Encouraging Private Sector Research & Development into Alternative Post-Capture Carbon Management Technologies in Canada

by

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Abstract

Canadian industrial carbon dioxide emissions exacerbate climate change and decrease the likelihood of Canada meeting its 2020 greenhouse gas targets. One approach to reducing emissions is to capture the carbon dioxide and treat it as waste, disposing of it underground; this method has gained political favour in Canada but is not yet commercially viable and presents a range of potential problems – for example, it is an unproven technology, is not yet commercially available, and is very expensive. Alternative forms of post-capture carbon management offer an opportunity to fix the gas in marketable products, but due to a number of factors, there is little incentive at present for private sector investment in a field that is still largely in the research and development stage. I analyse these barriers and argue that the federal government needs to play a stronger role in encouraging such research and development, offering policy options that would enable it to achieve that objective.

Keywords: Post-capture carbon management; climate change mitigation policy; research and development; carbon capture and utilisation; induced technological change

Dedication

To all the friends I've missed tremendously while focusing on my studies over the past few years, and to those with whom I have had the good fortune to become friends during that time: I love you dearly. I hope my work assists in my goal of making this planet a better place for us to enjoy sharing.

Acknowledgements

I would like to thank: Dr. Nancy Olewiler for her assistance and encouragement throughout the development of this Capstone; my fellow environmental policy Capstone group members, Terri Blackburn, Amanda Card and Claire Havens, for constantly challenging the way I think and for their friendship and support; Professors Benoit Laplante and Mark Jaccard for significantly and positively enhancing my conception and experience of both learning and work; Julie Vanderschot and Greg Smith at Environment Canada for inspiring the topic of this Capstone; the School of Public Policy at Simon Fraser University for its excellent Masters program and for funding my attendance at the Globe 2012 conference; and, of course, my family, whose love and support I always appreciate.

Innovation success is essential to our prosperity and quality of life. Canada has capacity and advantages that should position us well for leadership in innovation, but we are falling well short of our potential. The current economic situation should stimulate our ambition for greater innovative success, and the failure to heed this stimulus will compromise our progress and standard of living — perhaps permanently.

Munroe-Blum and MacKinnon, Institute for Research on Public Policy, 2009: 9

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List of Acronyms

CCEMC	Climate Change and Emissions Management Corporation (Alberta)
CCS	Carbon capture and sequestration
CCU	Carbon capture and utilisation
CO_2	Carbon dioxide
CRA	Canada Revenue Agency
DOI	Digital Object Identifier[1]
EC	Environment Canada
EOR	Enhanced oil recovery
GHG	Greenhouse gas
GJ	Gigajoules
IPCC	Intergovernmental Panel on Climate Change
IRAP	Industrial Research Assistance Program
Mt	Megatonnes
NEB	National Energy Board
NPRI	National Pollutant Release Inventory
NRC	National Research Council of Canada
NRCan	Natural Resources Canada
OAG	Office of the Auditor General of Canada
PCCM	Post-capture carbon (dioxide) management
PCCM-a	PCCM alternatives (to CCS and EOR)
PPP	Public-private partnership
SDTC	Sustainable Technology Development Canada
SOI	Statement of Interest
SR&ED	Scientific Research and Experimental Development program
t	tonnes

[1] Digital Object Identifiers (DOI) are the stable, permanent internet locations of electronic documents. I have used DOIs where readily available. See: *http://www.doi.org/* to resolve DOIs, and *http://www.doi.org/faq.html* for more details.

Executive Summary

Canada lacks a comprehensive strategy to support private sector research and development into alternative technology options for managing captured carbon dioxide.

Without additional new technological options, Canada is likely to exceed its 2020 Copenhagen greenhouse gas target by nearly thirty percent. Industrial and electric utility facilities such as coal-fired power plants are a major source of carbon dioxide (CO_2), the most prevalent greenhouse gas, accounting for over half of Canada's 2010 greenhouse gasses. CO_2 emissions can be reduced at these sites by either making process changes so that less CO_2 is produced or by separating the CO_2 from a stream of waste gas, capturing it (carbon capture), and then sending it by pipeline to be managed nearby or at a distance, ideally stopping the CO_2 from entering the atmosphere. How best to manage that CO_2 is a major focus of this paper. The field that covers all options I have termed post-capture carbon management (PCCM).

Two main approaches to carbon management after its capture (i.e., post-capture) have received large amounts of public money to develop them as climate mitigation strategies. These are enhanced oil recovery (EOR) and carbon capture and sequestration (CCS). Neither are effective strategies at present, and both are highly subsidized by Canadian governments with little climate benefit. A set of options, which I have labelled post-capture carbon management alternatives (PCCM-a) offer value-added uses of CO_2, but are mostly in the research and development (R&D) stage of the innovation process. I have coined the terms PCCM and PCCM-a because the field is not clearly delineated, with CCS sometimes also meaning EOR, and EOR being subsumed under another category that is intended for the legitimate recycling of CO_2 (carbon capture and utilisation). PCCM-a, then, means CO_2 management alternatives to CCS and EOR.

EOR involves pumping the captured CO_2 into mature oil wells to force more oil out. This technique is well-established, but the availability of suitable sites is often overstated, the CO_2 doesn't necessarily remain underground permanently, and it is used to extract more fossil fuels, which will be combusted and lead thus to more CO_2 emissions in the future. Calculations indicating a (small) net storage of CO_2 via the process do not appear to include lifecycle analyses, and are therefore potentially misleading. EOR is not an effective climate change mitigation strategy.

Government policy has focussed on EOR and a second option: CCS. This involves pumping the waste CO_2 into deep saline aquifers, where it should remain for up to 1000 years if correctly managed. It is an unproven technology, not yet commercially available, suffers from a number of drawbacks, and is very expensive. The federal government is developing regulations for CCS, and much of the responsibility will be left up to the provinces, which are working on their own sets of regulations. An example of the questionable cost-benefit ratio of CCS is the Shell Quest Project, a $1.35 billion CCS facility under construction in Alberta. The project has received at least $865 million in public funding ($120 million from the federal government and $745 from Alberta's technology fund, generated by carbon pricing) . It will only store up to 1.2 Mt/year. With Canada expected to emit 785 Mt in 2020, it is barely a scratch. Unfortunately, CCS is an example of governments picking winners, putting all their eggs in one basket and hoping for the best. Governments have a history of mispicking winners at great expense to taxpayers. CCS and EOR present a threat of path dependence (technology lock-in), a phenomenon that occurs when a number of factors (such policy or engineering choices) produce a technological outcome that does not permit a simple reversal or replacement of the technology once it has been adopted.

PCCM-a reframes CO_2 as a value-adding product, fixing the CO_2 in other chemical structures. PCCM-a is, for the most part, in the very early R&D stage, and is receiving little private sector support for a number of reason that I mention below. Examples of PCCM-a include using CO_2 for:

- Production of algae (which can be turned into biofuels, plastics);
- Chemical feedstocks (to make fertilisers, synthetic fuels for off-peak wind energy battery storage, plastics); and

- Mineral carbonisation (producing materials that can be used in construction).

Canada lacks a comprehensive strategy to encourage private sector R&D into PCCM-a, and I present and analyse a set of policy options for improving that situation. To develop my analysis, I use a set of three guiding questions:

1. *What is the current private sector R&D situation in Canada?*
2. *What are the barriers to the private sector investing in PCCM-a?*
3. *How can policy instruments best address these issues?*

To find answers to those questions, my methodology involves an extensive literature review, primarily based on reports from Canadian government (federal & provincial), industry, international organisations, think tanks, foreign governments and academic literature. I also attended a major international conference in Vancouver, BC on business, sustainability and the environment, called Globe 2012.

What, then, are the main barriers to R&D, and why should the government be involved in influencing technology R&D? Briefly, there are several spillover effects that concern firms performing R&D – the main two are:

- *Knowledge externalities*, which arise when third party firms gain the benefit of another's work; and
- *Adoption externalities*, which exist where other firms benefit from lower production costs that were not enjoyed by the originator of the technology until it had (if at all) succeeded in working out a profit-generating method of diffusion

Due to these externalities and to information asymmetries, "the uncertainty associated with the returns to investment in innovation is often particularly large" (Jaffe, Newell and Stavins, 2004: 8). Society frequently gains benefits that the R&D firm is often unable to capture – according to Parsons, "R&D spillovers are very significant," and thus provide the "primary rationale" for government intervention (2011: 9). The federal government recognises this, and acknowledged the importance of R&D with an entire chapter in the recent 2012 budget.

There are over 100 technology-related federal assistance programs; these can be divided in to two categories:

1. *Direct support*, which refers to loans, grants, and procurement; and
2. *Indirect support*, which may include tax credits for R&D, R&D allowances, and lower taxes on R&D employee wages.

The preferable type of support "is determined by the market or system failure being addressed and the type of R&D that the government wants to stimulate" (Industry Canada 2011: 16). In 2008, indirect support was about ten times higher than direct support in Canada, but some critiques suggest a lack of empirical evidence to support a preference for one or the other of the support mechanisms.

Assessments of the federal R&D programs tend to focus on several points that relate to my research. The current framework is confusing and difficult for firms to navigate; program overlap has also resulted from the plethora of programs. Canadian businesses do not spend enough on research and development, suggesting that the programs aren't working well; the system leads to rent-seeking behaviour on the part of consultants, which siphons funds away from actual R&D work; the system also generates perverse incentives for firms to remain small – rather than promoting the growth of small Canadian R&D firms. An example would be the Scientific Research & Experimental Development (SR&ED) program. Finally, the future of some programs is uncertain, and a number of key programs have ended.

The issues that informed my policy problem can be summarized by three key points:

I. *General issues*: these are the problems that apply to R&D in general, such as the knowledge & diffusion externalities;

II. *PCCM-a issues*: the current federal R&D programs are not as effective as they need to be, because:

- There are too many programs;
- The programs are poorly targeted,

- PCCM policy is too narrow (i.e., ‘winners’, to the virtual exclusion of PCCM-a options),
- The federal suite of R&D programs suffers from poor design; and
- There is weak support in the post-R&D innovation stages (e.g., rewards for commercialization are taxed too highly); this is improving with reduced taxes on corporate income.

III. *No federal carbon-pricing policies*: without a (sufficiently high) price on CO_2 emissions, there is little incentive for GHG-producing firms to invest in R&D to reduce their annual emissions.

I assess five policy options for dealing with the lack of strategy to encourage PCCM-a R&D in Canada:

1. Maintain the status quo
2. Improve current R&D-incenting programs, without specifically targeting PCCM-a
3. Amend current programs to target PCCM-a R&D
4. Amend current programs to target PCCM-a R&D by creating a new program for PCCM-a R&D; and
5. Establish and maintain a technology fund from which qualifying firms wishing to perform PCCM-a R&D may draw

Using four key criteria (effectiveness, administrative feasibility, political viability, and whether the option minimises direct costs to taxpayers) measured qualitatively to analyse the options, I recommend that options 4 and 5 be implemented, but sequentially. As option 4 could be developed and implemented in a shorter time frame than option 5, it could function as the foundation for option 5: when option 5 becomes more politically feasible (for example, if a carbon price is ever set and accepted by stakeholders), the program will largely have already been established, making the transition simpler than implementing option 5 alone.

Initial funding for option 4 could come from either tax credits or a special fund for grants. Though the latter is more difficult to justify in the current economic climate, CCS projects are receiving huge grants, and a percentage of funds for additional CCS projects could be redirected toward PCCM-a R&D. Both options 4 and 5 are designed to ensure that post-capture carbon management alternatives are not crowded out of the picture. Making this explicit both within the general R&D program suite and within the broad PCCM suite (by giving political attention to PCCM-a) may also encourage private sector firms to explore R&D opportunities beyond the two most popular ones, and may ultimately benefit Canada, both economically and socially. Successful technologies could be exported, and make Canada a global leader in the mitigation of anthropogenic climate change.

I conclude that EOR is a dubious climate change mitigation option; CCS is risky, financially wasteful and myopic, and that PCCM-a presents Canada with an additional option worthy of R&D funding. If we're going to pick winners, we need to be far more careful in our assessment of the range of options, and should pick winning groups rather than specific technologies. I also note that if we're really serious about dealing with our CO_2 emissions, the federal government needs to start pricing carbon – doing so would create no deadweight loss, increase the incentive to reduce emissions, and would help to deal with an important pollution externality.

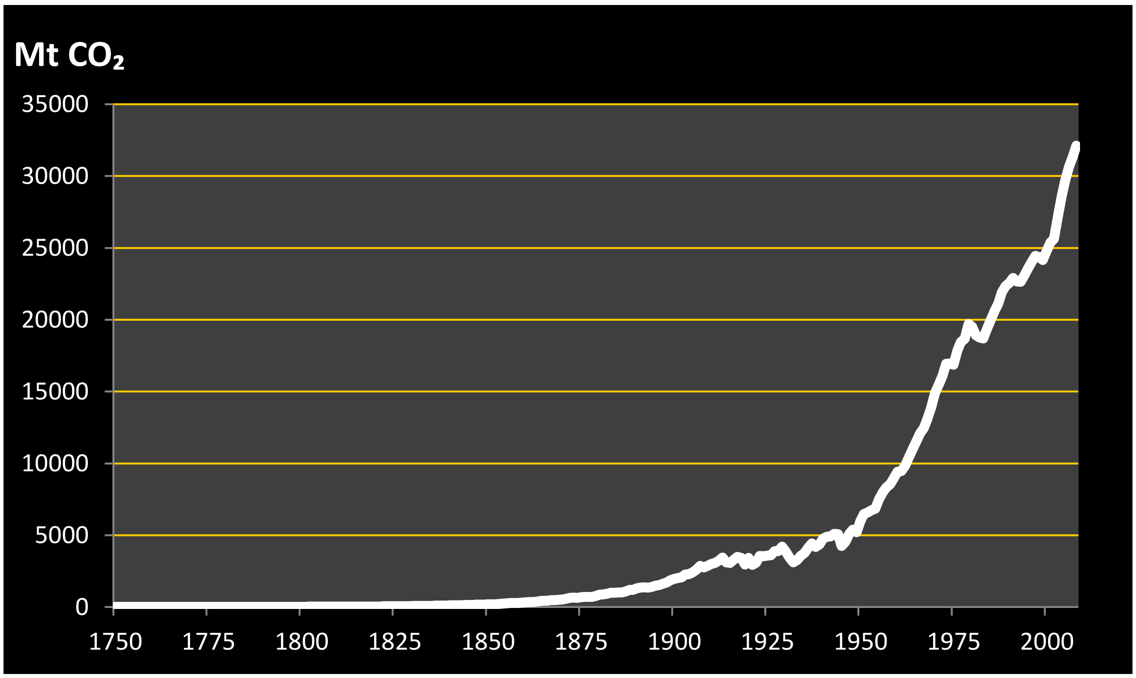
Such large investments of public money require better oversight, as is evidenced by the Shell Quest example. I suggest that the Office of the Auditor General of Canada (OAG), which has an environment and sustainable development mandate, direct the OAG's Commissioner of the Environment and Sustainable Development to perform regular performance audits of projects, including investigations into the process used to determine which climate change technology solutions receive funding.

1. Introduction

Climate change is a global problem unprecedented in magnitude and significance. The effects of industrial and post-industrial era human activity – particularly from the combustion of fossil fuels for heat, industrial processes, and transportation – will be discernable in the atmosphere for hundreds of years or longer. Greenhouse gasses accumulating in the atmosphere trap heat that would otherwise be reflected or emitted into space, and thus contribute to the *greenhouse effect* – an increase in atmospheric, surface and ocean temperatures that lead to additional climatic impacts. We continue to exacerbate the problem, even with consensus among the scientific community that we are having a real and rapid effect on the atmosphere that could, in conjunction with other effects of human activity, be a driver of mass extinctions, both on land and in the sea. If countries – their constitutive populations, businesses and governments – truly wish to minimise the negative climate change-related impacts that have been predicted by organisations such as the Intergovernmental Panel on Climate Change (IPCC 2007: 45-54), then leadership and long-range planning is imperative. Governments often have far greater motivation to attend to policy issues that have an immediate and noticeable effect. Long-range planning has low political pay-off, is subject to uncertainties (both due to the complexities of modelling the future and to the possibility of unforeseeable events), and may involve high capital expenditures in the short-term. In addition, there is always the possibility of outright failure – or worse, the creation of new problems in the future.

Carbon dioxide (CO_2), a greenhouse gas (GHG) that exists naturally, is also produced by human activity, primarily as a by-product of fossil fuel combustion (*Figure 1*). The rapid rate at which we are emitting carbon dioxide is overwhelming the ability of natural systems to manage it, and progressively worsening anthropogenic climate change is the result (Jaccard, 2005: 17-18). A major (but by no means the only) source of carbon dioxide emissions is industrial activity and electricity-generating utilities, referred to collectively as large point sources. In this paper, I develop and analyse policy options for encouraging private sector business investment in research and development that explores ways to manage carbon dioxide emissions from large point sources other than the two favoured methods that treat it either as a waste product in need of disposal (carbon capture and sequestration) or as a way to extract more GHG-producing oil from mature wells (enhanced oil recovery).

Figure 1. Global CO_2 emissions from fossil fuel combustion, 1750-2008



Calculations based on dataset from: Boden, Marland, and Andres (2011)
DOI: 10.3334/CDIAC/00001_V2010

In *Section 2*, I present the background information that has framed my approach to dealing with the issue at hand, starting out by giving a theoretical explanation of how we have created the complex problem that is climate change. I then look at Canada's contribution to the global accumulation of GHGs and single out one aspect of the economy that, if we are to mitigate climate change, will need to reduce its emissions significantly: large industrial and utility point sources of CO_2. There are two main approaches to reducing CO_2 emissions (input and process modifications to decrease CO_2 output, and carbon capture combined with various methods to manage the captured emissions). Recognising that both approaches are important, I focus on *post-capture carbon management* (*PCCM*) methods, arguing that the two best known and supported methods (carbon capture and storage, and enhanced oil recovery) are both insufficient and non-optimal ways to mitigate climate change. These details highlight a need for increased research and development (R&D) into better and more efficient options, which I have termed *post-capture carbon management alternatives (PCCM-a)*. The section culminates with a statement of the policy problem that I have identified, which, expressed in a simplified form, is that Canada lacks a comprehensive strategy to support private sector research and development into PCCM-a technologies to manage captured CO_2 emissions.

I make the case that the private sector businesses have a responsibility to find better ways to manage captured carbon because they are the source of such a large amount of the very emissions that are causing climate change.[2] Since the private sector faces a number of barriers that discourage R&D in that area, I argue that the federal government needs to play a leadership role in stimulating private sector R&D by way of policy. In *Section 3*, I describe the methodology that I used to research, produce, analyse the policy options most appropriate to achieve that.

Section 4 contextualises the private sector R&D situation, from the perspective of post-capture carbon management alternatives. I do this by describing the main federal R&D-stimulating programs, and follow up with major critiques that have been published over the last few years. In the last month, the Government of Canada delivered its 2012 budget; the budget set aside a chapter to deal with some of those critiques and offered the start of a series of policy changes that the government will roll out over the next year and in the 2013 budget. I have ensured that these changes, many of which remain to be clarified by the government, are factored in to my analysis. This allows me to move on to developing policy options in the next section.

I devote *Section 5* to an explication of the main policy options available to improve private sector R&D of post-capture carbon management alternatives, followed by an analysis of those options. I offer my recommendations in *Section 6*, and suggest

[2] From herein I use *private sector* as shorthand for *private sector businesses.*

several aspects of the problem that will need future analysis. Finally, after the *References* section, I have included a backgrounder on PCCM-a.

2. Post-Capture Carbon Management Research and Development: Is there a Role for Federal Policy?

> Government policy … has a significant impact on emissions. In this respect, future emissions will be shaped by existing government measures, as well as future measures that will be implemented as part of Canada's plan to reduce emissions to the target established in the Copenhagen Accord of 607 Mt by 2020 … [Modeling with] no major technology changes and factoring in current government measures … results in a baseline scenario whereby emissions reach 785 Mt by 2020 (or 54 Mt) above 2005 levels. (Environment Canada. *Canada's Emissions Trends*, 2011: 19)

I have researched and written this paper with the intent of positioning it within the growing movement to create effective and efficient strategies for reducing Canada's greenhouse gas emissions. As the federal government's own data show in the document quoted above, Canada is on a path to failure in this respect. Trying to "stop the oil sands" or impede shale gas development (both sources do and will contribute to increased emissions) is unlikely to be effective in the current political climate. Demands, wishes, and dreams of Canada dropping production of its fossil energy resources are useful for fuelling both debate and a degree of political pressure, but their effect has not – at least, not yet – become sufficiently powerful to divert Canada's emerging course. Pragmatic solutions, then, are needed: solutions that recognise the set of constraints that frame them, and that find ways to operate within those constraints to assist in reducing the nation's GHG emissions. It is in the spirit of such pragmatism that I offer here an attempt to find policy options for encouraging the better management of Canada's emissions problem.

2.1. Climate Change: A Tragedy of the Commons

While scientific research reinforces the argument that climate change is occurring and is due to human activity, debate ensues about how to reduce GHG emissions. We know that we must dramatically reduce our emission of GHGs such as carbon dioxide, nitrous oxide and methane, but doing so involves short term economic, social and political consequences. Pressured by high-emission sectors of the economy wishing to avoid incurring abatement costs, and by groups of taxpayers wishing to avoid paying for government spending on mitigation measures, maintaining the status quo may appear to be the safest short-run choice for any sitting government – a safer stance than embarking on an ambitious and potentially risky climate action plan.

One argument for inaction is that the invisible hand of the market is best able to manage the problem. In many cases, markets are indeed the most efficient means for attaining desired ends, but many environmental problems, including climate change, occur or are exacerbated because of market failures. Anthropogenic climate change is an example of the *tragedy of the commons*: the costs of emitting GHGs are insignificant to the average utility-maximizing rational actor when compared with the expenses that actor may accrue when attempting to limit her emissions. All other things remaining equal, the actor will choose to emit (Hardin, 1968). Our atmosphere is a public good, in that everyone has access to it and consumption by one person does not limit its availability to others. A corollary of this fact is that since causing long-term damage to the atmosphere may ultimately affect everyone, any person or organisation contributing to atmospheric degradation will not be subjected equally to the effects; it is also the case that particular areas and populations may be more vulnerable to the direct or indirect effects of climate change than others (IPCC 2007: 50-2). It is therefore more financially attractive, for example, for a factory to continue to emit GHGs than it is for it to incur the cost of minimising those emissions: the cost will be incurred instead by third parties, a social cost. This is a classic case of a negative environmental externality, the remedying of which requires government intervention. Policy intervention may be in the form of direct regulatory instruments (e.g., performance standards or technology standards), or incentive-based instruments such as tradable emissions permits, taxes on polluting goods or on emissions, and subsidies (Goulder and Parry 2008: 5).

2.2. Climate Change Mitigation

Pressure from the scientific, academic and ecology-related communities, as well as from concerned individuals, has made it impossible for governments and businesses to ignore climate change and its causes. Although the issue has been met with varying levels of enthusiasm by governments around the world, some have chosen to implement mitigation policy. There are two main options to reduce anthropogenic GHG emissions: emit less, or stop the emissions from being able to affect the atmosphere.

The first main option requires producing fewer greenhouse gasses by altering our practices and processes – for example, reducing the size of our cattle industry, using equipment designed to be more fuel-efficient, or altering the choice of fuels or chemicals that we use to generate goods and services. This option may involve high costs for large point sources of CO_2, and without policies in place to encourage such modifications, there is little or no incentive for a large emitter to reduce its emissions. However, governments can ameliorate (to some extent) the market failure by carbon pricing.

CO_2 has an implicit value. As discussed above, when treated as a waste product and emitted into the atmosphere, the negative effects of the emissions are not borne by the emitter, generating a negative externality, that is, a cost to society (in this case, global society, since the effects of CO_2 emissions are not localisable to their source regions). Carbon pricing is a market-based policy instrument intended to internalise those normally external costs. Instead of using strict regulatory 'command-and-control' style policy to dictate how a firm must reduce its CO_2 emissions (for example, via technology standards or performance standards, which are often inappropriate, inefficient, or excessively costly, due to technological heterogeneity within a sector), governments can use carbon pricing as a way to motivate firms to find the most cost effective way to achieve the desired emissions reductions at their facilities. Policy instruments for carbon pricing include cap-and-trade (emissions trading), carbon taxes, and emission-reduction credits (Tietenberg, 2005: 279-301). Although emissions trading is in its early stages for CO_2, the instrument has proven successful in the past for reducing sulphur dioxide levels in the US, and was also successful in the 1980s in phasing out the use of chlorofluorocarbons (CFCs) and in encouraging the transition from leaded to unleaded gasoline (Stavins, 2005: 334-354).

The second of the two main options for mitigating CO_2 pollution is to capture waste gasses before they are emitted into the atmosphere and to find a way to ensure that they do not get released into it. While these two approaches are simultaneously necessary, it is with the latter that this study is concerned.

With respect to capturing GHGs, it would be ideal to capture them from as many sources as possible. For pragmatic reasons, scale is a factor that affects our capacity to do so. Capturing GHGs from small sources, such as gasoline-powered automobiles and household furnaces is, at present, impracticable: although in aggregate, small sources contribute significantly to GHG emissions, capturing those emissions would be burdensome on both the users and on any organisations tasked with managing them post-capture. GHG collection devices would be necessary (and may have little net benefit if GHGs are produced in manufacturing them), public information campaigns would have to explain what to do (and, as with recycling bins outside apartment buildings, would risk being misunderstood or ignored), and collection depots (to which many people would drive) and disposal services would have to be set up. The inefficiencies implied by such a system therefore make it impractical. Applying technological improvements to small sources as they are manufactured (or finding lower or zero emission substitutes) and fuel-switching are thus more efficient and effective methods for reducing their GHG outputs.

Large point sources, such as coal-fired utilities and industrial operations, present a far greater opportunity for GHG capture. As relatively large quantities of GHGs may be emitted from a single or a small number of points at a facility, capturing those emissions can be efficient and effective. Sufficiently high carbon pricing would also encourage the wider implementation of this method at Canada’s large point sources. In some cases, the captured GHGs may be saleable, usable or disposed of in a manner that has a far lower impact on the environment. An example of this is the capture and use of landfill methane for energy purposes (IEA 2009).

While there are a number of greenhouse gasses, and reducing the output of each is important, the IPCC asserts that CO_2 is "the most important anthropogenic GHG" (2007: 36), and notes that global emissions of CO_2 increased by roughly eighty percent between 1970 and 2004, with an acceleration in the last decade of that period (36). Chemically, CO_2 poses a major problem: it is non-combustible, and is a "chemically unreactive molecule under standard conditions" (Styring 2011: 10). These properties have led to it being regarded as having too high an energy trade-off associated with chemically converting it into a less damaging molecule to be worth the effort or expenditure (10). Producing GHGs to manage relatively smaller quantities of GHGs is clearly counterproductive.

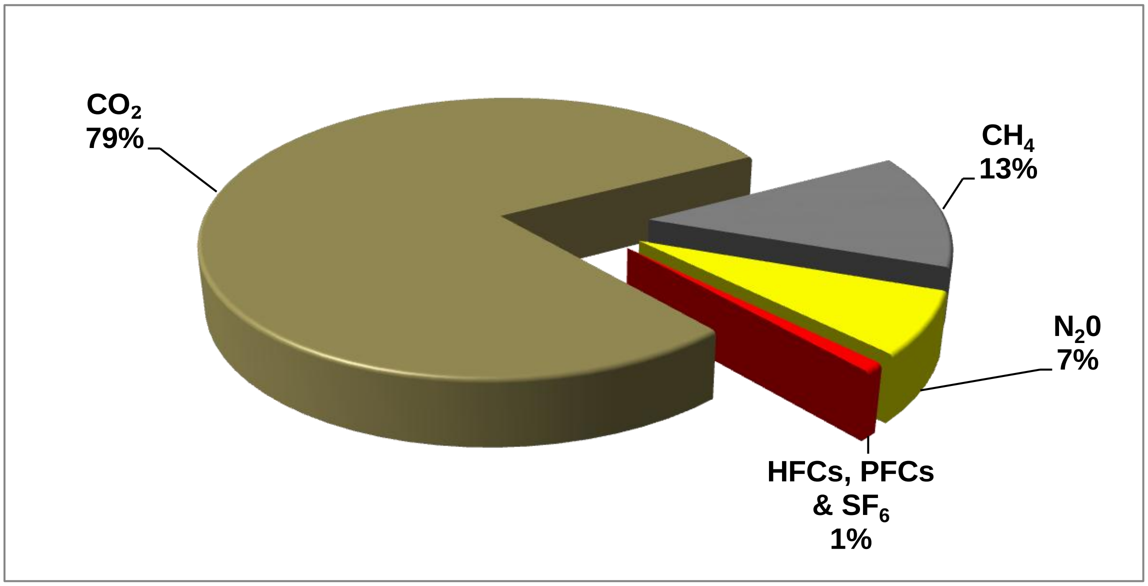
2.2.1. Canada's Carbon Dioxide 'Contribution' to Global GHG Emissions

In Canada (as in most countries), CO_2 is the GHG that is produced in the greatest quantity (see *Figure 2*, below). Due to its current low commercial desirability, and to it representing the largest proportion of emitted GHGs, I shall be concentrating on policy options for mitigating CO_2 specifically rather than all GHGs. All facilities emitting over 50 kilotonnes GHGs/year are required by Environment Canada to report their annual emissions to the National Pollutant Release Inventory (NPRI), disaggregated by gas.[3] In 2009 Canada's total GHG output was 690 Mt (Environment Canada 2011: 19); facilities reporting to the NPRI were responsible for about 251 Mt of those GHGs, with just over 93%, or 233 Mt of that being CO_2 (my calculations, based on: Environment

[3] Government of Canada. *Canada Gazette*. Vol 145, No. 40 (1 Oct., 2011). http://www.gazette.gc.ca/rp-pr/p1/2011/2011-10-01/html/notice-avis-eng.html#d101. Accessed on 20 Oct. 2011. Note that voluntary reporting by facilities emitting below 50 kilotonnes is encouraged.

Canada 2010: *Emissions Data by Facility* Excel spreadsheet).[4]

Figure 2. Canada's total GHG emissions by gas, 2009



Source: Environment Canada (2011) *National Inventory Report 1990-2009*. P18.

2.2.2. Large Point Source CO_2 Emissions: The Impetus for Post-Capture Carbon Management (PCCM)

One of the key strategies for the management of CO_2 emissions from large sources is *carbon capture and storage* or *carbon capture and sequestration* (both abbreviate to CCS). There are two forms of CCS, both of which involve separating the CO_2 from an emissions flow, transporting it to a storage location, and then pumping it underground, where it is supposed to remain for a long time, likely over 1,000 years and possibly far longer (IPCC, 2005: 14).

[4] Approximately 1 Mt of the 251 Mt reported in 2009 came from the sub-50 kilotonne GHG facilities (my calculations). Spreadsheet with data current as of September 23, 2010 available at: http://www.ec.gc.ca/ges-ghg/8044859A-3843-4832-B161-B5C12E1A500A/Emissions%20par%20installation%20-%20Facility%20emissions.xls. Accessed on 13 Oct. 2012.

The first form of CCS is an established method called *enhanced oil recovery* (EOR). By pumping CO_2 into mature conventional oil wells, otherwise unrecoverable oil may be forced out. According to a 2009 report, there were seven such projects in Canada, assisting in the recovery of an additional 35,000 barrels of oil per day (Alberta Economic Development Authority: 14).[5] Since some oil fields contain formation gas or are proximate to natural gas processors (gas plants separate CO_2 out in order to clean their primary product, methane), easy access to the CO_2 can make it an attractive option for some energy companies. EOR is also referred to as *enhanced hydrocarbon recovery*, as similar techniques may be used to extract natural gas from gas wells and, if it becomes economically feasible, from unminable coalbed methane seams (Natural Resources Canada, 2006: 26-7).

Although EOR is often promoted as a legitimate aid in efforts against climate change, there are concerns. First of all, it assists in the extraction of more fossil fuels, which, upon combustion, will release more GHGs into the atmosphere. Leaks may occur, particularly where regulation fails to address seal verification issues (MIT, 2010: 4), and some companies reuse the CO_2 (US Dept. of Energy. National Energy Technology Laboratory, 2010: 24), which creates a potential for losses during transfer. EOR is also limited by the current lack of CO_2 pipeline infrastructure (discussed below), the potential for CO_2 supply to greatly exceed demand, and by dependence on the price of CO_2 and on oil prices – lower oil prices reduce the EOR demand for CO_2.[6]

The second form of CCS involves pumping the captured CO_2 into deep saline aquifers or depleted oil or natural gas fields and then sealing it permanently underground (Natural Resources Canada, 2006: ix). Although promising, this method is still in its early stages, and faces public optics problems related to safety and permanence, high costs, and low availability – there are only eight large-scale facilities in operation globally

[5] The largest commercially operational facility in Canada is located in Weyburn, Saskatchewan. Using CO_2 transported by a 325 km pipeline from North Dakota in the US, the facility injects approximately 2.4 Mt CO_2 per year (Alberta Economic Development Authority: 14).

[6] As well as the explicit economic value of CO_2 that arises from the demand for it in EOR operations, CO_2 has an implicit value, the *carbon price* (see section 2.2).

(six more are under construction) (Global CCS Institute 2011: vii). Time is also a factor – it can take five to ten years (or longer) for storage assessment and characterisation of new sites (57). In Canada, some energy companies are investing in this form of CCS – Spectra Energy is a notable example, storing about 190 kilotonnes of CO_2 annually from its sour gas processing plants in small-scale CCS projects. Acknowledging the rise in GHGs associated with shale gas extraction and processing (which has only recently become an economically viable resource), Spectra estimates that expanding production in north-eastern British Columbia could generate an additional 18 Mt per year (2011: 1-2), and is investing in a 2.2 Mt per year CCS feasibility project that would be among the world's largest.[7]

While EOR adds value to captured CO_2 and can offset some of the costs associated with CO_2 capture and transportation, the aquifer storage variant is entirely a cost for any company wanting to dispose of its CO_2. Without a sufficiently high financial penalty for releasing CO_2 into the atmosphere, it may be more cost-effective for some companies to emit and pay the low carbon penalty than to invest in CCS or pay for their emissions to be dealt with by a CCS-capable business. For most of the large emitters, the highest cost associated with CCS is the capture of CO_2 (Natural Resources Canada 2006: 48), though costs are projected to decrease in the future by 20-30% (IPCC 2005: 344). As the method for capturing CO_2 is not uniform across sectors, large emitters also face differing marginal abatement costs.

The huge financial cost of CCS storage facilities also raises important questions – such as whether governments would be better off investing in alternative technologies for emissions reduction rather than for large underground CO_2 waste dump facilities. Consider the Shell Quest CCS project, a recipient of $865 million in public funding, with an estimated cost of $1.35 billion (the figure includes development, construction and ten

[7] According to the National Energy Board, the Horn River Basin shale gas plays in northern British Columbia, which are still in the early stages of development, contain about six times the average amount of formation CO_2 than occurs in BC natural gas pools (2009: 12-3).

years of operation). It is expected to sequester up to 1.2 Mt CO_2 per year.[8] Even if the project does reach that level of storage, and the country's emissions remain stable at 2009's level of 690 Mt for the next decade or so, it would take approximately 57.5 CCS projects of Quest's scale to achieve a 10% (69 Mt) reduction.[9] In other words, to achieve a 10% reduction in GHGs, my overly-conservative back-of-the-envelope estimation suggests that – barring any technological change that reduces costs further – it would cost in the region of $77.63 billion; public funding at a similar level would cost Canadian taxpayers just under $50 billion!

CO_2 transportation pipelines are a proven technology, and are deployed across the U.S., though there is currently only one pipeline in Canada (between a coal gasification plant in North Dakota and the Weyburn-Midale EOR project in Saskatchewan) (Global CCS Institute 2011: 48). A planned 240 km CO_2 pipeline, the Alberta Carbon Trunk Line, will have a 14.6 Mt CO_2/year capacity, collecting CO_2 from multiple sources north of Edmonton, and transporting it to EOR operations in South-Central Alberta.[10]

Natural Resources Canada (NRCan) considers storage to be the least expensive of the three stages of CCS, although it is not made clear whether their numbers factor in the costs associated with large subsidies that may be used in order to construct storage facilities (2006: 56). The Canadian costs for storage are estimated to be in the region of $3-$9/t CO_2, and the additional cost of monitoring is estimated at roughly U$0.1-$0.3/t CO_2 (2006: 56, citing studies by Thambimthu 2004 and IPCC 2005).[11] However, note that for the Shell Quest CCS facility, there is an implicit carbon storage price of approximately $112.50 / tonne CO_2 (my calculation, based on 12 Mt of storage over ten years at a total cost of $1.35 billion).

[8] ICO_2N. Quest Project Quick Stats. http://www.ico2n.com/ccs-in-canada/first-projects-in-canada/shell-quest. Accessed on 6 April, 2012.

[9] For Environment Canada data, see: *Canada's Emissions Trends* (2011: 11) and *National Inventory Report 1990–2009: Greenhouse Gas Sources and Sinks in Canada* (2011: 17)

[10] Enhance Energy Inc. http://www.enhanceenergy.com. 8 Oct. 2011.

[11] All dollar amounts are in Canadian dollars unless otherwise indicated.

In Canada, large investments in CCS/EOR have been made by the federal and provincial governments, as well as by the private sector. As I have indicated, EOR alone is insufficient to manage Canada's annual CO_2 output, which I calculated above to be 233 Mt in 2009. The Western Canada Sedimentary Basin, where the majority of oil extraction occurs in Canada, has a sequestration capacity of 570 Mt CO_2 (Bachu, 2004: 2). Many oil reservoirs are excluded from that estimate due to their being too small to be either suitable or economically feasible for EOR and subsequent storage. It is therefore necessary to employ other methods for dealing with CO_2. Although the non value-added form of storage is commonly considered the only viable alternative (and EOR is simply a subset of that), there is a danger associated with placing too much emphasis on it: path dependence, or technology lock-in. In the context of technology, path dependence is a phenomenon that occurs when a confluence of factors (social or environmental events, policy or engineering choices, for example, any or all of which at the time may not seem particularly significant) produce a technological outcome that does not permit a simple reversal or replacement of the technology once it has been adopted. A classic example of technological lock-in is the QWERTY keyboard (David, 1985). While more efficient keyboard layouts have been developed (better, for example, in terms of ease of learning to type), the QWERTY keyboard was a response to the mechanical problems of early typewriter keyboards, which jammed easily if keys were pressed too rapidly in succession. The layout, designed to slow typists down by keeping commonly-used letters apart, has prevailed beyond its usefulness. Computer keyboards – which have no risk of jamming – continue to use the QWERTY layout, as almost everyone who can type has learned using that system, and would be at a temporary loss trying to negotiate a new layout. More efficient layouts such as DVORAK and AZERTY failed to catch on when computers became household items in the 1980s.

Since the abatement of negative environmental externalities associated with public goods tends to be costly, government policy is an important tool for correcting that market failure; policy operates as a signal, and the private sector will normally adjust its operations accordingly if the related costs are lower than the price of any non-compliance penalties. Jaffe, Newell and Stavins discuss the problem of choosing a single technology policy option, which operates as a strong signal. They note that:

> If the government encourages the diffusion of a particular technology, it is possible that it could become so entrenched in the market place that it stifles, at least for a time, the development of some other, superior technology … [In order] to avoid accidentally helping entrench the wrong technology, it is desirable for policy to be 'technology neutral,' encouraging all efforts that achieve specified objectives *without* focusing on a particular approach. (2004: 16-17)

Path dependence is thus a concern that will inform the policy options I offer in subsequent sections.

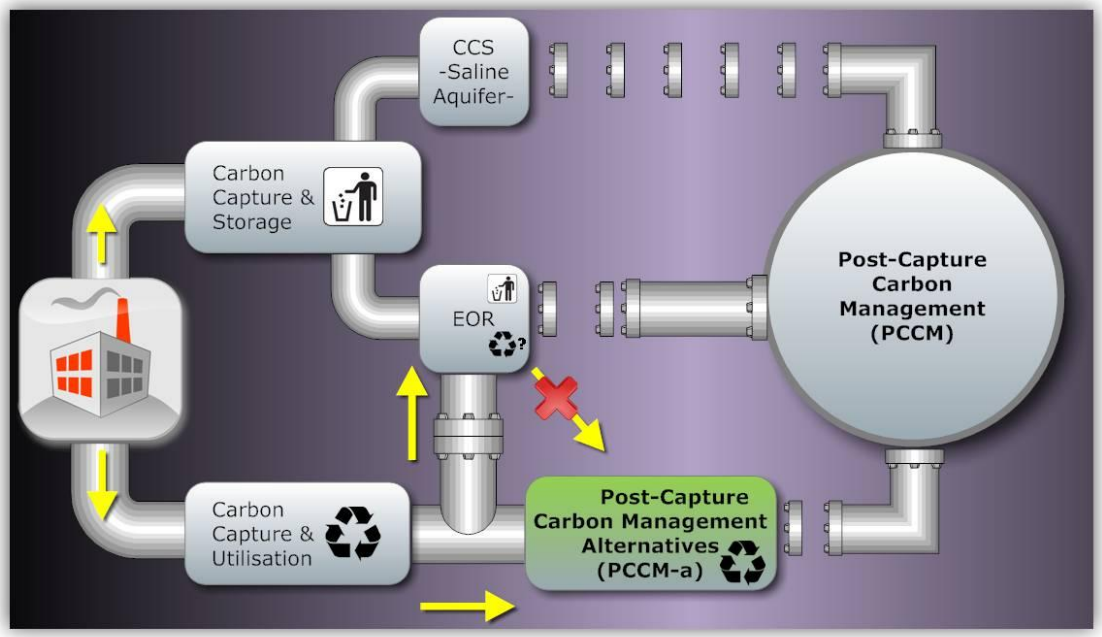
There are good reasons to hope that geological storage will provide an adequate solution to the unsustainable emission of CO_2 into the atmosphere – in particular, it is the ability to sequester large quantities of CO_2 that make it such an attractive idea. Does this mean other options should be ignored? Are there other options? Are they worth investigating, given that investment dollars are a scarce resource?

Other options do in fact exist, and are starting to be taken seriously. A relatively new field – *carbon capture and utilisation* (CCU) – is gaining traction as a way to add value to CO_2 by making use of it as an input for production rather than disposing of it as a waste product underground. There are three main CCU uses for CO_2 currently being investigated: (i) as a chemical feedstock for producing other chemicals and fuels; (ii) for the accelerated mineralisation of certain rocks by carbonisation (generating a product that could be used in construction); and (iii) to grow algae to make biorenewable materials and fuels (Low Carbon Futures 2011: 1-2). All three of these potential uses are still in the R&D stage, as they have a high energy penalty that needs to be reduced in order to make them efficient and cost-effective.[12] These ideas are not being touted as a replacement for CCS, but rather as complementary to it, and may be worth considering

[12] The *energy penalty* associated with a process is the amount of energy required for the process to be completed. This is of concern in the development of climate change mitigation technologies, as the additional fuel required may negate the purpose of the process - the aim is to improve energy efficiency, not to reduce it. Excessive energy penalties may lead to financial losses and / or net increases in GHGs. The energy penalty associated with PCCM is itself an important justification of R&D to find ways to reduce it.

in Canada, so I shall discuss them in greater detail later. Since the term CCS is often used ambiguously in the discourse (sometimes meaning carbon capture and sequestration, but at other points also meaning EOR), I use CCS specifically to denote the permanent geological sequestration of CO_2 as a waste product. CCU also lacks a clear definition, as it is sometimes exclusive of EOR, but on other occasions inclusive of the technique. To assist in disambiguating these terms, I have coined the expressions ***post-capture carbon management*** **(PCCM)** for times when it is necessary to talk about the entire field of options available for dealing with CO_2 *after* being captured from large point sources, and ***post-capture carbon management alternatives*** **(PCCM-a)** for any non-CCS/non-EOR variants.[13]

Figure 3. The PCCM field and its constitutive elements



[13] These variants are currently categorised as CCU, but I wish to leave room for future innovation for managing CO_2 that may not be covered by CCU either.

To facilitate comprehension of this currently convoluted field, I offer in *Figure 3* (above) a visual map of PCCM and the relationships of its constitutive approaches. Now that a number of ways to manage captured CO_2 have developed, there is a clear need for a term to denote the entire field (PCCM), and one to denote CCU options that do not include EOR (PCCM-a). For a more extensive review of CCU, see *Appendix A*.

2.3. Barriers to Research and Development: Externalities

> Economists and other social scientists have demonstrated that the R&D activities of private firms generate widespread benefits enjoyed by consumers and society at large. As a result, the overall economic value to society often exceeds the economic benefits enjoyed by innovating firms as a result of their research efforts. This excess of the *social rate of return* over the *private rate of return* enjoyed by innovating firms is described by economists as a positive externality or spillover. These spillovers imply that private firms will invest less than is socially desirable in research, with the result that some desirable research projects will not be undertaken, and others will be undertaken more slowly, later, or on a smaller scale than would be socially desirable. (Jaffe, 1996)

Investing in unproven technologies – particularly in the absence of government signalling – involves uncertainty and risk. Technological innovation and diffusion (adoption) have the potential to benefit rival companies, reducing firms' motivation to devote resources to either when dealing with public goods: "A successful innovator will capture some rewards, but those rewards will always be only a fraction – and sometimes a very small fraction – of the overall benefits to society of the innovation" (Jaffe, Newell and Stavins, 2004: 6-7). *Knowledge externalities* arise when third party firms gain the benefit of another's work; *adoption externalities* exist where other firms benefit from lower production costs that were not enjoyed by the originator of the technology until it had (if at all) succeeded in working out a profit-generating method of diffusion; and *network externalities* occur when users of a technology benefit incrementally as the number of users reaches and exceeds a critical mass.[14] Due to information asymmetries, “the uncertainty associated with the returns to investment in innovation is often particularly large” (8).[15]

2.3.1. The Role of Government in Encouraging Private Sector R&D Investment in the Post-Capture Carbon Management Alternatives (PCCM-a) Field

> Recently, companies have begun to study technologies – some already in use – that capture CO_2 emissions and store them safely away from the atmosphere in underground sedimentary layers. This promising avenue for preventing emissions does not represent a huge conceptual leap from other efforts to prevent pollution from fossil fuels, although business is eager to offload as many of the development costs as possible on government. (Simpson, Jaccard and Rivers, 2007: 121)

In agreement with Jaffe’s description of the difference between the social and private rates of return on R&D that I used at the start of *Section 2.3*, Parsons (2011: 9) notes that that the social rate of return from “R&D spillovers are very significant,” and thus provide the “primary rationale for an R&D tax subsidy.” Nordhaus (2002: 263) cites a number of extensive studies of the relative rates of return on general R&D investments in the US; these studies indicate a social rate of return of 30% to 70% per year, a far higher range than for the private rate of return on capital of 6% to 15% per year.

Government clearly has a key role in making CO_2 emissions-reduction technology R&D viable. In countries with a single centralised government, politicians are able (constitution – or lack thereof – permitting) to enact laws and regulations in such a way that if necessary, they take precedence over other laws or regulations. In a federal

[14] One method for governments to reduce the exposure of domestic R&D firms to loss of revenues due to knowledge and adoption externalities is to strengthen its intellectual property laws. Intellectual property theory and policy is beyond the scope of this paper.

[15] Parsons notes that while these externalities, together called the *spillover effect*, are negative for the firms experiencing them, they provide a positive social benefit for the economy, and that “R&D spillovers are very significant,” and thus provide the “primary rationale for an R&D tax subsidy” (2011: 9).

country, such as Canada, the situation is more complicated. The Constitution Act gives jurisdiction over certain domains of activity to the federal government, and over others to the provinces. When it is to the advantage of one or the other(s), they tend to attempt to maintain their jurisdiction. To further complicate matters, there are grey areas where either may act, or where it is advantageous to turn a blind eye to particular jurisdictional infractions, and sometimes federal-provincial partnerships are preferred. I have chosen to omit municipal governments – which are, in constitutional terms, creations of the provinces – from this discussion due to their relatively low capacity for revenue-collection and related low budgets.

Due to a lack of explicit designation of responsibility for environmental policy in the Canadian Constitution, environmental policy is the purview of both senior orders of government. This gives both the ability to enact climate change-related laws and regulations, as well as to avoid doing so when it is not politically expedient. In some cases, where both opt not to act, citizens may have the ability to force change by way of the courts. Due to the effects of the concurrent jurisdiction of federal and provincial governments, as well to court action, there has been "a proliferation of environmental rules and standards to such an extent that one needs a 'road map' to work through the legal maze" (Blakes Lawyers 2010: 1). In order to avoid becoming entangled in the jurisdictional nuances of Canadian environmental policy, I shall be considering the issue of encouraging greater R&D in CO_2 management technologies at the federal level, though provincial considerations will be necessary at certain stages of my analysis and recommendations.

In *Section 4*, I elaborate upon the main sources and recipients of R&D funding in Canada. R&D is performed in both the public and private sectors, in public-private partnerships (PPPs) between the two (or three, when federal and provincial governments provide assistance), and in higher education institutions. Each of these loci of activity play an important role in furthering innovation; while there may be opportunities for improvement to all of them, I concentrate here on encouraging the private sector to perform more PCCM-a R&D for three reasons:

- *Scope*: Encouraging innovation in the public sector and in higher education centres requires different policies from those that would apply to the private sector. Policy options would have to be overly broad (e.g., “fund more!”) to cover the range of research loci, and would thus offer little in the way of practical solutions. Narrowing the scope to one location – the private sector – makes addressing the problems specific to that sector possible.

- *Concentration*: According to figures from the federal Science Innovation and Technology Council, environmental R&D accounted for less than two percent of the total 2007 industrial R&D expenditures – the breakdown of largest expenditures is as follows: ICT manufacturing (18%); R&D services (8%); computer services (8%); pharmaceutical manufacturing (7%); aerospace products and parts manufacturing (6%); software (5%); telecommunication services (4%); motor vehicle and parts (3%); oil and gas extraction (3%) and finance and insurance (2%); the other 36% was spread in smaller amounts among other industries (2011: 30).

- *Ethical*: Anthropogenic GHGs may be generated during the production phase and/or may be latent in the products sold for consumption, released at the point of use, or when decomposing post-use. Modern economies are highly dependent on fossil fuels to provide heat, light, motive sources, and industrial processes. Until viable substitutes for these fuels are found, businesses depend on their ability to continue to produce GHGs, and without sufficient motivation (legal or financial), may choose not to reduce their share of the county’s aggregate annual GHG output as doing so often requires expense, and thus a reduced profit margin. As the GHGs are a negative externality, society incurs any future costs (in the form of climate-caused problems) by default. It is entirely reasonable to expect businesses to assist in finding ways to reduce Canada’s GHG output.

It is not enough to demand that the private sector fund more R&D, as not all businesses or industries are equally competitive, and those that are both unable to either absorb the costs (i.e., continue to make a profit, but at a lower level) or to pass them through to consumers may be forced to exit the market. The Canadian natural gas industry, for example, emits GHGs (primarily methane and CO_2) during the extraction and processing of natural gas; when natural gas is combusted during consumption, more CO_2 is created. The industry is part of a deregulated and highly competitive integrated North American market, and has recently experienced a huge decrease in the price of its product. A National Energy Board (NEB) study of new wells drilled in 2009 in Western Canada (the location of about 95% of domestic production) found an average supply cost of C$6.97 per gigajoule (GJ) (NEB 2010: 1). After dropping by about a third from its mid-2008 sale price to an average price of $3.76 in 2009, new well production became uneconomic. Natural gas production continued, however, for reasons including the need to maintain the rights to land leases while hoping for the price to rise again, and due to lower marginal costs for the older wells (NEB: 1). Coercing the Canadian natural gas sector to invest in PCCM-a R&D could damage the industry further, and could easily push investment capital to the U.S. (where production is cheaper), negatively affecting remote communities dependent on resource extraction, and reducing provincial royalty revenues.

If private sector activity is a major source of GHGs, it is fair to ask that sector to contribute toward finding ways to mitigate them – it has an ethical duty to help resolve the problems it creates. It may be able to offset some of the social costs created by producing environmental externalities – according to the IPCC, "Public benefits of RD&D [research, development and deployment] investments are bigger than the benefits captured by the private sector, justifying government support of RD&D" (2007: 20).[16]

The lack of clarity over jurisdictional matters and responsibilities in climate policy serves as another limiting factor for R&D: it induces uncertainty in the market, and hence risks for private sector investors. "The lack of consistency or absence of regulatory and policy frameworks at the provincial level around the development of CCS technology," argues Spectra Energy in a review of federal R&D support, "remain a cause of concern over the medium to long-term and are not fully developed" (2011: 3). The federal government has set a 2020 GHG target, and the provinces have set their own targets (mostly based on percentage reductions, with amounts and target dates differing by

[16] This is corroborated in Lenjosek and Mansour's review of econometric analyses comparing private and social rates of return on R&D investments. The authors' found: (a) the social rate of return may be up to five times greater than the private rates of return, and private rates of return are "generally higher than those observed for other capital investments"; and (b) private R&D generates higher rates of return than does public R&D (1999: 251).

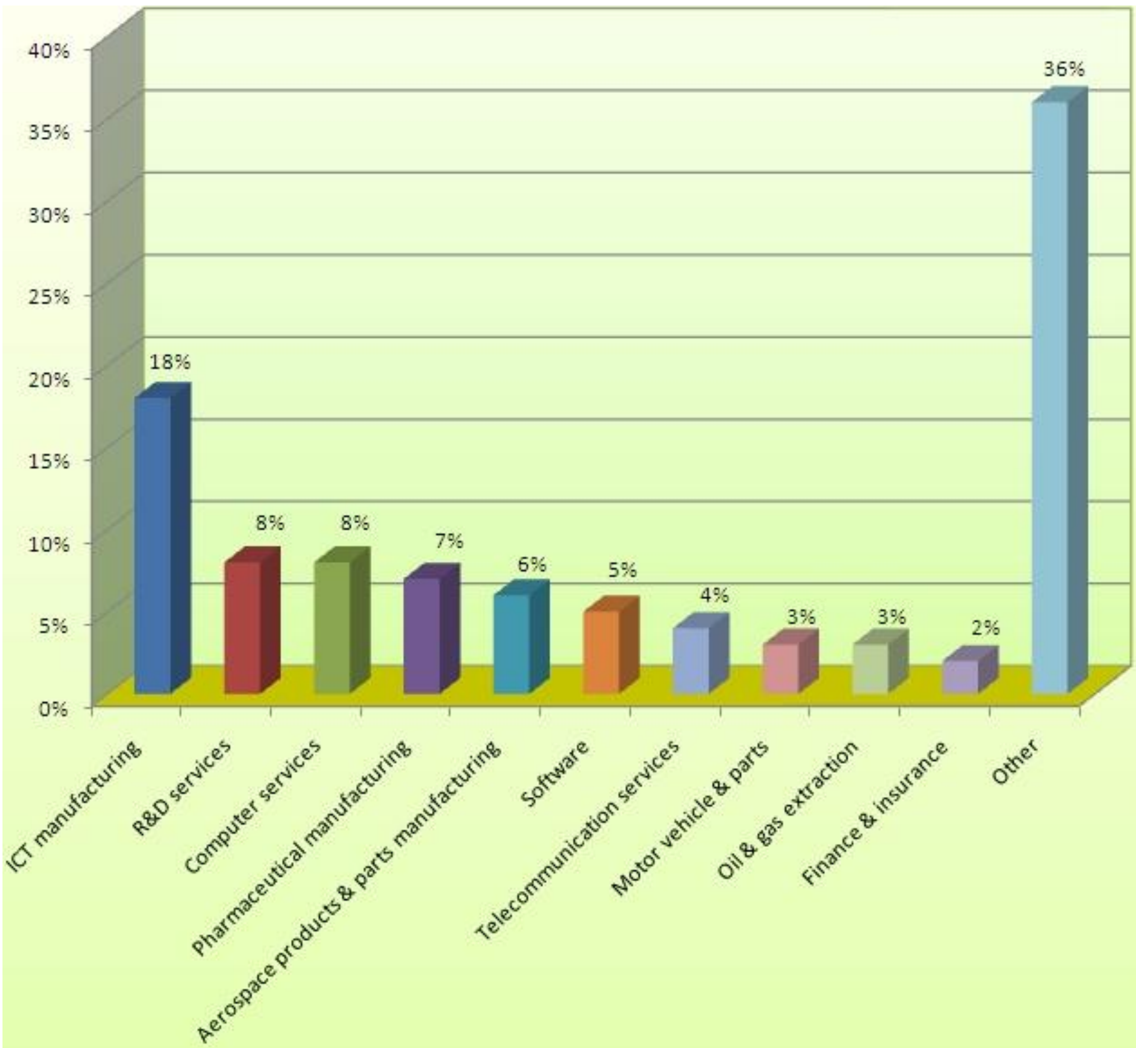
province) (Environment Canada 2011: 11, 49). The Federal government has a set of key measures to assist in attaining its target (47-48), each of which has a direct or indirect impact on R&D funding decisions; the provinces have their own preferred measures (such as the BC Carbon Tax, Alberta's Specified Gas Emitters Regulation and Technology Fund, and Ontario's Feed-in Tariffs and coal-plant phase out) (47). Each province has its own view of the best policy course to take, and some of these preferences conflict – for example, BC, Manitoba, Quebec, and Ontario all favour an emissions trading scheme under the Western Climate Initiative, whereas Alberta is opposed to the notion of participating in such a cap-and-trade plan, arguing that along with potential negative financial consequences, the "requirements would be onerous and targeted disproportionately at energy producing jurisdictions" (Government of Alberta 2008: 39). Each province has competitiveness concerns, and wishes to protect certain industries from incurring costs that might reduce tax revenues or eliminate them entirely by forcing firms to exit the (provincial) market due to an inability to absorb or pass-through abatement costs. Examples include portions of the energy sector, and energy-intensive trade-exposed industries such as iron and steel, cement, and chemical fertiliser manufacturing.

R&D policy may be one of the few areas of GHG abatement policy that could benefit both levels of government, and is thus less likely to generate dispute, although the question of where to locate the R&D may be contentious, as may be decisions pertaining to the kind of R&D that receives federal government support. With recession-related tightened public sector budgets, there is also the matter of finding an appropriate source for the money required to fund R&D.

Figure 4 (below) provides a breakdown of 2007 industry contributions to R&D. Any PCCM-related R&D would appear as a sub-2% contribution in the 'Other' category (since 2% is the minimal level of disaggregation in the 2011 Science, Technology and Innovation Council report). Data on general industrial R&D spending from two Statistics Canada reports indicate a downward trend in Canadian firms' R&D budgets; however, this may be an effect of the recession, as the organisation forecasts a 5% increase from 2010 in 2011 (2011: 4):

Businesses performing industrial research and development (R&D) in Canada anticipated spending $14.8 billion (in current dollars) in 2010. This is down 6.2% from actual spending reported in 2008 and 2.6% from 2009 planned spending estimates. In 2008, companies spent $15.8 billion on industrial R&D, down $852 million for a 5.1% decline from 2007. (2010: 5)

Figure 4. Business expenditure on R&D – contribution by industry, 2007



Data adapted from: Science, Technology and Innovation Council, 2011: 30. Note that the 'Other' category was not disaggregated further.

2.4. Induced Technological Change

Human ingenuity usually occurs without the need for government intervention. However, the cost of attempting to solve some problems by developing new technology can outweigh the expected returns to investors. Induced technological change (ITC) refers to the use of government technology-push and technology-pull policy to create economic incentives to encourage technological development, speeding up the process, and / or channelling efforts in a desired direction. R&D funding is an example of such a push policy, as by reducing the risk of a project, it is more capable of attracting investors, and thus gives the project a chance to survive the innovation stage of development and increases the likelihood of it moving through the demonstration phase and into commercialisation. Technology-pull policies also influence market behaviour, drawing new technologies into the market by affecting how companies act (for example, by implementing direct emissions control policies, governments can encourage emitters to improve their current technology, or develop novel technological solutions to reduce their emissions) (Goulder, 2004: 3-4).

2.5. Summary & Statement of Policy Problem

> If technological change is not free, can we expect Adam Smith's 'invisible hand' to choose the right level of investment in both innovation and diffusion of new technology? (Jaffe, Newell and Stavins, 2004: 5)

Long-term planning difficulties, market, environmental, knowledge, adoption, and network externalities, uncertainty and risk, the need to reduce CO_2 emissions from large point-sources, and the current state of capture, storage and management of CO_2 are all factors that shaped this policy analysis. The policy problem I have identified and used to inform and develop a set of policy options and recommendations may be stated as follows: **Canada lacks a sufficiently comprehensive strategy for encouraging private sector R&D into post-capture carbon management alternatives to CCS and EOR.**

3. Methodology

Having been aware of – and interested in – carbon capture and storage for some time, I was surprised by the release of the Centre for Low Carbon Futures' report, *Carbon Capture and Utilisation in the Green Economy* mid-2011. I had not come across the concept of reframing captured industrial CO_2 emissions as a factor input to production, and had simply considered it a dangerous waste product that needed to be discarded anywhere but the atmosphere or ocean. My interest piqued, I determined to find out whether Canada was paying attention to the relatively new idea – particularly as a month earlier, the Government of Canada and the Government of Alberta had announced joint funding of the $1.35 billion Shell Quest CCS project (contributing $120 million and $745 million, respectively) in Fort Saskatchewan, Alberta.[17] This project is a key element of Alberta's $2 billion commitment to GHG reduction via CCS.

My preliminary search for CCU in Canada bore no fruit, but increased my interest in the topic and led to my decision to do more extensive research on the matter: that was the genesis of this Capstone. My initial research question was concerned with why it appeared that Canada's private sector was not recognising the potential value-added applications of CCU; after a number of media scans and internet search engine scans, I found that CCU projects are often not labelled as such (rather, they frequently refer more narrowly to their topic, e.g., algal biofuels research). This led to my realisation that CCS, EOR and CCU are often used idiosyncratically and in an overlapping manner (EOR being conflated with CCU, for example), and is why I coined the expression *post-capture carbon management* (*PCCM*) to cover them all, and *post-capture carbon management*

[17] Government of Alberta. *Alberta Inks Deal for Shell Quest CCS Project: Province, Feds Partner with Industry to Move CCS Technology Forward*. 24 June, 2011. http://alberta.ca/acn/201106/30771C28EE8FC-F24F-E03C-1BA374D3C893A32B.html. Accessed on 25 March, 2012.

alternatives (*PCCM-a*) to indicate any method not covered by the dominant two, CCS and EOR.

I then moved on to policy considerations, wondering whether PCCM-a was being considered by policy-makers, since they have the capacity to influence the direction of industrial research, which in this field, in the Canadian context, appeared to be lacking. I succeeded in finding out that the federal government is involved in supporting algal biofuels research (e.g., at the National Research Council's Ketch Harbour facility), but it rapidly became clear that CCS (and/or EOR) had been chosen as a technology 'winner' and that the vast majority of funding was aimed in that direction.

Having identified a policy gap (elaborated in my policy problem statement at the end of the previous section), I developed three broad questions to guide my research:

What is the current private sector R&D situation in Canada?

What are the barriers to the private sector investing in PCCM-a?

How can policy instruments best address these issues?

Once I had answered the above questions, I developed a range of policy options and then assessed them by using a set of criteria and measures; these are to be found in the following sections.

To answer the guiding questions, I performed a literature review, using a variety of sources. Government, industry and university websites provided a large amount of my quantitative data, particularly with respect to the level of funding, the criteria for receiving funding, and the kinds of R&D that are receiving the funding. Reports from reputable international organisations (such as the International Energy Agency and IPCC), foreign governments (e.g., the U.S. Department of Energy's National Energy Technology Laboratory) and foreign think-tanks provided my non-Canadian information. Critiques of Canadian R&D policy and programs were instrumental. To further inform my work, I made use of academic articles in economics journals that examine the theoretical issues relating to the effectiveness of R&D in addressing public goods problems such as climate change. I also attended a major international three-day conference (GLOBE 2012) that brought together senior government officials, industry leaders, academics and environmental non-governmental organisations to discuss the opportunities and difficulties facing the world as it aims towards (or at least attempts to aim towards) a more sustainable form of growth.

The second question required that I consider whether the common framing of CO_2 as a *waste* product artificially limited the opportunities for R&D funding to manage it. Information for that was sourced entirely from non-Canadian sources, as there is a poverty of domestic information on the matter. *Appendix A* contains a backgrounder on PCCM-a, the product of my research on that matter.

That second question also made me ask, as a preliminary exploration, *is enough being done?*, since it is not always the case that more of something is beneficial. To contend with this in as objective a manner as possible, I used Environment Canada's *Emissions Trends* (2011) document to find the most recent projections for national 2020 GHG emissions. While the report does not disaggregate GHGs by gas, the fact that CO_2 is the main GHG of concern, and is produced in the largest amounts (IPCC 2007: 36), indicates that the greater proportion of Canada's 2020 GHG emissions will be CO_2. *Canada's Emissions Trends* provides baseline scenarios involving no further federal actions (i.e., beyond those underway) to mitigate GHG emissions, and thus served as a metric for determining whether "enough" is being done. I also approached the problem of (in)sufficiency by accessing literature on path dependency (technological 'lock-in') in conjunction with academic assessments of the likelihood of future success with CCS, and then considering whether CCS will be sufficient to manage Canada's large point-source CO_2 levels, and what would happen if the technology is not as successful as hoped.

The last guiding question, concerning policy instruments, I researched via a literature review (e.g., economics articles on policy instruments related to R&D).

During the later phase of writing this Capstone, the Government of Canada delivered its 2012 budget. Due the release of a federally-convened expert panel on R&D under the auspices of Industry Canada in the fall of 2011 that had argued convincingly that Canada's R&D program suite requires rethinking and reorganising to improve the social returns on investment, an entire chapter of the budget was dedicated to R&D policy. The chapter contained initial announcements about changes, but added that further announcements over the course of the fiscal year and in the 2013 budget, should be expected (60). I have incorporated the announced changes where relevant, but have chosen not to speculate about the content of future updates the government may offer.

4. Contextualizing Private Sector R&D for Post-Capture Carbon Management Alternatives within the Federal R&D Framework

> As part of our plan for jobs and growth, our government has made very substantial investments in science and technology. Such investments are necessary to help sustain a modern, competitive economy. They encourage innovation–new ideas, which lead to new products and services, and ultimately to new, highly skilled, well-paying jobs. The key is to leverage private sector investment in research and development. In spite of our efforts so far, *Canada is not keeping up with other advanced economies on this crucial front*.
>
> (The Honourable Jim Flaherty, Minister of Finance, delivering Canada's 2012 federal budget. My emphasis)[18]

In *Section 2*, I outlined the meta-problem, climate change, and described Canada's 'contribution' to the problem and the need for national mitigation strategies, and showed that carbon dioxide (CO_2) comprises the majority of Canadian climate-forcing emissions. Since the problem of CO_2 emissions is so large, and as there are so many different sources of those emissions, I then selected a major driver of the problem – large point sources in the industrial and utility sectors – for the purpose of developing policy options to reduce their impact. I coined an expression, *post-capture carbon management* (PCCM) to cover all forms of CO_2 abatement technologies and techniques for dealing with CO_2 that can be captured rather than emitted, and showed how a set of externalities negatively impact the likelihood of private sector firms investing in research

[18] Full text of the budget delivery is available at: http://www.parl.gc.ca/HousePublications/Publication.aspx?Pub=hansard&Language=E&Mode=1&Parl=41&Ses=1&DocId=5488801&File=0#SOB-7213162. Accessed on 30 March, 2012.

and development (R&D) PCCM activities and, more narrowly, in PCCM alternatives (PCCM-a). These externalities, or market failures, merit government intervention, and I selected the federal government of Canada as the appropriate level from which a national strategy to incent private sector PCCM-a R&D could be developed. As the 2012 federal budget acknowledges, "Canada's private sector has historically lagged in terms of business investments in research relative to the size of our economy," and that "Canada's business sector has seen a declining trend over the last decade" (Ministry of Finance, 2012: 57).

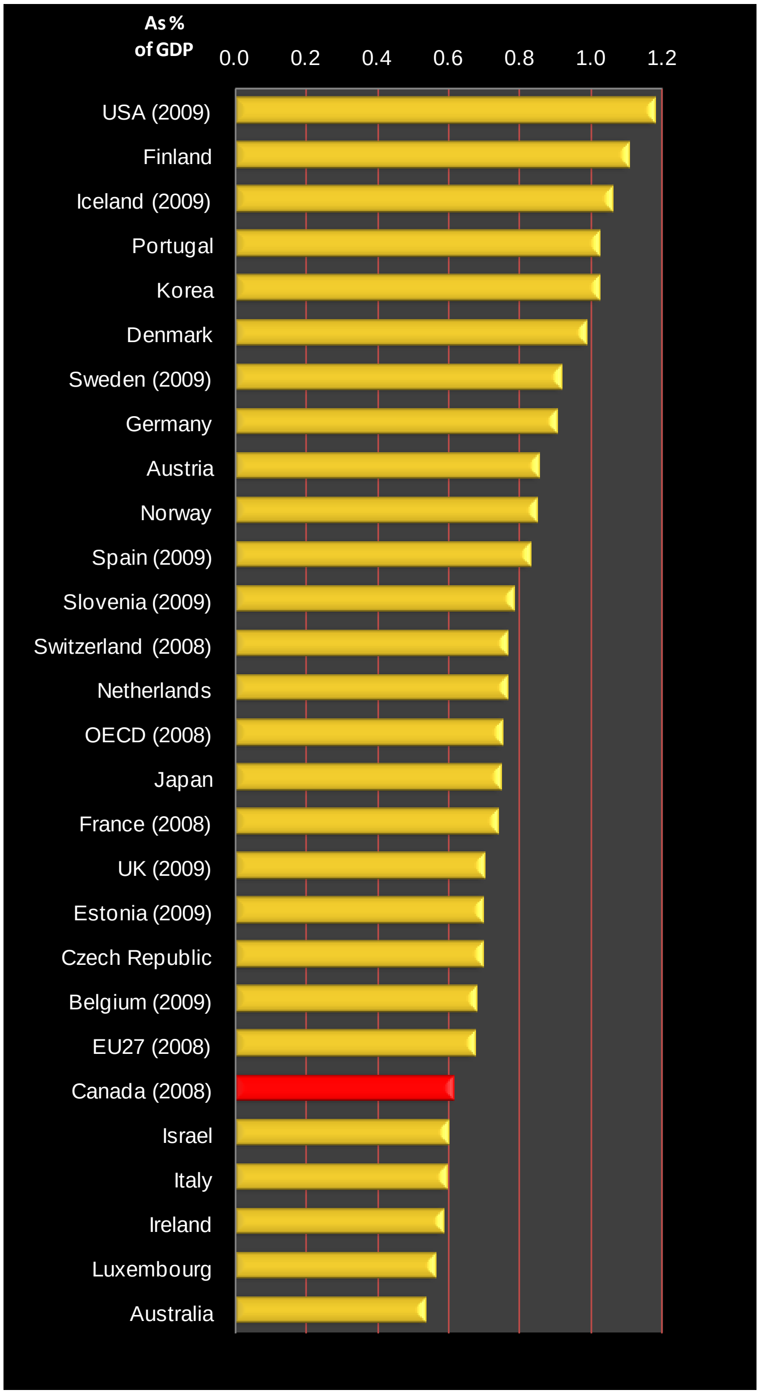
With these points in mind, I next examine the current general R&D situation in Canada, followed by a look at the major suite of programs available to the private sector. I discuss major critiques of the programs, and position the policy problem within the current policy environment.

4.1. Research and Development in Canada

> Businesses are doing too little research of their own and are failing to invest sufficiently in new, productivity-enhancing technology. Inventors who launch new companies find both venture capital and entrepreneurial expertise in short supply ... [Canada has] a business community with far too few innovative companies that qualify as global champions. (Coalition for Action on Innovation, 2010: 2)

With 0.61% of its 2008 GDP budgeted for R&D, Canada's federal budget outlays or appropriations for R&D were below the OECD average (*Figure 5, below*).

Figure 5. Government budget outlays or appropriations for select OECD countries, 2010



Data Source: OECD (2011) *OECD Science, Technology and Industry Scoreboard 2011*.
DOI: 10.1787/888932486659

There are two support mechanisms governments can employ to encourage private sector investment in R&D: direct support and indirect support. *Direct support* refers to loans, grants, and procurement; *indirect support* may include tax credits for R&D, R&D allowances, and lower taxes on R&D employee wages (Industry Canada 2011: 16).[19] The preferable type of support "is determined by the market or system failure being addressed and the type of R&D that the government wants to stimulate," where *system failures* denotes "the lack of coherence among institutions in an innovation system and in incentive structures" (16). In 2008, indirect support was about ten times higher than direct support in Canada (OECD 2010: web[20]). In a review of the main federal tax incentive program, the Scientific Research and Experimental Development tax credit (SR&ED), Parsons and Philips find a lack of empirical evidence to support a preference for one or the other of the support mechanisms. They also note that "there is some evidence suggesting that using direct and indirect assistance jointly may undermine their effectiveness" (2007: 34), so the federal discrepancy between the two may be intentional. In a later paper, Parsons draws attention to a more important problem:

> The rewards from R&D and other innovative activities are taxed, often at rates above many of Canada's international competitors, creating a disincentive to commercialize, develop and produce new products and services in Canada. This likely has a negative impact on the level of R&D and the amount of spillover benefits accruing to Canada. (2011: 13)

Funding for general R&D in Canada comes from six major sources: the private sector itself, federal and provincial governments, higher education institutions, private non-profit organisations and foreign investment. Federal policy can thus affect funding not only by determining who receives government assistance and by what mechanism, but also by determining some of the conditions that promote or discourage investment in

[19] The Industry Canada report *Innovation Canada: A Call to Action – Review of Federal Support to Research and Development – Expert Panel Report* is also known colloquially as *The Jenkins Report* and as *The Expert Panel Report*.

[20] Indirect support was 0.22% of GDP, while direct support was 0.022% of GDP. DOI: 10.1787/888932333006. Accessed on 21 March, 2012.

R&D by any of the six domains. The policy problem is thus a function of three major variables:

- The *policy recipients*
- The *policy programs*; and
- The *policy environment*.

Federal funding flows to three recipient sectors: the private sector (in 2009: $267 million), higher education ($2.8 billion), and the federal public sector (i.e., intramural R&D, at $2.6 billion) (Industry Canada 2011: 16). In 2009, the federal government funded 0.17% of the $16,146 million in total private sector expenditure on R&D; the vast majority of the remainder came from the private sector and from foreign investment (Science, Technology and Innovation Council, 2011: 14).

The private sector is the focus of this capstone, and is thus the recipient of interest. I consider the other two variables in greater detail below.

4.2. Current Policy Programs

There are over 100 federal programs and institutes operating to encourage R&D in Canada (Industry Canada 2011: 3-3). The key programs relevant to private sector post-capture carbon management (PCCM) innovation are described below, according to the kind of support (indirect or direct) that they provide. Following the program descriptions (4.2.1 to 4.2.2) and the relevant highlights of the most recent federal budget (4.2.3) in this section, I survey the available major critiques of federal R&D-incenting initiatives and consider whether the budget responds adequately to the concerns they raise (4.3).

4.2.1. Indirect Support

4.2.1.1. Scientific Research and Experimental Development Tax Credit (SR&ED)

Administered by the Canada Revenue Agency, the SR&ED is Canada's main R&D tax incentive program, and is the primary source of federal support for R&D in

Canada. It is a transfer from taxpayers to private firms that encourages investment in R&D by reducing firms' marginal costs. As a tax credit, it is a market-based approach that does not dictate exactly how firms engage in their R&D, though there are conditions that determine the kinds of firms and the projects that qualify for the tax credit (PCCM-a R&D would fit into the experimental development and applied research categories[21]). Canadian-controlled private corporations are permitted to claim an investment tax credit of "35% up to the first $3 million of qualified expenditures for SR&ED carried out in Canada, and 20% on any excess amount," and other kinds of Canadian business (e.g., partnerships and proprietorships) can claim an investment tax credit of 20% on qualifying expenditures (Canada Revenue Agency, web[22]). The SR&ED amounted to over $3 billion in 2009 (Department of Finance, 2010: 86).

4.2.2. Direct Support

4.2.2.1. Industrial Research Assistance Program (IRAP)

The IRAP is administered by the National Research Council of Canada (NRC), aimed at small and medium sized enterprises. The program assists with the development and commercialisation of technology by offering "expert technical and business advice, financial assistance, access to business information, contacts, and national and international networks," providing "customized solutions to some 10,000 SMEs annually."[23] IRAP funding for 2010-11 was $237.3m, but was much larger than previous years (2007-8 and 2008-9 budgets were each about $86m) due to support from the stimulus program (Industry Canada 2011: 3.8)

[21] *Experimental development* is R&D performed to "achieve technological advancement to create new materials, devices, products, or processes, or improve existing ones," and *applied research* is that which advances "scientific knowledge with a specific practical application in view" (see following footnote for source).

[22] Canada Revenue Agency. *Scientific Research and Experimental Development: About Our Program*. http://www.cra-arc.gc.ca/txcrdt/sred-rsde/bts-eng.html. Accessed on 20 Oct. 2011.

[23] National Research Council of Canada. *Benefits to Canadians*. http://www.nrc-cnrc.gc.ca/eng/ibp/irap/about/benefits.html. Accessed on 30 Nov. 2011.

4.2.2.2. ecoEnergy Innovation Initiative and Technology Initiative

Budgeted at $97m for 2011, the ecoEnergy Innovation Initiative exists "to support energy technology innovation to produce and use energy in a more clean and efficient way"[24].

The purpose of the ecoEnergy Technology Initiative is to assist in "the search for long-term solutions to reducing and eliminating air pollutants from energy production and use"[25]. Funding for this program has already been fully allocated. All five projects selected by NRCan are CCS, EOR or a combination of the two; no funds were allocated for CCU.[26]

4.2.2.3. Clean Energy Fund

NRCan's Clean Energy Fund was set up as part of the federal stimulus package to invest in "large-scale carbon capture and storage demonstration projects and smaller-scale demonstration projects of renewable and alternative energy technologies"[27] The fund, which is now fully allocated, made available $795m over a five-year period; in 2009, three CCS/EOR projects received $466m of that figure. Up to $146m will be divided among the eighteen smaller projects selected for funding; none of these are PCCM-a related.[28,29]

[24] Government of Canada. *ecoACTION*. http://ecoaction.gc.ca/ecoenergy-ecoenergie/technology-technologie-eng.cfm. Accessed on 3 Dec. 2011.

[25] Ibid.

[26] NRCan. *EcoENERGY Technology Initiative: Projects*. http://www.nrcan.gc.ca/energy/science/1335. Accessed on 3 Dec. 2011.

[27] NRCan. *Clean Energy Fund Program*. http://www.nrcan.gc.ca/energy/science/programs-funding/1482. Accessed on 30 Nov. 2011.

[28] Government of Canada. *Action Plan: Clean Energy Fund Program (Budget 2009 and Budget 2010)*. http://www.actionplan.gc.ca/initiatives/eng/index.asp?mode=7&initiativeID=122. Accessed on 20 Nov. 2011.

[29] NRCan. *Renewable Energy and Clean Energy Systems Demonstration Projects*. http://www.nrcan.gc.ca/energy/science/programs-funding/1514. Accessed on 20 Nov. 2011.

4.2.2.4. Sustainable Technology Development Canada (SDTC)

Sustainable Technology Development Canada (SDTC) is a not-for profit foundation established by the federal government in 2001. It funds and provides support for "the demonstration of clean technologies which provide solutions to issues of climate change, clean air, water quality and soil," and is mandated to "act as the primary catalyst in building a sustainable development technology infrastructure in Canada."[30]

The federal funding agreement for SDTC requires that SDTC put out a call for statements of interest (SOI) from interested parties wishing to develop new technologies that qualify under the program. The SOIs are then assessed, and those considered promising are asked to complete a full proposal containing a greater level of detail (e.g., explaining the work to be performed, expected end-users, environmental costs and benefits). The full proposals then undergo a business and technical evaluation, and those that pass are offered contracts (Robinson Research, 2009: 2)

SDTC has two funds: the $590m per year SD Tech Fund and the $500m per year NextGen Biofuels Fund.[31] Both address gaps that make moving from R&D to market entry difficult for many firms. The SD Tech fund aids projects in the late-development and pre-commercial phases, as there is a significant decrease in financing at these points. Next generation biofuels present a high level of risk to debt and equity financers (when compared with established technologies), making the high capital expenditure involved at the technology development and demonstration and the product commercialisation and market development stages a significant barrier for firms. The NextGen Biofuels Fund assists firms that have reached the pilot phase and are ready but unable to move beyond (in some cases, the SD Tech Fund will ready firms for this

[30] SDTC. *About SDTC: SDTC Profile*. http://www.sdtc.ca/index.php?page=sdtc-profile&hl=en_CA. Accessed on 4 Dec. 2011.

[31] Treasury Board of Canada Secretariat. *Reports on Plans and Priorities 2010-2011: Natural Resources Canada: Up-front Multi-year Funding*. N.d. http://www.tbs-sct.gc.ca/rpp/2010-2011/inst/rsn/st-ts02-eng.asp. Accessed on 8 Feb., 2012. Note: Environment Canada is a joint provider of this funding; totals reflect the combination of the two departments' contributions.

fund). While firms do not have to repay the SD Tech Fund financing they receive, the NextGen assistance "incorporates a requirement that all contractual agreements between SDTC and Eligible Recipients include repayment terms based on free cash flow over a period of 10 years after project completion."[32]

In a supplement to its 2010 annual report[33], SDTC details the forty-one projects completed to date. Of these, only one was focused on PCCM-a: CO_2 Solution Inc., which received $1 million in funding from SDTC, completed its "proprietary bio-technological platform for the efficient capture of carbon dioxide ... from power plants and other large stationary sources of emission" in 2006 (SDTC 2010: 40). Initially, the intent had been to use the captured CO_2 for mineralisation, but SDTC reports that the company, now renamed CO_2 Solutions Inc., has since changed its focus to capturing CO_2 for underground sequestration purposes.[34]

The only project related to PCCM-a currently funded by SDTC is a Menova Energy Inc. biofuel project. The goal is to develop and demonstrate a "Solar Concentrating Photo Bio-Reactor ... for sequestering CO_2 emissions from compressor stations (and other installations in the fossil fuel, power generation sector), and for the subsequent production of biofuels" (117). While SDTC supports much-needed cutting edge R&D in Canada, SDTC, therefore, it has yet to fund a project explicitly intended to fix captured CO_2 for mid- to long- term periods.

[32] SDTC. *Funding: About Our Funds*. http://www.sdtc.ca/index.php?page=about-our-funds&hl=en_CA. Accessed on 4 Dec., 2011.

[33] The 2011 report had not been made available to the public at the time of writing.

[34] Although no reason is given, my hypothesis is that the company found it easier to attract investors to a CCS-based project given the high level of government focus on the technique over the last few years.

4.2.3. Economic Action Plan 2012: R&D in the Latest Federal Budget

Table 1. Federal Budget 2012: Key Points for Private Sector PCCM-a R&D

• **$400 million to help increase private sector investments in early-stage risk capital, and to support the creation of large-scale venture capital funds led by the private sector.**
• **$100 million to the Business Development Bank of Canada to support its venture capital activities.**
• **$110 million per year to the National Research Council to double support to companies through the Industrial Research Assistance Program (IRAP).[35]**
• **$67 million in 2012–13 as the National Research Council refocuses on business-led, industry-relevant research.**
• **Streamline and improve the Scientific Research and Experimental Development tax incentive program (SR&ED).**

Adapted from: Ministry of Finance (2012) *Jobs, Growth and Long-Term Prosperity: Economic Action Plan 2012*. p 53.

On March 29, 2012, Finance Minister Jim Flaherty tabled the latest federal budget, *Jobs, Growth and Long-Term Prosperity: Economic Action Plan 2012*. The budget contained a section on R&D, largely a response to Industry Canada's 2011 assessment of the post-invention stages of innovation (R&D, demonstration, and diffusion via commercialisation) in Canada. The report offered a range of ideas for

[35] This item is not entirely "new" money – the 2011 budget had already promised $80 million over three years to the IRAP (Department of Finance, 2011: 145). It is also noteworthy that the $64 million announced for "clean energy technology and innovation" in that budget (109) for the following 2012/13 fiscal year is not mentioned in the actual 2012/12 budget.

improving and strengthening Canada's capacity in the field, and I have noted them where relevant in the following section, which is my assessment of the current programs affecting PCCM-a R&D. The budget provides for $1.1 billion for direct innovation support over the next five years, and $500 million in venture capital. Note that these measures are not specifically intended for PCCM-a R&D, but apply to the general process of innovation. *Table 1* (above) highlights the key points from the 2012 budget that are relevant to this paper.

One of the most positive aspects of this budget for PCCM-a is the two pools of venture capital being made available ($400 million plus the confirmation of an earlier pledge to give $100 million to the Business Development bank of Canada). This satisfies a major concern of critiques such as those from the Coalition for Action on Innovation (2010: 3-4) and Manning and Mintz (2012: 7-9). While this development – along with many of the other measures – will undoubtedly benefit R&D activities in Canada, the benefits will be divided among a wide range of innovation activities, making it impossible to tell ex ante whether PCCM-a R&D will be better off than before, as other demands for funding may continue to crowd it out. At least the new sources of venture capital give it a better chance.

Although I have chosen to focus strictly on R&D, support for other stages of innovation – such as commercialisation –may also be of benefit to PCCM-a, albeit indirectly, as investing in the early R&D stage will be less risky if the chances of commercialisation are improved. The budget contains provisions for the Canadian Innovation Commercialization Program to receive $95 million over three years (starting in 2012-14), with $40 million per year thereafter (53).

4.3. Program Assessments

Although available literature does not offer an assessment of these programs from either a PCCM-a or general PCCM perspective, there are a number of recent critiques that address the general effectiveness of Canada's main two R&D support programs, the SR&ED and the IRAP. Attention tends to be centred on the SR&ED, most likely due to its relatively large financial scale. Overall, Parsons found that even with “access to some of the world’s most generous R&D tax incentives,” businesses “spend relatively little on research and development” (2011: i). According to a Department of Finance analysis, Canada has one of the highest tax subsidy rates (defined as “the percentage reduction in the cost of R&D capital arising from tax incentives” (2009: 44)). In a comparison of the tax subsidy rates of thirty-six countries, Canada ranked third behind France and Spain with a rate of 30.2% (the median was 10.7%) (2009: 45). The problem, states Parsons, is that “the rewards generated by R&D and other innovative activities are taxed at rates above many countries, creating a disincentive to commercialize and develop new products and services in Canada” (2011: i).[36] An outcome of this is that some firms may opt to record expenses in Canada and profits in other countries that have lower tax rates; firms can use transfer pricing to shift funds to subsidiaries in the lower-tax countries.[37] One proposed policy for minimising this effect involves “exempting this income from Canadian tax or taxing it at a preferential rate, as is done (or is being considered) by certain countries” (Department of Finance. Advisory Panel on Canada’s System of International Taxation, 2008: 98 para. 8.16). The Coalition for Action on Innovation adds that the “current system of tax credits ... is inconsistently applied across industries and sizes of companies” (2010: 3).

Other than the SR&ED and IRAP, both of which have a high profile, the Innovation Canada expert panel found that the “current suite of [other R&D] programs to develop and deploy the talent needed to meet the needs of innovative businesses is a patchwork of largely subscale initiatives,” and that “adequate tools do not exist to comparatively assess relative program effectiveness” (Industry Canada 2011: E.8). Of the 60 programs that the panel reviewed, the SR&ED accounted for approximately seventy percent of the available R&D support (6.2). The panel also notes that the overwhelming number of small programs “virtually ensures that there will be little awareness among potential business sector beneficiaries of the many programs” (3.12).

[36] Canada’s corporate tax rates are becoming increasingly competitive, so the concern noted by Parsons may be less of a problem than when he was performing his research.

[37] Olewiler, Nancy. Personal communication. Also see: Department of Finance. Advisory Panel on Canada’s System of International Taxation, 2008: 86 para. 7.30-7.31.

4.3.1. SR&ED Assessments

Considering the costs and benefits of the SR&ED, Parsons found it provides a small net benefit to Canada, though not large enough to avoid the risk of it becoming a net cost (2011: 10). As a caveat, he notes that the results are highly dependent on the underlying assumptions – particularly those related to estimates of the R&D spillover effect[38] – and that even if there are net benefits, the program is not necessarily optimal (8). The Innovation Canada panel is more cautious, concluding that "the calculation of net benefit is not sufficiently precise at this time to permit a benefit-cost ranking of the government's business R&D support programs, not to fine-tune the mix between SR&ED and the portfolio of direct expenditures" (6.7). Finding ways to reduce the costs of R&D and/or increase the benefits would improve the likelihood of achieving net benefits; Parsons offers four broad options to achieve this, though does not go into detail about how to achieve the benefit-increasing suggestions (see *Table 2*). For decreasing the costs, Parsons sees progress both with respect to reducing the dependence on distortionary taxes (via the lowering of the federal corporate income tax rate and the adoption of the HST in Ontario), and to the reduction in compliance and administrative costs, though there is still much room for improvement there (12).

Table 2. Options to Increase the Net Benefit of Canadian R&D Tax Incentives

Increase Benefits	Decrease Costs
Increase the amount of R&D generated for every dollar of tax incentive	Decrease the cost of financing the tax subsidy – rely on the least distortionary taxes to raise revenue
Increase the spillover benefits associated with business R&D in Canada	Decrease compliance and administrative costs

Adapted from: Parsons, 2011: 11

[38] Key parameters that introduce uncertainty due to estimation error are (a) the additional R&D performed per dollar of tax credit, and (b) the social rate of return on business R&D expenditure (Industry Canada, 6.7)

The design of the SR&ED credit has unintended negative consequences. Even though small firms are favoured with a higher tax credit rate under the program as an attempt to make up for their lower capacity for accessing financing (35% credit on spending up to $3 million, versus a 20% credit for medium and large firms – the largest gap between the two in the OECD), there is a perverse incentive for small companies to inhibit their own growth, an effect that is detrimental to the economy. This problem arises because as a company expands, "it may lose its favoured status ... and face a significant increase in its tax burden. Indeed, simply moving from a qualifying small [firm] to a public or foreign-controlled company results in an immediate reduction in the eligible SR&ED credit rate" (Parsons 2011: 18). Parsons suggests that in addition to the expected decrease in corporate tax rates, the gap between the small / large tax credit rates should be reduced and made gradual rather than a simple jump from one rate to another when a firm increases in size (18-19).

The Innovation Canada expert panel took issue with the disproportionate reliance on the SR&ED to assist Canadian R&D. Concerned that "federal support for innovation may be overweighted toward subsidizing the cost of business R&D rather than other important aspects of innovation," they argue for a rebalancing of the "mix of direct and indirect funding by decreasing spending through the SR&ED program and directing the savings to complementary initiatives" (Industry Canada, 2011: E.10). Like Parsons, they consider the SR&ED to discourage firms from growing (E.10). Additionally, they find the administration and compliance costs to be too high for small firms (roughly fourteen percent of the value of earned credits, compared with around five percent for larger companies); and cite the "unpredictability about qualification," and the resultant need for firms "to resort to retaining consultants," as causing costs to outweigh much of the benefit of the program (6.8). The panel made five recommendations based on these problems, namely:

(1) Simplify compliance and administration;

(2) Make qualification more predictable;

(3) Improve cost effectiveness;

(4) Be more accountable (by providing performance data on a regular basis); and

(5) Phase the implementation of these changes in, and consult with the provinces (as most provinces offer SR&ED top-ups) (6.10).

In *Canada's Innovation Underperformance*, Creutzberg draws attention to the SR&ED's low ability to achieve the outcome for which it was created: "The fact remains that Canada has not sufficiently improved its business R&D performance over the nearly three decades that the federal government has maintained the SR&ED" (2011: 7). The Coalition for Action on Innovation (2010: 3) identified three major problems with the SR&ED:

- the lack of refundability except for enterprises that meet the narrow definition of 'Canadian-Controlled Private Corporations' (CCPCs) makes the credits useless to unprofitable, publicly traded companies;
- the definition of eligible research is restrictive and excludes much innovation-related investment; and
- the administration of the program by the Canada Revenue Agency is often adversarial and unpredictable.

A further criticism of the SR&ED is that a cottage industry of consultants has arisen in order to help R&D firms successfully obtain the credit. According to a recent Globe and Mail article, "Eligibility is overly complex, forcing many companies to rely on high-priced consultants – some of whom charge percentage-based "success fees" of up to 30 per cent" (McKenna, March 25, 2012). The 2012 federal budget reiterates that 30 per cent claim, adding "or even more" (71).

4.3.1.1. Federal Budget 2012: Modifications to the SR&ED

In response to the Innovation Canada expert panel report, the 2012 budget states an intent to "Streamline and improve the SR&ED," by "removing capital from the expenditure base, making it more cost-effective through design improvements and a measured rate reduction, and providing greater predictability through administrative improvements" (Department of Finance: 60). Although lacking in detail, these plans appear to satisfy (to some extent) the panel's recommendations 1-3 and possibly 5 (see

Section 4.3.1). The budget did not directly address the concerns of the Coalition for Action on Innovation listed above, only paying lip service to the Coalition's contention that the institutional attitude of the Canada Revenue Agency (CRA) makes accessing the SR&ED more complicated than needs be by determining that the CRA shall "Enhance the existing online self-assessment eligibility tool" (70). To reduce the scale of the siphoning-off of tax credit dollars by consultants, the budget "proposes to allow only 80 per cent of these contract payments to be used for the purposes of calculating the SR&ED tax credits" (70). In addition, a study of the contingency fees charged by consultants and tax-preparers was announced to better assess the matter. More details on the federal strategy are to be announced over the next year and in the next annual budget (60).

4.3.2. IRAP Assessments

From consultations, the Innovation Canada federal expert panel found the IRAP to be "widely regarded as an effective, well-run initiative that facilitates R&D and commercialization activity by small and medium-sized enterprises" (5.12). The panel's main recommendation was to "Increase IRAP's budget to enable it to build on its proven track record of facilitating innovation by SMEs throughout Canada" (5.13). The panel also recommended that IRAP, along with the other R&D and innovation programs, be consolidated into an arm's-length funding and delivery agency, the Industrial Research and Innovation Council in order to reduce overlap and simplify the overly-complex realm of federal innovation funding sources.

In an internal review of the IRAP[39], Natural Resources Canada's recommendation relevant to this study related to the decline in program reach: funding was being concentrated on a progressively smaller number of recipients. Whether that

[39] The review, *Impact Evaluation of the NRC Industrial Research Assistance Program (NRC-IRAP)*, examined the IRAP's performance from 2006-7, but is not dated properly on the web site. http://www.nrc-cnrc.gc.ca/eng/evaluation/evaluation-irap.html. Accessed on 16 Jan. 2011.

is still the case is not possible to determine as the next review is not expected to occur until 2013.

4.3.2.1. Federal Budget 2012: Modifications to the IRAP

The budget proposes an extra $110 million per year, commencing in 2012-13, to double support for firms via the IRAP. This, it is claimed, "will allow the National Research Council to support additional small and medium-sized businesses that create high-value jobs, and to expand the services provided to businesses" by the program (61).

4.3.3. Other Program Assessments

R&D program assessments tend to focus on the SR&ED and IRAP. Although the Innovation Canada expert panel also examined smaller programs, it did not include disaggregated assessments of them in its report. The panel's primary recommendation is that the federal government create a new body, the Industrial Research and Innovation Council, which would "enhance the impact of programs through consolidation and improved whole-of-government evaluation" (xii).

It is interesting that the budget, in responding directly to the Innovation Canada report, made no reference to the Industrial Research and Innovation Council for which the report had asked. It is possible that the administrative complexity of reorganising such a large number of programs for administration by a single agency was too great for the federal government to assess properly between the release of the report in late 2011 and the presentation of the 2012 budget in the following March. As I noted above, the government intends to release more details about its innovation strategy over the next year, so the panel's desired agency may still be an option on the table. An indication of this in the budget may be surmised from the discussion of the $67 million in 2012-12 to "support the National research Council in refocusing on business-led, industry-relevant research" that is "demand-driven ... consistent with the recommendations of the Expert Panel" (68).

Sustainable Development Technology Canada, according to Alex Wood of Sustainable Prosperity, is the one area of support for the green economy that the government has done well, and because of this, “there has been much interest from various countries looking to set up their own funding vehicles for clean technology to replicate the SDTC model.”[40] Wood notes his concern that the 2012 budget might not continue funding SDTC, which is running out of money; the budget does not mention the program at all. SDTC’s President and CEO Vicky Sharpe issued a cautious press release immediately after the budget, congratulating the government’s decision to better support innovation, without mentioning the significance of being omitted from the budget.[41]

SDTC is required to produce independent interim reports. Robinson Research found that the SD Tech Fund’s rationale is strongly supported, noting the “funding gap continues to exist and the evidence indicates the Fund does not displace private sector funding for projects” (2009:4). The report also commends SDTC’s continual process of self-improvement, indicated by an increase in the success rate of statements of interest and proposals, and by the reduced time taken to complete contracts (5). The difficulty in attaining outside financing for projects was also identified (5), but this may be less of an issue after the measures to rectify that problem included in the 2012 federal budget. Although subject to several caveats about methodology, the report’s extensive cost benefit analysis was positive, expecting significant net benefits over the next few decades. The report examined 25 projects, finding "net present value of the total quantifiable benefits from this set of projects will range from about $446 million to $1.1 billion, with a central estimate of about $750 million" (8). However, this is tempered by the next sentence: "While the projected benefits may seem very high, another perspective, comparison with Canada’s overall GHG emissions, may add context. The 25 projects reviewed are forecast to reduce Canada’s annual emissions of CO2 by less

[40] Alex Wood, Senior Director, Policy and Markets at Sustainable Prosperity. “Scrapping SDTC Would Be a Big Mistake.” 1 March, 2012. http://www.sustainableprosperity.ca/article1020. Accessed on 1 April, 2012.

[41] SDTC News Room. “SDTC CEO Comments on Federal Budget.” 29 March, 2012. http://www.sdtc.ca/index.php?mact=News,cntnt01,detail,0&cntnt01articleid=293&cntnt01origid=15&cntnt01detailtemplate=news-details&cntnt01returnid=143&hl=en_CA. Accessed on 1 April, 2012.

than 1%" (8). SDTC could clearly do more to encourage emissions-reduction technologies including PCCM and PCCM-a.

4.3.4. Key Points Distilled from Program Assessments

Canadian innovation policy is clearly neither as effective nor as efficient as it could be. It is certainly not terrible, but there is much room for improvement, and the 2012 budget appears to be a step in the right direction, at least in principle, but there is no guarantee that the funds are going to carbon capture alternative technologies. The current suite of programs, in conjunction with the way in which they are managed, has not been sufficient to encourage much R&D into PCCM-a technologies. In general, the critiques of the current program situation offer several key points relevant to the design of policy options for dealing with the PCCM-a problem I have identified as the inspiration for this paper:

- The current framework, involving a huge number of programs, most of which are dwarfed in size by the SR&ED and IRAP, is confusing and difficult for firms to navigate. Program overlap is also a result of the plethora of programs;
- Canadian businesses do not spend enough on research and development;
- The system promotes rent-seeking behaviour (e.g., by consultants), reducing the funds available for actual R&D;
- Rather than encouraging the growth of small Canadian R&D firms, the SR&ED creates a perverse incentive that may be influencing some of them to remain small enough to continue being eligible for the credit;
- SDTC's future is uncertain, and although it appears to be a strong program, it does not support enough R&D to reduce GHG emissions.

4.4. Policy Environment

Private sector activity is determined in part by the policy environment in which it occurs – for example, governments may intentionally constrain how firms operate, determine the kinds of goods and services they can provide, which ones receive funding or incentives, and by directing the economy (affecting inflation and exchange rates) may indirectly influence business investment decisions. Since uncertainty increases the risk of investment losses, firms often look to the government for signals that indicate policy directions. From these signals, firms can assess whether the business an investment opportunity stands to provide may soon become regulated, outlawed, or favoured above other competing substitutes, or whether any of these factors may be applied to complementary goods and services, indirectly affecting the value of the investment.

The current policy environment for businesses interested in PCCM-a R&D involves a high level of uncertainty. Overlapping and sometimes conflicting GHG policies exist at the provincial and federal levels of government, and as indicated in the Environment Canada paragraph at the head of *Section 2*, Canada is extremely unlikely to meet its Copenhagen commitment of reducing the national GHG output to 607 Mt by 2020 (it is projected to miss the target by 178 Mt), in part due to the policy emphasis placed on developing the oil sands in Alberta (EC. *Canada's Emissions Trends*, 2011: 19). Risk can earn a premium for investors, but the high degree of uncertainty involved in R&D for PCCM-a lowers the expectation of a satisfactory return when other less risky opportunities – that may have a similar expected return on investment – exist.

There are numerous ways governments can make such investment less risky – for example, by implementing and enforcing binding GHG regulations. Technology standards are clear signals, though economically inefficient.[42] Using a technology-pull policy such as carbon pricing (see *Sections 2.2* and *2.4*) would be a more effective clear signal as it enables businesses to determine the net difference between marginal benefits and marginal costs of emissions reduction more easily than would command-and-control style regulations. In fact, the Canadian energy sector and other high CO_2-emitting industries "overwhelmingly supports a price on carbon and [have] done so since 2006-2007," no longer "preferring voluntary measures and subsidies to a carbon price,"

[42] *Technology standards* (also called *design standards*) are policies that determine which kind of technology a firm must use to achieve a policy goal such as a maximum allowable level of emissions (e.g., retrofitting coal-fired electricity plants with scrubbers); these are particularly inefficient in situations of heterogeneous technology.

as "many industry associations and firms now value minimizing risk and policy uncertainty over pure cost minimization" (Sustainable Prosperity 2011:3). Signalling needs to be clear, or it can lead to a negative outcome: signalling an intent to regulate at some vague point in the future is insufficient, and may even make investment more risky, as it confirms that the current policy environment will be destabilised (i.e., the status quo will no longer prevail) without helpfully indicating *when*.

Another option - a technology push policy- is for a government to choose a winner, to focus assistance on one technology to the exclusion of others in the hope that it will succeed via the competitive advantage bestowed upon it. Picking winners, however, "can be a mug's game," as "within each industry, one does not know which firms will be 'stars' or 'dogs' – exceptional or poor – performers" (Manning and Mintz 2012: 2). CCS is clearly the chosen 'winner' in Canada, yet, as Canadian environmental economist Dr. Andrew Leach pointed out in a recent blog post:

> The Government has failed to address what I have called 4 hard truths about the implementation of CCS in Alberta. First, CCS is expensive and so the existing $2 billion CCS fund will only deliver, at best, 4Mt/yr of emissions reductions, getting us about 3% of the way to our long-term goal. Second, technological improvement does not mean that the average cost of new CCS projects will decrease over time. Third, there is only one exit strategy for the government from long-term CCS funding, and that is the implementation of more stringent GHG emissions policies. Finally, significant changes in energy markets suggest that CCS may no longer be the most cost-effective option for significant GHG emissions reductions in the province.[43]

Choosing a winner also has the inevitable effect of channelling potential funding away from other projects that are implicitly expected to be 'losers' in the long run. In a defence of direct subsidies, Creutzberg notes that while governments tend to pick winners by subsidizing the R&D for particular technologies (and thus distorting the market), a better

[43] Dr. Leach is talking directly about the Alberta government here, but the federal government also has a large stake in CCS being a winner. *Time to Come Clean on CCS*. 11 March, 2011. http://andrewleach.ca/canadian-climate-policy/time-to-come-clean-on-ccs/. Accessed on 14 March, 2012.

solution may be to select a *sector* rather than a technology to be the 'winner' (2011: 9). SDTC can thus be viewed as an attempt to address support for the sustainable development technology sector, but it is far too broad to deal effectively with any one problem, such as what to do with captured CO_2.

When researching federal signals for support of non-CCS/EOR PCCM, the only signal I was able to find was made at an international level. Canada is a member of the *Carbon Capture, <u>Use</u> and Storage Action Group*, (emphasis mine) which reports to the Clean Energy Ministerial, a high-level global body created to find ways to encourage policies and programs that encourage the development of clean energy technology. It is interesting to note, though, that in the literature produced by the Action Group to date, CCU is not included in the picture: the group's April 2011 recommendations to the Ministerial completely fails to address CCU, and tellingly states its purpose. "The Carbon Capture, Use and Storage (CCUS) Action Group was established to provide recommendations to the Clean Energy Ministerial (CEM) on concrete, near-term actions to accelerate global CCS deployment" (2011: 3).[44] Failing to mention or contend with a technological direction that is explicitly included in your own group's title does not suggest that they, or the federal government, have begun to take PCCM alternatives to CCS/EOR seriously yet. Failing to take an option seriously constitutes a tacit signal: investors beware!

[44] Carbon Capture, Use and Storage Action Group. *Recommendations to the Clean Energy Ministerial*. Apr. 2011. http://www.cleanenergyministerial.org/pdfs/CCUS_AG_Final_report.pdf. Accessed on 15 Feb. 2012.

5. Policy Options & Analysis

The issues that informed my policy problem, that **Canada lacks a sufficiently comprehensive strategy for encouraging private sector R&D into post-capture carbon management alternatives to CCS and EOR**, can be summarized in three key points:

i. *General issues*: these are the problems that apply to R&D in general, such as the knowledge, diffusion and network externalities;

ii. *PCCM-a issues*: the current federal R&D programs are not as effective as they need to be, because:

(a) There are too many programs;

(b) The programs are poorly targeted,

(c) PCCM policy is too narrow (i.e., rather than letting the market decide, the government appears to have chosen CCS and EOR as the 'winners', to the virtual exclusion of PCCM-a options), weak support in the post-R&D innovation chain (e.g., rewards for commercialization taxed too highly)

(d) The federal suite of R&D programs suffers from poor design; and

(e) There is weak support in the post-R&D innovation stages (e.g., rewards for commercialization are taxed too highly).

iii. *No federal carbon-pricing policies*: without a (sufficiently high) price on CO_2 emissions, there is little incentive for GHG-producing firms to invest in R&D to reduce their annual emissions.[45]

[45] Additionally, the poor integration with provincial GHG mitigation strategies likely reduces the effectiveness of the existent federal programs. Resolving this patchwork of federal / provincial GHG management strategies is beyond the scope of my current research.

5.1. Policy Options

The situation I have described presents decision-makers with a range of options. As is usually the case with policies, each has strengths and weaknesses that should be considered prior to selection for implementation. A policy is not usually judged on one factor alone, as policies involve making a series of tradeoffs, and to acknowledge this I offer a set of criteria with which to judge the policy options, along with measurements for assessing each policy's performance with respect to the individual criteria. Briefly, the policy options are as follows:

1) Maintain the status quo (*Section 5.1.1*);

2) Improve current R&D-incenting programs, without specifically targeting PCCM-a (*Section 5.1.2*);

3) Use a targeted approach to improve programs for PCCM-a R&D purposes (*Section 5.1.3*). This policy option is further subdivided to allow for (a) amending the current programs, and (b) creating a new program for PCCM-a R&D; and

4) Establish and maintain a technology fund from which qualifying firms wishing to perform PCCM-a R&D may draw (*Section 5.1.4*).

5.1.1. Maintain the Status Quo

The factors that currently discourage private sector firms from investing in PCCM-a R&D (such as knowledge, adoption and network externalities) are unlikely to disappear, making such investment risky for Canadian firms for the foreseeable future. Maintaining the status quo – continuing the government programs that do exist, without explicitly encouraging PCCM-a R&D – would enable Canadian R&D dollars to be spent on other worthy projects, while PCCM-a R&D may be performed abroad, at the expense of companies operating in nations that may have more funds available to promote R&D. Due to the aforementioned externalities, Canadian companies and Canada would stand to benefit from foreign work once any new technologies become available. If successful technologies are developed abroad that turn out to be capable of generating a profit, market forces will determine the degree and speed of adoption; Canadian firms may then have incentives for adapting, refining and improving those technologies.

5.1.2. Improve Current R&D-incenting Programs – without specifically targeting PCCM-a

Since there are a number of programs that have already been implemented in Canada to make performing non-specific R&D more attractive for the private sector, improving those programs could reduce the contentions that have been highlighted by several recent reports (see *Section 4.3*). The SR&ED and IRAP are the two major programs that could be improved upon. The SR&ED has been the more frequently and heavily criticized of the two, particularly with respect to program design, which currently encourages firms not to expand, and creates an opportunity for consultants to siphon-off large portions of the gains from the tax credits. By improving these programs, R&D activities may increase (all other things remaining equal) in all areas, some of which may be related to PCCM-a. The 2012 federal budget includes provisions for improving both the SR&ED and the IRAP, but details are currently minimal. SDTC, for which future funding is uncertain, could be reendowed, though as I have shown above, SDTC has not attracted non-biofuel PCCM-a R&D activities for inclusion in its portfolio. Key examples of changes that could have a positive effect include:

- Altering the SR&ED's eligibility requirements and / or its firm size-related tax credit levels to encourage small R&D firms to grow and to allow larger firms to benefit from R&D assistance (large firms may have a greater capacity to see R&D all the way through to commercialisation, so including them may increase the chances of some R&D success);
- Funds could be better distributed across the R&D programs, with reallocation to direct support programs achieved by providing fewer overall tax credits through the SR&ED (this would encourage greater competitive behaviour on the part of eligible firms);
- Commit to continue funding SDTC for at least the next five to ten years; and

- Acting on the Industry Canada expert panel's idea to create an Industrial Research and Innovation Council to aggregate and oversee the whole R&D program suite.

5.1.3. Use a Targeted Approach – to improve programs for PCCM-a R&D purposes

Targeting has the benefit of increasing the likelihood of R&D activity occurring in the PCCM-a field. There are two ways in which this policy option could be orchestrated: (a) current programs (particularly the SR&ED, IRAP and SDTC) could be amended to include particular incentives for PCCM-a R&D, or (b) a new program specific to PCCM-a could be created.

(a) Amending current programs with sections that are targeted toward PCCM-a R&D could reduce program/administration learning time for firms already familiar with the current version of the programs, as an amended program's main structure and rules would remain the same, and any pre-existing relationships developed between firms and the government agency overseeing the program(s) could continue. Creating a new PCCM-a program within SDTC could mirror the model already used by SDTC to channel funds into biofuels research.; If the government (i) continues to fund SDTC, and (ii) does not follow Industry Canada's expert panel recommendation that all R&D programs be folded into an Industrial Research and Innovation Council, then SDTC would be the logical forum for a targeted program. Using the already-established SDTC for this purpose would avoid the panel's too-many-programs critique. If using SDTC is not considered desirable due funding constraints, then funding via tax credits in the manner of SR&ED may be more feasible.

(b) Creating a new program from scratch would enable government to address specific issues related to PCCM-a (e.g., the 'winner' status given to CCS, or the high level of risk associated with investment) that might otherwise not be relevant in a general R&D program, and could thus reduce barriers experienced by firms that may be specifically interested in PCCM-a R&D. An advantage of this approach is that by keeping the incentives separate from the more general R&D programs, firms that have no interest in or capacity for PCCM-a R&D would be less likely to attempt to argue for special clauses to suit their own needs in the future, as may happen if current programs are amended. A side benefit of that would be that the impact of freeriders on the general R&D programs would not affect users of the targeted program. If the government decides to act on Innovation Canada's call to fold all innovation funding into a single Industrial Research and Innovation Council, funding will likely still be designated for particular activities, so the new program could exist within that framework.

As with version 'a' of this policy option, a new program would require a source of government funds, and offering tax credits and other tax incentives throughout the innovation chain may be easier to approve than creating new grants (though the latter should not be ruled out).

5.1.4. Establish and Maintain a Technology Fund – from which qualifying firms wishing to perform PCCM-a R&D may draw

A grant-based technology fund would require a flow of capital available for funding R&D projects. There are two ways such a fund could be established and maintained: it could (i) be allocated within a budget envelope in the federal budget, or (ii) be created and sustained by charging large point sources pollution fees for GHG emissions above an annual threshold. The two options are not mutually exclusive, and could thus work in tandem. Either way, that is a matter of how the program is funded.

(i) Creating a fund within the budget would be a way to subsidise the R&D via grants. Private sector firms that meet or exceed an established set of criteria designed to ensure that the R&D is in the PCCM-a field would be able to access the fund, which would need to be replenished annually.

(ii) Charging firms pollution fees (taxes) for emitting GHGs over a threshold would generate a revenue stream that could be used specifically for the technology fund. Sources emitting over 50 kilotonnes tonnes of GHGs each year are already required to report their emissions to Environment Canada under the *Greenhouse Gas Emissions Reporting Program*, so there is already a monitoring system in place (Environment Canada, 2010: 1). Excluding the voluntary reporting of emissions by firms operating below the threshold, 450 facilities reported exceeding the threshold; 56 of them each had GHG levels above 1,000 kilotonnes (i.e., 1 Mt), 244 emitted between 100 and 1,000 kilotonnes, and 150 between 50 and 99.9 kilotonnes (my calculations, based on Environment Canada's online data tables[46]).

The Government of Alberta currently employs a policy instrument of this nature to encourage its large point sources to reduce their annual GHG emissions. Facilities emitting above 100 kilotonnes per year are currently charged $15/tonne of excess GHGs, and have the option to direct the money to the *Climate Change and Emissions Management Fund* (they can otherwise choose to purchase Alberta-based offset credits, or buy or use emission performance credits)[47]. An advantage of using pollution fees as an instrument (rather than another existing tax) is that amounts collected need not go into general revenues, and may therefore be earmarked for specific initiatives such as a technology fund. A second advantage is that a pollution fee corrects distortions rather than creates them as do income, consumption, or other forms of taxation. Thus there is less deadweight loss to the economy.

The fund is managed by an independent arm's-length not-for-profit organisation, the Climate Change and Emissions Management Corporation (CCEMC). Alberta's model "appears to be working," according to the Conference Board of Canada, citing the fees collected and the fact that all compliance options are being used (2010: ii). Payments into the fund in 2007 and 2008 were expected to provide $120 million for clean technology investments in 2010, and are forecast to be in the area of $70 million/year in the long term (18). The fund accumulated $70 million in 2010, and will be "invested in projects and technology to reduce greenhouse gas emissions in Alberta."[48] Unfortunately, from a PCCM-a perspective, "most of Alberta's investment goes toward carbon capture and storage" (Conference Board of Canada: 28-9). A scan of CCEMC's

[46] Environment Canada's 2009 data is available at: http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=8044859A-1. Accessed on 4 Jan. 2012.

[47] Government of Alberta. *Greenhouse Gas Reduction Program*. http://environment.alberta.ca/01838.html. Accessed on 4 Jan. 2012.

[48] Government of Alberta. *2010 Greenhouse Gas Emission Reduction Program Results*. http://environment.alberta.ca/03501.html. Accessed on 4 Jan. 2012.

2010/11 *Annual Report* shows only one CO_2 utilisation project supported in 2010's funding Round One (Enerkem Inc. received $1.8 million towards a $5.46 million biofuel project), and none in 2011's Round Two and Round Three.[49]

The Conference Board of Canada (2010: 26) emphasises the benefits of tying a technology fund to other instruments to enhance its effectiveness:

> Technology investments are likely to be more effective when combined with other instruments. They improve the effectiveness of the policy instruments they are combined with. Technology funds provide a more focused approach than do broader technology investments and can, therefore, contribute more effectively. Linking the base revenues for technology funds to emissions provides a direct and useful link between the sources of emissions and potential solutions.

In addition to providing a source of revenue for PCCM-a R&D, a technology fund linked to a price on excess GHGs would motivate those affected to find ways to reduce their annual GHG outputs without dictating how they ought to go about doing so. Introducing flexibility into compliance options enables firms to determine the best market-based solution to the situation, allowing for greater economic efficiency (Keohane, Revesz and Stavins, 1998: 313-4; Hahn, 2000:378-80). While a technology fund could be made available to any firm engaging in PCCM-a R&D, in principle, it provides a greater incentive for the firms paying into the fund to perform that kind of R&D too, as they would be, in effect, recouping some of their money and putting it to a use that may lead to further GHG output reductions for them in the future.

Financing PCCM-a R&D by pricing supra-threshold GHGs may in some cases be a tax on consumers of the goods produced by the emitting firms. This can occur when the firm obliged to pay for excess emissions is unable to absorb the additional costs and can pass on those costs to the consumers of their products. Whether the firm can pass costs along depends on the state of its market (elasticities of demand in the market in

[49] CCEMC: *Projects Selected for 2010/2011 Funding*. http://ccemc.ca/annualreport/funded-projects.php#. Accessed on 5 April, 2012.

which it sells its output). For example, firms facing relatively elastic demand for goods or services due to high levels of international competition or substitute products at home may find passing compliance costs on to consumers results in a loss of business and to dominance of the market by foreign firms. In addition to a reduction in Canadian competitiveness (which may or may not be significant, depending on the share of GDP generated by the existence and operation of said firms); another concern is carbon leakage. While implementing a particular GHG policy in Canada may lead to a reduction in national GHGs and help Canada meet its target, the business responsible for the generation of those GHGs may shift abroad (the firm might relocate, or a foreign competitor might increase its production levels in order to supply Canadian markets with a lower-cost product than domestic producers are able to offer). Moving the source of GHGs does nothing to reduce the global level, and may in fact increase the amount of them and of other pollutants, as the foreign company may lack regulation entirely.

A consideration that ought to be mentioned – though it is beyond the scope of this analysis to attempt to solve – is that since Alberta already has a technology fund established as part of its climate mitigation strategy, a federal-provincial agreement will be necessary.

5.2. Criteria & Measures for Assessing Policy Options

For the purpose of determining the relative merits of the policy options detailed in *Section 5.1*, I grade the policy options by applying a number of criteria that are directly relevant to the problem statement. *Table 3* (below) lists the criteria I selected, offers a simple definition of each, and indicates the measurement system I use to assess each of them in relation to the individual policy options.

Table 3. Policy Criteria and Measures

Criterion	Definition	Measure (based on literature review)
Effectiveness	Ability of the policy to respond to PCCM-a problems outlined at start of *Section 5* (i.e., potential to stimulate private sector PCCM R&D alternatives to CCS & EOR). The '*possibility of improving post-R&D support?'* criterion asks whether the program could be designed to deal effectively with the common criticism that federal support is uneven across the innovation process. These issues will be assessed individually in a separate 'Effectiveness' table, then averaged for inclusion and comparison with the other criteria and measures.	*Individual assessments*: Yes / No *Possibility of improving post-R&D support?* Yes / No *Overall effectiveness*: High / Medium / Low
Administrative Feasibility	Degree to which the option requires new legislation, the creation of new programs, infrastructure or intergovernmental cooperation	High Medium Low
Political Viability	Expected level of political support from key stakeholders	High Medium Low
Minimises Direct Costs to Taxpayers	Taxpayer responsibility for providing funds. This is graded relative to the current costs associated with programs in operation.	High Medium Low

The qualitative measures *low*, *medium*, and *high* ascribed to criteria in the table relate specifically to the individual criterion in question: they do not offer comparative analysis between criteria. For example, for the *administrative feasibility* criterion, a high ranking would be positive, suggesting that it would be relatively simple to implement and administer, when compared another option that would be more administratively complicated.

The *effectiveness* of the options is determined by a pre-screening process. I do this by scoring five effectiveness-related criteria – such as the ability of the option to deal with the problem of the current program suite being too narrow – in a table, averaging the scores, and then inserting the result under *effectiveness* in the main assessment tables. Where helpful, I have included brief qualitative comments in the *effectiveness* tables. One problem highlighted in the program assessments earlier in this paper is that there are too many R&D programs, leading to a confusing array of programs. For this reason, I have included a criterion to indicate whether implementing the policy option under consideration would be likely to ameliorate that problem; note, however, that in some cases, adding a new program that targets PCCM-a R&D makes the problem moot, as firms interested in such research would no longer need to struggle with working out which aspects of which programs are available to support them. It does not reduce the too-many-programs issue for R&D in general, but that is not the focus of this paper.

When assessing the possibility of a policy to improve post-R&D support (also under the *effectiveness* criterion), I consider the *possibility*, rather than whether the policy would *actually* lead to an improvement. In other words, the criterion is judged according to whether it has the capacity to enhance any future policies –beyond the scope of this paper – directed at the later stages of the innovation process. For this reason, I weight the results of this effectiveness sub-criterion less heavily than the other sub-criteria.

5.3. Analysis

Note that in analysing the merits of the policy options under consideration, I acknowledge the relevant developments contained in the 2012 federal budget. Even though changes to the (e.g.) SR&ED have been announced and are intended to improve the program and mitigate some of the Industry Canada expert panel's concerns, details of *how* this will be done and the precise changes involved are not yet available, and thus I do not presume that they will necessarily be enacted or be effective. Additionally, since the government has stated that it will be rolling out more program changes over the fiscal year and in the next budget (Department of Finance, 2012: 60), but not confirmed what those changes entail, I do not engage in conjecture, and understand the baseline to be the status quo as it stands immediately after the 2012 budget delivery.

5.3.1. Maintain the Status Quo

Effectiveness (Does the policy option help ameliorate the following problems?)	
Too many R&D programs	No (sustains current levels)
PCCM -a not targeted	No
PCCM policy too narrow (i.e., CCS & EOR picked as 'winners')	No
Poor program design	No (doesn't incorporate important critiques)
Possibility of improving post-R&D support?	No
RESULT:	LOW

The ***effectiveness*** of maintaining the status quo is **low**. As explained in a previous section, there are too many barriers that discourage private sector investment in PCCM-a R&D in Canada. Without making performing this R&D more attractive for firms, Canada is unlikely to see a significant increase in such activity in the near future. This low rating applies even more strongly to CCS/EOR alternatives, and is further cemented by the fact that the funding for a number of current related R&D programs has been fully allocated, with no indication that they will be re-funded in the future.

Criteria	Effectiveness	Administrative Feasibility	Political Viability	Minimises Direct Costs to Taxpayers
Measurement	Low	Low	Medium – High	Medium

This policy option receives a **low** ranking under ***administrative feasibility***, as although it would require no additional effort on the part of the federal government, the large number of very small programs (over 100 – see *Section 4.2*) that exist to stimulate general R&D necessarily lack the economies of scale that would occur with a more co-ordinated effort, and in some cases overlap. With such a large number of programs, there is more than likely a significant amount of administrative overlap, presenting an unnecessary cost and fewer net dollars to be spent on R&D.

The ***political viability*** of doing nothing new is ranked **medium-high**, as it depends on the perspective from which it is judged. At a domestic level, Canadians concerned about climate change have not chosen PCCM-a R&D as a cause (and for the most part are probably unaware of it as an option, or CCU as a concept), and it therefore has little media attention or political traction: from the domestic perspective, political viability is high.[50] However, at the international level, Canada has been receiving heavy criticism for its GHG-reduction efforts, particularly on account of the oil sands activity in Alberta and for the federal government's recent decision not to renew Canada's Kyoto

[50] I make this claim based on personal empirical evidence (very few people who have asked me about this paper during its composition knew about CCU/PCCM-a beforehand), and on a late 2011 CCS-perception online survey of 1,548 Canadians conducted by Insightrix Research, Inc. on behalf of Carbon Management Canada. The survey found greater knowledge of CCS in provinces investing in the technology, but overall, only 14% of respondents knew what CCS is (margin of error: +/- 3% at a 95% confidence level). Since CCS is a far older and more established concept than CCU, it seems reasonable to extrapolate from this data that (far) fewer than 14% of Canadians are aware of CCU/PCCM-a. Survey data source: Canadian Newswire. *CCS Awareness Higher on Prairies than the Rest of Canada*. 8 Feb. 2012. http://www.newswire.ca/en/story/917991/ccs-awareness-higher-on-prairies-than-the-rest-of-canada. Accessed on 20 March, 2012.

commitments.[51] Since taking a leadership role in finding technological solutions to climate change could reduce some of the international criticism, the political viability of maintaining the status quo ranks medium (though not low, as there are not specific calls for Canada to take that kind of action).

The ability of this option to ***minimise direct costs to taxpayers*** would not change, so I have ranked this criterion **medium** due to the fact that current federally-funded R&D incentivising programs that provide tax credits are effectively subsidising the R&D that occurs under those programs. There would be no additional costs to taxpayers above and beyond those outlined in the current budget; however this criterion does not merit a high ranking as a number of the critiques I discussed in *Section 4.3* suggest that the status quo is not an optimal allocation of taxpayer dollars to R&D-encouraging programs.

Maintaining the status quo gives Canada the option to free-ride on other countries' R&D efforts. At the Globe 2012 conference held in Vancouver, BC in March 2012, James Rogers, the Chairman, President and CEO of Duke Energy, USA argued that it is more attractive to companies to invest their R&D dollars in China.[52] With a weaker environmental regulatory environment (than in North America) combined with support from the Chinese government and better opportunities for returns to scale due to a significantly larger population, China is becoming, Rogers noted, a hotbed of climate R&D activity. The research taking place in China costs the Canadian taxpayers nothing, though they stand to benefit from any important technological developments. Wouldn't it

[51] See, for example, (a) Tait, Carrie and Steven Chase. "Europe Labels Crude from Oil Sands Dirty Fuel." *Globe and Mail*. 4 Oct., 2011. http://www.theglobeandmail.com/report-on-business/international-news/european/europe-labels-crude-from-oil-sands-dirty-fuel/article2191203/. Accessed on 4 Feb., 2012. and (b) "Canada Under Fire Over Kyoto Protocol Exit" *BBC News*. 13 Dec., 2011. http://www.bbc.co.uk/news/world-us-canada-16165033. Accessed on 4 Feb., 2012.

[52] *Globe 2012: 12th Biennial Conference & Trade Fair on Business & the Environment*. Vancouver, BC, March 14-16, 2012. James Rodgers was a panel member for the session, *Energy Dialogue: Collaboration & Innovation for the 21st Century*, where he made these remarks.

be in Canada's interest to keep its PCCM-a R&D minimal and simply free-ride off the hard work of others?

At first glance, this seems like a smart and cheap policy option, albeit somewhat of a cynical one. Let others do the work and incur the costs of development and any concomitant mistakes, then benefit later. However, it fails to take into account the matter of risk. Maintaining the status quo based on the intent to free-ride makes the dangerous assumptions that the policy environment in other countries will not change and that private sector interests will not change either, China may be an ideal place for performing R&D today, but perhaps not tomorrow. Relinquishing control over the R&D by free-riding may be cost effective, but it is risky and myopic. It also diminishes Canada's potential to be a world leader on important matters such as climate change, and removes the possibility of Canadian companies owning the intellectual property rights to globally important technology.

5.3.2. Improve Current R&D-incenting programs – without specifically targeting PCCM-a [53]

Effectiveness (Does the policy option help ameliorate the following problems?)	
Too many R&D programs	No (sustains current levels)
PCCM -a not targeted	No
PCCM policy too narrow (i.e., CCS & EOR picked as 'winners')	No
Poor program design	Yes
Possibility of improving post-R&D support?	Yes (improvements could lay foundation for this)
RESULT:	LOW

[53] Note that improving current programs is here understood not to mean improving by combining them (for example, into an Industrial Research and Innovation Council, a recommendation of the Innovation Canada expert panel), but rather, improving the ones that currently exist as individual programs.

Making general improvements to the current R&D support programs (beyond the changes made in the 2012 budget) without providing specific incentives to focus on PCCM-a is ranked **low** for ***effectiveness*** as all other things remaining equal, companies that currently do R&D will likely be faced by the same set of trade-offs when deciding what kind of R&D to finance.[54] A 'better' program suite means it is also relatively better for the kind of non-PCCM R&D that they currently perform. There is a possibility that a better general R&D support program would encourage some firms that do not currently do PCCM-a R&D to get into the field, but there is no simple and reliable way to assess how likely that is (a survey would be useful, but would require knowing which firms are or have been interested in doing such R&D but have been unable to do so – and this is information that tends not to get published widely). Since CCS and EOR are the two popular PCCM streams, effectiveness is likely to be even lower when narrowing considerations to the alternatives field. Post-R&D support could be applied across the board under this option.

Criteria	Effectiveness	Administrative Feasibility	Political Viability	Minimises Direct Costs to Taxpayers
Measurement	Low	Medium	High	n/a

Administering a program that has already been implemented rather than creating an entirely new one reduces the burden on both the government and on any firms who are familiar with the program. Relationships that have developed between the two groups could be maintained. Depending on how extensive the changes are, there may be a need for the administrators to learn to navigate the updated program, but since the basic structure would remain (at a minimum), it should not be too cumbersome. ***Administrative feasibility*** is therefore ranked as **medium**.

[54] Improvements mentioned in *Section 5.1.2* include altering aspects of the SR&ED to promote growth of R&D firms by changing eligibility requirements, altering the funding distribution to reduce indirect support in favour of greater direct support, and committing to funding SDTC for an additional five to ten years, and creating an overarching federal R&D body.

The ***political viability*** of this option is **high**, as altering an R&D support program would have little effect on the public radar (unless it suddenly imposed a huge burden upon taxpayers), and would benefit companies that wish to make use of the improved program. The public would not perceive themselves as losing, and the private sector would benefit from the modifications.

Assessing whether the policy option ***minimises direct costs to taxpayers*** is not possible ex ante, hence the designation of **n/a** in the criterion cell. Increasing program budgets, all other things being equal, would be a greater expense to taxpayers – but simplifying the SR&ED while improving accountability, cost-effectiveness and predictability (recommendations from the Industry Canada report) could reduce medium to long-term direct program costs to taxpayers after the transaction costs associated with the program reformation are complete.

5.3.3. Use a Targeted Approach – to improve programs for PCCM-a R&D purposes

Two “versions” of this option were described in *Section 5.1.3*:

(a) Maintain current programs (particularly the SR&ED, IRAP, and SDTC) and amended them to include particular incentives for PCCM-a R&D, and
(b) Create a new program specifically to incent private sector PCCM-a R&D.

- I have scored these separately in the effectiveness tables below; all rankings are relative to the status quo. When compared in a matrix with the other policy options later, they will be considered as distinct options.

(a) Effectiveness of maintaining & amending current programs to target PCCM-a

Effectiveness (Does the policy option help ameliorate the following problems?)	
Too many R&D programs	No (sustains current levels)
PCCM -a not targeted	Yes
PCCM policy too narrow (i.e., CCS & EOR picked as 'winners')	Yes (creates a more even playing field)
Poor program design	No (inherits program design flaws)
Possibility of improving post-R&D support?	No (since that aspect remains unaltered)
RESULT:	**MEDIUM**

(b) Effectiveness of creating a new program specifically to incent private sector PCCM-a R&D

Effectiveness (Does the policy option help ameliorate the following problems?)	
Too many R&D programs	Yes[55]
PCCM -a not targeted	Yes
PCCM policy too narrow (i.e., CCS & EOR picked as 'winners')	Yes
Poor program design	Yes (past flaws may be avoided during program development)
Possibility of improving post-R&D support?	Yes (improvements could lay foundation for this)
RESULT:	**HIGH**

[55] I score this positively, as creating a well-promoted, targeted program for PCCM-a renders the problem moot.

(a) ***Maintain and amend current programs***:

Criteria	Effectiveness	Administrative Feasibility	Political Viability	Minimises Direct Costs to Taxpayers
Measurement	Medium	High	Medium	Medium

In favour of this option is the lower learning curve for firms to participate in currently-existing programs, as the underlying structural parameters of the programs would be similar. Businesses that already make use of available programs may be able to maintain their working relationships with administrators, and by targeting PCCM-a R&D, it would enhance the effectiveness of the current programs, which I have identified elsewhere as being insufficient in their present form. However, by working within the framework of a current program, the targeting aspect may be affected by the way the broader program is shaped by its overarching policy, and does not offer a better foundation for supporting the post-R&D innovation stages. For these reason, I ranked the ***effectiveness*** for version (a) **medium**.

The ***administrative feasibility*** receives a **high** ranking on account of two main factors: the potential for working relationships being maintained (as this is also beneficial to the administrators), and the existence of an overall program structure that would not have to be designed and learned from scratch.

The ***political viability*** of this option is **medium**, as it would be unlikely to upset any specific stakeholder groups, but would likely not generate much or any political capital either. There is a possibility of some non-PCCM-a sectors trying to argue that they too should be given a specially-tailored niche within an existing program, and there may be some contention over the equity of the program. .

If successful, adding a special PCCM-a section to a current program would cost taxpayers more than they currently contribute, as there would likely be greater industry interest in performing more of such R&D. Although such increased interest is not a bad thing (given that the aim of the policy is to generate exactly that), it does result in a **medium** ranking for the option – ***minimises direct costs to taxpayers***.

(b) *Create a new program specific to PCCM-a*

Criteria	Effectiveness	Administrative Feasibility	Political Viability	Minimises Direct Costs to Taxpayers
Measurement	High	Medium	High	Low

By creating a new program specific to PCCM-a R&D, the government would be sending a signal to the private sector that PCCM-a is important (and important enough to merit its own program); there is a feedback loop here in which raising the profile of a particular form of R&D would make it more attractive to investors, which in turn would lead to more R&D and thus make the field more viable, making it even more attractive and less risky. In particular, if the program designers learn from critiques of the programs that currently exist, many of the problems associated with those could be worked around from the outset, as there would be an absence of the bureaucratic inertia that tends to sediment over time with some well-established programs. It also offers an opportunity to support the whole pre-commercialisation innovation process. In terms of ***effectiveness***, version (b) of this policy option receives a **high** ranking.[56]

The ***administrative feasibility*** of this version would differ from the other because of the need to develop and implement a new program. This may involve new

[56] Note that a new program could be created under SDTC, using the NextGen Biofuels Fund as a model. The 2nd *Interim Evaluation Report* performed by Robinson Research indicates SDTC is a relatively healthy and well-functioning organisation (4-9), and thus bureaucratic problems such as unpredictability associated with the CRA's management of the SR&ED could be avoided (see Parsons 2011: 12).

staffing needs (though it is possible that some who already administer current programs could be assigned to the new one), and would certainly involve a higher learning curve for those running the program. A benefit for this criterion is that it would enable administrators to be more specialised and able to apply their skills and knowledge to a program with a relatively narrow scope (cf. the current broad programs), so after the initial learning curve has been overcome, administration could easily become more simple than for the broader programs. I have ranked this as **medium**.

The ***political viability*** of version (b) is **high**. It receives a superior ranking to the other version because it offers a gain in political capital: it is an attempt to stimulate business activity (particularly post successful R&D), and could be used as an example of the federal government taking climate change seriously. It is much easier to identify and promote the R&D that goes to PCCM-a when an entire program exists specifically to encourage it than when such R&D occurs within the framework of a larger program that has a generic name. Of course, with the implementation of a new program comes trade-offs: it is possible that other R&D stakeholders may contend that the program directs funding away from their particular interests. In order to maintain this high ranking, then, framing and timing would be key to minimize negative optics.

The criterion **–** ***minimises direct costs to taxpayers*** **–** ranks **low**. This policy option does not necessarily include ending other programs (a move that would certainly affect the political viability of the policy). In addition to program development costs and the possible administrative learning curve associated with early implementation, there would therefore be the cost of additional R&D support, which could be in the tens or hundreds of millions of dollars. Some of the cost of funding the program could be redirected from the programs that general PCCM R&D would have had to use in the past to reduce the financial impact to taxpayers, but that may not be sufficient to fund the entire program. Funding could also be sourced by earmarking a percentage of all future CCS investments to be put towards the PCCM-a program (or, amounting to the same outcome, by determining to match a percentage of future CCS investments with a contribution to PCCM-a research funding pots). Funding via tax credits would not require such large capital outlays, and would reduce direct costs to taxpayers significantly. However, since it is more prudent to be conservative in cost estimation, I will leave this criterion measured as high.

5.3.4. *Establish and Maintain a Technology Fund – from which qualifying firms wishing to perform PCCM-a R&D may draw*

Effectiveness (Does the policy option help ameliorate the following problems?)	
Too many R&D programs	Yes[57]
PCCM -a not targeted	Yes
PCCM policy too narrow (i.e., CCS & EOR picked as 'winners')	Yes
Poor program design	Yes (Should make use of best practices and experiences of other jurisdictions that have a climate change technology fund)
Possibility of improving post-R&D support?	Yes (A portion of the fund could be reserved for companies that make it beyond the R&D phase)
RESULT:	HIGH

A technology fund would act as a strong incentive for encouraging private sector firms to engage in PCCM R&D. It is a subsidy with specific conditions tied to its use. Firms that may otherwise opt to use their own R&D investment dollars for non-PCCM purposes would have a greater reason to use them for PCCM R&D if their investment could be topped-up by a flow from a technology fund. The Conference Board of Canada's 2010 study of the economic impact of climate-related technology investments had a favourable view of technology funds; the study noted that:

> An ongoing commitment of funds is essential because innovation and technology development should be viewed as an ongoing process rather than an event. Also, because it is difficult to predict both the results and expenditures that will eventually be required, an ongoing commitment to

[57] Again, I score this positively, as creating a well-promoted, targeted program for PCCM-a renders the problem moot.

invest based on project milestones and measured outcomes may be preferred to one-time or short-term programs. (22)

As this policy option specifies the technology fund would be maintained after its instantiation, the level of ***effectiveness*** is ranked **high**, on the condition that the funding be guaranteed for a sufficient period of time (e.g., five or ten years, with ten being preferable). Program objectives should be established at the outset, and to maintain accountability, independent program reviews should be performed periodically for the purpose of confirming that the objectives are being adequately pursued, and to bring the program back on track if those objectives are not being met. Leaving room for future new funding sources would benefit the program too (e.g., designing the program so that fees from a price on carbon, if implemented, could supplement or replace the initial funding source). By guaranteeing a minimum lifespan for the program, along with an option for the government of the day to renew it as it nears its end, a signal would be sent to industry to alleviate concerns about the possibility of the program being short-term and ineffective. As Robinson Research suggest in their review of SDTC, thought "should be given to specifying a date that would trigger consideration of future renewal at least two years in advance of the termination of the renewed agreement" (2009: 7).

Criteria	Effectiveness	Administrative Feasibility	Political Viability	Minimises Direct Costs to Taxpayers
Measurement	High	Medium – High	Medium	Medium

The ***administrative feasibility*** of a technology fund is **medium-high**. It may involve creating a body to manage it, but it could benefit from Alberta's experience technology fund experience, reducing the learning curve. Once mature, the program ought to be fairly simple to administer, as it would largely be a matter of assessing whether applicants meet a set of predefined criteria for receiving funding. An arm's-length not-for-profit such as SDTC or Alberta's CCEMC (perhaps even SDTC itself) would be an appropriate administrative body for the fund.

The ***political viability*** of this policy option is **medium**. While it would be popular with the potential funding recipients and potentially with the public, the politics surrounding the method for supplying the fund with a stream of capital could be challenging. If the source of the funding were to be – as in Alberta's case – large point source CO_2 emitters, then it would encourage the polluters themselves to engage in PCCM R&D, and offer them an opportunity to recoup some or all of their costs associated with their emissions.

To what degree the option ***minimises direct costs to taxpayers*** is also difficult to assess without knowing to what policy environment the implementation of the fund would be subject. Subsidies/grants would be a high direct cost (even though the social rate of return on the capital investment into PCCM-a R&D might reduce that impact). Conversely, a price on CO_2 emissions would make the fund a low direct cost to taxpayers (costs here might be close to the level of administration expenditures). Since there is currently no national price on carbon, this criterion is ranked high in the short run, but, given the increasing need to reduce national emissions, carbon pricing becomes more likely in the future (though admittedly, not certain). Given that the technology fund would need to be maintained over a long time period, I have ranked this option as **medium**, balancing short and long term funding source potential.

5.3.5. Comparative Criteria Matrix

Table 4. Comparative Criteria Matrix for Policy Options to Encourage PCCM-a R&D

Policy		Effectiveness	Administrative Feasibility	Political Viability	Minimises Direct Costs to Taxpayers
1: Status Quo	§5.3.1	Low	Low	Medium-high	Medium
2: Non-targeted program improvements	§5.3.2	Low	Medium	High	n/a
3: Target - Maintain and amend current programs	§5.3.3 a	Medium	High	Medium	Medium
4: Target - Create a new program specific to PCCM-a	§5.3.3 b	High	Medium	High	Low
5: Tech fund for PCCM-a	§5.3.4	High	Medium-high	Medium	Medium

Please refer to the next page for explanation of colour-coding and interpretation of results.

5.3.5.1. Comparative Criteria Matrix: Interpretation

In *Table 4* (above), I have generated a criteria matrix to aid comparison of the relative merits and weaknesses of the policy options, using a colour-coding system to facilitate interpretation. **Red** indicates a weak score, **grey** a neutral score, **grey-green** a slightly-above-neutral score, and **green** a positive score.

Options 1 and 2 do not fare well, particularly on the *effectiveness* front, and may now be eliminated from consideration. A limitation of criteria matrices in lieu of a non-subjective weighting system is that when policy options are close in measurement outcome value, one that appears slightly weaker than another may in actuality not be so. Options 3, 4 and 5 are all close in overall value; attempting to discern amongst them by ascribing points (positive=2, neutral 1, and weak 0, with 1.5 for slightly-above-neutral) results in a tie between 3 and 4 (five points each) and option 5 being favoured by just half a point (five-and-a-half points).

The proximity of these higher contenders demands a choice be made; since the intent of this Capstone is to improve the effectiveness of Canada's R&D policy so that it encourages PCCM-a R&D, I feel justified in giving the *effectiveness* scores slightly greater weight over the other criteria. This eliminates option 3; I discuss how to manage the similarly-scored options 4 and 5 in the next section.

6. Conclusion

The key findings of this research are that (i) Canada cannot afford to rely on CCS alone as a method for managing its CO_2 emissions; (ii) PCCM-a offers potential value-added assistance in reaching national climate targets; and that (iii) private sector firms face significant obstacles that discourage investment in PCCM-a R&D, indicating that (iv) there is a role for the federal government to play in encouraging such R&D and that (v) the current policy environment is insufficient to fulfill that need.

6.1. Recommendations

As they are so close in their scoring and since they are not mutually exclusive, **I recommend developing and implementing both policy options 4 and 5, but sequentially**. In fact, as option 4 – *Use a targeted approach to improve programs for PCCM-a R&D purposes* – could be developed and implemented in a shorter time frame than option 5, it could be used as the foundation for option 5. When option 5 (*Establish and maintain a technology fund from which qualifying firms wishing to perform PCCM-a R&D may draw*) becomes more politically feasible (for example, if and when a price on carbon is set nationally), the program would largely have already been established. With a functioning administration, private sector awareness of the availability of the funding source for PCCM-a R&D, application frameworks and criteria known, and professional relationships developed already existent, the transition would be more simple than implementing option 5 alone. Initial funding for option 4 could, as indicated in the analysis above, come from either tax credits or a special fund for grants. Though the latter is more difficult to justify in the current economic climate, CCS projects are receiving huge grants, and a percentage of funds for additional CCS projects could be redirected toward PCCM-a R&D.

The intent of my research was to alleviate Canada's lack of **a sufficiently comprehensive strategy for encouraging private sector R&D into post-capture carbon management alternatives to CCS and EOR**. Both options 4 and 5 are designed to ensure that post-capture carbon management alternatives to CCS and EOR are not crowded out of the picture. Making this explicit both within the general R&D program suite and within the broad PCCM suite (by giving political attention to PCCM-a) may also encourage private sector firms to explore R&D opportunities beyond the two most popular ones, and may ultimately benefit Canada, both economically and socially. Successful technologies could be exported, and make Canada a global leader in the mitigation of anthropogenic climate change.

6.1.1. Accountable Oversight

Having made my recommendation to implement policy options 4 and 5, two further issues require brief discussion: how to safeguard against generating path dependence, and how to ensure Canadian's money is being spent wisely on whatever PCCM and PCCM-a technologies receive funding. When hundreds of millions of taxpayer dollars are being funnelled in particular directions, the federal government has a responsibility to ensure that is making the best investments it can, given the information available at the time. It also needs a way to reassess decisions periodically in case new information or technology develops, and to ensure that future options are not constrained unnecessarily by contemporary decisions.

Path dependence, or technological lock-in, was raised as an issue in *Section 2.2.2*. At that stage I raised the matter in order to alert readers to the fact that the huge investments in CCS and EOR are crowding-out alternative options such as PCCM-a. Since I argue that path dependence ought to be avoided as best as possible, I have had to reflect on my own policy recommendations to ensure that they do not perpetuate the problem. I maintain that focusing on a suite of PCCM technology options reduces the problem of governments picking winners, as it spreads the risk of failure across multiple technology avenues. PCCM-a is not restricted to a single technological direction, and offers a number of CO_2 uses that could be pursued simultaneously (including, but not limited to use as a chemical feedstock, for mineralisation and for algae production). While a discussion of implementation is beyond the scope of this paper, there is the question of who (or what body) should make decisions about such large expenditures on Canadians' behalf. Although the final decision of such matters falls to our elected politicians, they would do well to make decisions based on the considered opinions of experts. A panel of experts from key stakeholder groups (including bureaucrats, academics, scientists, engineers, and industry leaders) would be able to make informed recommendations, and if convened for that task, ought to do so as transparently as possible.

While an expert panel could help make higher-quality decisions than those that are being made federally at present, the process needs a reliable level of oversight. A technology fund could be managed by an arm's-length not-for-profit organisation along the lines of Sustainable Technology Development Canada, so long as its decisions undergo periodic review by a highly accountable body. With such large amounts of money at stake, this could be performed by the Office of the Auditor General of Canada (OAG), which has an environment and sustainable development mandate. The Commissioner of the Environment and Sustainable Development operates on behalf of the OAG to provide "parliamentarians with objective, independent analysis and recommendations on the federal government's efforts to protect the environment and foster sustainable development," and would therefore be ideal.[58]

A first step to ensuring that we do not get locked in to CCS or EOR would be for the Commissioner to perform a full performance audit (also called a value-for-money audit) of Canada's CCS and EOR technology investments to date, taking into account the costs and expected benefits of the projects that are underway, and paying special attention to the cost per tonne of CO_2 that will be reduced by each project.[59] If tasked

[58] Office of the Auditor General of Canada. Commissioner of the Environment and Sustainable Development. http://www.oag-bvg.gc.ca/internet/English/ cesd_fs_e_921.html. Accessed on 21 April, 2012.

[59] A *performance audit* asks, "Are programs being run with due regard for economy, efficiency, and environmental impact? Does the government have the means in place to measure their effectiveness?" Office of the Auditor General of Canada. *Performance Audits*. http://www.oag-bvg.gc.ca/internet/English/au_fs_e_9365.html. Accessed on 23 April, 2012.

with a performance audit, the Commissioner would also be responsible for reviewing the procedures used to select which projects receive funding.

6.2. Further Considerations

- Given that the Government of Canada has made clear (in the 2012 budget) its intention to alter its R&D policy over the course of the next two years, but has not revealed many of the details, it will be necessary to consider whether those changes, when made official, support or discourage increased PCCM-a R&D, and whether they affect my recommended policy options.
- A national carbon price would be an excellent source of funds for PCCM-a R&D.
- Exempting or reducing intellectual property-related income may further encourage general R&D in Canada; doing so for PCCM-a R&D could make it more attractive, though by how much is unclear.

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Appendices

Appendix A.

"Make Haste, Not Waste": Backgrounder on Post-Capture Carbon Management Alternatives (PCCM-a)

Carbon dioxide (CO_2) is generally viewed as a waste product, and therefore removing it from combustion waste streams for the purpose of dumping it permanently underground (that being the intent of carbon capture and sequestration, CCS) is viewed as an inconvenient cost to large point source emitters. Other than its use in enhanced oil recovery (EOR), which has a limited CO_2 consumption capacity and often is non-permanent, CO_2 has largely been ignored as a factor input to production. This may be attributed to the nature of CO_2, which is "considered to be a thermodynamically and chemically stable molecule under standard conditions" (Styring et al. 2011: 4), thus making it difficult (i.e., costly) to react with other chemicals to produce goods (the stability of CO_2 is also a reason for its persistence in the atmosphere). The main current applications are listed in *Table 5* below. With CO_2 fixation periods ranging from days to centuries, some applications are clearly more beneficial for the purpose of climate change mitigation than others. Some of the listed applications make use of naturally occurring CO_2 wells, and others use CO_2 from CO_2 production processes developed before capturing CO_2 from industrial sources became a necessity in regions that have introduced CO_2 emissions regulations (IPCC 2005: 332).

Table A. Examples of Current Industrial Uses for CO_2

Chemical product class or application	Annual global market (Mt yr)	Quantity of CO_2 consumed per Mt product (Mt CO_2)	CO_2 source	Fixation period
Urea	**90**	65	Industrial	Six months
Methanol	**24**	<8	Industrial	Six months
Inorganic carbonates	**8**	3	Industrial, Natural	Decades to centuries
Organic carbonates	**2.6**	0.2	Industrial, Natural	Decades to centuries
Polyurethanes	**10**	<10	Industrial, Natural	Decades to centuries
Technological	**10**	10	Industrial, Natural	Days to years
Food	**8**	8	Industrial, Natural	Months to years

Notes:
(a) Natural sources include fermentation and geological wells.
(b) Fixation period indicates duration between creation and degradation of product (i.e., time period before the fixed CO_2 enters the atmosphere).
(c) There is a high level of uncertainty associated with the figures in this table; however it is indicative of available uses.

Adapted from: IPCC 2005: 332

This difficulties associated with making CO_2 more widely useful have not yet been resolved, but that does not mean they cannot be. The main challenge is the energy penalty associated with using CO_2 – that is, the amount of energy necessary to synthesise something usable from the gas either negates the benefits associated with using it, or adds too much to the cost of production to be considered worthwhile. Pricing carbon emissions would certainly make PCCM-a more economically feasible than it currently is, and would encourage greater innovation in the field. Carbon pricing, while an environmentally sensible policy option, is often met with resistance by negatively affected stakeholder groups (such as industrial sectors that include large point sources) and is, at present, frequently not considered politically popular enough by politicians to implement in many regions or countries. In lieu of sufficient carbon pricing policies, the development of PCCM-a requires finding other ways to encourage research and development (R&D) in the field.

There are currently three major potential applications for PCCM-a, assuming the cost of employing it can be reduced to the point where it is attractive enough to producers. Carbon dioxide can be used:

- for the production of algae;
- as a chemical feedstock; and
- for the carbonation of minerals. (IPCC 2005: 277-319)

Most of the applications possible under these three options are in the R&D phase, and have their respective advantages and disadvantages. Continued R&D is important, as it will assist in finding ways to reduce both the aforementioned energy penalty and the disadvantages particular to each of the three uses.

The production of algae is perhaps the most intuitive option: green plant life consumes CO_2 in order to assist with photosynthesis. Microalgae production can generate a greater quantity of biomass-per-area than most commercially produced crops, and can occur on land that normally could not sustain agriculture (including salty areas); the algae itself can be used for the production of food, fertilisers, bio-oils/fuels and proteins, and chemical feedstocks (Styring et al., 2011: 35). Large scale production is not yet competitive, mainly due to the large amount of energy needed to grow and process the algae, and to high production costs (35): R&D could decrease these problems. In Canada, the federal government is funding public sector research in this field via the National Research Council, which considers algal biofuels as "ideal for biofuel because they are not a food source, they don't need agricultural land and they can produce up to twenty times more oil than traditional biofuel crops like corn".[60] A major drawback of biofuels as a climate change mitigation option is that as soon as biofuels are combusted, the CO_2 that had been fixed by the algae is released into the atmosphere (Global CCS Institute, Mar. 2011: 39). For this reason, I am of the opinion that biofuel production ought *not* to be considered a climate change mitigation option, though it may nevertheless be a superior option to the extraction, transport and combustion of fossil fuels for a number of other reasons.

[60] National research Council Canada. *NRC Drives Strategy to Commercialize Mass Production of Biofuel from Algae*. 4 June, 2010. http://www.nrc-cnrc.gc.ca/eng/multimedia-releases/biofuels.html. Accessed 18 Feb., 2012.

As a chemical feedstock, CO_2 can be reacted with other compounds to produce synthetic liquid fuels, act as a substitute or replacement for petrochemical intermediaries in the chemical industry, be polymerised into polycarbonates (high-strength lightweight impact-resistant compounds that can be used as a glass substitute, and for body armour) and polyurethanes (bulk plastics) (Styring et al.: 17-21). As with algae-based biofuels, the synthetic fuels in this section would emit CO_2 when combusted (for example, when synthetic diesel is used to power an automobile). The high energy penalty associated with making synthetic fuel is due to the fact that as a byproduct of fuel combustion, the CO_2 needs to be converted back up to a higher energy form to be of use. Although this seems to detract from the conceptual benefit of using it to produce synthetic fuels, these fuels could be used for energy storage, as an energy vector. A common problem with some renewable energy sources – particularly wind power – is that when the wind produces power in off-peak periods, it cannot be stored. Using reforming reactions, locally-stored CO_2 could be turned into synthetic fuels using the excess energy produced by the wind turbines, and those fuels could then be combusted when peak demand is not able to be met by renewables (Styring et al.:18). The CO_2 would be emitted, creating no direct net benefit but in areas where excess energy demand might otherwise be met by fossil fuel combustion, no *new* or additional CO_2 would be produced and emitted in supplying that power using biofuels. Therefore, as an energy vector, CO_2-based synthetic fuels could assist in climate change mitigation, and make renewables such as wind power more financially attractive.

Mineral carbonisation offers the most long-term method for removing CO_2 from the cycle, and is "considered suitable for hundreds to thousands of years" (Global CCS Institute, Mar. 2011: 39). Some applications of mineralisation are PCCM-a, but one, which results in the disposal of mineralised CO_2 is a kind of carbon capture and utilisation (CCU), and is certainly worthy of continued research. Reacting CO_2 with alkaline and alkaline-earth minerals (e.g., magnesium oxide and calcium oxide, which become magnesium carbonate and calcium carbonate, limestone, respectively) fixes the CO_2 into products that can be used in construction, in mine reclamation, or can simply be disposed in, for example, abandoned quarries. Disposal removes the value-adding benefit of many of the other CCU opportunities, but it has significant advantages over the other major disposal option, CCS. CCS requires costly regulation and monitoring, for hundreds or thousands of years (since the intent is to keep the CO_2 sequestered for that long), and is vulnerable to leaks if not managed correctly, or from unforeseeable events in the future such as earthquakes or warfare. Carbonising minerals and disposing the product would not require monitoring of disposal sites, and regulation would likely be minimal (perhaps only relating to where disposal may be permitted). According to Lackner et al., the amount of available minerals is "sufficient to allow utilization of the large known fossil-fuel reserves while avoiding build-up of atmospheric CO_2" (1995: 1153). Mineral carbonisation produces an exothermic reaction (IPCC: 321), which may help reduce the energy penalty currently involved in the process if that heat can be captured for reuse either in the process itself, or for other purposes. It is also of potential use in situations where capturing the CO_2 from a waste stream is prohibitively expensive (for example, in cement manufacture), as carbonisation can be performed directly with flue gases, bypassing the need to capture the CO_2 (Styring et al.: 12). Steel converter slag and asbestos can also be converted into carbonates, potentially adding value (though asbestos may not be completely converted, posing a possible safety risk) (ibid).

There are two main challenges for mineral carbonisation. The first is the sheer mass of mineral needed (which in most cases would have to be mined), which creates extraction impacts and transportation problems along with their associated energy penalties. The second is that the minerals need to be processed, as surface area needs to be maximised by crushing the minerals to improve reaction potential. Styring et al. state that it takes between 1.6 and 3.7 tonnes of minerals to fix a tonne of CO_2, and that storage efficiency would be under 70% due to the factors just mentioned (13). The first problem is easier to work around – rather than transporting minerals for processing, the CO_2 could be piped to areas rich in those minerals for processing on site, and any value-added processed minerals could then be transported, as minerals normally would be.

The three main streams of current PCCM-a research should not be considered the only potential options for using waste CO_2, as more uses may be discovered as research continues. Firms in some other countries are already exploring multiple options and developing novel applications. In Australia, for example, MBD Energy Ltd. is growing algae using CO_2 from LFEs. MBD Energy's Algal Synthesis project "occurs in large fully enclosed plastic membranes containing nutrient-rich waste water exposed to sunlight. Piped waste CO2 is continuously fed to the algae causing the biomass to double every 24 to 48 hours," and the resultant algae is available for use "for a variety of commercial purposes including feedstock for biofuels, animal feed and fertilisers."[61] MDB Energy's research is encouraged by the Australian government's progressive decision to impose a carbon tax and emissions trading program on LFEs mid-2012. This is an excellent example of how creating an environmentally beneficial policy environment can create new business opportunities: legislated economic pressure to reduce CO_2 emissions can potentially generate new industries and put a country at the cutting edge of technology research and development. Unless the world actually officially gives up on reducing CO_2 emissions, these technologies and techniques will be developed and will become profitable – the question is, where will that business be based?

The key points to derive from the PCCM-a options are:

- There is an opportunity to generate revenues from the CO_2 which would otherwise be a waste product.
- There is an associated opportunity for the creation of new industries.
- Some elements of the private sector stand to benefit from CCU in the future.
- Most of the potential uses are still in the R&D phase.
- Significant investment is required to complete the R&D phase and move into demonstration and commercialisation.
- There is currently a high energy penalty associated with turning CO_2 into a useful product.
- Not all LFE CO_2 sources are equal: some industries separate CO_2 as a part of their production process and thus the cost is already a part of the product price (e.g., at natural gas processing plants), but others do not need to do so in order to make a marketable product, and capture techniques are more expensive.[62]
- The capture problem is not unique to CCU, as CCS and EOR both necessitate capturing CO_2 too. PCCM-a can therefore both piggy-back on the capture R&D currently underway for CCS and EOR purposes, and, as noted above, be used in lieu of sufficient capture technologies in cases where flue streams containing CO_2 in their mix would be sufficient to generate the desired chemical reactions.

61 MBD Energy Limited. http://www.mbdenergy.com/co2_solutions.php. 22 Feb, 2012.

62 This also presents the shale gas industry with an opportunity to improve its public image. The shale gas industry, which is in its infancy, has been receiving constant media attention recently on account of its perceived environmental impacts (many of which have not yet been adequately researched). Finding an application for the CO_2 that is separated at the processing plants could help to give the industry better environmental credibility.

- PCCM-a is not likely to replace CCS and EOR in the near-to-mid-term, but could assist in the mitigation of climate change. Together, the three comprise what I have called *post-capture carbon management (PCCM)*. Considering them in isolation from each other limits opportunities for removing as much CO_2 as possible from large point source waste streams, and ignores the potential economic benefits doing so could provide in the future.