2050, a technical response to arrest or reverse changes within another decade or so may be the least bad option then available – despite its risks, and despite the severe political and legal problems it would pose.

This leaves **mitigation** – measures to reduce climate change by cutting the emissions of greenhouse gases that are causing it. The largest share of these emissions is carbon dioxide (CO_2) from burning carbon-based fossil fuels – coal, oil, and natural gas. Other significant shares are CO_2 from deforestation, and a few other gases (methane or CH_4, nitrous oxide or N_2O, and various fluorine chemicals) from agriculture and a few industrial processes. Emission cuts will slow human-driven climate change – big enough cuts can eventually stop it – but they will take a long time to make a difference. The climate system responds so slowly to changes in human activities that the next few decades of change are largely beyond our control: slowing climate change has been compared to steering a supertanker. Mitigation efforts we make now will slow climate change in 30 to 50 years. Moreover, while it might seem attractive to wait and learn more about how severe climate change will be before cutting emissions, this would be a dangerous course because it would postpone even longer the time when the cuts start to slow climate change. The long delay between action and payoff makes mitigation the most urgent response to climate change, but also makes it contentious: people disagree strongly over what they are willing to do to avoid environmental harms, even potentially catastrophic ones, 50 years or more in the future.

3. The Scale of Mitigation Required.

Stopping human-driven climate change requires slowing and eventually stopping the current increase in atmospheric concentrations of greenhouse gases. Human activities have already raised the concentration of CO_2 from about 280 to 380 parts per million (ppm) since the 19th century, and are now increasing it about 2 ppm per year. Emissions of other greenhouse gases are raising the climate effect of current CO_2 emissions by about one-third. If we do not control emissions, atmospheric concentrations of greenhouse gases will keep growing: projected levels in the year 2100 range from about

600 to more than 1,000 ppm. Limiting climate change requires bringing the growth rate of concentrations down to zero – a much harder task than stopping the present increase in emissions. The concentration of CO_2 in the atmosphere is a stock, like the volume of water in a nearly full bathtub, to which current emissions are an added flow, like a running tap. Limiting the concentration – stopping the water from rising – requires not just holding emissions constant but cutting them sharply, eventually to nearly zero.

But what concentration limit should we aim for? Targets from 450 to 750 ppm CO_2 have been discussed, with 450 to 550 ppm most widely proposed: 550 ppm would roughly double the pre-19th Century CO_2 level, while 450 – 500 ppm of CO_2 alone would have roughly the same climatic effect as a CO_2 doubling when the climate effect of other greenhouse gases is included. Higher concentrations mean greater risks, but there is no definitive way to identify what levels must be avoided. Various unlikely but possible forms of catastrophic change have been identified, but no one knows at what concentrations these might occur, if at all. And for the more likely non-catastrophic changes, deciding how much climate-driven disruption we are willing to endure – or, more accurately, how much we are willing to impose on our children and grandchildren – is a political judgment that science can inform but not make. Still, many knowledgeable observers have judged that the risk of serious disruptions is likely to mount with total greenhouse-gas concentrations beyond about 550 – 600 ppm, and some have argued that even levels above 450 -500 ppm carry risks that we should on all accounts avoid.

Given a target for limiting atmospheric concentrations, many different emissions paths over time can meet that target. A concentration limit is roughly equivalent to a fixed budget for cumulative global emissions over the entire 21st century. In allocating this budget over the century – deciding how much to emit when, while keeping the century-long total within the budget – low-cost emissions paths all tend to have a similar shape, in which emissions rise for a while, then turn and decline later.

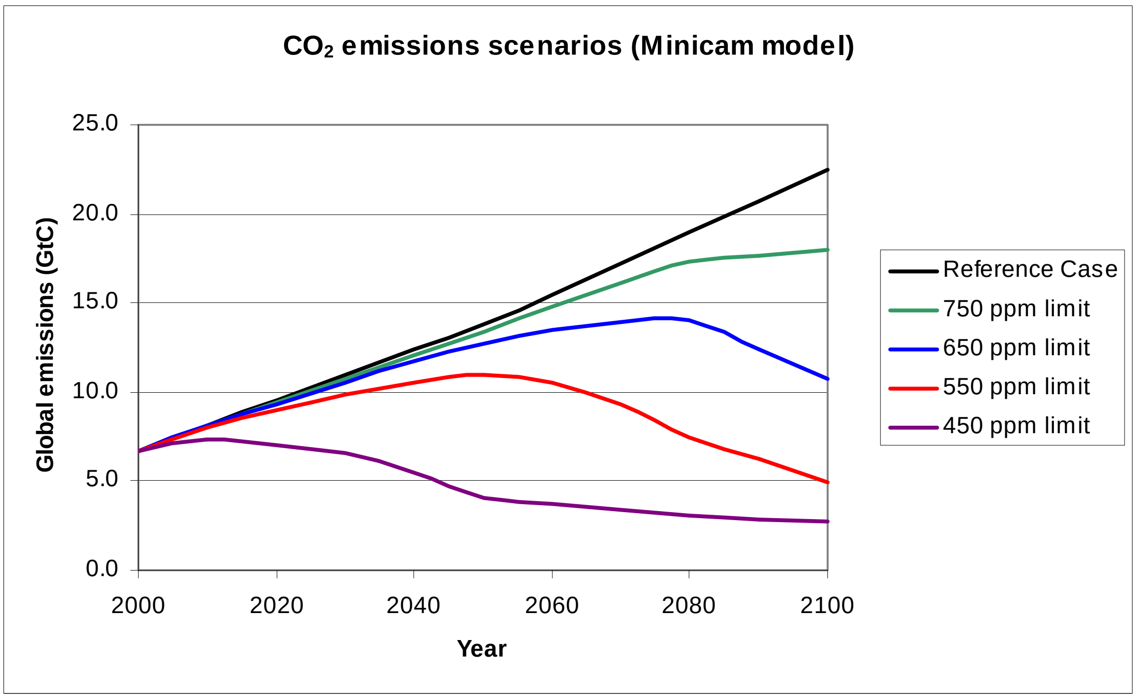
To hold concentrations to some reasonably prudent limit, these reductions must be large. While the median of recent projections of uncontrolled emissions has them nearly doubling by 2100,[1] scenarios to meet a 550-600 ppm limit require emissions to peak before 2030, then drop as much as 30% below 2000 levels by 2050. To meet lower limits, emissions must peak earlier and then decline faster. The table and figure below show summaries of the requirements of various stabilization levels, from two major recent assessments. Note that all these cuts are in *global* emissions: achieving these in the context of a growing world population and economy requires the rich industrialized countries to cut even more sharply to allow room for growth in the rest of the world.

[1] Without efforts to reduce emissions, they could even increase much more than this. The upper bound (95th percentile) of recent projections is for more than a four-fold increase.

Alternative stabilization levels: Implications for Climate Change and Emission Cuts

Stabilization level (CO_2-equivalent)	Resultant global warming	Year of CO_2 emissions peak	Emission reduction by 2050 (relative to 2000)
445-490 ppm	2.0 – 2.4 ºC	2000-2015	-50% - -85%
490-535 ppm	2.4 – 2.8 ºC	2000-2020	-30% - -50%
535-590 ppm	2.8 – 3.2 ºC	2010-2030	+5% - -30%

(source: IPCC Working Group III, 2007)



(source: Clarke et al, 2007)

4. How to cut emissions: Technologies to transform the world energy system.

The need for such extreme emission cuts poses a stark choice for the future of human energy use: what energy sources and technologies will come to dominate the global energy system over the next few decades, as production of cheap conventional oil and gas declines? If we sustain and expand conventional use of coal and move toward high-carbon synthetic fuels from coal or unconventional sources, emissions will grow rapidly and CO_2 concentration may well exceed 1,000 ppm by 2100. If, on the other hand, we move strongly to energy sources that do not emit greenhouse gases, emissions may decline enough to meet some reasonably prudent limit on concentrations. But these climate-safe energy sources must be deployed in enormous quantities: to limit concentrations to 450 to 550 ppm, the new climate-safe energy supply in place by 2050 must be roughly equal to today's total global energy supply, perhaps up to twice as much.

The major types of climate-safe energy technology are well known. They include conservation and efficiency improvements in energy conversion and use; renewable sources such as wind, solar, and biomass; nuclear power; and technologies for carbon capture and underground sequestration, which allow use of fossil fuels without emitting CO_2 to the atmosphere. More distant prospects include deep geothermal energy, solar energy captured in space and transmitted to the Earth's surface, and nuclear fusion.[2] While many analyses have identified particular mixes of technologies that could make the required shift by 2050, how these technologies will actually develop cannot be predicted. Many areas could have breakthroughs that make them attractive candidates for large-scale use. For example, two long-standing favorites to bet on are a large drop in the cost of solar photovoltaic cells, and the development of technically, commercially, and politically viable nuclear fusion. But there is no basis for predicting which technologies will see such breakthroughs, if any. As in many past technology transitions, there will probably be a few winners and many losers: roughly equal shares to each technology is an unlikely outcome. But experience in other areas of technology policy suggests that policy-makers cannot pick these few winners in advance, and should not try.

Climate-safe energy technologies mostly cost more than high-emitting technologies. There are a few important exceptions – climate-safe technologies that are as cheap as or cheaper than conventional fossil technologies. For example, substantial further cost-saving efficiency improvements are available in many areas of energy use, and wind-generated electricity on the best sites can now provide a small fraction of total generation in a system at costs comparable to conventional sources. But it is unlikely that cheap or free gains can provide more than a small share of the climate-safe energy needed. Technological advances will probably make all types of climate-safe energy cheaper and more attractive, but will require a combination of major investments in R&D, demonstration-scale projects, and early market roll-out of new technologies to move down learning curves. Present levels of research, development, and investment in climate-safe sources are utterly inadequate relative to what is required.

Shifting the energy system to more expensive climate-safe sources will impose costs on the whole economy, although estimates of the size of these costs vary widely. Two recent assessments have compiled estimates of the cost of stabilization from several energy-economic models, as shown in the table below. Although the estimates span a wide range, most models show the cost of even ambitious stabilization targets as less than 1 – 2% loss of future world economic output. Except for the highest estimates, these costs appear quite manageable for rich countries, particularly in view of the large income

[2] Hydrogen is not on this list, because it is the answer to a different question. Like electricity or gasoline, hydrogen is an energy carrier, not a source: it is not collected directly, but must be produced using some other primary energy source. Hydrogen can be produced using high-emitting sources such as coal or oil sands, or non-emitting sources such as solar or nuclear-powered electrolysis of water. Whether a hydrogen economy helps or hurts climate stabilization depends on which sources predominate.

growth projected over this period. For example, the IPCC cost projections all correspond to reduced annual GDP growth rates of less than 0.12% through 2050.

Reduction in world economic output from atmospheric greenhouse-gas stabilization

Stabilization level (ppm CO_2 or CO_2-eq)	**2030**	**2050**	**2060**	**2100**
IPCC 2007: Median and range of results from multiple models				
445-535 total CO_2-eq	< 3%	< 5.5%		
535-590 total CO_2-eq	0.6% (0.2% - 2.5%)	1.3% (<0 – 4%)		
590-710 total CO_2-eq	0.2% (-0.6% - 1.2%)	0.5% (-1% - 2%)		
Clarke et al 2007 – Results of three models				
450 CO_2 (520 total CO_2-eq)			1.3% 1.9% 6.7%	1.2% 1.5% 16.1%
550 CO_2 (660 total CO_2-eq)			0.3% 0.4% 2.3%	0.6% 0.8% 6.8%

These cost estimates have a few major uncertainties, some of which some probably make them too high and some too low. The three most important uncertainties concern technological innovation, changes in behavior and lifestyle, and how mitigation policies are enacted. While innovation is included in the estimates, it is represented as a fixed rate of progress, which does not reduce the costs of climate-safe energy technologies in response to mitigation efforts or R&D. Similarly, people make no changes in their behavior or lifestyles in response to climate change, except to adjust to changes in energy price as they have in the past. More realistic representations of these processes would probably bring reductions, perhaps large ones, in estimated costs. On the other hand, these estimates also assume optimal worldwide policy that allows cost-minimizing cuts anywhere, anytime, so the atmospheric limit is met at the lowest possible cost. Less efficient and less flexible policies could raise the cost of any specified limit several-fold.

5. But what do we actually do? Policies to motivate the required energy transition.

Identifying potential technologies that can achieve the required emission reductions says nothing about what policies should be enacted. Government policies rarely specify what technologies are deployed: technologies are much more strongly and directly determined by private investment decisions. If climate-safe sources are to grow as needed to limit climate change, most of the R&D to develop them and virtually all the investment to deploy them will have to come from private businesses. But the required private investments are not occurring: because climate-safe sources cost more, most investment is going into conventional technologies, especially coal-powered electrical generating stations. The primary job of public policy is to shift these private decisions toward climate-safe sources, by providing clear, sustained incentives that make these sources more attractive business propositions relative to conventional sources. Several nations and sub-national governments have taken the first steps down this path by enacting preliminary mitigation policies, but none of these has yet been sufficiently strong or long-term to stimulate mitigation decisions of the required scale.

Limiting climate change requires cutting worldwide emissions, not just those of any single country, so action is required at both national and international levels. The rest of this note ("Part 1") outlines how to design practical and effective national mitigation policies. Its companion ("Part 2") elaborates the required links between national and international actions, and proposes a strategy to move toward effective global mitigation.

Economy-wide policies: emissions taxes and tradable emissions permits

Effective and politically practical mitigation policies need three components: economy-wide measures that make emissions costly; targeted sectoral measures; and support for research and development in climate-safe energy technologies. Economy-wide measures form the core of a mitigation strategy. By making emissions costly – putting a price on them – these measures can make it profitable to cut emissions and develop non-emitting technologies. This prospect of profit in cutting emissions creates the required incentives for private investment and R&D. The likely high cost of greenhouse-gas control – substantially higher than the cost of addressing other environmental issues – makes it essential that these economy-wide policies be market-based. Such policies allow flexibility in how firms respond, thereby lowering the cost of achieving environmental goals and providing stronger incentives for innovation.

The major forms of market-based policy are emissions taxes and tradable emissions permit systems, often called "cap-and-trade" systems. Under an emission tax, a fixed fee is charged for each ton emitted. Under a cap-and-trade system, emitters must hold a permit for each ton they emit. Permits are issued by the government in some fixed quantity, and may be freely bought and sold thereafter. Under either policy, individual emitters can choose how to respond to the policy: under a tax, they may choose any mix of cutting their emissions and paying the tax; under a permit system, they may choose any mix of cutting their emissions and acquiring the necessary permits. If, as usually assumed, emitters seek the cheapest way to meet their obligation, either policy should motivate cuts until the marginal cost of reductions (the cost of the last ton reduced) is equal across the economy, and so achieve the environmental target at the lowest possible cost. The biggest difference between the two policies comes from uncertainty in the cost of reductions. An emissions tax fixes the marginal cost of mitigation at the tax level, but leaves uncertain how much emissions are cut to reach that cost level; a permit system fixes the total emissions level, but leaves uncertain the cost of achieving that level. Either of these policies can be varied to allow flexibility in the timing of mitigation, either over-complying today and holding a credit against future obligations or emitting more today by borrowing against future emissions (with appropriate insurance for failure or bankruptcy). In addition, various hybrids of the two policies have been proposed, most commonly a cap-and-trade system with a "safety valve," a price at which the government will issue extra permits so the marginal cost of cuts can never go higher.

The two forms of policy also differ in their symbolism and their politics. Most broadly, any policy called a tax is an easy target for opponents. Moreover, unless emission taxes are somehow compensated, they make a large financial transfer from emitters to the government. A permit system makes the same transfer if emitters must buy their permits in an auction, but permits are rarely distributed this way: instead, they are usually given away to current emitters as part of the political bargaining to adopt the policy. But while these factors have long made permits the politically favored form of market-based policy, there is mounting evidence of high price volatility in permit markets that may hinder their ability to provide the clear and sustained incentives needed to motivate investment. Because emissions taxes let the incentive level be precisely fixed, and adjusted over time as required, this experience with permits increasingly suggests that taxes merit more serious consideration than they have received – despite their political risks. These risks can also be reduced by designing a tax system to reduce or eliminate the transfer from emitters to the government, by defining some emissions level as the zero point for the tax, with taxes charged or rebated for emissions above or below that level.

A key issue in designing economy-wide mitigation measures is whether the policy is applied upstream or downstream. Upstream policies charge the tax or require the permit at the point where a unit of carbon-based fuel enters the economy – the well, the mine, the oil sand, or the point of import – based on its carbon content. This charge then follows the unit of fuel through the economy, raising the price of all goods in proportion to their use of emitting energy and providing incentives to reduce emissions in all sectors. To ensure that the policy is tightly coupled to emissions even though it is not applied at the point of emissions, a credit must be generated – the tax rebated or a new permit issued – when a unit of fuel is used in a way that avoids the expected CO_2 emissions, such as petrochemical manufacture, combustion with carbon sequestration, or export.

Downstream policies, by contrast, charge the tax or require the permit where a unit of fossil fuel is burnt, the point of actual emissions. Downstream systems have the benefit of targeting actual emissions; they provide a direct incentive to the emitter, which may better catch their attention than a price increase buried in their purchase of fuel. Downstream systems also have political advantages. They provide the symbolism of imposing a burden directly on emitting facilities, so mitigation looks like a business responsibility that households do not have to pay for. At the same time, downstream systems make it easier to secure the consent of those nominally bearing the burden, by giving them permits for free, carving out targeted exemptions, or providing rebates. But a downstream system cannot be truly economy-wide, because this would require tracking emissions from millions of sources, including every home, business, and vehicle. Consequently, downstream policies are only ever applied to some small subset of emitters, usually some combination of the biggest sources and those in particular industry sectors. This unavoidable limit in the policy's scope makes it less efficient, because incentives to cut emissions do not reach the whole economy. It also creates many administrative complexities and opportunities for gaming, as emitters try to re-define, re-design, or modify their facilities to move them outside the boundaries of the policy.

The final major design decision for economy-wide policies is their stringency – the tax rate or number of permits issued – both its initial level, and how it will be adjusted over time. Under a permit system, the number of permits issued can be set to track the desired emissions path, perhaps with an escape valve to avoid extreme costs. Under a tax, rates can be based on estimates of the marginal cost of the desired mitigation level. Although estimates vary widely, typical estimates of the tax to meet a 450-550 concentration constraint would start in the \$5 – 10/tCO_2 range, then increase over time.

Estimated carbon prices for 2030 and 2050 from two recent assessments are shown below. For comparison, a price of \$100/tCO_2 corresponds to a price increase of about 90 cents per gallon of gasoline, 3.6 cents per kwh of electricity generated with natural gas, and 9.5 cents per kwh of electricity generated with coal. Long-standing popular wisdom that citizens would rebel at such energy price increases has been called into question by the relatively calm acceptance over the past two years of similar and larger oil-price fluctuations due to market conditions alone and the prospect of further such increases.

Estimated Carbon price for climate stabilization (\$/tCO_2)

Stabilization level (ppm CO_2 or CO_2-eq)	**2030**	**2050**
IPCC – Range of multiple models		
550 total CO_2-eq (no induced tech change)	\$20 - \$80	\$30-\$155
550 total CO_2-eq (with induced tech change)	\$5-\$65	\$15-\$130
Clarke et al 2007 – Results of three models		
450 CO_2 (520 total CO_2-eq)	\$46, \$52, \$105	\$127, \$157, \$230
550 CO_2 (660 total CO_2-eq)	\$4, \$7, \$31	\$19, \$10, \$67

Targeted sectoral measures

In an idealized economy characterized by perfectly competitive markets, perfectly rational decision-making, perfect foresight, perfect information, and no agency costs, these economy-wide measures would be all that was required for mitigation policy. Even in real economies they are a central, essential part of the response, because they can spread incentives for mitigation and the associated burdens broadly across the economy. This increases their effectiveness, limits costs, and limits opportunities for gaming. Moreover, because they can be imposed at any point in the energy system, they can be implemented with a relatively small administrative burden. But these measures cannot provide the complete solution in real economies, for both economic and political reasons. They cannot be fully effective and efficient because the collection of decisions that determine emissions in real economies – decisions in markets for energy and energy producing and using capital equipment, as well as many government and other non-market decisions – differ from idealized perfect markets in highly consequential ways. Moreover, these policies lack the flexibility to respond to the real configuration of political interests, which may be necessary to make them politically feasible.

For both these reasons, economy-wide market-based measures must be supplemented by two additional components of mitigation policy. The next component consists of targeted sectoral measures. These can be required for three distinct reasons. First, because of various market failures, many decisions with powerful emissions effects are driven by other factors than energy prices. Consequently, market-based measures that operate through energy markets are not uniformly effective across the economy. For example, building design and construction practices virtually lock in a stream of emissions over the lifetime of the building, but these decisions are largely determined by building codes, not energy prices. In such cases, the effect of economy-wide measures can be augmented with more narrowly targeted policies, e.g., measures to increase the energy efficiency of buildings, appliances, and vehicles. Sometimes these narrower policies can also be market-based, defining some relevant environmental target and letting firms respond flexibly to meet it. In other cases, conventional regulations such as performance standards, or information and labeling measures, may be most effective and efficient.

Second, some decisions have such large consequences for emissions that it is prudent to target them explicitly rather than assuming they will respond as expected to the economy-wide measures. These cases may be most common when a mitigation policy is first enacted, for example if decision-makers respond slowly to the new policies due to information limits, perceptual lags, or established decision routines. The thousands of coal-fired electrical generating stations now in development worldwide provide a prominent example. Each of these will lock in high emissions for 50 years or more, or else compel a costly early abandonment or awkward retrofit. There would be a large benefit in policies to force consideration of future emissions in these decisions. There are a few alternatives to conventional pulverized-coal boilers – including one technology called "Integrated Gasification – Combined Cycle" (IGCC) that is in already in operation in several plants – that can much more easily be retrofitted in the future to capture and sequester carbon. Policies to motivate switching currently planned plants to IGCC or some other technology compatible with future carbon capture, most likely involving some combination of regulation and subsidy, would greatly expand the low-cost opportunities available in the future to cut emissions, at a small cost today.

Third, there are some decisions clearly within the province of governments that have enormous emissions implications. Examples include the regional planning, zoning, and infrastructure investment decisions that shape settlement patterns and consequently energy demand in both transport and buildings. In addition, there are various fiscal and regulatory policies, as well as government expenditures, that can decisively influence investments in major energy-resource projects. Canadian examples include the Federal and Provincial policies influencing the rate of development of the oil sands; permitting and licensing decisions for major new hydroelectric developments, such as Site C on the Peace River or Lower Churchill Falls; and the regulatory and licensing environment for the Canadian nuclear power program. In many such cases, simply giving greater consideration to future greenhouse-gas emissions in policies that are not explicitly about climate change can powerfully influence future emissions and the future options that will be available to reduce them.

Government support for climate-safe energy R&D

The final major component of an integrated mitigation policy is support for key areas of climate-safe energy research, development, and demonstration projects. Developing climate-safe energy on the required scale will require a huge increase in R&D in multiple technology areas – efficiency improvements, renewable resources, nuclear power, and carbon capture and sequestration. Many of the advances to be sought are too risky, too long-term, and too resistant to private capture of the benefits to motivate the required efforts from private investors alone. There is consequently a strong case for carefully designed programs of government support, through direct public R&D programs, subsidies to private projects, and partnerships. Although such public support is desirable in many areas of energy technology that are too far from commercialization to generate adequate private investment, the case is most compelling for the most remote and risky but highest-payoff technologies, such as space solar, deep geothermal, and nuclear fusion. Serious pursuit of any of these would require a massive public effort, whose size and challenge has been compared to the World War II Manhattan Project.

6. Designing a complete mitigation strategy: issues to consider

These three policy components are the building blocks from which national governments, or provincial and state governments, can build integrated mitigation strategies. Sufficiently strong economy-wide measures are of primary importance, because they are the only component to apply incentives to reduce emissions to all sectors. Specific sectoral measures can supplement the economy-wide measures to target areas of high-value opportunity in either public or private-sector decisions, or areas where the broader measures may be ineffective. Sectoral measures and R&D support also provide tools to make mitigation more politically feasible. They can achieve this by supporting areas of national technological advantage and so promoting national competitiveness in a climate-constrained world, and by managing the domestic distribution of the policy's burdens across regions or sectors. The detailed design of each component and how they are integrated will vary across jurisdictions in response to specific characteristics of their economies and their specific configuration of political interests.

Despite this variation in detail, there are certain challenges to designing an effective, low-cost, and politically feasible mitigation strategy that are likely to arise in most settings. The remainder of this note sketches the three most important of these challenges, and provides some general guidance on how to respond to them.

Beware large transfers, seek ways to avoid or compensate them:

Big domestic transfers of costs and benefits – among regions or industry sectors, or between private firms and the government – are the bane of environmental policy. Serious mitigation efforts can impose substantial costs on particular groups, and may also create substantial opportunities for profit. Large transfers, and large inequities in the distribution of these burdens and benefits, can make enacting policy impossible, unless policies are carefully designed to avoid or offset these transfers. For example, the main reason emissions taxes are so rarely enacted above trivial levels despite their many advantages is the large transfer they create from emitters to the government. In Canada, the most serious distributional obstacle to mitigation has been making the burden acceptable to Alberta and Saskatchewan, which have both the most upstream oil-and-gas operations and the greatest reliance on coal-fired electricity in the country and so would bear a disproportionate burden from any economy-wide mitigation policy.

Because of differences in the structure of energy economies, the distribution of mitigation burdens and benefits will be unique to each jurisdiction. Enacting mitigation policy will usually require tuning the details of policies to soften the burden on the hardest hit and on those whose consent is most essential. This can often be achieved by designing the details of mitigation policy to let these groups collect some windfall rents. As in all policy-making, however, skepticism is required in assessing groups' claims of how much they are hurt. For example, coal-burning electric utilities may operate in competitive and regulatory environments that let them pass cost increases through to their customers, in which case the problem is not compensating the utilities, but compensating their customers. Demands to give away the store – e.g., to exempt high-emitting industries from an emissions tax, or to give all emission permits to incumbents for free rather than auctioning them – should be expected, and resisted. In a permit system, auctioning all permits and giving them all away form the endpoints of a bargaining range: the problem is finding a reasonably efficient and politically practical point in the middle.

If the flexibility available within design of economy-wide mitigation measures is not sufficient to make the distribution of burdens acceptable, the design of sectoral measures and R&D support programs may provide additional ways to manage the distribution of benefits and burdens. For example, subsidies for demonstration plants or infrastructure in climate-safe energy can be targeted at regions bearing the largest costs from economy-wide mitigation policies. In some cases, however, mitigation policy alone may not allow enough flexibility to reduce the burdens to the biggest losers to acceptable levels. Such cases may call for broader political bargains, in which those most burdened by mitigation policy are compensated through other means outside of climate-change policy.

Respect capital lifetimes, but watch out for trickery:

The cost of mitigation can be greatly increased if policies require premature abandonment of existing capital. The long-term transformation of the energy economy required by serious mitigation will be costly enough. It is imperative not to inflate costs unnecessarily by imposing policy shocks suddenly or without warning. To avoid such shocks, economy-wide policies should start at relatively weak levels – just strong enough to get investors' attention and signal that emissions will be costly over the lifetime of current investments. For example, policies could be implemented within one to two years – essentially immediately – with an emission cap at a level close to present emissions, or an emissions tax of perhaps \$5 - \$10/tCO_2. (Recall that \$10/tCO_2 means about 9 cents per gallon of gasoline, 0.36 cents/khw of gas-fired electricity, and 0.95 cents/khw of coal-fired electricity.) Stringency should then increase in a credible, pre-announced way to allow phased retirement of older, higher-emitting capital and planning of new investment and technology development. Because mitigation policies must be kept in place for decades, their stringency, scope, and details will have to be adjusted over their lifetimes to respond to new information and changed capabilities. But these adjustments should also be gradual enough, and announced with enough notice, not to interfere with orderly investment planning and technology development.

Economy-wide policies do not explicitly distinguish new investments from existing capital: rather, they leave decisions on the timing and character of new investments and the retirement of old capital up to investors. For some sectoral policies, however, it may be preferable to distinguish new emissions sources from old ones explicitly. This may be valuable, for example, when a flood of new long-lived investment is occurring in a sector that carries long commitments to future emissions. Changing the character of these new investments may require strong measures that would be excessively costly to apply to existing facilities in the same sector, because their emissions characteristics are largely fixed. Examples might include the current build-up of coal-fired electrical generating stations worldwide, and the rush of investment now underway – with preferential federal tax treatment – in the Canadian oil sands.

There is one large risk posed by different treatment of new and old sources, however: the perverse incentive to extend the life of old sources so they can continue to benefit from lenient regulatory treatment. This risk accounts for one of the areas of greatest contention and failure under the US Clean Air Act, the New Source Performance Standards. The lesson from this and other experience is that if policies favor old sources over new ones, this preferential treatment must be firmly committed to phase out over a reasonable time horizon, perhaps one coupled to the remaining lifetime of assets used for tax accounting, to ensure that the old sources are not kept running forever.

Pursue national benefit by promoting innovation and supporting competitiveness

All mitigation policies provide some degree of incentive for innovation. This is especially true of the market-based, economy-wide measures that are the core of the proposed three-part strategy. But national economies differ in their opportunities for commercially successful innovations in climate-safe energy, due to differences in their endowments of energy resources and existing technological capabilities. Mitigation policies can be designed to promote innovation in areas of strength, to pursue competitive advantages in a climate-constrained world economy. Policies might achieve this, for example, by coupling targeted R&D support with regulatory requirements that create domestic markets in the most promising areas. In Canada, promising technology areas to seek national competitive advantage might include carbon capture and sequestration, biomass fuels from forests or other lingo-cellulosic materials, and nuclear power. In contrast, wind and solar-power technology may be less promising areas to seek Canadian competitive advantage, in view of the large technological lead held by firms elsewhere.

While the details of mitigation policy can be crafted to promote focused areas of national competitive advantage, mitigation policies in aggregate will impose costs, particularly on the highest emitting sectors. Consequently, firms that are exposed to trade, operating in high-emitting industries in countries undertaking serious mitigation, will suffer a competitive disadvantage. If economy-wide policies are made revenue-neutral by recycling revenues to cut other taxes, the increased tax burden on high-emitting sectors will be partly offset by a decreased burden and improved competitive position in low-emitting sectors. Still, this shift will make at least a major disruption of trade patterns, perhaps a substantial loss for nations where high-emitting sectors are most active in trade.

These competitive effects of mitigation are one of the major links between national and international mitigation efforts. In particular, they are the basis for the widespread claim that mitigation leadership by a few nations will be ruinously costly and ineffective, because emissions will "leak" outside the mitigation zone through movement of investment in high-emitting industries. Under this argument, the only feasible approach to global emissions reduction is for all nations to move together, at whatever speed they can all agree on – probably very slowly.

These are risks that must be taken seriously in considering mitigation policies. But the arguments that have been advanced for these effects thus far are largely theoretical and the actual evidence for them is quite thin – in part because actual mitigation policies have been very weak, adopted very recently, or both. The actual severity of these effects will depend on the detailed design of a mitigation strategy, the speed at which it is adopted and intensified, the size of the economy adopting it, and how many jurisdictions of what size move together, either simultaneously or in close enough succession.

Avoiding competitive disadvantage and leakage are one reason to pursue coordinated international mitigation rather than relying on separate national or sub-national efforts, but not the only one. International coordination can also increase the effectiveness and reduce the cost of mitigation, by extending and strengthening each component of mitigation strategy. For economy-wide measures, international agreements can set global targets, and commitments and metrics for national efforts to reach them. They can also broaden the market in which market-based policies operate – with appropriate provisions for implementation and verification – and so strengthen the incentives for businesses to develop and deploy climate-safe technologies. For sectoral measures, international agreements can fix parallel adoption of consistent measures to harmonize regulation of traded goods such as appliances or vehicles, and can provide a forum for analyzing measures' effectiveness and exchanging best practices. For R&D programs, international agreements can establish participation and cost-sharing agreements for specific large initiatives, support exchange of information and technology, and establish common technology-assessment processes. In all these areas, international coordination can make mitigation cheaper and more effective by applying policies consistently over larger markets, and can increase governments' willingness to make costly efforts by building their confidence that others will match these efforts. International action can bring these benefits whether it precedes or follows national actions – either negotiating the details of national actions in advance to build a consistent international system, or joining and coordinating separately developed national actions after the fact.

In view of the global nature of the emissions-control problem, one major puzzle of current climate-change policy is how much activity is underway at sub-national levels – states, provinces, and even municipalities. This is most pronounced in the US, where federal rejection of emission regulation co-exists with actions by more than 30 states. The most extreme case is California which is developing a complete emissions-control system including state-wide emissions targets, tradable emission permits, regulations of motor-vehicle emissions, and many other measures. Sub-national governments may have several reasons for doing this – e.g., some measures may be cheap symbolic politics; some may carry local co-benefits such as air pollution control; some may promote the competitive position of local industries; and some may seek to inspire (or shame) national governments to follow. But while some of these initiatives are making real contributions in the absence of serious national and international action, it is unlikely that such regional and local initiatives can deliver and sustain the magnitude of cuts that are needed. As deep cuts carrying real costs come into play, there will be a need for action by major nations, supported and coordinated by international negotiations.

Part 2 of this note examines this link between national and international mitigation, and outlines options to move toward broad international mitigation. In particular, it presents options to reduce the risks of competitive disadvantage to mitigation leaders and consequently emissions leakage. On this basis, it proposes an approach to international mitigation that may hold the promise of overcoming the current deadlock.