Governing Carbon Removal: Deploying Direct Air Capture Amidst Canada's Energy Transition

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Carbon dioxide removal (CDR) technologies, such as direct air carbon capture and storage (DACCS), will be critical in limiting the rise of the global temperature over the next century. Compared to other forms of CDR, DACCS requires little land and carries fewer environmental risks. Still, scaling up DACCS technologies requires the support of a complex array of policies and infrastructure across multiple overlapping policy areas, such as climate, energy, technology innovation and natural resource management. DACCS policies will be built on the foundations of existing policies in these areas and will be influenced by the structure and content of this policy landscape. While the literature on DACCS and other CDR technologies acknowledges the path-dependent nature of policy development, it has tended to focus on abstract policy prescriptions that are not rooted in the specific political, social and physical (infrastructural) context of the implementing state. This thesis addresses this deficit by identifying the key policy foundations for developing and deploying DACCS at scale in Canada. Drawing on socio-technical transitions theory, particularly the multi-level perspective, I identify the constituent policy areas that are likely to form the future DACCS policy regime. The purpose of this policy review and analysis is to show that the policies used to deploy DACCS will need to address systemic issues of social acceptability; financing climate mitigation innovations; energy system and resource constraints; coordinating and regulating carbon storage and transport; and establishing general climate policies that support the role of DACCS in the transition process. Using a database of Canadian climate policies (n=457), I populate these key policy areas with existing policies, which enables me to map and analyze the emergent DACCS policy landscape in Canada. The growing body of literature on the policies needed for scaling up DACCS provides a basis for analyzing the adequacy of Canada's current policies while creating system maps has allowed me to identify the potential trajectories of the system by identifying potential niches and broader landscape influences within the system, as well as identifying gaps and potential barriers to the system transition process. This thesis contributes to our understanding of national-level DAC policy development by providing a framework for identifying components of the DAC system and linking those components to desired policy outcomes.

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Lastly, I thank my family and friends for their patience in listening to me while I talked out my ideas and for their support.

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List of Abbreviations

Abbreviation	Meaning
ACTL	Alberta Carbon Trunk Line
A/R	afforestation/reforestation
BECCS	bioenergy with carbon capture and storage
CCS	carbon capture and storage
CDR	carbon dioxide removal
DAC	direct air capture
DACCS	direct air carbon capture and storage
ECCC	Environment and Climate Change Canada
HTA	hard-to-abate
ICCSKC	International CCS Knowledge Centre
IPCC	Intergovernmental Panel on Climate Change
ISED	Innovation, Science And Economic Development Canada
ITC	investment tax credit
LULUCF	land use, land-use change and forestry
MLP	Multi-Level Perspective
NET	negative emissions technology
NRCan	Natural Resources Canada
OPBS	output-based pricing system

1. Introduction

With goals of achieving net-zero emissions by 2050, historically high-emitting countries like Canada are in the process of determining what policy measures can best fulfill their responsibility to incentivize innovation and the development of new methods to reduce their annual carbon dioxide emissions (Asayama, 2021; Fyson et al., 2020; Pozo et al., 2020). The IPCC's 2018 special report on the world's current emission pathways was their first significant signal of how critical net-negative emissions are for ensuring successful climate mitigation over the next century (IPCC, 2018). Although the report cautions states against over-relying on carbon dioxide removal (CDR) (as opposed to emissions reductions) to meet national climate goals, all of the IPCC's pathways that limit global warming to 1.5°C or lower involve the large-scale deployment of CDR (IPCC, 2018; Gasser, 2015; Realmonte et al., 2019).

While nature-based CDR will play a significant role in drawing down atmospheric carbon, the anticipated scale of CDR over the remainder of the century will be anywhere from 100 to 1000 gigatonnes of CO_2 (IPCC, 2018; Ritchie & Roser, 2020). It is unlikely that Earth's ecosystems have the capacity to support removal at such a scale, while nature-based means of storing carbon themselves lack the resilience and permanence to store CO_2 for long periods securely (Buck, 2019; Thom et al., 2018). Even if emissions ceased, the natural environment would not be able to remove enough carbon to halt and begin reversing planetary warming quickly enough to preserve the current social and environmental order. Consequently, one promising means of achieving this goal is scaling up negative emissions technologies (NETs). Direct air carbon capture and storage (DACCS), in particular, is one such group of technologies that can remove the excess stock of carbon in the atmosphere (IPCC, 2018). DACCS is certainly not the only promising NET, but it will be an important one because of its low level of environmental risk and land use, and because it captures carbon independently of an emissions source. Since DACCS is energy intensive and will likely cost hundreds of dollars per ton of CO_2 it captures, its deployment is contingent on instituting financial incentives (to compensate for its lack of clear co-benefits) and constructing the infrastructure needed to change the socio-technical system supporting the technology.

There are numerous uncertainties around the appropriate climate mitigation strategies, in addition to global decarbonization, that will need to play out to help limit planetary warming to 1.5°C, from changes in agricultural practices to infrastructure and planning decisions. What is certain is that the scale-up of CDR will need to happen concurrently with the low-carbon energy transition (IPCC, 2018; Peters & Geden, 2017). This is partly because the direct air capture process is so energy-intensive: the growth of DACCS is contingent on having access to a stable supply of renewable energy and, therefore, expanded renewable energy infrastructure. The availability of renewable energy, as well as political support for scaling renewables, will be critical in DACCS scale-up and the transition process as a whole.

For DACCS and some other prominent NETs, being located near sites with suitable geology for CO_2 storage is another important consideration for developers. In some cases, this may require additional infrastructure for transport (e.g. via pipelines, potentially including some repurposed fossil fuel pipelines). Even though large-scale DACCS deployment will not happen until mid-century or later, given the level of system changes that DACCS requires – including those deployment barriers mentioned above and other social (e.g. acceptability), political (e.g. climate policy context, job creation), economic (e.g. business model for DACCS and market incentives), and legal (e.g. accessing pore space) barriers – states will begin to coordinate its development amidst the near-term low-carbon transition (IPCC, 2018). For this reason, governing CDR is best understood through a systems approach wherein government policymakers must take active steps to account for the contingencies associated with CDR and coordinate change within industry and society. This will be important, for example, in supporting the development of niche ways to use and commercialize carbon.

This study will identify the ideal policies for supporting the development of DACCS in the Canadian landscape.[1] Although DACCS developers, like Canada's Carbon Engineering, are ready to commercialize, the technology remains prohibitively expensive and energy-intensive, requiring additional support. There is an increasing body of literature from academia and governments that speculates on future strategies for governing CDR; however, most either assess a large array of NETs, making only limited recommendations on pathways to development for individual technologies like DACCS, or otherwise focusing on low-cost (but ultimately impermanent) nature-based means of CDR. Moreover, few studies have assessed how a country with Canada's physical, regulatory, social, political, and economic landscape will enable or impede its proliferation.

Although scarcely mentioned in the literature, Canada is an interesting case study for several reasons. Canada has one of the highest per capita emissions rates globally and is already warming at twice the average rate (Warren & Lulham, 2021; World Resources Institute, 2021). The country has also historically been a major petroleum exporter, which has left certain provinces financially dependent on fossil fuel extraction. Although individual provinces and

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[1] I define 'ideal' as the policies that are necessary to optimize DACCS scale-up in the context of the sociotechnical system. Gaps in the system will be identified with reference to these ideal policies.

territories retain significant control over climate-related policy, the Canadian Government has nevertheless set the ambitious target of reaching net-zero emissions by 2050 (Environment and Climate Change Canada [ECCC], 2016). Canada has geological formations to store gigatonnes of CO_2, though this potential varies from province to province (Hares et al., 2022). Alberta, where pore space is abundant relative to most other provinces, has long since initiated the lengthy and expensive process of establishing transport infrastructure and a clear regulatory regime for carbon storage (Bankes, 2019). Few countries have managed to do the same. Meanwhile, the Federal Government has recently introduced new funds and incentives to support NETs, CCS, and carbon pipeline infrastructure across the country, as well as a federal backstop carbon tax (ECCC, 2022a). Developing CDR infrastructure may present a unique opportunity to transition the state (and its industries) from a fossil fuel economy to a CDR leader. Given this potential, coupled with persisting uncertainties around how Canada will reach its climate mitigation targets, my research aims to investigate the potential of DACCS deployment in Canada by reviewing policy recommendations within the existing literature and specific policies that already support CDR. By situating DACCS in the context of the socio-technical system, as well as in its own sub-system, this thesis develops criteria and visualizations that enable me to draw conclusions about gaps in the system and necessary steps in the pathways to scaling up the technology.

1.1 Research Questions and Objectives

1. What policies are required to build and expand the infrastructure, economic incentives, regulatory regimes, and protected niche markets needed to support the large-scale development of direct air carbon capture and storage technologies in a manner conducive to a just, low-carbon socio-technical transition in Canada?
    a. Do existing policies serve these functions? What are they? How do existing incentives, regulations, and path-dependencies aid or impede DACCS scale-up?
2. What are the gaps in the system supporting DACCS?
    a. What kinds of policies will the government need to implement to address these gaps?

1.2 Roadmap

This study begins with a literature review that describes the scope of the existing literature related to DACCS and public policy. There is a sizable collection of literature on the technologies themselves, their necessity in the climate mitigation toolkit, and the sociopolitical implications of their use. Yet, the scope of specific policies on individual NETs internationally is also limited at best. Moreover, separate groups of literature inform the discussions within this study, such as evolutionary economics, historical institutionalism, socio-technical systems and transitions, carbon pricing schemes, carbon capture and storage (CCS), carbon lock-in, climate governance, and renewable energy policy. This chapter introduces Frank Geels' Multi-Level Perspective (MLP), a heuristic for describing systems change and potential points of technological lock-in in the system, which serves as the study's theoretical framework.

The third chapter of this study describes the methods used over the study's various stages. These methods include the soft-systems methodology I used to understand how visual maps of complex systems can reveal the feedbacks and leverage points critical for implementing effective governance solutions; the additional review of CDR-specific policy objectives and recommendations described in the literature; the qualitative 'framework' analysis that underlies the study's design; and the 'gap analysis' that will later reveal discrepancies between the current system's design and the 'ideal' system for DACCS deployment, as well as the policies needed to move from one to the next. This chapter also addresses the potential limitations of the research design.

The fourth chapter presents the study's results and describes how the results table is organized and how it is meant to be read. The main results are presented in a table that captures six distinct thematic categories, and begins to reveal how important CDR specific policies and accounting procedures will be for DACCS scale-up. This section will also begin to identify gaps in the policy framework while explaining how the methodology yielded the results described.

The fifth chapter is the discussion, in which I analyze the study's results. Here I will explain how the recommendations made in the literature instruct the system's development. While identifying specific policy examples for each system 'objective,' my analysis will apply the study's theoretical framework, the MLP. This chapter will conclude with a discussion of the contributions of my research.

The thesis concludes with a summary of the study's objectives and an explanation of how my analysis resolved my research objectives. In this chapter, I will also speculate on future research avenues and reiterate my contributions.

2. Literature Review

This section will provide the knowledge foundation needed for understanding the technology at the centre of this study, the theoretical framework, and other concepts that support my analysis of the system. This literature review will be divided into six main sections. Section 2.1 uses the literature to explain concepts and my rationale for studying CDR and DACCS using a system transition perspective. It also introduces the MLP, which provides a framework for understanding what the system looks like. Section 2.2 outlines the co-requisites needed to deploy DACCS in the physical system (i.e., surplus renewable energy, geological pore space, and transport infrastructure). The subsequent three sections each focus on a different category of barriers to DACCS, with each outlining challenges, potential policy solutions, and application in the Canadian context. Section 2.3 describes the economics of socio-technical transitions and DACCS implementation. Section 2.4 covers the politics of implementing DACCS, while section 2.5 outlines the ethical and social barriers that may inhibit scale-up. Lastly, section 2.6 discusses interactions within the system.

2.1 Understanding DACCS and Systems

2.1.1 Why Remove Carbon via DACCS?

Experts anticipate that over the next century, some of the required CDR will be achieved through nature-based sequestration via afforestation and reforestation (A/R); a large volume of trees and other vegetation would be able to naturally absorb and store a significant amount of the CO_2 from the ambient air (IPCC, 2018; Doelman et al., 2019; Mykleby et al., 2017). Planting trees is a comparatively cheap and easy way of sequestering carbon. However, it is not a sufficient CDR strategy for several reasons. The carbon stored in forests is vulnerable to natural events, like forest fires which are more frequent amidst the climate crisis, which would ultimately return CO_2 to the carbon cycle (Keleman et al., 2019). Planting the trillion or more trees needed to sequester hundreds of gigatonnes of CO_2 from the atmosphere would also decrease the Earth's surface albedo; this would (counterproductively) increase local warming because the dark-coloured tree cover would not reflect much sunlight away from the Earth’s surface (Trillion Trees, 2020; Mykleby et al., 2017). Moreover, incentivizing tree planting alone can result in planting the wrong kinds of trees or planting trees in unfit ecosystems (particularly those already efficient natural carbon sinks); this can lead to reforestation efforts becoming "a net GHG source rather than a sink," as in Ireland’s LULUCF sector (O’Donnell, 2020; Schenuit et al., 2021, p. 6).

Another CDR method centred in international climate models, bioenergy with carbon capture and storage (BECCS), solves some of these issues by burning mature vegetation as biomass in bioenergy production – capturing process emissions and permanently storing the carbon output all while generating renewable energy (Strefler et al., 2021; Consoli, 2019). While BECCS is a more efficient and reliable means of CDR, developers would still be competing with agriculture and locals for arable land to achieve negative emissions; in a 2021 research article, Brack and King highlight that, at scale, BECCS feedstocks will demand anywhere from 2.8 to 7 million km^2 of land, or 1-2 times the area of India. Additionally, like other carbon capture technologies, BECCS faces the challenge of storing recovered CO_2. Nevertheless, the IPCC's special report expected that BECCS will need to remove the equivalent of up to 16 gigatonnes of CO_2 from the atmosphere per year ($GtCO_2e/yr$) by 2100 to maintain a 1.5°C warming trajectory (IPCC, 2018, p. 17). With many more negative emissions technologies (NETs) in development, there is a growing spectrum of alternative CDR methods such as ocean alkalinization, ocean fertilization, and enhanced rock weathering, which all involve dispersing minerals or artificial substances into a natural environment to amplify its existing carbon removal capacity; still, few novel NETs have been tested at scale (Royal Society, 2018). However, technologies like BECCS build upon the considerably more mature and well-understood technology: carbon capture and storage (CCS). CCS works by filtering carbon from industrial emissions sources before it can enter the atmosphere (Royal Society, 2018). Though CCS is not a NET – and is itself controversial because it may justify prolonging fossil fuel extraction for energy production – innovations in CCS have enabled the development of several NETs while also building some of the knowledge and infrastructure needed for transporting and storing CO_2.

Direct air carbon capture and storage, or DACCS, is another technology that builds upon CCS. DACCS is a technology that filters carbon from ambient air rather than a concentrated source like BECCS and CCS (Beuttler et al., 2019). In contrast to BECCS and A/R, DACCS does not have high land demands; the technology is also fairly flexible in terms of location since it does not require fertile lands (which is needed for growing trees or biomass feedstocks) (Beuttler et al., 2019). However, DACCS is not without its drawbacks; filtering diffuse amounts of carbon from the air requires substantial amounts of clean energy, as well as access to secure geological carbon storage (Smith et al., 2016).

Realmonte et al.'s inter-model assessment of DACCS (2019) suggests that, if successfully scaled, it could account for 10-15% of the world's energy consumption by 2100 (p. 7). For DACCS to achieve a net reduction in atmospheric CO_2, facilities must be supplied entirely by renewable energy; generating energy for DACCS by burning more fossil fuels would render the technologies useless at best, or else a contributor to emissions if it cannot remove the same amount of carbon that its energy source emits (Fajardy et al., 2019; Strefler et al., 2021). More specifically, a techno-economic review by Erans et al. (2022) demonstrated that a facility (based on DACCS developer Carbon Engineering's design) fueled by coal-fired energy would still likely have negative lifetime carbon emissions (by a narrow margin). However, it would also drive further fossil fuel demand and, therefore, emissions. This contrasts CDR via BECCS, wherein the carbon contained in biomass is captured and stored after having been burned to generate bioenergy. BECCS generates more than enough energy to sustain facilities and sell excess energy, a co-benefit that would justify the use of the technology even without the urgent need for CDR (Bellamy, 2018; Fajardy et al., 2019; Strefler et al., 2021). Both of these technologies are otherwise resource-intensive because they will markedly increase the demand for the materials and resources (water, for example) used in the process of carbon removal (Realmonte et al., 2019). For example, DACCS plants, like the ones Carbon Engineering operates, require chemicals like sodium hydroxide, which itself is created in a highly energy-intensive process (Realmonte et al., 2019). As a corollary, operating DACCS plants at scale and supplying their high energy demands will be relatively expensive and will require regulation to ensure that a given energy grid can support a DACCS plant (Strefler et al., 2021). So although DACCS has some key advantages compared to other NETs, integrating the technology into the socio-technical system will require a high level of coordination.

2.1.2 What Is a Socio-Technical Transition?

This study is informed by the idea that climate mitigation strategies, particularly one that includes CDR, are best understood through a systems approach (IPCC, 2018). This approach emphasizes the barriers in current policies and infrastructure (e.g. renewable energy capacity) that impede the diffusion of new climate mitigation technologies, regardless of their apparent effectiveness or urgency (Bernstein & Hoffmann, 2019; Geels et al., 2017). For example, establishing geological carbon storage could conflict with local opposition and be delayed by a lack of financial support since storing carbon underground, in general, means that it cannot be resold for profit. Unlike similarly environmentally disruptive energy and resource extraction projects, commercial opportunities associated with carbon storage and utilization are minimal while significant investments are needed to scale up storage and DAC efforts. The imperative for CDR entails transitioning from the current 'socio-technical system,' which cannot adequately support the needs of NETs, to a new regime across socio-political and technological institutions and systems (Schenuit et al., 2021).

A socio-technical system is made up of “the linkages between elements necessary to fulfil societal functions,” including new technologies that enable the functioning of modern society (Geels, 2004, p. 900). In their seminal paper on socio-technical systems, Trist and Bamforth (1951) observe how the introduction of mechanization to optimize production in the post-World War II British coal-mining industry fragmented relationships between workers and managers and led to conflict. The new system required small groups of workers to be physically distant from other groups while also making their work more specialized and segregating work shifts in the mines. In the case study, mechanization psychologically altered the workers’ perception of time and their interpersonal relationships while also necessitating new organizational procedures and bureaucracy to manage the new groups and their conflicts. Political changes spurred these system changes; the government nationalized coal mines and railroads during the post-war economic crisis and persisting labour shortages (Trist & Bamforth, 1951). Moreover, the government revitalized coal mining infrastructure to improve yields and support their regime’s energy security; coal represented around 90% of the British energy mix (Planète Énergies, 2015). Stimulated by external pressures and the country’s energy needs, the production of new mining technologies forced the reorganization of social processes by changing the way workers interacted. In turn, the reproduction of new social norms and understandings shaped what kinds of technologies and policies the government instituted. This example shows how science, technology, industry, policy, culture, markets, and users are all connected to drive change within a social system (Geels, 2004, p. 906). To further understand how such complex socio-technical systems can change when new technologies enter the market and gain traction, I will explain Geels’ theory of socio-technical transitions, which builds upon this conception of systems. The following will also explain why this framework is appropriate for understanding carbon lock-in and the role of CDR and DACCS in low-carbon transitions.

Frank Geels, whose 2002 and 2004 papers first introduced his theory of ‘socio-technical transitions’ (and the ‘Multi-Level Perspective’ (MLP) framework he uses to characterize transitions pathways), established a theory of change for socio-technical systems that distinguish the three ‘levels’ that make up the system and determine socio-technical pathways. The first is the regime itself, the makeup of which encompasses socio-technical systems theory. Exogenous factors that comprise the landscape of society influence the regime: “material and environmental conditions, external agents, [and the] larger socio-cultural context” (Geels, 2004, p. 908). This second ‘landscape’ level can experience shocks that radically disrupt the order within the system (i.e. war, natural disaster, recession, etc.). This level is backed by the theory of historical institutionalism, which stresses that agency is shaped by the “macro-contexts” of institutions and the historical chain of events that have shaped the values and physical structure of the system (Roberts et al., 2018, p. 309). In the Trist and Bamforth example, the post-war conditions of scarcity in Britain were a landscape-level change; its historical circumstance determined the country’s institutional priorities. The last condition is the availability of niche technologies which, when landscape conditions destabilize a regime, can gain traction and progressively shift, or else radically reconstruct, the architecture of the system.[2] The final corresponding epistemic pillar of Geels’ theory comes from evolutionary economics, a theory which highlights the adaptive, progressive changes in material production and consumption that can both align with or impose change on the dominant technological regime. In either case, evolutionary economics understands that successful niche technologies fulfill a functional role within the system by cooperating with existing technologies and institutions. Again, given the impetus for post-war recovery and mass production, the mechanized “long-wall method of coal-getting” could grow from a niche in this way (Trist & Bamforth, 1951, p. 3). This had both stabilizing (by creating the conditions for coal production and economic growth) and destabilizing (due to the sociological impacts on workers) effects on the system and the

Figure 1

Levels of the MLP

F.W. Geels / Research Policy 31 (2002) 1257–1274 1263

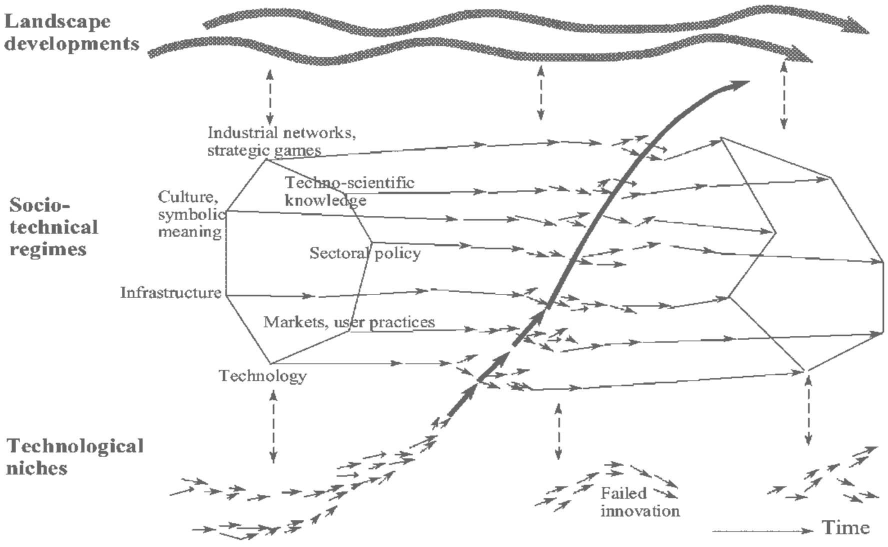

Fig. 5. A dynamic multi-level perspective on TT.

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[2] See Figure 1, which demonstrates how niche technologies enter the regime (Image from Geels, 2002)

Figure 1 illustrates how the different levels of the MLP influence systems change. Adapted from "*Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study*," by F. W. Geels, 2002, Research policy, 31(8-9), 1263. Copyright 2002 by Elsevier Science B.V..

interdependent network of actors it encompasses. In practice, this perspective includes markets and forces of competition that determine which technologies will thrive, as well as non-market forces like regulations and other supply-side factors (Geels, 2004).

These interdependencies are not negative things. In the production process, specialization of labour between and within different firms allows for greater efficiency and productivity because when a firm produces more goods, they become cheaper; this leads to economies of scale and a competitive advantage in the market (Arthur, 1989; Geels et al., 2017; Smith, 1776). This drive toward economies of scale is a core tenet of economic liberalism, and these interdependencies drive the free market. Indeed, climate policies that support low-carbon technological innovations typically aim to subsidize a niche technology until it can achieve an economy of scale (Geels et al., 2017; Nemet et al., 2018). However, the scale of interdependent technologies in the dominant regime can also obstruct progress toward a low-carbon transition. The literature uses the term 'lock-in' or, more specifically, 'carbon lock-in' to describe how historical events and decisions have resulted in path dependencies that restrict new technologies from gaining traction in the market (Cairns, 2014; Cecere et al., 2014; Geels et al., 2017; Sato et al., 2021; Schenuit et al., 2021; Unruh, 2000). Lock-in, like in Trist & Bamforth's example, occurs on a technological level (e.g. mechanization), an institutional level (reorganization of labour, coal dependence), and an individual behavioural level (worker conflicts) wherein the existing competencies and routine of individuals inhibits their ability to accept technological change (Trist & Bamforth, 1951; Unruh, 2000). Since the existing socio-technical regime has been designed around the dominant, carbon-intensive technologies of the last century, it is difficult for a system to make the 'jump' to a low-carbon economy because the status quo depends on its continued functioning.

2.1.3 How Does this Framework Apply in the Context of Climate Mitigation and CDR?

To escape socio-technical lock-in and enable climate mitigation are goals which demand decarbonization and the scaling of CDR, both of which, I argue, are essential in the transition to a 'low-carbon system.' This ideal future socio-technical system is one in which society is simultaneously:

(a) almost entirely powered by low-carbon renewable energy,

(b) actively mitigating climate change by restoring the volume of CO_2 (or CO_2e) in the atmosphere and carbon cycle to pre-industrial levels, and

(c) able to adapt and sustain itself without compromising the quality of human life and ecosystems.

'Low-carbon,' therefore, characterizes both emissions and the atmospheric concentration of CO_2. Although some of the technologies needed for achieving condition (a) are well-established, those required for fulfilling the other conditions are not: NETs in particular.

Moreover, large socio-technical systems are stabilized by 'network technologies:' the infrastructure that connects and supports different parts of the system (Bernstein & Hoffmann, 2019; Geels, 2004; van der Vleuten, 2006). In post-war Britain, new mining techniques were a niche that, after integrating into the regime, supported a broader network of technologies within the socio-technical system. Since current network technologies, such as energy grids, provide insufficient support for NETs innovation, there must be changes in the policies and infrastructure of the regime as a whole to improve technological innovation and diffusion. Even in the absence of an external shock, the dominant regime can work to either stabilize or destabilize the landscape; government policy can have a role in causing a landscape shock, like a recession, or hasten the pace of socio-technical change by promoting niche innovations and building new infrastructure to support them (Roberts et al., 2018). Though climate change itself is also a landscape condition that impacts decision-making within the regime, its impacts for the past several decades have been too temporally distant to qualify as a shock; politicians and private companies can ignore or delay their responses to climate predictions because its impacts surface relatively slowly and impact countries differently (Slawinski et al., 2017). To supplement weak landscape pressures, governments can use policy to strategically alter incentives within the regime to enable the development of network technologies such as NETs, renewables, and niche innovations.

Due to the system demands of DACCS specifically, a system transformation is essential. The technology entails new infrastructure and a simultaneous transition in existing technologies and the socioeconomic institutions that support them. The energy requirements of DACCS are so great that the use of the technology at scale is only feasible after low-carbon energy becomes available in a region. In the terms described in the previous paragraph, the feasibility of DACCS in condition (b) depends on the energy transition described in condition (a). The challenge of a low-carbon energy transition is not only introducing new technologies themselves but preparing the infrastructure (part of the technological landscape of the system) on which they will be contingent. However, to do so, the government policy regime must also be amenable to (inciting) change. Generating the political will to do this may require the formation and support of socio-political coalitions from private firms, civil society, international institutions, and other states (Roberts et al., 2019). Moreover, while carbon lock-in has constrained the progress of the low-carbon transition, some authors worry that providing incentives for carbon removal technologies will further entrench carbon lock-in in the global economy (Asayama, 2021; Hirschhausen et al., 2012; Muraca & Neuber, 2018). Ultimately, the perspective of the socio-technical transition is useful for understanding CDR's logistics and governance needs because it encourages me, as a researcher, to take stock of the many conditions and contingencies that factor into systems change and determine whether a technology will produce net benefits within the system.

2.2 Landscape and Infrastructural Requirements for DACCS

In outlining how the literature describes three key co-requisites to DACCS deployment – energy/heating demands, carbon storage, and transport – this section will illustrate how landscape pressures and their economic, political, and socio-cultural ramifications factor into CDR governance. Fulfilling these corequisites involves scaling network technologies and infrastructure, socio-political cooperation and coalitions, economic incentives to secure financing, and a diverse array of eco-innovations to best suit the needs of a region as they introduce NETs to their climate strategies. In doing so, each subsection will help to identify those challenges that warrant investigation in later sections of this thesis. In what follows, I will present facts and figures that further elaborate on the landscape barriers and regime support specific to Canada (drawn from government reports), beginning with the country’s energy mix.

2.2.1 Energy and Heat Requirements

The first of these co-requisites is for the system to have sufficient renewable energy capacity. It is important to note that DACCS is not a singular technology, and various companies have developed different processes for chemically capturing CO_2 from ambient air, each of which has different energy demands. These include DACCS developers like Climeworks, which uses “alkaline-functionalized adsorbents” to extract CO_2 from the air under careful temperature and pressure controls; Carbon Engineering, which uses “liquid alkali metal oxide sorbents” to chemically filter out CO_2 at high temperatures; and Global Thermostat, whose technology uses a “solid amine-based sorbent material” to separate CO_2 (Beuttler et al., 2019, p. 2). Although all of the technologies have high energy demands (especially Carbon Engineering), some companies are implementing innovative solutions to reduce that burden. For example, in Climeworks’ ‘Carbfix2’ partnership, their DACCS plant is powered by a neighbouring geothermal power plant; captured carbon is subsequently injected into subsurface basalts in the immediate vicinity (Minx et al., 2018; Fuss et al., 2018). The company also uses low-grade waste heat to separate carbon in some of its facilities, which reduces its technology's energy requirements (Fuss et al., 2018). While this technique has generated concerns that injecting carbon underground may trigger seismic activity, its innovation in management and technology marks significant progress toward reducing the energy burden of their DACCS design (Fuss et al., 2018). Depending on the development of this innovation, the energy requirements of Climeworks' product may be significantly lower than its competitors if a facility uses industrial waste heat. Although integrated assessment models used for climate change research have historically simulated CDR via BECCS and A/R, the IPCC's forthcoming AR6 report assesses DACCS at the same level of technological readiness as BECCS, with a substantially higher mitigation potential (IPCC, 2022).[3]

Although renewables currently represent 80% of newly installed energy capacity around the world each year, to reach appropriate lifecycle carbon efficiencies, DACCS must either be deployed in mostly decarbonized countries like Iceland and Norway, or else supplied directly by its own modular solar photovoltaics (Erans et al., 2022). In Canada, renewables account for 18% of the total primary energy supply and 66.3% of electricity production (NRCan, 2017; NRCan, 2022). This varies dramatically between provinces; some provinces are almost entirely decarbonized, like Manitoba and PEI, where fossil fuels generate less than 1% of total electricity (NRCan, 2022).[4] Meanwhile, Alberta and Saskatchewan, the provinces with the most known geological pore space for carbon storage, source only about 11% and 18.5% of their electricity from low-carbon sources, respectively (NRCan, 2022). While DACCS should be deployed near storage sites to reduce transport costs, the energy mix of these provinces makes them incompatible. Not only do they have substantial fossil fuel reserves, they are the only two landlocked provinces, meaning that they cannot incorporate as much tidal/hydropower as the rest of the country (Canada Energy Regulator, 2022a). Co-locating DACCS facilities in proximity to both renewable energy and geological carbon storage represents another major challenge for deployment, especially in a country with as diverse an energy portfolio as Canada. Policy-makers, therefore, must acknowledge that coordinating proximate transport and storage for carbon are corequisites for implementing any CDR regulations or incentives.

2.2.2 Storing Carbon

There are various prospective methods and geological spaces to store sequestered carbon (Aminu et al., 2017; Kelemen et al., 2019). The Oil and Gas Climate Initiative (2022) has

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[3] 5-40 $GtCO_2e$/yr compared to 0.5-11 $GtCO_2e$/yr

[4] 15% of electricity is supplied by nuclear

identified up to 400 gigatonnes of storage in geological basins across Canada. The main types (oil and gas reservoirs, basalt aquifers, and unusable coal beds) all involve injecting compressed CO_2 into porous rock formations that can effectively absorb carbon (IPCC, 2005). The IEA's (2016) legal and regulatory review on carbon storage indicates that most jurisdictions issue two types of permits for CO_2 storage: one to regulate the management and operation of a storage project and another to permit access to pore space (which can be owned privately or publicly). For example, in Australia and most of Europe, the government owns the pore space in geological rock formations and issues leases and tenure agreements accordingly. In areas like the U.S., subsurface mineral rights are held by whoever owns the surface property (Bankes, 2008, p. 5). According to Bankes (2008), "the general rule in Canada is that ownership of the pore space likely accrues to the owners of the mineral title and not the owner of the surface title" (p. 6). Since "Canadian law recognizes that mineral rights may be privately held" rather than owned by the Crown, as is the case in a significant portion of the country, the issue of ownership complicates these permissions (Bankes, 2008, p. 6). In saline aquifers, for example, the Crown owns all water, and therefore, the water within the aquifer, but pore space ownership within the same geological site is not always clear (Bankes, 2008).[5]

Regarding regulation, standards apply at the provincial level for storage in Canada–although the environment is generally a shared responsibility between federal and provincial authorities (Bankes, 2008). So far, Alberta has the most developed legal and regulatory framework for addressing liability, permits, and policies in carbon storage in the country (Bankes, 2019). This is fitting, considering the high storage volume available in the province (International CCS Knowledge Centre [ICCSKC], 2021). Other provinces, including Ontario, have begun their own investigations of potential storage sites and regulations (Ministry of Northern Development, Mines, Natural Resources and Forestry, 2022). While an advantage of DACCS is that it can be co-located with storage, that may not be the reality for companies attempting to build facilities in areas where regulations are still unclear. Therefore carbon captured in industrial facilities and power plants via CCS, as well as from DACCS, may need to be transported long distances to appropriate storage sites.

Storing captured carbon for any of these technologies still requires substantial infrastructural investments to develop pipelines for transporting CO_2 from facilities (Aminu et al., 2017; Fuss et al., 2018; Keleman et al., 2019). The CO_2 from CCS projects has most often been sold for use in a technique called enhanced oil recovery (EOR), in which CO_2 is injected into

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[5] While significantly lower than both BECCS and A/R, some DAC technologies have significant water requirements and water loss potential (Realmonte et al., 2019).

depleted oil wells to displace oil that would have otherwise been inaccessible (Aminu et al., 2017). While this technique helps to build a business case for CCS and CDR, it is controversial because it entails extracting and burning fossil fuels (Asayama, 2021; Mabon & Littlecot, 2016). One alternative for utilizing carbon is exemplified by Carbon Engineering's efforts to use CO_2 to create synthetic low-carbon fuels for use in planes and other vehicles for which electrification is not yet an option (Carbon Engineering, 2021). Still, pending further innovation to enable carbon utilization in commercial products to make recovering CO_2 profitable, CDR developers must figure out how to store massive amounts of carbon without relying on EOR to finance their efforts (to not enable further fossil fuel extraction and emissions).

2.2.3 Transporting Carbon

The most likely, lowest-cost, and lowest-carbon option for CO_2 transport is via pipelines (Fuss et al., 2018). Pipelines have been used to transport things like water, natural gas, and oil since ancient times, while the first large-scale CO_2 pipelines were constructed in the U.S. in the 1970s (IPCC, 2005). Since CCS will likely be the only means of reducing emissions from hard-to-abate sectors (those without viable low-carbon alternatives) like cement and plastic production, some sort of CO_2 pipeline network to connect facilities will be necessary for a country like Canada, where manufacturing contributed over CAD 170 billion to the economy in 2020 (Riehl et al., 2021; Johnston, 2021). Several projects are already in operation, most in Alberta, where many complex pipeline networks exist. Alberta's Quest project currently transports CO_2 for storage in saline aquifers, while the Alberta Carbon Trunk Line (ACTL) transports CO_2 for EOR (Riehl et al, 2021). The lack of transport infrastructure across the country and worldwide may be what ultimately inhibits the growth of carbon capture and removal efforts (Riehl et al., 2021). The additional cost of transport and storage is part of the reason for this. The estimated cost of transport and storage is anywhere from CAD 31/tCO_2 in Alberta (where infrastructure is relatively well established) to CAD 189/tCO_2 in Quebec (Riehl et al., 2021). Just as cars need roads, CDR requires pipeline infrastructure (Riehl et al., 2021).

Yet, just as the roads and cities designed to accommodate cars have systematically 'locked in' the de facto means of transport in the current socio-technical regime, the layout of pipeline systems may enforce limits on where carbon can be transported and stored (Cairns et al., 2014; ICCSKC, 2021). For example, suppose pipelines were to be exclusively located according to the needs of CCS sites (as is the case in Alberta and Saskatchewan, where active EOR projects make capture, transport, and storage profitable for private investors). In that case, it may be more difficult to locate DACCS proximate to a grid supplied by mostly renewable energy and transport. Thus, the state of infrastructure and economic incentives in the system may serve to ‘lock out’ even technologies similar to CCS by advancing the more profitable option. This reading of the literature indicates that it is important to construct infrastructure mindfully and adaptively, with one potential model being via transport ‘hubs,’ per the ICCSKC’s recommendations. These hubs would act, as seaports have in cities around the world, as sites of collection with shared, government-backed infrastructure to promote economic activity (Valiaho, 2020).

With a “build it and they will come” philosophy, a report by the ICCSKC (2021) notes that, although the government’s support for technology is still tenuous pending the proposed federal CCS tax credit, the money that the government is willing to offer in support of general infrastructure is different from the funds being offered in support of technological innovation. The ACTL received CAD 63.2 million federally and CAD 459 million provincially, which financed almost half of the project (Valiaho, 2020). Although the project delivers CO_2 to EOR sites, the ACTL nevertheless transports carbon from multiple industrial facilities for permanent storage (Valiaho, 2020). As Valiaho (2020) observes, the Oil and Gas Climate Initiative has already offered over a billion dollars to support the development of five international ‘kickstarter’ hubs capable of transporting hundreds of megatonnes of CO_2 per year by 2030. All of these emerging carbon transport and storage projects are funded in large part by oil and gas companies to incentivize growth in CCS and EOR. However, they will potentially be accessible to DACCS and other CDR projects because public and private institutions typically share the cost of large-scale infrastructure like pipelines (Saha & Ibrahima, 2020). In Canada, provincial and federal regulators oversee all pipelines through their lifetime (ECCC, 2022a). In the scope of the larger-scale low-carbon transition, these hubs become part of the landscape: network technologies that lower the cost of innovation and operations.

While it is important to consider how the proliferation of carbon pipelines might contribute to fossil fuel hegemony, they will continue to play a role in the energy transition because they do not exclusively support one type of technology or storage site–both for DACCS and CCS in hard-to-abate sectors (Gough & Mander, 2022). Given that efforts to scale CDR and CCS are far from sufficient in terms of tonnes of removal capacity, the integration of interim technological regimes for infrastructure is a necessary long-term investment (IPCC, 2018). Coordinating jointly funded infrastructure is a non-negligible consideration in the process of governing CDR and the low-carbon transition. Therefore, it is important that government powers provide funding, regulations, and oversight to ameliorate these barriers to implementation and incentivize innovation. In what follows, I will explain how locating niche markets can help DACCS and complementary technologies mature, bring costs down, and enter the market with the support of economic policy supports like carbon pricing and loans. Rather than explaining the external costs associated with landscape transitions, I will also highlight the cost barriers of the technology itself.

2.3 The Economics of DACCS Implementation and Transitions

Based on the previous section, it is clear that there should be a role for CDR in the low-carbon socio-technical transition. This section will explain why its high costs currently impede the scaling of DACCS operations; it will also discuss a variety of options for reducing this and other economic or financial barriers of niche technologies in general and DACCS specifically. These options include locating niche markets, establishing carbon pricing and government financing programs, and improving carbon utilization technologies.

2.3.1 What are the Economic Pathways and Barriers to Scaling DACCS?

Evolutionary economics holds that the economy constantly changes and reorganizes as it adapts to new innovations and external influences (Boulding, 1991). Over time, technologies can grow, decline, or remain a stable presence in the market, depending on how well they suit the needs of actors in the system (Boulding, 1991). Since cost is an important selection criterion for consumers confronted with different options (in this case, for carbon removal), the high costs associated with many niche technologies are a significant barrier to implementation (Geels et al., 2017). The approximate cost of DACCS today (per AR6 estimates) ranges from 84-386 USD per tonne of CO_2 (IPCC, 2022).[6] There is some consensus in the literature that niche markets need to develop around the technology to lower these costs and foster its development; when a carbon price is in place, niche markets allow technologies to be competitive against other CDR options, the price of abatement, and the price of carbon (see Figure 2) (Cairns, 2014; Cecere et al., 2014; Meckling & Biber, 2021; Nemet et al., 2018). In their assessment of the cost and potentials of an array of NETs, Fuss et al. (2018) provided the following definition: “niche markets exist when early adopters have a higher than average willingness to pay for a technology” (p. 8). This willingness to pay is important in overcoming the cost barriers of DACCS because greater demand for a commodity generates competition within the market, enabling developers to improve their product further, bring costs down, and increase returns; all of these factors help a technology to scale. DACCS, for example, has been used in “submarines to reduce the CO_2 levels of ambient air in closed systems” (Fuss et al., 2018, p. 13). Therefore,

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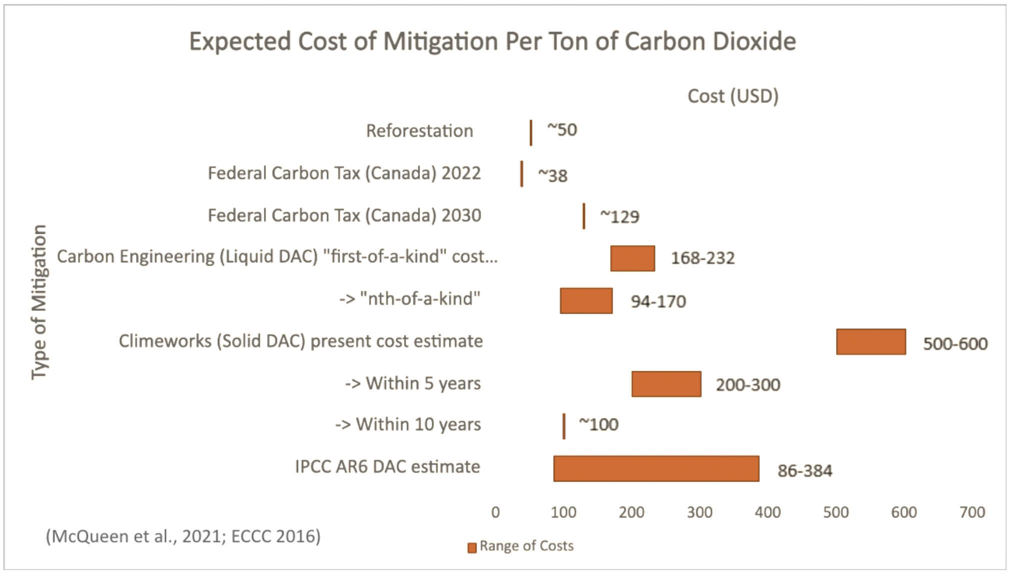
[6] Compared to 15-400 USD/tCO_2 for BECCS, 0-240 USD/tCO_2 for afforestation/reforestation, and 45-100 USD/tCO_2 for soil carbon sequestration

niche markets are important drivers of socio-technical change because they introduce incremental change into the socio-technical regime while providing time for society and its physical landscape to adapt and accommodate innovations (Cecere et al., 2014).

The dominant technologies within a socio-technical regime have the support of network technologies and the market as a whole since they work together to make the system function. The system favours technologies compatible with the dominant regime; infrastructure, policy, industry operations, the general public, and the economy rely on fossil fuel-intensive production and consumption. Geels et al. (2017) observe that low-carbon transitions are disruptive "because they threaten the economic positions and business models of some of the largest and most powerful industries… which are likely to protect their vested interests" (p. 464). This means that when a low-carbon substitute becomes available, a wide range of socio-political groups, businesses, and individuals actors in the regime will act to delay its adoption and subsequent change from their preferred techno-economic status quo (Cecere et al., 2014; Cairns, 2014; Geels et al., 2017).

Figure 2

Expected Cost of Mitigation Per Ton of Carbon Dioxide



Since changing a system in small increments is cheaper and easier than periodically shutting down and overhauling the system when more efficient technologies become available, a slow transition process is not necessarily bad for the system. However, delaying the start of a larger-scale transition to a new and more efficient stream of technologies typically means forfeiting long-run profits in favour of short-run gains (Arthur, 1989). For example, in the automobile industry, the diffusion of electric vehicles has been inhibited by "the fact that new capabilities (that are difficult to acquire) are required to develop electric propulsion engines…, consumers are not yet attracted by them," and those steep infrastructural investments required to establish a sufficient number of charging stations (Cecere et al., 2014, p. 1044). Compared to conventional cars of the past century, equipped with gasoline and internal combustion, it is still generally much more difficult to find fueling stations and professionals knowledgeable enough to service an electric vehicle. The new technology is incompatible with the dominant regime and the system's infrastructural landscape and competencies. In a paper problematizing the standard short-term time scale of business decision-making under conditions of uncertainty which impede sustainable transitions, Slawinski et al. (2017) highlight the prevalence of "present-time perspectives" (p. 261). Firms tend to assign "temporally distant" threats like climate change less urgency than short-run business concerns (Slawinski et al., 2017, p. 261). While introducing incremental change in the economy is important in creating the conditions for a transition, particularly from the perspective of evolutionary economics, a transition will progress too slowly if it is solely driven by market actors who disregard the long-run consequences of maximizing short-run profit-making (Cecere et al., 2014; McKelvey, 1997). In sum, the short-term business cycle tends to overestimate the costs of addressing long-term threats like climate change, which yields insufficient investment in new mitigation solutions. Government policies are designed to counteract this market failure by internalizing the cost of market externalities (like environmental degradation and pollution) through taxes and subsidies to correct the structure of market incentives (Bellamy, 2018).

2.3.2 What Economic Policies Can Shift Market Incentives?

There are a variety of recommendations on how specific economic policy tools can facilitate the role of CDR in the low-carbon transition (Borth & Nicholson, 2021; Cox & Edwards, 2019; Fajardy et al., 2019; Grant et al., 2021; Lezaun et al., 2021; Meckling & Biber, 2021; Strefler et al., 2021). For instance, the government can intervene to correct markets by directly supporting DACCS or otherwise providing incentives to encourage others to adopt the technology. One way they do so is by pricing carbon to reflect the environmental harms of emissions; after pricing carbon, a negative market externality, "firms and consumers will automatically internalize the costs [of the emissions associated with a product or service] to achieve a given emissions abatement goal" (Baranzini et al., 2017, p. 12). Therefore, putting a price on emissions incentivizes abatement itself and the development of innovative technologies to assist abatement (Strefler et al., 2021). A company may choose to reduce their emissions by adapting its production process to reduce their emissions and avoid taxation or else simply pay the tax.

The government may use tax revenues, for example, to finance CDR infrastructure (Strefler et al., 2021). In contrast, if the government were to legislate a requirement for carbon capture in every power plant and industrial facility, they risk entrenching old technology and inhibiting innovation while potentially sparking resentment from private sector actors by removing their ability to choose their preferred means of reducing emissions. Carbon pricing systems, coupled with tax credits and other forms of targeted government assistance, conversely allow firms to choose their most efficient option and maximize their gains. When the government increases the cost of carbon emissions, the costs of technologies like DACCS are lower relative to the carbon price; subsequently, the lowered relative cost of DACCS will enable more users to adopt the technology and develop a niche market in which it can mature. In what follows, I will outline the two main options for pricing carbon described in the literature, taxation and emissions trading, and their role in the energy transition.

The first economic policy option is instituting a carbon tax. As Tarufelli's (2020) review of CCS policy demonstrated, the literature shows that a revenue-neutral carbon tax-based system–that is, a tax for which revenues are either transferred to households or used to cut existing tax rates–can stimulate economic growth and incentivize the development of carbon capture technologies (including DACCS, CCS, and other NETs). A carbon tax entails less price volatility compared to the second economic policy option, emissions trading, a policy instrument which caps the 'supply' of carbon that polluters can emit by allocating emissions permits which they can either use or trade; a tax enables "more stable investment incentives" because when individuals know that the actual cost of carbon emissions and the rate at which the tax will increase over time, they will be less willing to pay to emit rather than abate emissions (Tarufelli, 2020, p. 7). A carbon tax reduces price uncertainty, which improves the consumer's ability to anticipate the cost of production in the future. This stability helps to incentivize CCS deployment because it makes CCS a comparatively cheaper means of near-term abatement in hard-to-abate industries that would prefer to not pay the CAD 170 per tonne of emissions that a tax like Canada's would require by 2030 (ECCC, 2022a). While the cost of DAC is currently above this price, data from the International Energy Agency (IEA) indicates that, across industries, the current cost of CCS falls below CAD 170 (Baylin-Stern & Berghout, 2021).

Conversely, emissions trading systems enable policymakers to set a finite limit on emissions, and as the European Union Emissions Trading System (EU ETS) is currently attempting, enabling them to integrate carbon offset credits via CDR projects into the system (Rickels et al., 2021). Similar to the scenario in which firms use CCS to reduce the amount of carbon they put into the atmosphere, this strategy would give firms the option of purchasing CDR credits from companies that operate NETs (or nature-based CDR) instead of abating all of their emissions. Though these options provide similar incentives to create change in the socio-technical regime, the emissions trading system designers must ensure that the same policies designed to incentivize decarbonization do not inadvertently enable further fossil fuel dependence by allowing firms to defer abatement indefinitely.

While implementing a carbon tax or a cap-and-trade system is the most apparent policy choice for decarbonizing the global economy, it is not evident that incentivizing DACCS is an appropriate or sufficient policy choice for climate mitigation (Campiglio, 2016; McLaren et al., 2019; Strefler et al., 2021). For example, in their analysis of the current portfolio of prominent CDR options, Strefler et al. (2021) note that increasing CDR scale-up would reduce carbon tax revenues by offsetting emissions and, therefore, reduce the tax revenue that the government might use to support scaling CDR infrastructure and loans. Consequently, more research is needed to understand the right way to incentivize NETs (for example, by indicating the timeline for when a subsidy may end from its outset). Although policymakers and researchers cannot predict all of the consequences of CDR and implement optimal policies in advance, we can draw upon analogous cases using the technologies that NETs incorporate to form policy (Buck, 2016). For example, niche markets and early adopters for solar photovoltaics (PVs) in Japan and Germany enabled the technology to develop, which lowered costs for later adopters (Elia et al., 2021). Research and development funding from the government and private sector helped to build the protected niche markets that allowed developers to improve their technology (Elia et al., 2021). A 2021 article by Elia et al. on the aforementioned technologies “shows that learning by-doing, learning by-researching and learning by-interacting are important drivers at the earlier stage of development, while during commercialization stages, the pre-eminent drivers are market demand, supply-chain dynamics, and economies of scale” (p. 14). By enabling learning in the early stages of development, subsidies can build an array of supply-side technology options, while a carbon price creates demand-side incentives for technological transitions. Applied in the context of CDR policy, the combination of these policies will drive down the cost of DACCS and enable technology scale-up.

2.3.3 What Policies Exist in Canada?

The following paragraph will briefly explain each of the main policy mechanisms currently established or in progress in Canada to illustrate how economic policies and incentives have begun to address these transition barriers. Canada has a number of policies at the federal and provincial levels to support the energy transition, such as “the [federal backstop] carbon pricing system, Strategic Innovation Program funding, the Net-Zero Accelerator, Canadian Infrastructure Bank low-interest loans, the Clean Fuel Standard, and the Investment Tax Credit; as well as Alberta’s Technology Innovation and Emissions Reduction (TIER) regulation and Storage Tenure Management” (ICCSKC, 2021). The federal carbon tax is currently CAD 50/tCO_2, with planned increases of 15 dollars each year (ECCC, 2022a). This tax applies in provinces without their own pricing system or whose pricing systems do not meet the minimum federal standard: “Ontario, Manitoba, Yukon, Alberta, Saskatchewan and Nunavut" (ECCC, 2022a). Other policies, like the Net-Zero Accelerator and the Canadian Infrastructure Bank low-interest loans, provide funds to support the growth and development of new technologies and system change. The Clean Fuel Standard serves a similar purpose; “to drive innovation at the lowest cost, the Clean Fuel Regulations establish a credit market... [in which] regulated parties (producers and importers of gasoline and diesel) must create or buy credits to comply with the reduction requirements," thereby creating “a market signal for investment in low carbon intensity fuels and technologies" (ECCC, 2022c). In similar existing provincial standards, producers have reached this goal by blending a percentage of ethanol (or another renewable fuel) into the gasoline supply (ECCC, 2022c). Lastly, the investment tax credit, which is still under review, will specifically support the development of DACCS, CCS, transport, storage, and equipment by allowing firms to subtract a substantial percentage of their costs from the taxes they owe the government (Department of Finance, 2022a).

However, the tax credit proposal has become controversial amongst Canadian academics, with over 400 signing a petition against the government’s proposal (Anderson, 2022). Their concern is that this tax credit constitutes a new addition to the federal government’s portfolio of subsidies to the fossil fuel sector. This, they argue, delays decarbonization by supporting an industry that should be in decline. This worry is not completely unfounded; according to a 2020 report by Oil Change International and Friends of the Earth, Canada provided one of the highest levels of public finance for fossil fuels among G20 countries at 10.6 billion USD per year (second only to China) (Tucker et al., 2020). Many of these funds were misappropriated from programs meant to support clean energy and green development; for example, 8 million CAD from the Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative instead went to natural gas refuelling stations (Environmental Defence Canada, 2021). Since CCS happens in conjunction with fossil fuel energy production and use, oil and gas companies are among those likely to take advantage of the tax credit.

Nevertheless, the tax credit is 10% higher for DACCS projects than for CCS (at 60% versus 50% and only 37.5% for storage transport and utilization) (Department of Finance, 2022a). Though the margin is small, this policy design prioritizes DACCS compared to CCS, which must be used in tandem with fossil fuels. By 2031 through 2040, the government plans to cut each of these rates in half, indicating that they do not intend to subsidize the technologies indefinitely, thereby reducing uncertainty in the market from the outset of the tax; instead, the tax credit will only support the technological maturation of carbon capture rather than becoming one of many hard-to-repeal subsidies (Department of Finance, 2022a). While the potential of CCS and CDR technologies both during and after the transition is great, the rollout of technologies like DACCS has to pre-empt the slow-moving process of decarbonization so that the technology can reach the necessary level of maturity. A tax credit, as a part of a portfolio of other policy tools, would support the socio-technical transition by making new network technologies more affordable and, in turn, capable of attracting further investment.

Notwithstanding this, it remains to be seen whether Canada has already constructed an appropriate policy mix to facilitate a transition in other parts of the socio-technical regime. The next section will focus on the governance concerns and recommendations that can help to scale DACCS in the low-carbon transition.

2.4 Political Barriers in Low-Carbon Transition Governance

As argued above, incentivizing the creation of bottom-up climate mitigation solutions via niche innovations is important in the scope of the transition. However, DACCS differs from other niche technologies (like solar PVs) because it is not especially marketable to consumers: the technology must be deployed at scale, but does not produce obvious co-benefits. I have already discussed the role of policymakers in establishing ‘protected spaces’ for improving niche technologies; in this section, I will discuss the role of policymakers in establishing the top-down regulations needed to construct, manage, and integrate CDR governance into the socio-technical system. This role involves shaping discourse, shifting institutional norms, and changing the infrastructural landscape of a system. Importantly, it begins with the question of whether states, as the highest political authority in a region, have the duty to perform carbon removal.

2.4.1 Who is Responsible For Scaling and Managing CDR?

Many authors have likened the challenge of managing CDR to waste management, for which the government typically assumes responsibility (Buck, 2020; Honegger et al., 2021; Poralla et al., 2021). Throughout history, local authorities have developed systems for waste disposal to avoid disease and the degradation of public goods in cities (such as streets and waterways). Removing carbon from the atmosphere is similar, authors like Holly Buck argue, because clean air and a stable climate can also be classified as public goods because they are non-excludable and non-rivalrous (Buck, 2020). Like carbon pricing, managing waste disposal and carbon removal are ways that a government can address the negative externalities associated with market activities. In both cases, coordinating waste collection requires substantial funds and central planning. It is too expensive for an individual to finance by themselves, nor would they have the incentive to do so given the limited profit-making potential of reselling waste (Barles, 2014). Through waste-sorting and recycling programs, most developed countries have implemented recycling programs to reduce the volume of waste they send to landfills (Barles, 2014).

Additionally, many manufacturers buy various recycling feedstocks to replace more costly virgin materials in the production process (Biddle, 1993). For example, the paper industry has long treated recovered paper from municipal waste collection and used it to create pulp for new paper products (Baeyens et al., 2010). In the case of CDR, this is analogous to carbon utilization. Besides EOR, CO_2 has had a variety of commercial uses over the past century, including in beverage carbonation, food preservation, and, more recently, the production of a growing number of materials like concrete and plastics (both of which are industries in which emissions are ‘hard-to-abate’) (Warsi et al., 2020). However, since not all waste can be recycled, storing what remains is left to the government and its proxies. Similarly, industry demand for carbon is not high enough to utilize the volume that capture technologies will (ideally) extract over the next century because of low global carbon prices and the low levels of technological readiness for utilization pathways (Gasser et al., 2015; Warsi et al., 2020). While avenues for commercialization exist for both, this reasoning suggests that the government must take responsibility for safely storing carbon as well. This is pertinent given that the impacts of climate change due to higher atmospheric concentrations of CO_2 will have an unprecedented impact on society, the economy, the environment, and human health (IPCC, 2018). In the case of CDR, this ‘incentive gap’ justifies public funding via carbon tax revenue or some other policy mechanism.

2.4.2 How Can Policy and Political Institutions Establish DACCS As A Transition Technology?

Based on their article outlining the barriers to CDR, Honegger et al. (2021) claim that the ideal CDR policy mix for overcoming this gap should: “i) clarify the intended role of CDR, ii) accelerate innovation to reduce cost barriers, iii) ensure public participation in the process of mobilizing

NETs, iv) promote long-term, rather than pilot projects for technologies, v) have robust carbon reporting and accounting procedures, vi) prevent side effects and maximize the co-benefits of carbon removal" (pp. 5-6). In effect, these recommendations seek to close the incentive gap by instructing policymakers to directly support innovation financially and to introduce measures to ensure transparency and diffusion of information on CDR throughout society, thereby reducing uncertainty in the system. However, this policy mix does not suggest that the state take responsibility for carbon removal and storage in the same way they do for waste management (however imperfect waste management systems like Canada's ultimately are) (Wilkins, 2017). Given that the dissimilarities between CDR and waste management are generally understated by this heuristic–including the differences in resource demands and the technological complexity of NETs–it is evident that merely designating CDR a government responsibility is an incomplete solution in in the context of a complex regime. In response to this complexity, policymakers must consider the trade-offs associated with path-dependent socio-technical regimes.

As historical institutionalism instructs, institutions shape "not just actors' strategies (as in rational choice), but their goals as well" (Koelbe, 1995, p. 237). This means that when the government institutions in charge of climate policy are confronted with trade-offs, the agency of individual policymakers is constrained by the institution's structure, which is shaped by random historical incidents and landscape changes (Koelbe, 1995). Rather than making self-maximizing, rational decisions, decision-making procedures and precedents shape their reasoning, constraining their choices and perception of what actions are feasible and legitimate. This is why the MLP emphasizes that transitions are often triggered by landscape shocks that destabilize the dominant regime; the system requires niche technologies to adapt to new conditions and restabilize (Geels, 2006). While simulating a landscape shock to destabilize a system is not exactly a feasible (or predictable) means of reconfiguring an outdated regime, policymakers can introduce incremental change in the landscape through infrastructure, ideology change (in terms of what pathways are deemed legitimate in public discourse), and coalitions between regime actors (Roberts et al., 2018). In sum, overcoming institutional 'lock-in' in path-dependent socio-technical regimes requires broad-based political support and change via markets and external pressures.

According to an article on the "politics of accelerating low-carbon transitions" by Roberts et al. (2018), when it comes to amassing political support for new technologies and systems change, it is important to create policies that maximize the co-benefits distributed to those who support the change (p. 304). Building coalitions between government institutions, business, and civil society allows transitions to “draw on support [and capital] from a wide constituency beyond just those with green convictions;” policymakers can emphasize the “more politically resonant issues” that transitions may benefit, “such as personal health, jobs, or security” (Roberts et al., 2018, p. 305). In this way, associating desirable co-benefits with a technology creates external pressures that enable institutions to justify more ambitious policy action despite lock-in pressures. According to the International Energy Agency (IEA), the growth of renewable energy technologies over the past two decades is owed to “stronger support from government policies and more ambitious clean energy goals” devised in conjunction with intergovernmental initiatives (IEA, 2021). These efforts have been supported by a variety of organized coalitions, including the International Renewable Energy Agency and intra-state organizations, which provide policy recommendations and connect industry actors with government decision-makers and technology experts (IEA, 2021). Coalitions such as these establish information-sharing networks that enable innovation by reducing economic uncertainty, legitimizing pathways to renewable energy development, and putting pressure on political regimes to shift their climate policies accordingly. Scaling renewables has also brought co-benefits like pollution reduction and job opportunities (United Nations, 2022). Under similar conditions of carbon lock-in, these factors enabled the success of renewable energy technologies. In order to see similar growth among NETs and overcome institutional lock-in, policymakers must institute similar policies and engage in partnerships to connect actors within the regime. Ideally, this will result in changes to market incentives, knowledge networks, and political institutions' decision-making structures. One specific action state policymakers can undertake is updating their Nationally Determined Contributions (NDCs) under the Paris Agreement to distinguish their CDR goals from their emission reduction goals (McLaren et al., 2019; Poralla et al., 2021). Proper monitoring, reporting, and verification protocols could force institutions to treat the two as separate conditions for successful climate mitigation and recognize the importance of drawing down atmospheric carbon.

2.4.3 What Challenges Will Impact CDR Governance In Canada?

Some models of climate pathways show that renewables and other clean infrastructure scale faster when funds are directed away from NETs and CCS; “in one comparison, near term mitigation is greater by 9.1 gigatonnes of CO_2 by 2030 when NETs were excluded” (Lenzi, 2018, p. 2). Therefore, another policy challenge is selecting which, if any, specific technologies to prioritize in policy development. Implementing CCS technologies alone would require CO_2 pipeline networks to connect industrial emissions sources to carbon storage sites. Coordinating this entails retrofitting costs, would deter emissions abatement by helping companies meet emission reduction targets without reducing fossil fuel consumption, and, if supported by the government, would arguably detract funds and resources from reliable mitigation projects (i.e. scaling energy infrastructure) (Minx et al., 2018; Realmonte et al., 2019). Although Canada houses and funds one of the world's only large-scale CCS projects, retrofitting Saskatchewan's Boundary Dam 3 required a budget of CAD 1.5 billion (Massachusetts Institute of Technology, 2016). The worry is that funding CCS and DACCS simultaneously (and other NETs) would also enable polluters to extend their reliance on fossil fuels and invest in new infrastructure that would create stranded assets should they be prematurely retired at a later stage of the low-carbon transition: essentially, wasting capital and stymying return on those investments (Dion, 2021). At the same time, some CCS may be necessary in more difficult sectors to decarbonize, as is the case for producing essential building materials like iron, steel, cement, and certain chemicals (Gross, 2021). In Canada, bitumen extraction itself is a sector that will require its own transition strategy because, as a product of "decades of government supported research and development" and a conduit of vested interests in both Alberta and federal politics, it is deeply embedded in the current socio-technical regime (Haley, 2011, p. 113). For example, CCS may be the only means of introducing incremental change to the carbon-intensive landscape of Alberta and Saskatchewan in practice. Since the existing policy frameworks in Canada have established that CDR governance will take place at the federal and provincial levels, as well as in the economy and industry, the political interests of individual provinces will be important going forward. Conversely, although DACCS deployment does not carry the same lock-in risk as point-source capture, it could still result in mitigation deterrence if policymakers do not properly establish its role as a transitional technology (Asayama, 2021). Some authors have described this as a ‘moral hazard’ that restricts the diffusion of CDR technologies; CCS may not be inherently bad for the climate and society, but it creates bad incentives (i.e. justification for mitigation deterrence) that risk impeding the low-carbon transition–and the legitimacy of DACCS within it (Jebari et al., 2021).

In so far as critics are concerned that DACCS and CCS will disincentivize efforts to decarbonize by providing the oil and gas sector with the opportunity to generate low-emissions electricity without actually abating emissions (or otherwise increase emissions due to the technology's high energy demands), the availability of low-carbon electricity is far from Canada's greatest concern amidst the energy transition. Apart from Alberta and Saskatchewan, only a small portion of Canada's emissions come from electricity production (8.4%), meaning that in most of Canada, negative emissions from CDR efforts would be mostly free from concerns about having access to renewable energy (assuming a given region continues using renewables to support the added energy demand of DACCS or CCS) (ECCC, 2022b).[7] This also means that DACCS projects would function separately from the country's efforts to decarbonize high-emitting sectors because the technology cannot be dependent on fossil fuel energy (ECCC, 2022b). Decarbonization and efforts to achieve negative emissions should not be grouped together under the same umbrella of mitigation strategies because carbon capture alone cannot even begin to offset the emissions from all other sectors. Considering that Climeworks' largest operational plant, Orca, only captures about 4000 tonnes of CO_2 per year, DACCS projects are far from making a proverbial dent in the atmospheric stores of CO_2; NETs will not actually result in negative emissions for several decades and therefore will not contribute to climate mitigation until they are scaled (Climeworks, 2022; Richie & Roser, 2022). As a reference point, Canada emits roughly 700 Mt CO_2e/yr (ECCC, 2022b). While the potential for growth in CCS and CDR technologies both during and after the transition is great, the rollout of technologies like DACCS in Canada has to pre-empt the slow-moving decarbonization process so that the technology can reach the necessary level of maturity and scale. In turn, policymakers must proactively establish coalitions and institutional norms to help the transition process. The following section will expand on the social and ethical implications of integrating CDR into transition frameworks.

2.5 The Social Dimensions of CDR In the Low-Carbon Transition

Although policy is important in creating the conditions for transitions, "institutional change tends to be designed into many parliamentary democracies through systems of checks and balances among the different branches of government,... [therefore] social change often precedes institutional change in democratic societies'' (Unruh, 2000, p. 322). Socio-technical systems theory, as Trist and Bamforth's case study exemplified earlier in this review, centres on how technological change impacts social relationships and cultural values. Therefore, this review would be incomplete without analyzing how DACCS and CDR will impact social conditions. This section will assess the social, cultural, and ethical ramifications of CDR in the low-carbon transition, emphasizing the aspects of technological change that facilitate 'just transitions' and those that have the potential to create social inequities. Then, it will highlight the social issues most pertinent for implementing DACCS in Canada (for example, by creating potential resource

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[7] These include oil and gas production (27%), transport (24%), buildings (13%), heavy industry (11%), and agriculture (10%)

scarcity). Lastly, this section will contemplate the ethical duties presented by assigning historical responsibility for emissions and how CDR may help to redress climate injustices.

2.5.1 'Just Transitions' and Social Acceptability

By its official definition, a 'just transition' is one which ensures that the workers who supported the old technological regime have adequate economic opportunities in the new regime; according to the International Labour Organization (ILO), "a just transition means greening the economy in a way that is as fair and inclusive as possible to everyone concerned, creating decent work opportunities and leaving no one behind" (ILO, 2021). Since CDR requires network technologies like carbon pipelines, geological storage, and other infrastructure, in addition to the production of a large number of NETs, the transition provides opportunities to re-employ workers displaced by decarbonization, especially those in the fossil fuel sector with transferable competencies (Downey et al., 2021). While the transition may not be as straightforward, expedited, or supply as many equivalent jobs as implied here, it will certainly create more jobs in other parts of the system. For example, scaling renewable energy capacity to meet DACCS demands will create jobs for the local population. However, in a broader sense, a just transition involves ensuring that the low-carbon transition does not create or worsen socio-economic inequities, and policymakers consult with the parties whose lives and livelihoods may be affected by the changes (ILO, 2021). Therefore, communities must understand whether the proposed transition technologies pose any risk to their future socioeconomic well-being.

Thus, social acceptability is a key consideration in the context of a just transition. For a business, the legitimacy and success of its operations against market competitors often depend on whether its customer base believes its conduct is ethical and sustainable, not only on whether the product or service it sells is desirable (Montiel & Delgado-Ceballos, 2014). In a democracy, the politicians similarly have to secure the approval of the electorate to maintain power. To secure social acceptance of new technology (and policies designed to incentivize the proliferation of that technology), both government and private sector actors must ensure that people in society have an understanding of the costs, limitations, and risks that it poses. In a 1982 article, Otway and Winterfeldt discuss this issue, finding that "positions for and against some technologies have taken on the character of ideological commitments" (p. 254). Social perceptions of new technologies are often shaped by socio-cultural discourse rather than a rational assessment of the costs and benefits of a technology. The authors note the old saying,"if you have a hammer in your hand, everything looks like a nail," communicating the idea that perception bias can lead individuals to over-rely on a technology. This is the reality of behavioural carbon lock-in; since society is reliant on fossil fuel-intensive technologies, it is difficult to imagine a decarbonized global economy. However, some worry that this bias will lead society to overestimate CDR's potential and underestimate decarbonization's urgency.

2.5.2 Is Scaling Up CDR Too Risky?

Despite the numerous arguments in favour of CDR in this review, it is important to recognize and address the concerns that incorporating NETs into the transition will result in injustice rather than successful climate mitigation. With a focus on social ramifications, climate researchers Kevin Anderson and Glen Peters wrote one of the most prominent (and highly cited) arguments against reliance on NETs, calling them “an unjust and high-stakes gamble” (Anderson & Peters, 2016, p. 183). For example, some have raised concerns that DACCS serves as a ‘greenwashing’ strategy to allow politically influential industries (like the oil and gas sector in Canada) to delay decarbonization as opposed to a legitimate means of climate mitigation (Erans et al., 2022). Anderson and Peters (2016) also reiterate the idea that CDR poses a moral hazard because the individuals who overestimate the capability of CDR as a climate mitigation strategy will not bear the full cost of that decision should NETs deter emissions abatement and subsequently underperform. Others have argued that the proposed scale of CDR deployment is hubristic because it “implies a major perturbation of land use and biogeochemical flows” (Minx et al., 2018, p. 22). Additionally, some contend that it is unjust to ‘bet’ on the success of technologies that have not yet been proven successful at scale, particularly if betting on negative emissions increases the risks borne by communities and ecosystems whose development and security are already disproportionately impacted by the climate crisis (Fuss et al., 2016; Lenzi, 2018; Minx et al., 2018).

In response to Anderson and Peters’ (2016) position, I would emphasize that it will be a long time before NETs can offset emissions sufficiently to actually help states meet their net carbon emission reduction targets because the technologies are far from capable of sequestering megatonnes or gigatonnes of CO_2 per year, much less the 34 billion $GtCO_2$ the world produces each year (Ritchie & Roser, 2020). In his article on the ethics of negative emissions, Lenzi (2018) writes that “NETs are medium time scale options with costs comparable to mitigation” (p. 2). They should not be considered a mitigation strategy so much as a means of adaptation because achieving emissions reductions via decarbonization is distinct from drawing down atmospheric carbon. Indeed, climate models also chiefly try to minimize mitigation costs but fail to account for the powerful intervening impacts that political, economic, and – importantly – social interventions have in enabling or disabling the development of different mitigation technologies (Lenzi, 2018). For example, since DACCS has relatively small land demands, lock-in potential, and relative flexibility in location compared to CCS and BECCS, developers may be able to avoid some social pushback. As explained in the previous section, creating shared social and political understandings of novel technologies helps policymakers establish them as legitimate (Unruh, 2000).

Moreover, even though the large portfolio of renewables (both existing and emerging) is vast enough to replace fossil fuels in terms of energy generation, the economic and energy-generating potential of these supply-side solutions does not alone guarantee their future implementation (Canadian Institute for Climate Choices, 2021). A research paper by Rogelj et al. (2018) finds that a sub 2°C warming scenario was not possible in climate models where "strong inequalities, high baseline fossil-fuel use, or scattered short-term climate policy" persisted (p. 325). This barrier has nothing to do with supply-side solutions but rather the level of development in the social contexts in which they are rolled out. Therefore, even if DACCS were a 'silver bullet' solution, it would not circumvent the social and political barriers that impede long-term climate policy. Rogelj et al. (2018) also found that decarbonization was more expensive in scenarios where poorer socio-economic conditions persisted for a longer period (Rogelj et al., 2018). Structural barriers to socio-economic development must not be neglected amidst the energy transition, even though overall economic growth should not be high to minimize warming (Rogelj et al., 2018). Yet, to avoid warming above 2°C at all, these scenarios also assume "a phase-out of industry and energy-related CO_2 production at a rate of [about 3% per year,]... combined with rapid upscaling of carbon capture and storage (CCS) and carbon dioxide removal (CDR)," which will inevitably impact employment and social stability (Rogelj et al., 2018, p. 326).

Scenario analyses like the one presented in Rogelj et al. (2018) make it clear that CDR cannot be used for continuing business as usual or addressed separately from issues of decarbonization and social justice; the barrier here is not that DACCS is inherently unethical, rather it is one of ensuring that its place and interdependencies in the network of mitigation solutions are understood by the general public so that DAC cannot be oversold as a mitigation option. However, some studies have found that models in which policymakers over-relied on NETs in their climate policy would see far worse levels of warming – because of the cross-sectoral challenges associated with scaling NETs and associated infrastructure to the degree necessary for significant mitigation – let alone achieve mitigation independent from efforts to decarbonize (Realmonte et al., 2019).

Ultimately, the conclusion that critics like Anderson and Peters reach does not logically follow from the premises of their general argument. Specifically, their assertion that "the mitigation agenda should proceed on the premise that [NETs] will not work at scale" because of the aforementioned risks is not compatible with the reality that NETs are involved in every potential climate mitigation pathway (Anderson & Peters, 2016, p. 183). Again, merely eliminating emissions will not remove excess carbon from the atmosphere. To neglect this reality and the significant role that CDR will play in the low-carbon transition would be to enable much more egregious climate injustices to come to pass in the future. Indeed, rather than 'an unjust gamble,' funding and deploying DACCS technologies as a part of a low-carbon transition strategy may be the only means of ensuring that the countries historically responsible for the highest volume of emissions rectify the damage they have caused by polluting the atmosphere.

2.5.3 What Social Barriers Impact Deployment In Canada?

Canada currently accounts for about 1.6% of global CO_2 emissions, but between the emissions it is historically responsible for and having one of the highest rates of per capita emissions in the world, the country bears a moral obligation to establish itself as an early mover for CDR technologies (Ritchie & Roser, 2020). Foundational in environmental ethics and law is the Polluter Pays Principle, which instructs that the party responsible for pollution pays the cost of remediating damages (Ransom, 2021). A carbon pricing system is a means of ensuring justice per the Polluter Pays Principle (Ransom, 2021). However, though these systems are viable at the state level (where a revenue-neutral tax can help to establish legitimacy), it is unlikely that Canada or any other historically high emitting, sovereign country will take legal responsibility for their contributions to planetary warming. By any measure, the last 20 years of climate negotiations have made it clear that assigning strict responsibility for emissions typically results in states being less willing to commit to binding reduction targets (Plumer, 2015). Nevertheless, Canada still has an opportunity to take a leadership role in climate mitigation, particularly to preemptively address social barriers to deployment.

As Erans et al. (2022) note in their comprehensive analysis of the techno-social barriers to DACCS, stakeholders and policymakers alike have yet to "develop a coherent position toward [direct air capture]" in the way that they have in opposition or support of CCS and A/R respectively (pp. 1390-1391; Reiner, 2016). In the absence of this leadership, establishing the legitimacy of targeted negative emissions policies "will be all the more difficult because public understanding and democratic deliberation on CDR lags other areas of climate policy" (Maher & Symons, 2022, p. 11). NETs are not well understood by the public in Canada and other developed countries, while carbon-intensive energy has been a driver of development and the economy; this entails a significant degree of political support for the oil and gas sector in the general public (Bellamy et al., 2019; Cox et al., 2020; Downey et al., 2021). Although avenues for public engagement in science policy are not well established in Canada, there is yet an opportunity for the federal government and sub-national actors to provide the opportunity for public consultation and public education on climate mitigation technologies (Craik, 2017). Conversely, if policymakers are able to establish functional coalitions between government institutions and technology developers, experts believe that the existing competencies within Canada's oil and gas sector will reduce the costs of innovation (Downey et al., 2021). According to Valente (2012), the literature shows that "social networks can be leveraged to accelerate behavioural change, improve organizational efficiency, enhance social change, and improve dissemination and diffusion of innovations" (p. 49). Per the innovations literature, niche markets can help diffuse technologies between and within communities and socio-political institutions (Valente, 2012). Therefore niche applications of DACCS to improve air quality in confined spaces like submarines have the potential to do more than provide a space for the technology to mature; they may help to overcome institutional, technological, and behavioural lock-in in Canada (Nemet et al., 2018; Lee et al., 2015).

Regarding the moral hazards associated with the technologies, there may be fewer risks given the socio-technical regime and landscape of Canada. The current framework of climate plans, standards, and laws have clearly signalled the government's intentions to achieve decarbonization and the years by which they aim to achieve their goals, namely, in the "2030 Emissions Reduction Plan" and the "Canadian Net-Zero Emissions Accountability Act," also known as the plan for "Net-Zero Emissions by 2050." Moreover, the outlook for CCS and DACCS in Canada differs from that of CCS in the US, where fossil fuels still account for a significant portion of the electricity supply. At the same time, most Canadian provinces have embraced the lower costs and co-benefits of renewables like hydro and solar and the community-level issues associated with scaling renewables; many US states lack the necessary infrastructure (Gross, 2016). However, Canadian CCS projects and DACCS pilot projects, like those in the US, have sold recovered CO_2 to supply EOR, which maintains the demand for fossil fuels.

DACCS also still has water requirements comparable to water-intensive CDR like BECCS and A/R; while water availability, in general, is not a concern in Canada, community-level disparities in water access and availability may stymy efforts to gain a social license to operate in some regions (Indigenous Services Canada, 2022). There is a significant overlap between potential storage sites and indigenous lands in areas like southern Saskatchewan (some of which are still under long-term drinking water advisories [DWA]) (White & Gauthier, 2019). In Canada, Indigenous communities are too often subject to environmental degradation from toxic waste and resource contamination, despite their land rights (Stefanovich, 2019). In addition to the risks this poses to Indigenous lives and livelihoods, the government's negligent environmental management has made it difficult for Indigenous groups to carry on traditional ways of living on their ancestral lands (Stefanovich, 2019). Indigenous communities have become 'sacrifice zones,' communities in which patterns of environmental racism and physical damage make it evident that they do not receive equal protection under the law (Lerner, 2012, p. 2). While there is little insight into how these historically disadvantaged communities feel about CDR and NETs, the pipeline infrastructure needed to transport carbon may be a significant social issue. Though pipelines will likely be necessary for transporting the carbon recovered from DACCS facilities, these pose their own hazards. As journalist Dan Zegart (2021) detailed, the rupture of multiple CO_2 pipelines in the U.S. resulted in the release of highly concentrated CO_2 and left locals with lasting respiratory issues. Despite the Federal Government's duty to consult with Indigenous groups, Canadian pipeline projects have been met with increasing social opposition, particularly from Indigenous groups whose land pipelines, like the Coastal GasLink pipeline in British Columbia, run through (BBC World News, 2020). Although these pipelines transport natural gas rather than carbon–and they are contested since they prolong fossil fuel reliance and construction risks environmental damage–it is possible that they may face similar blockades and dissent if nearby communities believe that they pose a risk to their safety or support an illegitimate, 'greenwashed' socio-technical regime. The construction of carbon pipelines in Alberta has thus far faced little public opposition. Time will tell if carbon pipelines prove a safety risk or if proper management can eliminate such risks. In any case, this section has shown how important it is for a regime to secure social well-being and justice by transitioning to a low-carbon system. Acceptance from and consultations with marginalized communities like these are vital if this transition is to be just and sustainable.

2.6 System Interactions

Research articles by Buylova et al. (2021), Fyson et al. (2020), Lenzi (2018), Morrow et al. (2020), and Pozo et al. (2020) all emphasize how CDR and NETs can support a just transition by enabling countries to stay within their carbon budgets without compromising development and equity. In line with these authors, I would argue that the critics of NETs who envisage a just low-carbon transition without the technologies are advocating on behalf of strategies that may have been the most effective and equitable choice thirty or more years ago when the international scientific community began to acknowledge anthropogenic climate change as a serious threat. Today, a state's non-binding emissions reduction targets and commitments to planting trees are no longer sufficient; even if we manage our emissions properly going forward, the stock of carbon in the atmosphere will remain there for centuries if no actors intervene (Buis, 2019). Moreover, as Jebari et al. (2021) highlight, policymakers do not have to choose between deploying CDR or scaling renewable energy production. Rather than mutually exclusive as critics fear, the technologies are highly complementary; for example, BECCS achieves both removal and energy generation, while certain DACCS technologies use geothermal heat (Jebari et al., 2021; Morrow et al., 2020; Realmonte et al., 2019). Promoting CDR is also not the same as implementing a significantly riskier geoengineering strategy like solar radiation management, nor does it necessarily connote a hope that it will deliver a 'silver bullet' climate mitigation solution (Lenzi, 2018; Otto et al., 2021). While some ethical issues surrounding CDR may entail actual risks, policymakers should allow such issues to guide regulation rather than entirely obstruct the development of the technologies. After all, the technical possibility of decarbonization by the mid-21st century does not equate to the scenario's overall viability and feasibility. "Typically, feasibility refers to a multi-dimensional concept that considers aspects of geophysics, technology, economics, societal acceptance, institutions and politics, among other disciplines" (Rogelj et al., 2018, p. 330). As the alternative to performing large-scale CDR via NETs, mid-century decarbonization is becoming less and less feasible as global mitigation efforts stall.

Path dependencies within the current sociotechnical system will, in part, determine what DACCS policy looks like in practice. Whereas the technologies to support the incumbent regime have "streamlined regulatory processes, user-friendly sources of information, and full-service vendors,... the costs of gathering and processing information, developing a patent portfolio, and designing and enforcing contracts relating to the purchase and installation of GHG-reducing technology can be prohibitive" (Brown et al., 2008, p. 129). Who pays these transition and scale-up costs again depends on policy support, regulations, funding availability, and individual business decisions. Unlike some literature seems to suggest, DACCS system policies will not be an entirely new and separate set of tools. Rather, the sub-system will develop within and amongst existing systems and policies, social conventions, institutions, and economic circumstances. Based on the observation that DACCS and CDR, essential in a low-carbon transition, can be implemented without worsening carbon lock-in with careful government management, this review has located several practical policy recommendations for deploying NETs in the literature. With an understanding of existing features of the Canadian landscape and climate policy, we can make better observations about how the system needs to change while minimizing the impact of path dependencies as mitigation deterrents. This section has characterized Canada's regime and landscape conditions by categorizing different types of system barriers and demands. While the different categories of policies and system barriers have allowed me to make sense of the regime-level governance challenges and recommendations within the literature on transitions and CDR, I have also found that these categories overlap significantly. For example, discussing economic barriers and contingencies for DACCS deployment required me to discuss policy tools like carbon pricing systems. Ultimately, the MLP theoretical framework has proven to be the best fit for my purposes because it has allowed me to identify the different components of a socio-technical system and how they interact with one another to shape economic, political, and social outcomes; it has also helped me understand how policy can stimulate systems change in the absence of an external landscape shock.

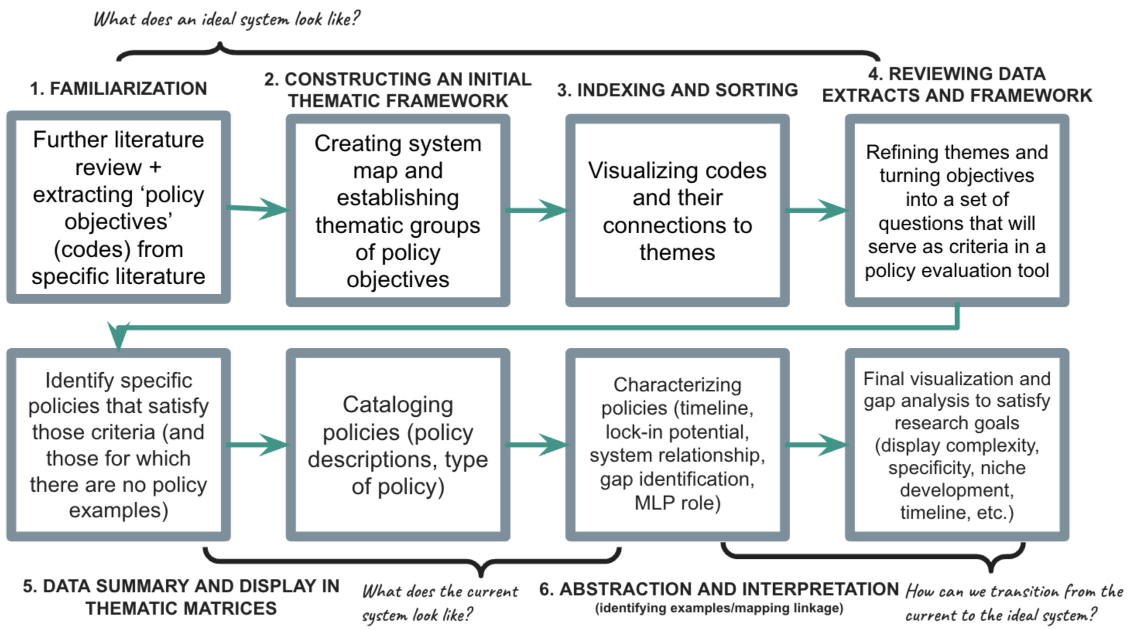
The study's theoretical framework was crucial in conceptualizing the system and designing a methodology to effectively sort and analyze the system's objectives. A 2021 paper by Schenuit et al. was one of the core studies that influenced this research in terms of theory and subject: the authors used the MLP as a means of "concept[ualizing] overall dynamic patterns in socio-technical transitions" (Geels, 2011, p. 26; Schenuit et al., 2021). The theory helps to "identify path-dependencies, lock-in incentives, and power distributions within a current system, as well as in emerging and diffusing innovation dynamics" (Geels et al., 2017; Schenuit et al., 2021, p. 3). By presenting a simplified model of a socio-technical system, the MLP enabled the authors to observe patterns in society that allow niche technologies to force change in the regime. Schenuit et al. (2021) applied the MLP to a range of case studies on CDR policy in 9 OECD countries (Ireland, Germany, Sweden, Norway, the United Kingdom, Australia, New Zealand, and the United States), identifying a host of policies directly related to CDR and discovered an emergent typology for CDR deployment strategies. They conducted their comparison by highlighting (1) the institutional setting, actors, and coalitions in the state; (2) CDR accounting and methods; (3) policy instruments; (4) relevant expert bodies and science; and (5) developments in CDR niches for each case study. Though I also explore these dimensions, this study differs from the methodology in Schenuit et al. because it focuses on a single case study not explored in their paper. I also adopted a systems understanding that expands the range of policies considered relevant to CDR deployment (e.g. the broader scope of climate mitigation and environmental/resource-related policies rather than technology-specific incentives). This study also focuses on a single NET rather than all CDR techniques, which include nature-based solutions. The following chapter explains how I used the MLP in combination with several methodologies to expand on the work done by Schenuit et al. (2021) and better understand the DACCS system.

3. Methods

The primary method of the study is framework analysis, a qualitative method developed by academics Jane Ritchie and Liz Spencer (Ritchie & Spencer, 1994). Framework analysis is a form of thematic analysis that adds the additional step of 'data summary and display' (Spencer et al., 2013). The method's steps–in order–include familiarization, constructing a thematic framework, indexing and sorting, reviewing the data extracts and framework, data summary and display in a thematic matrix, and, lastly, abstraction and interpretation. Framework analysis is suitable for this study because its design enabled me to collect, categorize, and visually display data as I investigated how themes map onto a project's case studies. As I described my research process in this chapter, I referenced the corresponding stage of the framework analysis and described how my application of the method departs from the standard application. Once the data was collected, summarizing and displaying it in a matrix and other diagrams further enriched the analysis with summaries, justifications, and commentary at various cross-sections and levels of abstraction (Spencer et al., 2013). I will also explain how I used several other tools and methods to supplement my analysis at different stages, tailoring the process according to my research goals. Figure 3 is a flow chart I created that describes the stages of the research process to show how each part of the methodology I describe work together to answer my research questions.

Figure 3

Research Stages Diagram



3.1 Familiarization and Constructing a Thematic Framework

The first two stages of framework analysis are familiarization and constructing an initial thematic framework. In this study, the two happened in unison. The purpose of these steps is to establish a characterization of what the system currently looks like. In the familiarization stage, "researchers immerse themselves in their data" to understand the context and ensure that the data supports the themes they develop for their analysis (Spencer et al., 2013, p. 362). Subsequently, constructing an initial thematic framework entails sorting topics explored in the familiarization stage into sets of themes and sub-themes. In the context of this study, the literature review I wrote at the beginning of the research process – during which I reviewed nearly 400 articles related to CDR, climate policy, theory, and methods – was essential in constructing an initial framework. Then, after establishing a comprehensive understanding of the literature, I extracted the elements I believed were most important for scaling up DACCS and plotted them on a mind map of the system (see Appendix A).

Developing an initial thematic framework (the second stage of the methodology) helped me to further familiarize myself with the literature in the context of my case study; I developed an initial thematic framework by continuing to plot the various nodes and connections within the DACCS system in Canada (at multiple levels of abstraction: from specific policy documents to general policy categories or sectors) based on the information I had learned about DACCS and its requirements.[8] Soft-system methodologies (which include the initial 'systemigram' I produced) model the components of complex systems, providing researchers with "insights into [its] overall construction and operation" at the early stages of conceptualizing the research problem (Mehler et al., 2010, p. 1). Other research studies, such as Ramsay et al. (1996), Blair et al. (2007), and Bellmann (2019), have applied systems thinking and systemigrams to aid management and policy decisions. Additionally, a few other studies utilize the MLP in conjunction with a soft-systems methodology. For example, a 2014 study by Morrissey et al. on agrifood regimes applied the MLP in conjunction with a soft-systems methodology, mapping the components of the system visually to clarify the flows of resources, associated processes sub-processes, and how each acts at each of the three MLP levels.

Similarly, Bößner et al. (2019) used the MLP to inform their flow diagram of the barriers and opportunities in the biogas technology system in Bali, Indonesia. Geels' papers on the MLP also typically contain visual aids to explain these complex system dynamics. These articles influenced this study's design in its early stages, incorporating systems thinking, systemigrams,

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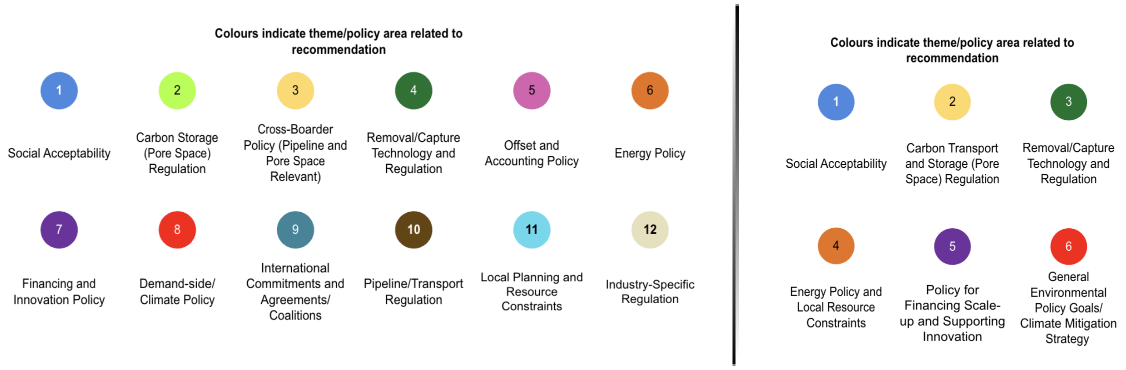
[8] See Appendix A for the initial systmigram

and other visualizations. The visualization and knowledge of the literature helped me identify key objectives in the system, such as having financial incentives for innovation and appropriate climate policies in place (e.g. a carbon pricing system). At this stage, I developed 12 themes based on how I had grouped policies in my map and my understanding of the technology's needs for scale-up. Figure 4 shows the theme categories and how they coalesced.

Figure 4

Theme categories



The themes I selected in the initial thematic framework construction stage (left) and the themes after they were narrowed (right). The initial themes were used to chart the codes developed in the subsequent stage (See Appendix B)

In addition to the comprehensive literature review, the familiarization process also involved selecting and closely examining a limited number of articles discussing CDR and DACCS policy. These articles serve as the data in a document analysis in which I extracted the objectives that the authors believe a DACCS system needs to fulfill. The article details and selection criteria are recorded in a table.[9] As a requirement, all articles had to discuss policies related to CDR technology. The articles also had to contain actionable policy recommendations rather than theorize about policy; those articles that discussed DACCS or Canada specifically were indicated in the table accordingly. For example, although Holly Buck's article, "Should carbon removal be treated as waste management: Lessons from the cultural history of waste," discusses an interesting public utility model of CDR governance and deployment, the article speculates on how the history of waste management may inform future policy development, rather than suggesting a particular strategy. There were several other articles that, while significant to the literature review, I excluded from the group for similar reasons.

While the literature review stage was my primary means of familiarizing myself with the discourse of the most relevant literature to my study in the first stage, closely reading these

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[9] See Appendix C. The table also includes the number of citations each article had at the time of selection. However, given that most of the relevant articles on NETs are very recent (published within the last five to eight years, with many in the last two years), the number of citations is not a particularly important selection criterion, especially since the selection includes white papers in addition to academic articles. Since the technologies themselves are still developing, the academic discourse around how to govern them is still an emerging area of literature.

articles in this stage allowed me to familiarize myself with the kinds of policies and infrastructure needed to construct the system. I first extracted the policy objectives and recommendations that the articles prescribed by coding the text of the articles, adding a code for each one in a particular article. This process was done manually by uploading the 23 articles to a Zotero file and adding the codes as tags in the application's interface. Throughout this paper, I will refer to these data extracts as policy objectives rather than 'recommendations' because, while some identify specific policies to introduce or change, others propose general goals that a future policy framework should fulfill. As shown in Table 1 below, I created new codes as I came across excerpts that seemed to suggest policy objectives. In addition to the inductive policy objective codes I developed, I used the 12 theme categories as an initial set of deductive codes. However, although I applied deductive codes, I did not review each article multiple times to ensure that I recorded every incidence of a particular code. While I did record numbers to indicate how often I observed a particular code, I do not believe these numbers are especially robust (as they would be in a bibliometric study). In the description of the following stage, I describe sorting these codes based on their thematic categories.

Table 1

Familiarization and Coding

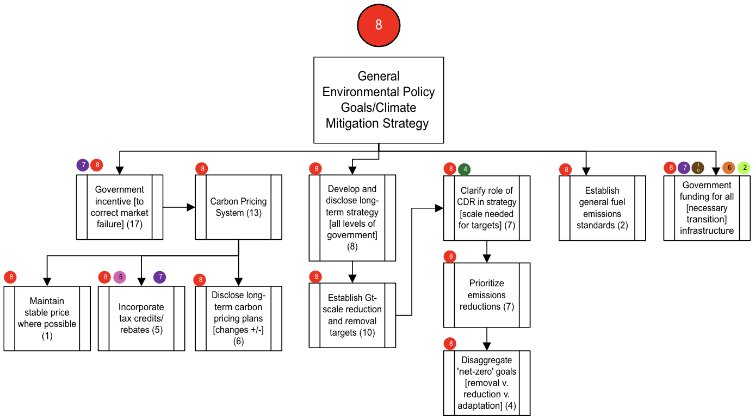
Source	Excerpt	Code
McLaren, D. P., Tyfield, D. P., Willis, R., Szerszynski, B., & Markusson, N. O. (2019). Beyond "net-zero": A case for separate emissions reduction and negative emissions targets. Frontiers in Climate, 1. https://doi.org/10.3389/fclim.2019.00004	"Avoiding double counting across two distinct regimes for target setting and monitoring of progress would require careful design, and would not be politically trivial." (McLaren et al., 2019, p. 4)	● Prevent double counting in national emissions inventory/NDC accounting ● Prevent double counting in emissions trading
Honegger, M., Poralla, M., Michaelowa, A., & Ahonen, H.-M. (2021). Who is paying for carbon dioxide removal? Designing policy instruments for mobilizing negative emissions technologies. Frontiers in Climate, 3. https://doi.org/10.3389/fclim.2021.672996	"Increasingly specify intermediary, sector-specific objectives, including for CDR-related action and elaborate a quantitative carbon budget that represents a fair share of the collective effort." (Honegger et al., 2021, p. 12)	● Establish intermediary, sector-specific objectives ● Back NDCs with specific policy instruments
Beuttler, C., Charles, L., & Wurzbacher, J. (2019). The role of direct air capture in mitigation of anthropogenic greenhouse gas emissions. Frontiers in Climate, 1, 10.	"DAC's biggest challenge is achieving climate-relevant scale, which—as any other NET–it cannot do without a sufficiently high price on carbon or other relevant policy measures" (Beuttler et al., 2019, p. 6)	● Carbon price ● Demand-side/climate policy

3.2 Indexing and Sorting

In a framework analysis, the indexing and sorting stage is where a researcher uses their thematic framework to label the data and divide it into chunks of similar codes (Spencer et al., 2013). The purpose of this stage is to impose order on the policy objective codes I developed and determine whether they could fit neatly into the thematic framework. After developing the codes, I sorted them into theme groups and ordered them in a hierarchical chart.[10] The objectives hierarchy chart allowed me to classify the sub-objectives (or means objectives) that fulfill the more fundamental system objectives indicated by the core organizing themes (Clemens & Reilley, 2014).

Figure 5

Extract from policy objectives chart (See Appendix B for full chart)



This process also involved filtering out redundant codes and drawing connections across codes and themes; some objectives in the literature were related to multiple themes. While I organized those codes under a primary theme, I noted other themes they were related to with a colour-coding system where each theme was designated a colour and codes were charted with marks bearing each colour next to them. This process was important for creating a more understandable map with a legend, rather than a cluttered diagram with arrows connecting each code to another (as my initial systemigram did). I ultimately added over 175 codes into the chart in Microsoft Visio, a portion of which is shown in Figure 5, to demonstrate its format.

3.3 Reviewing the Data Extracts and Framework

The next step, reviewing the data extracts and framework, entailed reading through the gathered data and thematic categories and further refining category labels since “initial thematic

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[10] See Appendix B

frameworks are often rather crude" (Spencer et al., 2013, p. 363). Therefore, the purpose of this stage was to create more coherent groups and remove redundancies. This is the stage in which I consolidated the theme categories into six themes and reformatted the objectives as close-ended questions in a spreadsheet. Since several categories had very few codes and had significant overlap with the codes in another theme, reducing the number of themes helped to streamline the data analysis. Additionally, as I reviewed the codes, I noticed redundancies and combined objectives that were similar. For example, the "International Commitments and Agreements/Coalitions" category did not ultimately include any state or sub-state-level objectives that could not have been placed in the "General Environmental Policy Goals/Climate Mitigation Strategy" category. The reason I rephrased the objectives as questions was to frame the objectives as criteria for an optimal DACCS policy, creating a tool for assessing the system. Each question asks whether a particular objective is present in the assessed policy framework. Thus the codes became a working framework for evaluating my case study in the following stages. Table 2 shows an example of these questions.

Table 2

Developing assessment questions from codes

Theme category	Code	Sample questions
Social acceptability and public interest	● Ensure appropriate public participation/education on CDR ● Just transition policy ● Conduct local consultations to identify community benefits	● Do the policies include measures to ensure project developers communicate potential risks and general information on the technologies to the public? ● Do the actors frame the problem in the context of a 'just transition' and CDR as a supplement, not a substitute, for decarbonization? ● Are developers expected to confer some benefit or economic opportunity to the local population?
Carbon transport and storage regulation and infrastructure	● Removal/storage as public goods ● Establish liability for leakage around storage sites ● Clarify pore space ownership	● Does government policy frame carbon removal and storage as public goods? ● Has the regime clarified pore space ownership and established liability for leakage?
Removal/capture technology availability and regulation	● CDR specific policy ● CDR technology deployment mandates ● Policy distinguishes types of NETs, their inputs, their sustainability	● Does the regime contain CDR or DACCS-specific regulations, plans, or near-term incentives (e.g. mandate for DAC-derived fuels)? ● Have policymakers instituted CDR deployment mandates (in their own operations or in the private sector)? ● Do policy plans differentiate

		between types of CDR, their needs, limitations, potential, and impacts?
Energy policy and local resource constraints	● Avoid fossil fuel energy dependence ● Consideration for local resource constraints (water availability and environmental damage)	● Is new infrastructure being designed to avoid fossil fuel energy dependence? ● Are project developers required to assess the sustainability of accessing local energy and resource constraints (i.e. water, land-use constraints) as critical inputs for DACCS?
Policy for financing scale-up and supporting innovation	● Government incentive ● Identify early niche markets/adopters ● Develop stable [non-carbon tax] revenue streams	● Do government incentives seek to correct the 'market failure' that has contributed to the climate crisis? ● Do government policymakers support the creation of a niche utilization market? ● Do the plans of domestic developers and/or policymakers help to secure multiple streams of revenue (e.g. rather than relying upon carbon-tax revenue alone)?
General environmental policy goals and climate mitigation strategy	● Prioritize emissions reductions ● Carbon pricing ● Disclose long-term carbon pricing plans	● Does each level of government primarily seek emissions reductions via energy system decarbonization? ● Does the regime have a carbon pricing system (carbon tax or cap & trade)? ● Have policymakers disclosed long-term carbon pricing plans (increasing or decreasing)?

3.4 Data Summary and Display

The first four stages functioned to understand what the ideal system for scaling up and coordinating the development of DACCS might look like. These stages partially fulfilled my first research question by identifying policies that would create that kind of change in the system. However, this data was not specific to Canada, as only three of the 23 articles discussed NETs in Canada at any length. Therefore I still needed to incorporate information about my case study to answer all my research questions. While I had followed the framework methodology steps until this point, a typical study of this format would evaluate the data gathered in the first four stages and populate a matrix with those codes, themes, and data extracts. Instead, my study used the data collected in the first stages as criteria by which to evaluate policy examples from an additional database. I adapted the data collection and analysis process to better address my research question and properly evaluate the existing policies related to DACCS in Canada. I drew from the Canadian Climate Institute’s climate mitigation policy database, which includes descriptions of all relevant policies at the federal and provincial levels (Bryan et al., 2022). The use of this database allowed me to characterize the existing system related to climate policy and interventions in Canada. However, since the database is specific to climate mitigation policy, I supplemented the data with additional environmental policies that I believed would be relevant to DACCS development which were not captured by the Canadian Climate Institute’s database (e.g. the Canadian Environmental Protection Act relevant responsibilities described within it). Although federal policies were more often the focus of my analysis, I highlighted relevant policies under provincial or shared jurisdiction. In addition, I drew on further examples of government policies from documents and laws that, as more general environmental (non-climate-related) policies, were not included in the database. The boundaries of the policies I chose to examine were determined by the types of policies highlighted within the database (which, for example, did not include tax law related to climate incentives). The total sample size (number of policies listed in the database) was 457. I compared these policies to the criteria derived from the literature and used them to characterize the policy landscape in Canada at present.

I summarized how the policy examples fit the criteria in the ‘data summary and display' stage. For all of these criteria, but especially those indicated as partially fulfilled or absent, I explained my reasoning to justify my assessment. In addition, the matrix includes several other columns, which include the purpose of the policy as stated in the database (or elsewhere for external examples), the type of policy action (which is also a categorization taken from the database), the related level of the MLP (landscape, niche, regime: culture, symbolic meaning; markets, user practice; techno-scientific knowledge; technology; infrastructure; industrial networks, strategic games; and sectoral policy), notable connections within the system, technology lock-in risks, and timescale for policy deployment (~2030, ~2050, ~2100 and beyond). These categories allowed me to summarize the important elements of specific policies while constructing the cross-sections of themes and cases typical of framework analysis. However, I did not assess all 457 policies in the database; I screened the dataset first and excluded the climate mitigation policies that would not affect DACCS development.

I also established a 'criticality' measurement to filter relevant policies in the sample from those irrelevant to scaling the system. Policy objectives that are directly related to the system and are necessary for its function were given a score of 3 (e.g. the technology itself, sorbent materials, subsidies); objectives that are indirectly related to the system technology but are still necessary were given a score of 2 (e.g. having a variety of storage options or a multi-modal CO_2 transport system); indirectly related objectives that optimize system functioning but are not strictly necessary were given a score of 1; all other objectives or climate mitigation policies in the database that do not fit these criteria were given a 0 and omitted, save for a few that serve as examples in cases where a particular type of policy action has been effectively implemented in another area or sector. After filtering policies, the number of relevant policies was n=174.[11]

It is also important to note that not all of the objectives in the matrix are policies that are explicitly recommendations or imperatives for a DACCS policy framework. In the matrix, I organized questions based on the objectives hierarchies I established in the indexing and sorting stage. This stage answered one of this study's core research questions through an investigation of how Canada's current system looks.

3.5 Abstraction and Interpretation

The final stage of the framework analysis is abstraction and interpretation, wherein the researcher must identify examples and map linkages between themes and cases. In this stage, I described my findings to tease out the gaps in the current policy framework and associations between different policy categories. First, I assessed my findings in relation to the MLP framework. Then, I explained why particular gaps might exist and how policymakers may fix them.

In this section, I referenced several sources on policy analysis containing example questions, including Cardno (2018) and Ritchie & Spencer (1994). Ritchie & Spencer (1994) identified distinct types of policy analysis questions, such as evaluative questions, which appraise the effectiveness of what policies exist, and strategic questions, which identify theories, policies, plans, or actions for the problems the researcher defined (p. 174). I used these questions to guide my analysis through the discussion section of this thesis. During this analysis, I again created a visualization of the system to update my earlier understanding of its components, organize my results, and aid my analysis.

The gap analysis is a critical part of the study because it allowed me to consider how policymakers might create change over time that favours CDR technologies like DACCS to reach scale by mid-century. A gap analysis is a management process used to determine the discrepancies between the current state of affairs within an organization or system and their ultimate performance goals for the future (Hayes, 2022). Although typically used in commercial settings to improve a company's efficiency, the benefits of taking a gap analysis approach to

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[11] Including policies from the CCI database and other Canadian environmental policies

analyze the results of this qualitative research include identifying the most critical areas where change is needed in the system and reducing some of the risk and uncertainty that investing in CDR entails. Since I designed the matrix in the previous stage to clarify gaps and potential lock-in risk, performing a gap analysis to determine how policymakers should address the gaps is the only step left to complete. I identified key governance gaps and barriers and summarized my rationale for identifying them based on the literature and existing policy examples. In my study, the objective of the abstraction and interpretation section was to understand how the necessary socio-technical transition will happen, using the MLP to create a theory of change. In doing so, I expanded on observations and policies noted in the matrix. This section was organized based on the categories of my thematic framework.

3.6 Limitations

Though I completed my research with results and analysis that answered my research questions completely, several factors limited the research activities I could complete to further support the results I present in the subsequent section. A first limitation of the study's results is that a number of the policies, including funding, incentives, and regulations, are currently being developed by government agencies. As a result, there were several assessment questions for which I did not have enough information to answer completely or definitively, given the limited scope of publicly available information at this stage. This ties into another limitation: this study does not include interviews of relevant parties to better understand the policies currently in development (and others that are still unclear relative to CDR). While I believe this would have revealed previously inaccessible information, I am also unsure that any government authorities would have been able to disclose any additional information had I the time to organize and conduct such interviews. It is certain that with the release of these policies and plans in the coming months and years, more information relevant to CDR and DACCS will become available and spur further technology and regulatory developments.

Another result of this limitation is that the policy examples I was able to draw on when constructing the matrix were limited, meaning that I often highlighted different features of the same policies across several theme sections. This did not reduce the quality of the analysis because the cross-system impacts of policies are important to highlight. Still, some of the criteria had only these ancillary aspects of policies as examples, which speaks to the system's gaps where there was inadequate support to fulfill important policy objectives.

The policy objectives that I used to assess the system themselves are also limiting factors in the scope of my results. I drew the objectives from the stated or implied policy recommendations within the 23 articles I located that specifically addressed NETs and policy. While this set of articles may not account for the complete breadth of literature that addresses these two subject areas simultaneously, they are the ones I was able to locate that both fit those criteria and made actionable recommendations. Although this is not a bibliometric study, the number of articles I used as data is low, which speaks to the newness of this area of study. Still, after collecting 175 objectives from the articles, I adapted them all into questions I would use to assess the current system (after removing redundant codes). In doing so, I treated all recommendations as somewhat equal, even though some were present in most articles, while others were only present in one or two. To manage this design issue, I grouped similar objectives and placed more prominent recommendations ‘higher’ in the hierarchy of questions. However, that was not the only criteria according to which I sorted them. Questions that were lower in the hierarchy (typically ordered as Roman numerals in the matrix) were often weaker recommendations that represented policymakers' options in the system's context (for example, determining whether a system has a carbon pricing system would be a core question, while determining whether it is a tax or credit-based system might be a lower tier question). For this reason, I also did not tally the number of criteria that the policy framework met; this number would not have been informative, given the nature and difference in the occurrence of recommendations in the literature. Though I attempted to design around these potential shortcomings, the resulting criteria are likely less user-friendly if readers assume the number of criteria that were met should be totalled by section rather than assessed on a case-by-case basis. Also, biases may have influenced my assumptions in the research process.

As noted in the subsections above, I did not review articles repeatedly in the coding process to ensure that I recorded accurate numbers for the frequency of particular policy objectives mentioned in the articles. Any numbers that I would be able to draw from that stage of the research would not be necessarily accurate or rigorous. Additionally, I assumed that, based on the design of the study, all of the recommendations made in the articles are credible recommendations. Examples include the assumptions that underlie the study itself (accepting the premise that CDR via DACCS is necessary for long-term climate mitigation and management), the fact that I am a single person coding data and combining sources of qualitative data, and my decisions on whether certain criteria are important ‘key’ criteria and what constitutes an objective to extract from the literature and include in the study. To avoid confirmation bias in the coding process, I extracted as many objectives as I could identify from each article, even though some only held slight differences compared to other codes I recorded, later reviewing them to remove redundant codes.

Further research should explore DACCS in Canada and other countries, utilizing some of the methods I could not use in this research, including interviews, comparative analysis, and quantitative methods. Moreover, given the framework I have already created for assessing DACCS systems, I expect to refine the objectives and categories further, adding new information when new significant studies in the subject area and policies are released (several relevant articles have already been published since I completed data collection).

4. Results

This chapter summarizes the findings of my research study, which examines the scope of Canadian policies related to DACCS development and scale-up. It will overview the results from each theme category, providing example criteria, policies, and gaps observed in the larger matrix. I will explain how the results table is meant to be read and interpreted. The table that follows records observations and descriptions of policies relative to the criteria I created throughout my research. Although I have excluded some columns of the table (to conserve space), such as criticality, policy descriptions, and policy type, the table is a comprehensive look at the kinds of policy objectives (column 1) and policy documents (column 3) I collected, as well as their position and influence within the socio-technical system, as indicated in the fourth and final column. The questions related to each theme category are addressed in separate table sections. The 'policy objective' column organizes questions with more central policy objectives, denoted by numbered questions and sub-objectives (or means objectives) that help to fulfill core objectives (Clemens & Reilley, 2014). The purpose of designing sub-objectives (ordered alphabetically or by Roman numerals in the table) was to group similar objectives and differentiate the different levels of abstraction that the criteria described. The second column indicates whether I observed policies that fulfilled each criterion during my research. I used three symbols to indicate criteria fulfillment: a black checkmark (✓) when the policy met the objective, a blue checkmark (✓) when the criterion was partially fulfilled, or a red (✘) when I could not locate a policy that fulfilled the objective in question. The next column lists policies that allowed me to determine whether the criteria were fulfilled; it occasionally explains the purpose or mechanism of the policy in question. The 'MLP Level' column is used to indicate which of the seven system components of the system I believe a particular policy objective or example would interact with; while some are self-explanatory (e.g. carbon pricing impacts markets and user practices), others may require further explanation and are accompanied by an additional note on my rationale for how they contribute to the creation and improvement of the system. Other sections lack MLP commentary because it is adequately captured by earlier commentary in the same theme section. Explanations and justification for the policies I highlight are not included for every policy in this chart, both in light of the spatial constraints of the table and because many are self-evident; however, the original Excel table in which I catalogued them includes this information in greater detail. I did not place policy examples exclusively in one section or another. Instead, I aimed to highlight the aspects of the policy that allowed it to meet each criterion separately. The final column lists the points of the socio-technical system at which the policies and objectives exert influence over the transition process and how the DACCS system develops within that process. These connections will be elaborated upon and analyzed in the subsequent discussion chapter.

Table 3

Policy Assessment

✓ =Policy is present, ✘ =Policy absent, ✔ =Partial fulfilment of criteria (complete gap identification)

	Policy Objective	Present?	Policy	MLP Level
	SOCIAL ACCEPTABILITY			
1)	Have government actors, developers, or other private sector stakeholders attempted to improve the public's awareness by increasing their communications about the role of carbon dioxide removal (CDR) and direct air carbon capture and storage (DACCS or DAC) in their long-term climate strategy?	✔	• DACCS, CDR, CCS mentioned in documents like the Healthy Environment and Healthy Economy plan, the 2030 Emissions Reduction Plan, and the Pan-Canadian Framework on Clean Growth and Climate Change • ECCC: Climate Action Awareness Fund	Regime: Culture, symbolic meaning; Regime: Markets, user practices; Regime: Technoscientific knowledge (some top-down action to incorporate technology into climate strategy creates awareness in society, which impacts markets)
a.	Do the actors frame the problem in the context of a 'just transition' and CDR as a supplement, not a substitute for decarbonization?	✓	• General guidance: "Do not set targets in isolation...Should the oil and gas sector not meet [40-45% below 2005 level] GHG emissions targets by 2030, other sectors would be required to do even more for Canada to achieve its target, or other approaches like carbon removal would need to be invoked" (ECCC 2022, p.196) from Canada's 2030 Emissions Reduction Plan • Employment and Social Development Canada: Future Skills Centre • Employment and Social Development Canada: Community Workforce Development Program • Employment and Social Development Canada: Sectoral Workforce Solutions Program • Employment and Social Development Canada: Skills for Success • ECCC: Supporting Sustainable Jobs program	Regime: Culture, symbolic meaning; Regime: Markets, user practices (labour transition)
b.	Have policymakers used existing regulations to reduce uncertainty and inform their community engagement approach (e.g. grassroots communication on existing protocols for managing hazardous materials and chemicals involved in the DAC process or general risks associated with different types of climate actions)?	✔	Municipal and provincial regulations and procedures can be applied to the hazardous waste involved in the DACCS process (e.g. potassium hydroxide in solvents). For carbon storage, some general principles apply at the federal level (e.g. the Crown owns all water), but there are many unanswered questions about the legal requirements for storing carbon in geological reservoirs, which will differ across provinces.	Regime: Sectoral policy; May aid/hasten niche development
2)	Do the policies include measures to ensure project developers communicate potential risks and general information on the technologies to the public?	✓	Impact Assessment Act and Canadian Energy Regulator Act, 2019	Regime: Markets, user practices; Regime: Culture,

				symbolic meaning (perceived risk of tech)
a.	Are there existing policy mechanisms in place to support bi-directional and/or iterative communications?	✓	Section 35 of the Constitution Act, 1982: common law duty to consult	
b.	Is information being communicated to the general public?	✓	Cabinet Directive on Regulation s.4.1; communicates the government's duty to ensure the regulatory process is transparent and includes meaningful public engagement	
c.	Is information being communicated to the communities that are local to the sites or proposed sites of carbon removal or carbon storage activities?	✓	See above	
3)	Does the regime require developers to identify the specific socio-economic, political, techno-infrastructural, and landscape conditions that determine a host community's needs and vulnerabilities?	✓	Impact assessment and duty to consult requirements (see above)	
a.	Do these requirements include measures to ensure that the energy and resource needs of the community can be met or expanded without disrupting local activity and welfare?	✓		
b.	Do existing policy guidelines include protections and community engagement processes for novel technologies?	✓		
	i. Are project developers required to gain consent or otherwise ensure social license to operate?	✓	2030 emissions reduction plan: Canada's next steps to clean air and a strong economy: "Ensure that all emission removal methods contemplated – such as nature-based solutions and carbon capture, utilization, and storage – uphold First Nations right to self -determination, including the minimum standard of free, prior, and informed consent [To be clear, this is not an endorsement of any emission removal technology. First Nations believe emission reduction must be prioritized over removal, however, given the emphasis in the most recent federal budget, any pursuit of emission removal approaches or technologies must be done with the free, prior, and informed consent of First Nations]" (Minister of Environment and Climate Change 2022, p.162).	
	ii. Are project developers required to hold iterative local consultations to ensure needs and concerns are addressed satisfactorily?	✓	Investing in Canada Community Employment Benefit for major infrastructure projects (Agencies like NRCan, Crown-Indigenous Relations and Northern Affairs Canada, and ECCC have projects meeting these requirements). Participation is encouraged but not required for the Investing in Canada Infrastructure Program participants.	

c.	Did regime policymakers co-develop engagement plans with historically disadvantaged segments of the local population (i.e. indigenous communities)?	✓		
d.	Are developers expected to confer some benefit or economic opportunity to the local population?	✓	In addition to policies above, cities like Vancouver and Toronto have Community Benefit Agreement (CBA) requirements; neither are likely sites of DAC or storage, but potentially set a precedent for municipal-level engagement. See above mention of Investing in Canada Infrastructure Program community benefit	
	FINANCING AND INNOVATION POLICY			
1)	Do government incentives seek to correct market failure?	✓	● NRCan: Energy Innovation Program ● ECCC: Low Carbon Economy Fund	Regime: Markets, user practices; Regime: Industrial networks, strategic games; Regime: sectoral policy; help finance niche development (prevent market 'lock-out')
a.	Does the government fund research and development (R&D) of negative emissions technologies (NETs) and requisite infrastructure?	✓	● Innovation, Science and Economic Development Canada: Net Zero Accelerator; funding development of low-carbon technologies ● ECCC: Clean Growth Program	Regime: Markets, user practices; help finance niche development (prevent market 'lock-out')
2)	Does policy provide incentives towards the goal of commercialization/establishing an economy of scale?	✓	● Innovation, Science and Economic Development Canada: Clean technology project investment	Regime: Markets, user practices; Regime: Industrial networks, strategic games
a.	Has the government regime incorporated tax credits and/or rebates for DAC into the carbon pricing system and general financing plan for CDR?	✓	● Innovation, Science and Economic Development Canada: Sustainable Development Technology Canada ● Department of Finance: Investment tax credit for carbon capture, utilization, and storage	Regime: Markets, user practices; help finance niche development (prevent market 'lock-out')
b.	Do the policies minimize investor risk and uncertainty (e.g. by making the criteria for crediting as clear and comprehensive as possible as soon as possible while NETs are in development)?	✓	● NRCan: Carbon Management Strategy (in development) ● [P] British Columbia: CCS regulatory framework (announced)	Regime: Markets, user practices; help finance niche development (as riskier investments)
c.	Has the regime disclosed plans to increase R&D funding for DACCS specifically?	✓	● Department of Finance: Investment tax credit for carbon capture, utilization, and storage (see above) ● Alberta: CCS investments	Regime: Techno-scientific knowledge (by promoting research and development)

	i. Has the regime disclosed plans to periodically reassess needs and alter incentives and timelines accordingly (i.e. adjusting subsidy timelines to meet demand in practice or lowering removal thresholds to expand credit eligibility)?	✓	• Department of Finance: Investment Tax Credit for CCUS will assess projects at five-year intervals to calculate the 'eligible use factor' that determines the ITC amount and whether recovery of credit is warranted if CO_2 is used for ineligible uses.	
3)	Has the regime indicated that they have plans to begin the near-term processes required for scaling up CDR?	✓	• Announcement of Federal CCUS investment tax credit • NRCan calls for CCUS proposals for its Energy Innovation Program and ongoing development of their National CCUS Modelling Framework • "[CCUS] is also a critical enabling technology for carbon dioxide removal solutions such as direct air capture" from Canada's 2030 emissions reduction plan (ECCC 2022, p.78).	Regime: Technology; Regime: Infrastructure
a.	Do the incentives include a mechanism designed to encourage sharing of knowledge and technology learning to improve the development of the system and its operation?	✓	• Department of Finance: Investment tax credit for carbon capture, utilization, and storage (ITC for CCUS) • NRCan: Energy Innovation Program called for proposals for CCUS Front-End Engineering Design Studies have the option to consent to NRCan sharing "information... across federal departments/ agencies, including but not limited to the departments and agencies represented in the Clean Growth Hub" • Alberta: CCS investments (see above) [CCS only]	Regime: Techno-scientific knowledge; Regime: Industrial networks, strategic games
b.	Do the plans of domestic developers and/or policymakers help to secure multiple streams of revenue (e.g. rather than relying upon carbon-tax revenue alone)?	✓	• NRCan: Energy Innovation Program (see above) • ITC for CCUS • Innovation, Science and Economic Development Canada: Net Zero Accelerator (see above)	
	i.Are policy incentives designed to promote/maximize the co-benefits of the technology to attract private investment?	✓		
	ii. Are the regime's policies designed to enable developers to access private financing/investment?	✓		
	iii. Are the regime's policies designed to enable developers to receive financing from public-private partnerships?	✓		
	iv. Are the regime's policies designed to directly pay for DAC development and/or operate its own facilities?	✘	While the Federal GHG Offset Protocol provides the basis for carbon removal crediting, there is not yet a specific set of guidelines for CDR/NETs (comparable to the Federal Landfill Methane Recovery and Destruction Protocol published in June 2022).	
c.	Do the policies create opportunities for the niche markets related to DAC (for CO_2 utilization or otherwise) to develop and/or support early technology developers and adopters?	✓	• NRCan: Energy Innovation Program's call for utilization proposals will open Fall 2023	Regime: Markets, user practices; help finance niche development; Regime: sectoral policy

	i. Do government policymakers support the creation of a niche utilization market?	✓		
	ii. Do the policy incentives exclude EOR (as an early utilization niche) or otherwise aim to limit the role of CCS in the energy transition?	✓	Proposed ITC for CCUS excludes EOR as an accepted use; projects may still allow EOR, but their ITC amount will be calculated according to accepted uses rather than total emissions removed or captured. EOR is not banned, and CDR seems to be a near-term priority; the government's strategy for scaling down CCS in the future is not yet clear.	
	iii. Has the government regime indicated its intent to act as a niche primary market by purchasing DAC to offset the emissions of its own operations?	✘	Public Service and Procurement Canada's green procurement guidelines are in development, but it's unclear whether they will extend to the purchase of removal credits. • "Public Services and Procurement Canada will develop new tools, guidelines, and targets to support the adoption of green procurement across the federal government" (Bryan et al. [CCI workbook], 2022).	
	GENERAL CLIMATE AND ENVIRONMENTAL POLICY			
1)	Does the regime have a carbon pricing system (carbon tax or cap & trade)?	✓	• ECCC & CRA: Greenhouse Gas Pollution Pricing Act • ECCC: Output-Based Pricing System Regulations • Alberta Emission Offset System • Alberta: Technology Innovation and Emissions Reduction (TIER) Regulation • British Columbia: Carbon Tax • Newfoundland and Labrador: Hybrid carbon pricing system • Nova Scotia: Cap-and-trade program • Saskatchewan: The Management and Reduction of Greenhouse Gases Regulations; Saskatchewan Fuel Charge Non-exhaustive list	Regime: Markets, user practices; arguably Regime: cultural, symbolic meaning (in changing society's perception of the cost of emissions); Regime: Technology (feasibility of niche technologies)
a.	Have policymakers disclosed long-term carbon pricing plans (increasing or decreasing)?	✓	• ECCC: Output-Based Pricing System Regulations (see above)	Regime: Markets, user practices
b.	Does the policy incorporate tax credits/rebates?	✓	• ECCC: Climate Action Incentive Payment (Federal Fuel Charge, see below)	Niche; Regime: Markets, user practices (specialized tax credits promote niche development)
c.	Does the regime maintain stability in pricing when possible?	✓	• The federal benchmark helps to create stability on the national level, though provincial cap and trade systems (Quebec and Nova Scotia) may be more unstable than provinces with a carbon tax.	
2)	Has the regime established general fuel emissions standards?	✓	• ECCC: Clean Fuel Standard	Niche; Regime: Markets, user

			● ECCC: Federal Fuel Charge	practices; Regime: sectoral policy
3)	Has the government created and disclosed their long-term climate mitigation strategy (including MT/GT-scale targets)?	✓	● 2030 Emissions Reduction Plan ● ECCC: Strengthening Canada's climate plan	Regime: Sectoral policy; Regime: Markets, user practices; Regime: Infrastructure; Regime: Culture, symbolic meaning; Regime: technology; Regime: Industrial networks, strategic games (financing niche development)
a.	Has policy clarified the role of CDR in this strategy?	✓	● NRCan: Currently developing Carbon Management strategy. Though it was initially labelled CCUS rather than CDR, based on the government's established definitions of the terms, they intend to capture NETs like BECCS and DACCS as well as point-source capture with the term. ● The 2030 emissions reduction plan: Canada's next steps to clean air and a strong economy, identifies a need to further develop the government's understanding of the country's future CDR strategy. It also includes DAC and CCUS separately in its projected emissions reduction opportunities estimates. ○ "Consider NETs as a compliance pathway for the Low Carbon Fuel Standard; Build an accounting framework for NETs by 2025; Invest in research, development and deployment and consider grants and incentives for R&D, pilot projects, and commercial scale development" (ECCC, 2022). ● British Columbia: Submission for the 2030 Emissions Reduction Plan involves CDR ● Alberta's current focus is CCUS and carbon transport infrastructure, but they have robust policy frameworks for offsets and carbon storage regulations (and to a lesser extent, Saskatchewan)	Regime: Sectoral policy; Regime: Markets, user practices; Regime: Infrastructure; Regime: Culture, symbolic meaning; Regime: technology; Regime: Industrial networks, strategic games (financing niche development and clearly marking how CDR will be used in climate governance, reduces uncertainty and may help nascent industries develop)
b.	Has the regime maintained decarbonization as a priority over removals (e.g. set timeline for total electricity decarbonization) to avoid mitigation deterrence/reduce lock-in risks?	✓	● ECCC: Currently developing the clean electricity standard for 2035	
	i. Does policy account for diminishing marginal returns of traditional mitigation spending (and indicate expected policy changes accordingly)?	✓	● 2030 Emissions Reduction Plan; principles for target design ○ "As stated in our inaugural report, Net-Zero Pathways: Initial Observations, the most likely net-zero pathways prioritize emissions eliminations and reductions. Removals and offsets should only be used as a last resort. If offset strategies overlap with other sectors' decarbonization plans, Canada may end up with a series of net-zero sectoral plans that do not actually achieve net-zero on an	

			economy-wide basis. We advise strongly against policies that allow one sector to claim emissions reductions in a different established sector for which credible options already exist to eliminate emissions with no offsets required" (ECCC, 2022, p. 172). ● 2030 emissions reduction plan: Key guiding principles to inform the development of quantitative five-year targets for the oil and gas sector; establishes near-term planning and objectives towards implementing longer-term solutions that take longer to scale, site, finance, and approve. ○ "Important prospective solutions to reduce GHG emissions at scale in the oil and gas sector, like carbon capture and storage, require large capital projects that take time to plan, approve, and build…it is realistic to assume that they could be built and operating by 2030" (ECCC, 2022, p. 173).	
	ii. Does government policy demonstrate the understanding that decarbonization is a necessary, but not sufficient condition for mitigation?	✓		
c.	Have policies disaggregated 'net-zero' reduction and removal goals?	✘	Canada's net-zero target (in practice) will require carbon removal, but there's no CDR target	
	i. Have policymakers separated reduction and removal goals in carbon accounting?	✘		
d.	Have government agencies sought to resolve and reduce regulatory barriers or issues for low-carbon innovations?	✓	NRCan, ECCC, ISED, and Health Canada: "Clean Technology: Targeted Regulatory Review – Regulatory Roadmap" & "What We Heard: Report on Regulatory Modernization"; involved stakeholder engagement to identify areas for improvement in the government's approach to clean technologies and regulatory modernization	Regime: Sectoral policy; Regime: Markets, user practices
	i. Does policy build off past transition successes (in industry or socioeconomic context)?			
4)	Do policies allign with international targets, goals, standards, and reporting protocol?	✓	● The Canadian Greenhouse Gas Offset Credit System Regulations complies with ISO Standard 14064-2 "entitled Greenhouse gases – Part 2 – Specification with guidance at the project level for quantification, monitoring and reporting greenhouse gas emission reductions or removal enhancements" and ISO Standard 14064-3 "entitled Greenhouse Gases – Part 3 – Specification with guidance for the verification and validation of greenhouse gas statements" SOR 2022-111 ● Canada's Enhanced Nationally Determined Contribution aims for "40-45% reductions below 2005 levels by 2030"	Landscape; Regime: Sectoral policy; Regime: Markets, user practices (international goals external to the regime but affect sectoral policy)

a.	Does the regime's definition of negative emissions and CDR align with international definitions?	✓	Again, with the caveat that the government will pull NETs under the same label as CCS as 'carbon management.'	Regime: Culture, symbolic meaning (how terms should be interpreted in policy)
b.	Do policymakers seek to cooperate within international coalitions and funds to drive the development of joint hubs and commercialization?	✓	Alberta: Carbon capture and storage investments. The province is funding six proposed hub projects currently exploring development options	Regime: Infrastructure; Regime: Industrial networks, strategic games
	i. Do the regime's plans for CDR align with its responsibility proportional to available storage and overall location suitability?	✓	● ECCC: Nature Smart Climate Solutions Fund ● Again lacking targets expressly for removal (as opposed to reductions). The above example only supports nature-based CDR. Too soon to gauge whether current R&D efforts will yield projects on a scale proportional to Canada's emissions and available pore space.	
5)	Has the government introduced intermediary, sector-specific transition/decarbonization objectives?	✓	● Innovation, Science and Economic Development Canada: Steel project decarbonization investments ● ECCC: Emissions cap on the oil and gas sector	Regime: Sectoral policy; Regime: Technology; Regime: Industrial networks, strategic games; Regime: Markets, user practices
a.	Have policymakers established stringent emissions standards for HTA industries?	✓	● See above ● ECCC: Emissions cap on the oil and gas sector	
b.	Have policymakers helped to identify or establish sector-specific niche opportunities (clean technologies)?	✓	● NRCan: Energy Innovation Program	Regime: Technology; Regime: Infrastructure; Regime: Techno-scientific knowledge
	i. Does the government promote near-term CCS for HTA industries?	✓	● ITC for CCUS ● Alberta: Industrial Energy Efficiency and Carbon Capture Utilization and Storage Grant Program	
	ii. Has the government placed limits on CCS for HTA industries or otherwise indicated when existing incentives will decrease or end?	✓	● British Columbia: FortisBC Clean Growth Innovation Fund (~$5M per year over four years) ● Again, omitting EOR uses from CCUS tax credit eligibility. Tax credit will be cut in half by 2031	
a.	Are there guidelines, financial incentives, or mandates already in place to incentivize specific (HTA) industries to purchase removal credits or invest in DACCS?	✓	● British Columbia: Cement Low Carbon Fuel Program ○ Some incentives in place to decarbonize HTA	
6)	Does the policy framework establish a robust MRV and accounting protocol [for technology developers and the general market]?	✓	See Q5 above	Regime: Sectoral policy; Regime: Techno-scientific knowledge (collecting reporting info); Regime:

				Markets, user practices
a.	Does the carbon accounting protocol include LCA of downstream CO_2 utilization?	✓		
b.	Is policy designed to avoid double-counting in the national emissions inventory/NDC accounting and in economic trade?	✓	Caveat→Alberta's Quest Project generates double credits	
7)	Does the regime have clear, existing regulations for carbon crediting?	✓	Still in development: "ECCC is currently developing the following federal offset protocols: Improved Forest Management on Private Lands; Livestock Feed Management; Direct Air Carbon Dioxide Capture and Sequestration; Enhanced Soil Organic Carbon" (ECCC, 2023)	Regime: Sectoral policy; Regime: Techno-scientific knowledge; Regime: Markets, user practices
a.	Have policymakers included a negative emissions crediting option for CDR activities that are not covered by the carbon pricing system?		See above	
	i. Is CDR incorporated into the offset system?		See above	
	ii. Are negative emissions credits separate from the existing carbon market crediting system?	✘	See above	
8)	Does the government promote the development of third-party (private or voluntary) industry standards?	✓	● ECCC & CRA: Greenhouse Gas Offset Credit System ○ "To generate credits, offset projects must go beyond common practices and legal requirements, and must not already be incentivized by carbon pollution pricing. GHG reductions must also be verified by an accredited third party" (Government of Canada, 2022)	Regime: Sectoral policy; Regime: Markets, user practices, Regime: Industry networks, strategic games
a.	Is there an accounting protocol for voluntary private-sector removals?	✘	Currently, the Federal Greenhouse Gas Offset Credit System only has complete protocols for "Reducing Greenhouse Gas Emissions from Refrigeration Systems" and "Landfill Methane Recovery and Destruction." As mentioned above, ECCC is currently developing a federal offset protocol for "Direct Air Carbon Dioxide Capture and Sequestration"	Regime: Sectoral policy; Regime: Markets, user practices
9)	Does policy address the stock of atmospheric GHGs, rather than just accounting for flows, by promoting 'cradle-to-grave' carbon accounting methodologies and regulations?	✓	● The 2022 National Inventory Report identifies the methodology for accounting and how it has been amended to reflect research insights. The protocol is still being developed and improved upon. ○ "ECCC is actively working with researchers to understand the discrepancies between "bottom-up" inventory methods and atmospheric measurements with the goal of improving the accuracy of inventory estimates in future editions of this report" (Minister of Environment and Climate Change, 2022).	Regime: Sectoral policy; Regime: Markets, user practices

a.	Does policy include plans to adjust or retire offset credits to maintain ambitious mitigation goals?	✓	• ECCC: newly introduced Greenhouse Gas Offset Credit System: Credit and Tracking System (CATS). The federal offset system is still in development • Saskatchewan: The Management and Reduction of Greenhouse Gases (Standards and Compliance) Regulations • British Columbia: British Columbia Greenhouse Gas Emission Control Regulation & British Columbia Greenhouse Gas Industrial Reporting and Control Act • Alberta: Emission Offset System	
	i. Are there independent standards (third-party) for CO_2-based products?	✘		
	CARBON CAPTURE AND REMOVAL TECHNOLOGY AND REGULATION			
1)	Have policymakers introduced CDR and/or CCS-specific regulations/policy?	✓	See previous sections; Federal Government's plans, ITC, Provincial regimes	Regime: Sectoral policy; Regime: Technology; Niche
a.	Does the regime contain DACCS-specific regulations, plans, or near-term incentives (e.g. mandate for DAC-derived fuels)?	✓	• ECCC is currently developing a federal offset protocol for "Direct Air Carbon Dioxide Capture and Sequestration"	
	i. Have policymakers instituted CDR deployment mandates (in their own operations or in the private sector)?	✘	Technology mandates exist at the federal level both for the market and for the technology and resources the government uses; the Zero Emission Vehicles Mandate outlines the government's "commitment to develop a zero-emission vehicle (ZEV) sales mandate for new light-duty, medium-duty, and heavy-duty vehicles, similar to those in California," while the Low-Carbon Fuel Procurement Program will provide "$227.9 million of funding "over eight years, starting in 2023-24, to the Treasury Board Secretariat to implement a Low-Carbon Fuel Procurement Program within the Greening Government Fund" to support the development of "low-emission marine and aviation fuels." The intention of this spending is to encourage industry development of more clean fuels for federal domestic air and marine travel as federal procurement continues to "prioritize the use of lower carbon materials, fuels, and processes." Moreover, the government also plans to use its buying power to provide "$2.2 million over five years, starting in 2022-23, to Natural Resources Canada to renew the Greening Government Operations Fleet Program, which will continue to conduct readiness assessments of federal buildings required to facilitate the transition of the federal vehicle fleet to zero-emission vehicles" (Bryan et al. [CCI workbook] 2022).	
	ii. Does the government prescribe CDR (or DAC) quotas and/or coordinate CDR deployment?	✘		

	iii. Does the government have plans to procure removal credits or DAC CO₂-derived products from developers?	✘		
b.	Have policymakers already implemented CCS-specific regulations, plans, or near-term incentives (a potential entry point for DACCS plans and incentives)?	✓		
	i. Does the regime contain specific regulations aimed at managing the risk of mitigation deterrence?	✓	See Q3b in previous section	
c.	Are there DAC and/or CDR-specific research and development efforts at any level of government?	✓	● NRCan: Carbon Management Strategy (in development) ● NRCan-Energy Innovation Program: Carbon capture, utilization and storage RD&D Call	
2)	Do policy plans differentiate between types of CDR, their needs, limitations, potential, and impacts?	✓	The existing information on NRCan's Carbon Management Strategy includes DAC, BECCS, and nature-based carbon removal, with no particular bias toward a particular DAC technology.	Regime: Sectoral policy
a.	Has the government planned a long-term deployment strategy for NETs in the context of the low-carbon transition, in order to avoid path-dependencies (typology of the regime's approach: incremental deployment, early integration, proactive approach)?	✓	See Q1c above	Regime: Sectoral policy; Regime: Markets, user practices; Regime: Technology (includes specific policies and market influence releasing an official government plan has)
b.	Has the government expanded CDR options by diversifying their early investments?	✓	See Q2	Regime: Sectoral policy; Regime: Markets, user practices; Regime: Technology; Regime: Techno-scientific knowledge
c.	Do regulations and/or plans differentiate types of DAC and their inputs (e.g. guidelines to prioritize LT DACCS in solar PV-based energy systems, co-location of LT with waste heat or geothermal power, generally parsing out the costs and energy efficiencies in a given context)?	✘	Too soon to gauge the specifics of policy	
	i. Does the government plan to combine low-cost, short-term CDR (nature-based) with long-term, high-cost CDR (DACCS)?	✘	Too soon to gauge the specifics of policy	
d.	Have government agencies sought proposals for research and development on specific technical issues related to DACCS (e.g. humidity, cold temperatures)?	✓	See Q1c above	

3)	Has the current regime introduced DAC-specific regulations, policies, or plans?	✓		Regime: Sectoral policy; Regime: Markets, user practices; Regime: Technology; Niche
a.	Does the regime seek to establish an early advantage in the industry by prioritizing early DACCS development?	✓	Canadian company Carbon Engineering has received $25 million in federal funding via the Strategic Innovation Fund (Carbon Engineering, 2019).	
b.	Do policies focus on transitioning pilot facilities to larger-scale removal projects?	✘	Too soon to gauge the specifics of policy	Regime: Technology; Regime: Sectoral policy; Niche
c.	Do policies or guidelines advise reassessing the scale of DACCS needed depending on climate mitigation target overshoots and the allocation of resources?	✘	Too soon to gauge the specifics of policy	
4)	Does government policy frame carbon removal and storage as public goods?	✘	Yet unclear what the model for DAC policy will turn out to be, though it does not currently seem like the government will take on technology-based CDR as a responsibility (despite established commitments for nature-based CDR).	Regime: Sectoral policy; Regime: Culture, symbolic meaning; Regime: Technology
	ENERGY POLICY AND LOCAL RESOURCE CONSTRAINTS			
1)	Do policies ensure that projects assess the techno-economic feasibility of deployment within a particular energy system (e.g. NET-focussed energy system modelling)?	✓	Impact Assessment Agency of Canada: Impact Assessment Act	Landscape (limitations of physical environment); Regime: Technology; Regime: Markets, user practices; Regime: Sectoral policy
a.	Does policy advise that DACCS is to be coupled with a non-intermittent renewable energy supply and/or systems designed to make optimal use of intermittent renewables?	✘	The United States' current plan for DAC stipulates that funded projects should utilize low-carbon energy. "This funding opportunity announcement (FOA), Direct Air Capture Combined with Dedicated Long-Term Carbon Storage, Coupled to Existing Low-Carbon Energy, will facilitate engineering studies of advanced DAC systems capable of removing 5,000 tonnes of CO_2 per year from the air—the equivalent of electricity used by more than 900 homes in the United States for one year. These systems will also be suitable for long-duration carbon storage. The studies will provide detailed information on the operation of these systems and potential investment costs that will allow DOE to accelerate research and development for existing DAC technologies, co-located with domestic low-carbon thermal energy sources, such as nuclear power plants, geothermal resources and industrial plants" (Department of Energy, 2021)	

b.	Has the government established guidelines for managing the trade-off between DAC and energy-efficiency policy targets?	✘	One means of managing this tradeoff also follows the United States' policy model; establishing regional DAC hubs in strategic locations across the country. By centralizing the capture and storage (or utilization) parts of the process, the need for pipeline transport lessens and it helps the project understand how much energy the process requires, while the project itself is still responsible for conferring community benefits (Department of Energy, 2022).	
	i. Is there potential for DACCS with modular energy systems?	✘	No particular plan or strategy to use DAC in combination with a particular energy source at the federal level, but NRCan's Small Modular Reactor (SMR) Action Plan is one potential option for powering DAC in the future; a study by Slesinski and Litzelman (2021), "shows that the need for low-carbon energy for DAC plants might incentivize the development of advanced nuclear plants and firm low-carbon resources more broadly" (p. 1).	
2)	Is new infrastructure being designed to avoid fossil fuel energy dependence?	✓	While new clean energy infrastructure is receiving a lot of government funding, it is not yet clear whether incentivizing the development of CCS infrastructure will lead to dependencies in the system: where fossil fuel-intensive production retrofitted with CCS will be locked into using the expensive technology and therefore locked-in to using fossil fuels. Whether the government will implement particular policies to prevent this from driving continued demand for fossil fuels amidst the energy transition remains to be seen.	Regime: Infrastructure; Regime: Technology; Regime: Sectoral policy
a.	Has the government developed electricity storage capacity to reduce peak supply issues in regions of interest?	✓	Increased emphasis on grid management, but not necessarily energy storage	
b.	Does each level of government primarily seek emissions reductions via energy system decarbonization?	✓	● NRCan: Strategic Interties Predevelopment Program ● Alberta: Renewable Electricity Act ● Alberta: Coal-powered electricity phaseout ● Alberta: Oil Sands Emissions Limit Act ● British Columbia: Industrial Electrification Rates ● British Columbia: CleanBC Program for Industry ● Nova Scotia: Emerging Renewable Power ● Nova Scotia: Offshore Energy Research Association ● Newfoundland and Labrador: Clean technology research and development ● Newfoundland and Labrador: Clean Technology Tax Credit ● Quebec: Quebec's 2030 Energy Policy ● Quebec: Acquisition, implementation, and commercialization of equipment and technologies that enable businesses, including SMEs, to reduce their GHG emissions	

			• Newfoundland and Labrador: Renewable Energy Plan	
3)	Are regulations in place to ensure prospective locations for NETs are properly assessed and meet technology needs?	✘	The beginnings of any protocol likely to be mentioned in forthcoming national Carbon Management Strategy	Landscape; Regime: Technology; Regime: Sectoral policy
a.	Are project developers required to assess the sustainability of accessing local energy and resource constraints (i.e. water, land-use constraints) as critical inputs for DACCS?	✓	• Impact Assessment Agency of Canada: Impact Assessment Act • Canada Energy Regulator	
4)	Is the government funding necessary energy transition infrastructure (e.g. increasing renewable energy capacity/availability, energy storage, etc. as well as DACCS relevant sources specifically like geothermal power)	✓	• NRCan: Expansion of clean electricity • NRCan: Establishing Pan-Canadian Grid Council • ECCC: Phase out of coal-fired electricity • NRCan: Smart grids	Regime: Infrastructure; Regime: Technology; Regime: Sectoral policy
5)	Does government policy restrict new fossil fuel energy infrastructure/plants (set moratoriums)?	✓	• See above, Phase-out of coal-fired electricity • Alberta: Coal-powered electricity phaseout • British Columbia: 100% Clean Electricity Delivery Standard • Manitoba: Coal phase-out • Ontario: Coal phase-out	Regime: Sectoral policy; Regime: Infrastructure; Regime: Industrial networks, strategic games
a.	Do upstream regulations help to manage the decline of the fossil fuel industry?	✓	The government is taking clear steps (above) to remove coal-fired electricity, but oil and gas are still major energy sources in several provinces (for whom CCS may be an attractive alternative to decarbonization which could worsen lock-in)	
	i. Are there opportunities to include fossil fuel sector partners in the transition process by leveraging technical knowledge and capital and/or positioning them as a regulatory entry point for DAC mandates?	✓	• Saskatchewan: Boundary Dam Carbon Capture Project • Alberta: Industrial Energy Efficiency and Carbon Capture Utilization and Storage Grant Program • Alberta: Carbon capture and storage investments	
	CARBON TRANSPORT AND STORAGE (PORE SPACE) REGULATION			
1)	Does the regime have some kind of protocol or regulatory framework in place for regulating geological carbon storage?	✓	• Canadian Environmental Protection Act • As a party to the London Protocol, THE AMENDMENT TO INCLUDE CO_2 SEQUESTRATION IN SUB-SEABED GEOLOGICAL FORMATIONS IN ANNEX 1 TO THE LONDON PROTOCOL is applicable; "the parties to the London Protocol have also adopted rules addressing carbon capture and storage in sub-sea geological formations, which may impact any DACCS or BECCS projects that utilize offshore geological storage" (Craik et al. 2022, p. 18). • British Columbia: Carbon capture and storage regulatory framework • British Columbia: Petroleum and Natural Gas Act: PETROLEUM AND NATURAL GAS STORAGE RESERVOIR REGULATION	Regime: Sectoral policy (changing existing policy and adding additional policies that are storage/transport specific)

			● British Columbia: Energy Statutes Amendment Act ● Alberta: Mines and Minerals Act ● Alberta: Carbon Sequestration Tenure Regulation ● Alberta: Technology Innovation and Emissions Reduction (TIER) Regulation ● Saskatchewan: Oil and Gas Conservation Act, O-2	
a.	Does policy differentiate between types of geological carbon storage (advantages, risks, permanence)?	✓	● Alberta: Alberta Emission Offset System (part of TIER) ● Saskatchewan: Oil and Gas Conservation Act, O-2 ● In the proposed federal CCUS tax credit, "the recovery mechanism ensures that the investment tax credit (ITC) is provided to the extent that CO_2 is going to eligible uses. At this time, only dedicated geological storage and storage in concrete are proposed to be eligible uses" (Government of Canada, 2022).	
b.	Does policy (regulation or incentives) ensure storage is permanent?	✘	● The amount of the federal CCUS investment tax credit is based on a given percentage of the cost of equipment used in CCS and DAC projects, it is not a credit provided based on the quantity of CO_2 stored. ● Alberta's regulatory storage framework (see above) generates offset credits for geological storage but also enables projects (e.g. Quest) to generate credits based on quantity captured, therefore generating double the credits for the same amount of CO_2 captured and stored. ● While approved by the federal government (February 2023), the details of BC's updated regulations for carbon capture and storage seem to not be available to the public as of yet. ● Saskatchewan is currently in the process of planning its provincial offset system (October 2022).	
	i. Has the government implemented a storage-based crediting system (or subsidies) to incentivize removals?	✘		
	ii. Does the government vary the value of storage credits depending on their permanence (biological vs. geological storage)?	✘		
c.	Does policy incentivize storage overutilization?	✓	The proposed federal CCUS investment tax credit is provided only for permanent geological storage and for uses wherein carbon will be permanently stored (only concrete is currently an eligible use). While it is important that storage is prioritized in the long run to ensure emissions are not re-emitted in use, providing incentives for the development of more utilization options and permanent uses for CO_2 is also an important part of the carbon capture business model. At the moment, rather than deliberately placing higher importance on storage to establish a regime that can store a high volume of CO_2 compared to carbon utilization, the government is	

			currently concerned with ensuring that carbon is permanently sequestered and can be accounted for accordingly; the difference in incentives for the two is incidental.	
3)	Has the regime policy established guidelines to ensure DACCS facilities are co-located with known storage sites?	✘		Regime: Infrastructure; Regime: Sectoral policy; Regime: Industrial networks, strategic games (may require access to existing sites developed for use in other industries–associated with fossil fuels)
4)	Has the regime clarified pore space ownership and established liability for leakage?	✓	● In the regulations mentioned above, Alberta has clarified liability and pore space ownership. Moreover, the government assumes post-closure liability for storage sites to further reduce risks and costs to industry and investors. However, this level of clarity on liability and storage is not uniform across the country; Alberta has been consulted by other countries' governments due to their expertise as an early mover on carbon storage regulation. In part, pore space ownership and liability can be extracted from existing regulations for natural gas storage, land ownership, and subsurface water and mineral rights. Therefore, for the rest of Canada, this legal issue will be a matter of deciding how to apply the law and where to introduce new amendments and new policies. ● Canadian Environmental Protection Act	Regime: Infrastructure; Regime: Sectoral policy; Regime: Industrial networks, strategic games; Regime: Markets, user practices
a.	Has the regime clarified regulation for offshore developments (storage and transport projects/infrastructure)?	✘	"Seabed license [acquired from] NRCan: no statute expressly authorizes the grant of seabed licenses for carbon dioxide injection operations. Licenses cannot be issued under the FRPFIA for use of the continental shelf. New legislation may be needed. Permit under the Canadian Environmental Protection Act ("CEPA") [acquired from] Environment and Climate Change Canada: permits cannot be issued for the sub-seabed injection of carbon dioxide. The CEPA must be amended to permit carbon dioxide injection" (Webb & Gerrard 2021, iv).	
	i. Have policymakers established the protocol necessary for enabling cross-border (US) carbon transport and storage?	✘		
b.	Has the regime made geological storage maps available to developers?	✓	Collect more information: NRCan seems to have comprehensive maps for existing and potential storage and transport networks but the public availability of these documents is unclear. Information should also be accessible (for developers) via academic/consultant sources.	

	i. Is the government investing in research and development for in-situ mineralization or other potential storage avenues (besides basal Cambrian sandstone)?	✓		
4)	Has the government designed and developed transport and storage infrastructure networks (or planned viable/optimal sites and routes)?	✓	See Q3b above	Regime: Infrastructure; Regime: Sectoral policy; Regime: Industrial networks, strategic games
a.	Can the regime make use of existing CCS hubs and networks?	✓	Alberta: Alberta Carbon Trunk Line	
b.	Have policymakers begun to scale up storage and multi-modal transport plans and infrastructure (like participating in creating hubs)?	✓		
c.	Has the government encouraged, coordinated, or helped to initiate shared infrastructure between private NET and CCS developers?	✓	The Alberta government is committed to investing over a billion dollars into the ACTL and Quest projects (Government of Alberta 2021). The team behind the Alberta Carbon Grid project, a collaboration between Pembina and TC Energy, is also working alongside the provincial government and collaborating with industry peers (Alberta Carbon Grid 2023). Shell's forthcoming CCS Hub, Polaris, has also received the support of the province (Shell, 2021).	

5. Discussion

This research aims to understand the changes that must be made to policy and infrastructure in Canada to support the scale-up of DACCS effectively. This chapter will review and analyze the policy gaps revealed in the results section and compare them against the results of similar studies discussed in my literature review; sections 5.1-5.6 will review each theme separately, referencing gaps and similar findings in the literature. My gap analysis also incorporates the study's theoretical framework, using the MLP to explain how policymakers can support the DACCS system amidst Canada's low-carbon transition. In doing so, I present the specific policies related to the criteria and thematic framework I built to assess the system. In section 5.7, I consider factors such as lock-in, the timeline over which particular policies must be introduced, and the relationships between policies across policy areas. Lastly, section 5.8 explains the contributions and implications drawn from the results of the study, namely, the methodological and theoretical contributions and the implications this research has for future policy.

Figure 6

MLP Diagram for the DACCS System

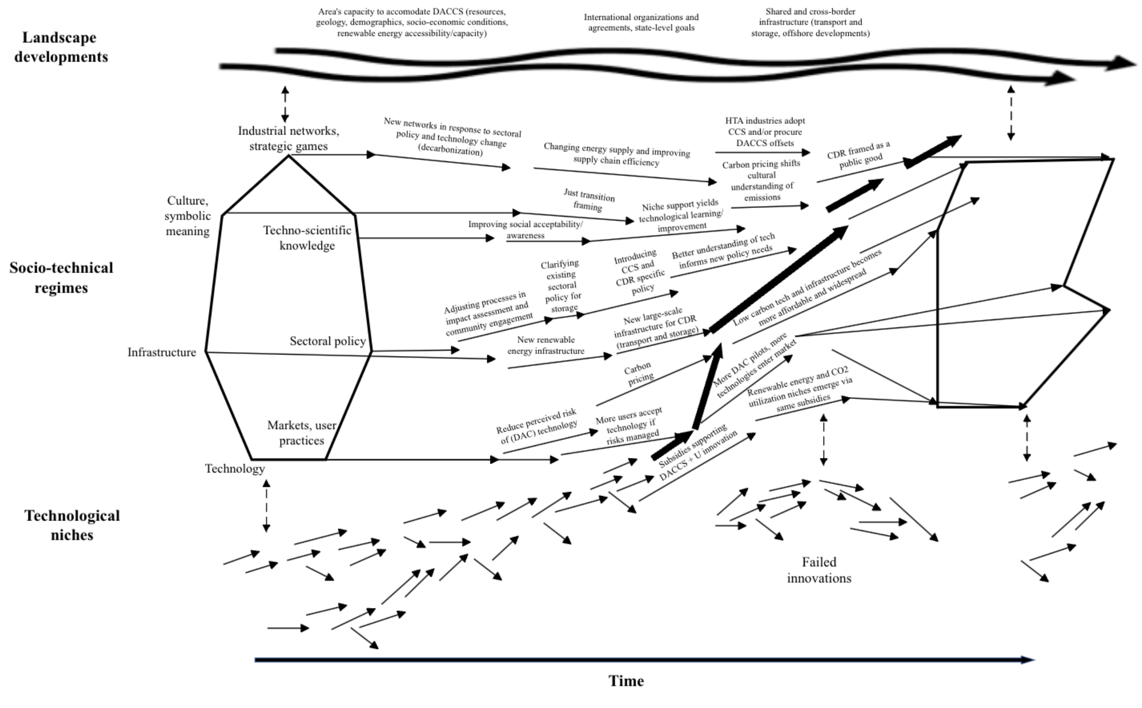


Figure 6 is adapted from a figure in Geels (2002) (see Figure 1 in the Literature Review). Adapted from "Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study," by F. W. Geels, 2002, Research policy, 31(8-9), 1263. Copyright 2002 by Elsevier Science B.V.. Like Geels' original diagram, it depicts the transition process. However, I have added specific forces that impact the development of DACCS within the system, as well as specific changes that need to happen to *support its growth, which policies will need to enact. Information within this diagram will be referenced through the different theme sections, thus acting as a guide for understanding how the MLP influences my analysis.*

5.1 Social Acceptability and Public Interest

The theme ‘social acceptability and public interest’ is intended to capture whether a regime has policies to support the public's interest in implementing technologies like DACCS. This involves the physical risks a technology poses to the environment and public health or safety, the public’s opinions about it, and how it may conflict with social values (Otway & Winterfeldt, 1982). For example, if the public perceived that introducing DACCS would result in job loss in another sector, opposition to the technology would make deployment and attaining a social license to operate more difficult politically (whether or not that belief was supported by fact). Providing information to the public early in the project can help prevent misconceptions and address legitimate community concerns. In addition, another aspect of this theme is whether project developers make contact with locals to understand such concerns. Some of the criteria I collected emphasized the importance of promoting public awareness of CDR and NETs; the government framing the technology’s role in the context of a just transition; using existing protocols to reduce uncertainty around risks and engage local communities; ensuring communication between project developers and communities; and identifying a region’s social, environmental, and economic vulnerabilities.

The first gap I identify in this section concerns whether the government is actively working to increase public awareness of DACCS and other forms of CDR. Although recent government publications and plans like the “Healthy Environment and Healthy Economy Plan,” “The 2030 Emissions Reduction Plan,” and the “Pan-Canadian Framework on Clean Growth and Climate Change” have signalled that the Government of Canada intends to integrate CDR, CCS, and DACCS into the national climate strategy, the documents only make mention of DACCS in high-level discussions of its role in the country’s long-term climate strategy. There is generally insufficient public communication about the technology to accompany this signal for scale-up. While this policy objective was not absent, this criterion is only partially fulfilled.

Other partially fulfilled criteria include the questions around whether project developers are required to hold iterative local consultations to address community concerns, whether policymakers co-developed their community engagement plans with historically disadvantaged population segments, and whether developers are expected to confer some benefit or economic opportunity to the local population. These criteria were marked partially fulfilled because some government programs, like the Investing in Canada Infrastructure Program’s Community Employment Benefit for major infrastructure projects, have guidelines for reporting on community benefits and engaging with those communities. However, participation is encouraged but not required for participants to receive the benefit. While government agency participants, like ECCC, NRCan, and Crown-Indigenous Relations and Northern Affairs Canada, have projects that meet these requirements, non-government contractors and other agencies are not committed to doing the same. At the municipal level, cities like Vancouver and Toronto have implemented Community Benefit Agreement (CBA) requirements; this will likely not impact prospective DAC or carbon storage sites, but it may set an important precedent for municipal-level engagement.

Additionally, several legal mechanisms at the federal level, like the Impact Assessment Act, satisfy some of the criteria in this category because they establish processes for identifying who is responsible for this kind of engagement and the duties for which they are responsible. However, a requirement like the duty to consult is a Crown obligation, expecting that the government hold appropriate consultations with relevant groups, not private sector actors. The Impact Assessment Act applies to any project in sectors including hazardous waste, renewable energy, oil and gas, transportation, mining, and more. However, it does not necessarily expect iterative communications or the conference of community benefits, which may be particularly important in scaling up novel technologies in the energy transition. In practice, the proliferation of DACCS technologies may impact sectoral policy in the regime by influencing how existing legal requirements like impact assessments and community engagement are performed. Though not required for all projects in Canada, CBAs may become more common due to the influence of landscape conditions, namely, U.S. DAC hub community benefit requirements, especially if they are situated close to the border.

In sum, the key gaps in the first theme, ‘social acceptability and public interest,’ had to do with insufficient government support for public awareness and communication about the need to scale up NETs and require that project developers sustain long-term, iterative communications with locals. Improving the public’s awareness of these technologies is important in the transition process. The socio-technical regime, according to Geels, has seven constituent parts (see Figure 6). Context-appropriate communications about NETs at the national and local levels impact the symbolic meaning of the technologies in society, reducing their perceived risks through techno-scientific knowledge sharing. This, in turn, influences user preferences and markets within the regime, helping project developers secure a social license to operate and avoid delays caused by societal backlash if a project is perceived as illegitimate or harmful. Subsequently, projects will be less risky to prospective investors. Iterative public consultations and CBAs are similarly important to the system because they help to assure communities surrounding the prospective sites for DAC or CO_2 storage that their lives and livelihoods will not be harmed by project development, particularly given how new the technology is and its resource intensity depending on the physical environment, socioeconomic conditions, and infrastructure in the area. All of these constituent parts factor into how the regime changes and whether the conditions can accommodate niche technologies as part of the country's portfolio of climate solutions.

Already, Canada has numerous programs in place to facilitate another requirement for policy related to social conditions, job creation, and reskilling in a just transition. These include ECCC's Supporting Sustainable Jobs Program, Employment and Social Development Canada's Sectoral Workforce Solutions and Skills for Success programs, and the Investing in Canada Community Employment Benefit for major infrastructure programs, all of which provide funding to support workers and communities affected by fossil fuel phase-outs and prepare Canada's workforce for a low-carbon economy through various job-training opportunities (Bryan et al. 2022). In the context of a sociotechnical transition, it is important that infrastructure projects and land use changes are designed to address rather than exacerbate the vulnerabilities of local communities by creating low-carbon job opportunities and providing benefits to aid sectors in transition.

A recent study by Satterfield et al. (2023) on public perception of offshore carbon storage associated with DACCS in Solid Carbon's B.C. project found that presenting the potential co-benefits (such as employment) was a "powerful predictor of support by a considerable margin," while "risk thinking [was] comparatively less influential" for the sample population (p. 13). Still, the literature suggests that perceptions of risks associated with storage, rather than the capture process, are consistently found to be a key criterion for acceptance, as well as the use of renewables within DACCS systems (Arning et al., 2019; Cox et al., 2020; Satterfield et al., 2023). Although public acceptability tends to be higher for nature-based CDR than for NETs, it also largely depends on how new infrastructure and technology projects are framed in public discourse (Bellamy, 2022; Buck, 2016). In turn, this depends on the dynamics and social relations in a particular social context, as well as effective government communications, which makes this policy dimension especially important in the early stages of the transition and DACCS scale-up.

- **Fulfilled policy objectives:**
    - **Some policies are in place to ensure job transition programs, public**

  - **consultations, and impact assessments happen.**
  - **Government communications and policy include 'just transition' framing of decarbonization process.**
- **Key gaps:**
  - **Insufficient government support for public awareness, communication about NETs, and the need for scale-up**
  - **Requirements for iterative public consultations and community benefits (potential to amend existing requirements)**

5.2 Policy for Financing Scale-up and Supporting Innovation

Appropriate government funding is a critical aspect of policymaking for the DACCS system and for the development of niche DAC technologies, which would otherwise be too expensive relative to existing network technologies and would be locked out of the system. The government also indirectly supports the technology through other policies that change market incentives; for example, with a high carbon tax, firms with hard-to-abate emissions may choose to offset some of their emissions by purchasing CDR credits if they cost less per ton than the tax. The Department of Finance's planned CCUS Investment Tax Credit (ITC) similarly incentivizes firms rather than the government to invest in DACCS (incentives that would not have existed for DACCS otherwise). The types of policies included in this theme category provide incentives for technology research and development, help to minimize investor risk and uncertainty, and support near-term scale-up by assisting developers in establishing a sustainable long-term business model (either via niche carbon utilization or financing technology directly). Such policies allow niches to mature and developers to improve their techno-scientific knowledge in the process.

As demonstrated in my description of the MLP, niche technologies can radically change a system and stabilize it amidst landscape changes. Moreover, providing financial incentives for investing in and directly funding a niche technology creates a protected market that allows the technology to mature and become more efficient and cheap, grow less dependent on subsidies, and more effectively integrate into the system. Some questions in this section sought to determine whether government policies promote the development of economies of scale (for CCS and NETs) and whether they plan to increase R&D funding for DACCS specifically. The questions also seek to determine the government's approach to supporting CDR and NET development, whether they intend to directly pay for DACCS via a public utility model or help to establish a combination of subsidies and private funding for technology projects.

The policies that are currently in place satisfy most of these criteria in this category. Funds for such projects are currently available through a variety of federal programs. Through the Energy Innovation Program, for example, NRCan will invest $319 million over seven years to “fund research, development, and demonstrations to advance the commercial viability of CCUS technologies” (Bryan et al. [CCI workbook], 2022). ECCC’s Low Carbon Economy Fund has committed “$500 million in funding for GHG-emission-reducing projects” (Bryan et al., 2022). Innovation, Science, and Economic Development Canada’s Net-Zero Accelerator will distribute “$3 billion over five years…which provides funding for development and adoption of low-carbon technologies in all industrial sectors” (Bryan et al., 2022). Even though DACCS projects may not be eligible for all of these funds, they will still help establish necessary network technologies and change the market incentive structure, therefore aiding the development of the DACCS system. The most significant policy being introduced is the Department of Finance’s ITC for CCUS, which will offer a higher credit (60%) for DACCS-related upfront costs from 2023 until 2030 (after which it will be halved) (Bryan et al., 2022). At the provincial level, the government of Alberta has provided funding to various CCS projects such as Shell Quest and the ACTL (Bryan et al., 2022). After announcing that the government is developing a regulatory framework for CCS and CDR, British Columbia has also signalled their support for technology scale-up.

The gaps in this section concern the need for more information regarding regulations and incentives currently in development. NRCan is in the process of developing a national carbon management strategy, so it is not possible to determine what future policy will look like. If uncertainty persists, it may undermine other market signals that would otherwise aid CDR scale-up. Similarly, the Department of Finance’s ITC for CCUS will be assessed at five-year intervals to calculate the ‘eligible use factor’ that determines the tax credit amount and whether credit recovery is warranted when CO_2 is used in ineligible projects; however, it is not yet clear if there will be potential to change the design of the credit depending on the needs of developers in practice (for example, extending the timeline of the credit in its first stage). Additionally, although the ITC excludes EOR as an ineligible use, there are no policies in place to minimize CO_2 use in EOR, and it is not clear whether the government plans to implement such policy; projects may still involve EOR, but their ITC will be calculated accordingly to accepted uses rather than total emissions removed or captured.

The only other ‘gaps’ present in the table are in questions for the sub-objectives that seek to characterize the typology of the government’s deployment strategy; since there is no indication that the government intends to pay for DACCS directly or act as a primary market by purchasing DACCS credits to offset their emissions, these criteria are not marked as present. However, given emerging policy changes, including the fact that Public Service and Procurement Canada is currently developing their green procurement guidelines, it is possible that the government could purchase removal credits in the future. Although some provinces lack incentives of their own (and may not be the most suitable locations for DACCS), the completeness of provincial policies has no bearing on this scoring. However, it is important to note that some policies, such as the ITC, will not extend to certain provinces because they have no CCS regulations; the only provinces that do are British Columbia, Alberta, and Saskatchewan. A regulatory framework, in this case, is a necessary precondition for accessing financing and requires proactive policymakers at the provincial level in interested areas.

The optimal order and strategy for rolling out these policies are still unclear. Meckling & Biber (2021) suggest an "incentives + mandates" policy strategy: mandates because of their lower political cost and incentives due to their effectiveness in scaling up renewables. Feed-in tariffs, new emissions standards, reverse auctions, and carbon pricing are all options that are likely to help incentivize DACCS (Lackner & Azarabadi, 2021). Though subsidies may be controversial (as evidenced by the backlash against the CCUS ITC), as calculated by Lackner & Azarabadi (2021), removing approximately 1500 $GTCO_2$ from the atmosphere at as low as USD 30/tCO_2 will result in a 45 trillion-dollar market, meaning that the subsidy needed to reduce technology costs would be fairly small by comparison (divided across countries and companies). Conversely, introducing policies like mandates and carbon pricing designates responsibility to the firms that will pay the cost that the government does not. Further research in this area should investigate how much and for how long DACCS needs to be subsidized (Fuss et al., 2018).

The results table shows the variety of federal programs that fund transition infrastructure and DAC and CCS innovation specifically. The government's support determines how niche technology developers shape their business models. For example, a regime in which sectoral policy is populated by CCS technology mandates or in which the government has committed to subsidizing DAC itself indefinitely would result in DAC developers that are less concerned with driving down production costs and improving the efficiency of their technology (becoming dependent on subsidies) compared to a regime in which the government provides grants and mostly indirect (non-subsidy) support to developers who would then need to secure multiple streams of revenue via utilization and other private sector partnerships. The latter establishes new industry networks specific to the transitioning regime's needs; Carbon Engineering's partnerships, for example, with Occidental Petroleum and Shopify, are a part of its business model, supporting its continuous improvement and technological innovation.

While subsidies are important to ensuring DACCS is not locked out of the market, they are not the only or most efficient means of bringing down cost barriers. Even the planned ITC has a set timeline to ensure developers know that the government intends to help DACCS become a regime technology but not fund it indefinitely. Other subsidies, like the billions of dollars the government spends subsidizing the fossil fuel sector annually, are much more difficult to stop once they are in place due to the impact doing so would have on the system as a whole (e.g. by causing job loss, rising energy prices, and political tensions) (Corkal et al., 2020; Timperley, 2021). In addition to policies targeted at financing technology scale-up, carbon pricing systems and other general climate policies across Canada also influence markets and user practices by making environmental protection and decarbonization an economic and regulatory issue. Besides offset and carbon trading markets, the federal benchmark carbon price sends signals through the economy that weaken the system's ties to the incumbent regime and create entry points for niches. These mechanisms change the way that the environment is valued culturally and socially, as well as economically. The following policy theme covers other climate mitigation policies that influence the preferences of those in the system and aim to reduce emissions through other mechanisms.

- **Fulfilled policy objectives:**
    - **Government incentives are in place to support the research and development of new technologies that will be a part of the transition.**
    - **The government is in the process of introducing policies (tax credits, rebates, further incentives) to incorporate DAC and CDR into the climate plan and carbon pricing. Plans aim to help developers secure multiple streams of revenue (government support, private investment, and niche markets).**
- **Key gaps:**
    - **Lack of information/uncertainty surrounding plans, incentives, and other policies related to CDR currently in development (e.g. ITC rules, the sustainability and path-dependencies implied by allowing EOR at scale,**

flexibility for adapting policy, the extent of government intervention, including government procurement prospects).

5.3 General Climate Mitigation and Environmental Policies

This is a broad category that includes climate policies such as national and provincial carbon pricing systems, GHG emissions reduction goals, standards, long-term climate plans, MRV, carbon accounting, and more. It also includes the international organizations and agreements at the landscape level that influence state-level climate goals. It does include market-based mechanisms (like carbon pricing systems) but not targeted subsidies like the ones on which the previous category focussed. These policies can reinforce the status quo or change the incentive structure in the system by changing price signals which impact decisions within markets and industrial networks. For example, Canada's Greenhouse Gas Pollution Pricing Act sets a federal benchmark price for carbon that will increase yearly by $15 from 2023 until it reaches $170/tCO$_2$e in 2030 (Bryan et al., 2022). This will make fossil fuel-intensive production considerably more expensive. Whether the regime has a carbon pricing system in place is a critical policy for the system as a whole, not just the DACCS system. The federal output-based pricing system (OBPS) and the federal fuel charge fulfill the criteria in this section, but they do not apply to every province; several provinces, including Alberta, Saskatchewan, and Ontario, have their own OBPS approved by the federal government but still have to apply the federal fuel charge. Others, like British Columbia, Quebec, and most maritime provinces, have their own systems entirely; some are cap and trade, and others tax-based. Though maintaining stability in a carbon pricing system is important for the same reason disclosing long-term carbon pricing plans is important (to reduce uncertainty), having any system in place to internalize the cost of emissions shifts cultural meaning in how society values carbon-intensive production compared to alternatives.

However, even with a carbon pricing system in place, the government's climate plans must demonstrate which strategies they will use in their mitigation policy and how they will measure the impact of each policy tool and technology. Although NRCan is developing a national carbon management strategy, existing mentions of NETs and CDR in Canada's climate plans lack clarity. For example, the 2030 emissions reduction plan includes a table indicating that the government anticipates DAC will contribute to 0.3% of emissions reductions by 2030 but includes no details on how policymakers will situate the technology concerning other climate mitigation efforts and aid scale-up. This lack of clarity is a partial gap. Provinces have indicated their intentions to scale up CDR and CCUS but lack specific strategies (or focus on nature-based CDR and CCUS). A gap related to this is the lack of distinction between ‘net-zero’ reduction and GHG removal goals. Government authorities must clarify whether forms of CDR should be treated as a reduction in emissions or as a removal, as a separate target accounted for in GHG inventory reporting. Currently, the distinction does not exist in Canadian policy. However, the still-in-development guidelines for the Federal offset protocol for DACCS within the ‘Credit and Tracking System’ associated with the OBPS will hopefully reduce some of these issues (ECCC, 2023a).

Another gap is the need for international coordination for establishing CCS and DACCS hubs. Although Alberta is set to help fund 6 CCS hub projects and the US Department of Energy is coordinating the development of several regional DAC hubs, there are no formal cross-border projects; whether this will be necessary is unclear. However, in some regions, it will likely be more economical to access close-by storage across the border than transport it to where storage exists in Canada, particularly in areas close to the border like Ontario, which has a low-carbon electricity supply but no large-scale storage prospects (Canada Energy Regulator, 2022a). Cooperation to establish hubs may also help reduce construction costs and help commercialization prospects in the future as well as offshore operations.

By contrast, in the United States, the Office of Clean Energy Demonstrations has committed 3.5 billion USD to create four regional direct air capture hubs nationwide. Funding opportunities like this help minimize the trade-off between DAC development and energy efficiency targets by strategically locating facilities to maximize efficiency across every part of the system (Department of Energy, 2021). This particular program does so through the Justice 40 initiative, under which 40% of the benefits of federal investments should confer to disadvantaged communities, which will ensure community benefit plans are in place; this will, in turn, ensure economic, social, and/or environmental conditions in the communities surrounding DACCS project sites are improved by, rather than harmed by, project development. This includes, for example, providing job opportunities to community residents, which benefits the project and individuals, and builds skills and competencies within the communities that can be transferred to work in other sectors or otherwise supporting transition infrastructure. This initiative fulfills several criteria in other theme sections that Canada’s policy framework does not fulfill, including having iterative public consultations and community benefits, supporting public awareness and bolstering scale-up efforts. Conversely, the U.S. lacks a national carbon pricing system or a federal benchmark like Canada’s. However, individual states have implemented their systems (the Biden administration has set the ‘social cost’ of carbon at 51 USD/tCO_2e) (Mindock, 2022). While an in-depth analysis of the U.S.’s, or any other country’s, climate policy is beyond the scope of this study; it is important to observe the different ways these DACCS systems are already developing in the low-carbon transition. A specific commonality across cases is how CCS is generally accepted and underway in countries with prominent fossil fuel sectors (Norway, U.S., Canada), wherein backlash to policy targetting decarbonization is common; the regions that have made the most progress developing CCS technologies, and therefore the regulatory frameworks and industrial networks needed to transport, store, and find profitable ways to utilize CO_2 are often the regions where the oil and gas sector contributes significantly to GDP and employment. Since CCS helps to establish the infrastructure and policy DACCS needs while providing co-benefits to economies like these, policymakers need to support CCS in the near-term while also supporting renewable technologies, solutions for HTA industry, and job transitioning programs to ensure that CCS yields to DACCS rather than further locking fossil fuel use into the system.

It is too early to tell whether the Canadian government plans to create sector-specific reduction/decarbonization targets besides in the oil and gas sector–though HTA industries like steel are currently receiving R&D funding to improve efficiency and reduce emissions. Incentivizing these industries for whom emissions persist to utilize CCS or purchase DACCS removals may be possible. Similarly, I noted other uncertainties around carbon accounting and crediting, like the lack of clarity around carbon accounting and crediting for voluntary private sector removals (private certifications) and the 2022 National Inventory Report’s reflection on its amendments to reflect research insights in the continued development and improvement of the protocol, ideally aligning with a ‘cradle-to-grave’ methodology for accounting for stocks and flows of GHGs. Moreover, independent standards for CO_2 utilization (requirements and rules set by an objective third party) and plans for retiring or adjusting offset credits in the future are additional uncertainties.

- ❖ **Fulfilled policy objectives:**
    - ➢ **Carbon pricing systems and emissions standards are in place at the federal and provincial levels.**
    - ➢ **Policies prioritize decarbonization and align with international goals and standards.**
    - ➢ **Government is developing more specific rules for CDR in carbon accounting and MRV.**

- **Key gaps:**
  - **Lack of clarity on the planned role of DACCS in meeting Canada's climate goals; policy distinction between reductions and removals (particularly for crediting purposes)**
  - **Establishing regional hubs and inter-state cooperation in the transition process**

5.4 Carbon Capture and Removal Technology and Regulation

This category identified policies that specifically target CCS, CDR, and DACCS. Although there is a clear overlap with the content of the previous section (in terms of policies being identified), the criteria within this section identify specific system considerations and changes that characterize the regime's response to the technologies. However, it is true that, despite this difference in the style of questioning, there were significant similarities between responses in this section and previous ones because the scope of relevant policies is too limited to explore this nuance.

Similar to prior questions on whether the government has indicated whether they intend to pay for DACCS-based CDR directly or whether the government has clarified the role of CDR in the climate strategy, questions in this section ask whether the government established DACCS-specific regulation, plans, or near-term incentives. This includes more specific questions like, "Does the government frame carbon dioxide removal and storage as public goods?" This prompted a similar response as an earlier question that sought to determine whether the government intends to pay for CDR. Framing CDR as a public good in policy documents would imply that the government is responsible for paying for it, and although the government is relatively willing to take responsibility for scaling up nature-based CDR, it has not necessarily shown the same commitment for NETs. For example, the government does assume responsibility for environmental protection through the Canadian Environmental Protection Act and has also committed to planting 2 billion trees by 2030 (Government of Canada, 2023). Although the government has funded initiatives like the 2 Billion Trees program as well as technology-focussed programs like the Energy Innovation Fund, the funding in the latter goes toward research and development rather than for the funds directly paying for removals as they do in the context of tree-planting programs and ecosystem preservation (likely attributable to the technology, associated delay in achieving removals, and a lack of co-benefits). Another question inquires as to whether there is a focus on transitioning pilot facilities to larger-scale removal projects, which is an example of an objective that will be essential for policymakers to consider when there are more pilot facilities in the country that require support to move beyond that stage of development. It is a longer-term consideration compared to questions about what kind of near-term support the government should provide. Still, the role that the government needs to take in managing and providing CDR will depend on the degree to which new market mechanisms related to CDR can provide sufficient social benefit, which is not necessarily reflected in the historical market failures that allowed climate change to progress.

As previous sections have highlighted, a clear gap in the policy framework is the absence of regulation specific to DACCS and overall CDR scale-up. For example, technology mandates in other sectors as a part of the government's climate mitigation strategy at the federal level exist, both for the market and for the technology the government itself uses (via the Zero Emission Vehicle Mandate, where-in the government committed to developing a "sales mandate for new light-duty, medium-duty, and heavy-duty vehicles" and the Low-Carbon Fuel Procurement Program which is meant to "encourage industry development of more clean fuels for federal domestic air and marine travel" (Bryan et al., 2022). A DACCS deployment mandate for the government or the private sector could happen. However, it is not analogous to the fuel emissions case because DACCS does not involve altering an existing process to be more sustainable; as is the core claim of this research, DACCS requires whole system coordination to function effectively with no reciprocal benefits for the system beyond aiding mitigation efforts. I recorded similar gaps in sub-questions that inquired whether the government has created guidelines for avoiding mitigation deterrence, periodically re-assessing removal targets, and for the different needs and appropriate conditions for specific types of DACCS technologies. Therefore, some of the gaps in this section were either redundant compared to previous sections, or it was too premature to assess the state of those specific criteria in Canada, particularly as announcements about more specific guidelines and regulations being developed emerged throughout the data collection study.

Though the similarities between the criteria I assembled and the data sources are not particularly informative because the criteria were drawn from the literature, interesting commonalities exist between embryonic CDR policy in the case studies explored in the literature and Canada. While Schenuit et al. (2019) were not concerned with noting gaps so much as creating neutral characterizations of different regime approaches to CDR policy and fitting them into a typology, the other OECD countries explored in the study demonstrated comparable governance gaps. Like Canada, the EU lacked CDR-specific policy at the time of the article's publication. However, several funding programs, like the EU Innovation Fund and the Horizon 2020 program, are open to CCS and CDR project proposals while also supporting “new geological storage projects such as Porthos in Rotterdam” (Schenuit et al., 2021, p. 5). Moreover, the EU plans to achieve net-negative emissions in the latter half of the century without specific targets and initiatives to reach such a goal. Despite being a long-term goal, the articles from which I collected objectives agree that achieving net-negative emissions requires near-term policy action. Like the higher level of CCS progress in Alberta with the Quest project, Europe, the Netherlands and Norway host two of the few large-scale CCS facilities worldwide (Porthos and Northern Lights, respectively). In Sweden, unlike in Canada, policymakers have set separate emission reduction and ‘supplementary’ removal targets to avoid near-term mitigation deterrence; CDR policy, as a whole, is treated as separate from climate law and policy. This, as I have discussed throughout this chapter, is a distinction that it is imperative that policymakers establish in CDR.

- **Fulfilled policy objectives:**
    - **Government is beginning to develop CDR and CCS specific policy.**
    - **Diversifying NETs investments and plans.**
- **Key gaps:**
    - **Long-term policy considerations: uncertainties in plans to help developers transition from pilot facilities to large-scale projects and NET-specific regulation**
    - **Non-market mechanisms: government (federal and provincial) strategy to avoid mitigation deterrence, plans for deployment mandates, CDR quotas, credit procurement, or framing CDR as a public good (if appropriate)**

5.5 Energy Policy and Local Resource Constraints

Since its high energy demand is a significant drawback of DACCS as a CDR technique, it is crucial to assess these energy systems, policy, and decarbonization progress as part of the technology system. Moreover, given the resource demands of different DACCS technologies, the availability of resource inputs in a region are important considerations for siting and policy-making. This section, therefore, concerns existing policy, infrastructure, and plans for decarbonization and questions concerning the system’s capacity to support DACCS and the feasibility of large-scale development.

Some of the questions in this section evaluate the suitability and sustainability of the energy mix in a region by determining, for example, whether DACCS is coupled with a non-intermittent renewable energy supply and whether developers have assessed the techno-economic feasibility of development within a particular energy system (e.g. NET-focussed energy system modelling). Other questions gauge the state of energy system decarbonization by revealing whether the government has set restrictions on new fossil fuel energy infrastructure. This is important because decarbonizing a region may make an area with geological carbon storage capacity that was previously unsuitable for DACCS an eligible project site, thereby increasing siting opportunities. Moreover, government commitments to phase out fossil fuels send market signals that help niche innovations (potential substitutes for incumbent technologies), develop and scale up overall energy infrastructure. Sectoral policy for energy directly changes the kinds of technologies that are dominant in the regime and motivate shifts in industrial networks as firms change their energy supply and attempt to decarbonize. Landscape developments, such as coalitions and agreements targeting decarbonization and the growth of renewables abroad (resulting in lowered costs), will also impact Canada’s transition progress and policy plans.

Overall, the policy framework for DACCS in Canada must address the strain that the energy and resource intensity of DACCS and other NETs may conflict with other priorities in the energy transition. There are several regulations and programs in place to ensure that large-scale projects assess the techno-economic feasibility in a given region; the Impact Assessment Act requires that proponents conduct an assessment of the environmental, social, and economic effects of their proposed project, which stakeholders and federal experts then review to determine whether it should be allowed to proceed. This is complemented by the work of agencies like the Canada Energy Regulator, which “review[s] energy development projects and share[s] energy information, all while enforcing some of the strictest safety and environmental standards in the world,” as well as the soon-to-be established Pan-Canadian Grid Council which will provide external advice in support of national and regional electricity planning (Bryan et al., 2022; Canada Energy Regulator, 2022b).

Although the energy and resource demands of a technology like DACCS may be taken into account in an impact assessment, energy policy planning that accounts for it will be largely exploratory, not policy requirement, since the technology and so uncertain (even though it will need to be a focus of such planning in the future). In contrast, though the U.S. is at a similar level of DACCS development to Canada, policy plans state that they “will facilitate engineering studies of advanced DAC systems capable of removing 5000 tonnes of CO_2 per year from the air–the equivalent of the electricity used by more than 900 homes in the United States for one year and plan facilities can utilize existing low-carbon energy” co-located with domestic low-carbon thermal energy sources, such as nuclear power plants, geothermal resources, and industrial plants (Department of Energy, 2021). Canadian policy, by comparison, has not begun to establish guidelines for managing the trade-off between DACCS and the energy-efficiency goals of climate policy. There is also no particular plan or strategy at the federal level to use DACCS in combination with a particular energy source. There is potential, however, to develop projects in combination with other domestic energy plans like NRCan’s Small Modular Reactor Action plan; according to existing studies, DAC may help advance the development of nuclear plants in the energy transition (Slesinski & Litzelman, 2021). The U.S., as Canada’s closest partner in trade and peer in CDR progress, is the case study with policies that fulfill criteria in this theme that are gaps in Canadian policy. While Canada lacks DACCS-specific policy, including requirements to couple plants with a low-carbon energy supply, the U.S. Department of Energy’s funding opportunity for DAC explicitly aims to leverage existing low-carbon energy to meet DAC energy demands (Department of Energy, 2021). It stipulates that DAC be coupled with “low-carbon thermal energy sources, such as nuclear power plants, geothermal resources, and industrial plants” in combination with long-term CO_2 storage to establish DAC systems; funding will support engineering studies to gather information on the operation of these systems (Department of Energy, 2021).

However, the extensive decarbonization policies at the federal and provincial levels fulfill many other criteria in this section. For example, whether the government primarily seeks emission reduction via electrification and total energy system decarbonization is a critical criterion for assessing the system's energy plans and infrastructure. Since federal and provincial governments share jurisdiction over energy, many provincial policy examples exist for this question. Alberta’s Renewable Electricity Act will require 30% of electricity in the province to come from renewables by 2030, in addition to their commitment to phase out coal-powered electricity by 2023 and the Oil Sands Emissions Limit Act restriction of GHG emissions above 100 MtCOe/year. British Columbia, a province which already generates ~87% of electricity from hydroelectric sources (and plans to reach 100% by 2030), reinvests carbon tax revenue into low-carbon technologies and discounts hydro rates to support industry decarbonization (Bryan et al., 2022). Provinces will need to continue funding this transition while also amending existing subsidies and regulations in the regime that may further entrench carbon lock-in. Although every province and territory has funding programs dedicated toward expanding their renewable energy capacity (i.e. Newfoundland and Labrador's clean technology research and development funding and tax credit or Quebec's 2030 energy policy plan to increase renewable energy production by 25%), there are several that signal significant system changes that may impact the rollout of DACCS. For example, Quebec's policy will support "mini-power-plant projects/wind farms," while Nova Scotia has established an Offshore Energy Research Association to support future renewable energy projects (Bryan et al., 2022). Modular energy systems like these may be the energy capacity 'top up' a region needs to host a DACCS facility.

Federal policies such as NRCan's Strategic Interities program aim to provide emissions-intensive regions with more low-carbon energy; the agency also provides pre-development support for clean electricity projects (Bryan et al., 2022). NRCan is also investing in developing smart grid systems to meet the varying energy demands of different regions and transport surplus power accordingly, which could help avoid peak supply issues for future DACCS projects. Notably, ECCC's plan to reduce fossil fuel emissions from electricity, mainly via the 2030 phase-out of coal-fired electricity, would make operating a coal-fired power plant without CCS (as Saskatchewan's Boundary Dam 3 does) unfeasible (ECCC, 2023b). However, despite national commitments to phase out coal-powered electricity, that only applies to coal as an energy source, not to other fossil fuels (oil and gas) on which the country is still largely reliant. Though this may be an entry point for CCS in the socio-technical regime, further policy action (including further phaseouts) is needed to address this dependency. Ultimately, it is important that regime policy focuses on scaling down fossil fuel energy in the country while supporting the growth of new network technologies with a particular focus on how the energy system will need to look to accommodate NETs by the middle of the century.

- **Fulfilled policy objectives:**
    - **Co-locate projects with non-intermittent renewables or waste heat**
    - **Government is funding necessary energy transition infrastructure and improving grid management.**
- **Key gaps:**
    - **Ensure projects assess the techno-economic feasibility of DACCS deployment within a particular energy system and resource context and increase renewable energy capacity in the system overall**
    - **Fossil fuel energy phase-out (particularly in key provinces)**

5.6 Carbon Transport and Storage Regulation

The availability of carbon transport infrastructure and storage opportunities is one of the most important considerations for siting DAC. This section organizes the criteria and policies relevant to pore space regulation and possible means of transporting carbon to storage sites. The location of geological pore space for CO_2 storage in the physical landscape of the system is not as limiting as the siting conditions for other forms of CDR like BECCS or afforestation; establishing the CO_2 storage regulations in relevant areas of Canada will be a challenge, especially since most of this regulation needs to take place at the provincial level (as opposed to a singular policy instrument at the federal level).

Subsequently, a key criterion for this policy category is whether the federal government or various provincial governments have such a regulatory framework. Federally, under the Canadian Environmental Protection Act (CEPA), CO_2, methane, and other GHGs are regulated as toxic substances. This gives the federal government some environmental authority around the regulation of carbon, despite the regulation of pore space itself falling under provincial jurisdiction (Bryan et al., 2022). Moreover, with Canada as a party to the London Protocol on the prevention of marine pollution, rules adopted by the parties to the protocol regarding carbon storage in sub-seabed geological formations apply to offshore geological storage prospects (Craik et al., 2022). As previously stated, the only provinces that have a carbon capture and storage regulatory framework in place are British Columbia via the Petroleum and Natural Gas Storage Reservoir Regulation and the 2022 Energy Statutes Amendment Act, which allows the government to grant storage licenses; Alberta through the Mines and Minerals Act and Technology Innovation and Emissions Reduction Regulation (TIER) which together clarify the government’s powers to issue evaluation permits, leases, and credits for carbon storage sites; and in Saskatchewan’s Oil and Gas Conservation Act’s provisions to regulate the safe injection of substances into subsurface formulations (Bryan et al., 2022). Since the basis of many of these regulations is sectoral policy–oil and gas sector regulation–other provinces will similarly be able to adapt existing legislation accordingly. While the entire country may not have pore space regulation, they exist in the regions with appropriate pore space and technological development (e.g. Carbon Engineering in BC, Quest in Alberta, and Boundary Dam in Saskatchewan).

As they develop, these regulations must also provide protocols for different types of geological carbon storage to account for their advantages, risks, and permanence. TIER, for example, includes specific protocols like Quantification Protocol for CO_2 Capture and Permanent

Storage in Deep Saline Aquifers. Saskatchewan's Oil and Gas Conservation Act defines a CO_2 storage project as:

> "A development that is the long-term isolation of CO_2 in subsurface geological formations, and is primarily applicable to saline aquifers and depleted hydrocarbon reservoirs. It does NOT preclude to storage associated with hydrocarbon recovery – CO_2 Enhanced Oil Recovery (EOR), and does NOT include CO_2 storage in unminable coal beds, basalt formations, shales, and salt caverns, and disposal of acid gas" (Government of Saskatchewan, 2020).

This example clarifies which kinds of sites count for long-term CO_2 storage. The difference in other provinces is still unclear by comparison. Though some provinces have begun to expand existing legislation to include CO_2 storage, the absence of federal guidelines and incentives to prioritize secure and permanent storage (and co-locate DAC projects with storage accordingly) may inhibit the development of CO_2 storage projects. The ITC will likely introduce some such incentives;

> "the recovery mechanism ensures that the investment tax credit (ITC) is provided to the extent that CO_2 is going to eligible uses. At this time, only dedicated geological storage and storage in concrete are proposed to be eligible uses" (Department of Finance, 2022b).

The ITC does not generate credits based on storage – rather, it is based on a given percentage of the cost of equipment used in CCS and DAC projects – and eligibility extends to all carbon storage (other than EOR) and to use in concrete the tax credit ensures permanent storage in the three eligible provinces (Department of Finance, 2022b). The aforementioned protocols for storage also include provisions to ensure appropriate storage sites.

However, pore space ownership and liability also need to be clarified by policymakers. In the regulations mentioned above, Alberta has clarified liability and pore space ownership. The government assumes post-closure liability for storage sites to reduce risks and costs to industry and investors. In the rest of Canada, pore space ownership and liability will likely be extracted from existing regulations for natural gas storage, land ownership, and subsurface water and mineral rights, although uncertainty persists in the interim. Therefore, this legal issue will be a matter of deciding how to apply existing laws, where to introduce new amendments and new policies, and how the CEPA will be applied in developing regulatory standards (Craik et al., 2022). The regulations must account for the variety of storage options in Canada (in-situ mineralization, basal Cambrian sandstone, large-scale utilization, etc.). These factors will also impact the kinds of industrial networks that firms must establish to access pore space and initiate projects.

As CDR and CO_2 storage operations become more widespread across the country, clarifying regulations for offshore projects will be an especially important governance gap to resolve, particularly given the projected volume of sub-seabed storage and the potential to avoid local resistance to DAC. Though NRCan grants seabed licenses under the Federal Real Property and Federal Immovables Act (FRPFIA), no legislation grants the agency authority to grant licenses to CO_2 injection operations; a project would also need to attain a permit from ECCC, which similarly cannot grant permits for CO_2 injection (Webb & Gerrard, 2021, p. iv). The CEPA and the FRPFIA need to be amended to allow offshore DACCS. Moreover, establishing cross-border CCS infrastructure and agreements – particularly pipelines – is another policy area that, while not strictly necessary for the DACCS system, may also be important in offshore CDR.

This section's last criterion concerns the government’s plans for storage and multi-modal transport networks. While NRCan is developing extensive plans and maps that make use of existing networks and infrastructure for CCS, there is not enough publicly available information about their plans to determine which criteria they address and which features may need further improvements to benefit a DACCS system rather than a CCS system. In the interim, provincial governments, like Alberta’s have in Quest and ACTL, can coordinate their own systems. The geology of a region is a landscape condition that, in part, determines where projects can be sited, though transport infrastructure would make more pore space accessible and, therefore, more sites (with renewables and other resources) eligible for hosting a DAC plant.

- **Fulfilled policy objectives:**
    - **Provincial policies are beginning to regulate permanent geological carbon storage and differentiate between types of CO_2 storage and their respective level of security and risks. Federal policies have begun to clarify offset crediting protocol.**
    - **Existing pipeline networks, storage policy/sites, and pore space regulation from oil and gas sector regulation can be reused.**
- **Key gaps:**
    - **Adapt existing policy to clarify pore space ownership, liability, and overall CO_2 storage regulations in provinces besides BC, AB, & SK (differentiate types of storage and account for CO_2 accordingly)**

- ➢ **Federal guidelines for storage, siting projects appropriately, and clarification on existing legislation (i.e. application of CEPA), particularly for offshore capture, storage, and energy generation**
- ➢ **Make (CCS) CO_2 transport plans publicly available**

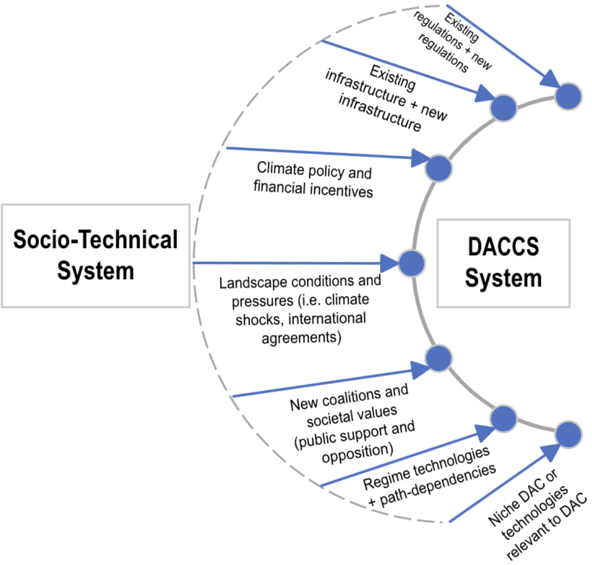
5.7 Analyzing the DACCS System

The 2021 article “Who is paying for Carbon Dioxide Removal? Policy Instruments for Mobilizing Negative Emissions Technologies” by Honegger et al. identifies several characteristics that policy for NETs should contain. These include recommendations that policy should accelerate innovation, aim to transition operations from pilot to large-scale facilities, include “robust carbon reporting and accounting procedures,” minimize side effects, seek public participation, and clarify the role of CDR in the national climate strategy (pp. 5-6). This article was one of twenty-three that I used to compile similar recommendations for CDR and DACCS-specific policies in the first stage of my data collection for this study. While observing similarities between my results and these data would not be especially meaningful because I purposefully extracted the recommendation and ‘policy objectives’ from articles like Honegger et al. (2021), one of the interesting parts of collecting the data was observing the objectives that authors across several articles agreed were important. For example, the suggestion to “pay attention to policy levers sooner rather than later [for NET deployment], because often the most challenging part of the innovation process is the move from development to large-scale deployment” from Cox et al. (2019) mirrors Honegger et al.’s (2021) recommendations that policy should specifically target and support the process of moving from pilot projects to large-scale CDR projects (p. 4). Similar articles, like Haszeldine et al. (2018), note that DAC, largely operating at the test pilot level currently, “will need scale up and cost reduction over the next 10-20 years,” further corroborating the need to focus on the transition, especially as it ties into the broader goal of building an economy of scale and commercializing DAC (p. 20). Nevertheless, neither the Honegger et al. article nor the other 22 articles I examined alone capture the full scope of policy objectives that my research yielded. For example, Honegger et al. do not discuss the role of niches in the CO_2 utilization market, while Schenuit et al. (2021) (“Carbon Dioxide Removal Policy in the Making”) highlighted the need for government support in developing CDR niches, including utilization. While there was significant, expected overlap between the articles, they complemented each other to create a more complete and specific array of policy objectives for the DACCS system, as a system within the larger sociotechnical system (see Figure 7).

Subsequently, the MLP was used to understand how the objectives described within the articles could influence the transition process.

Figure 7

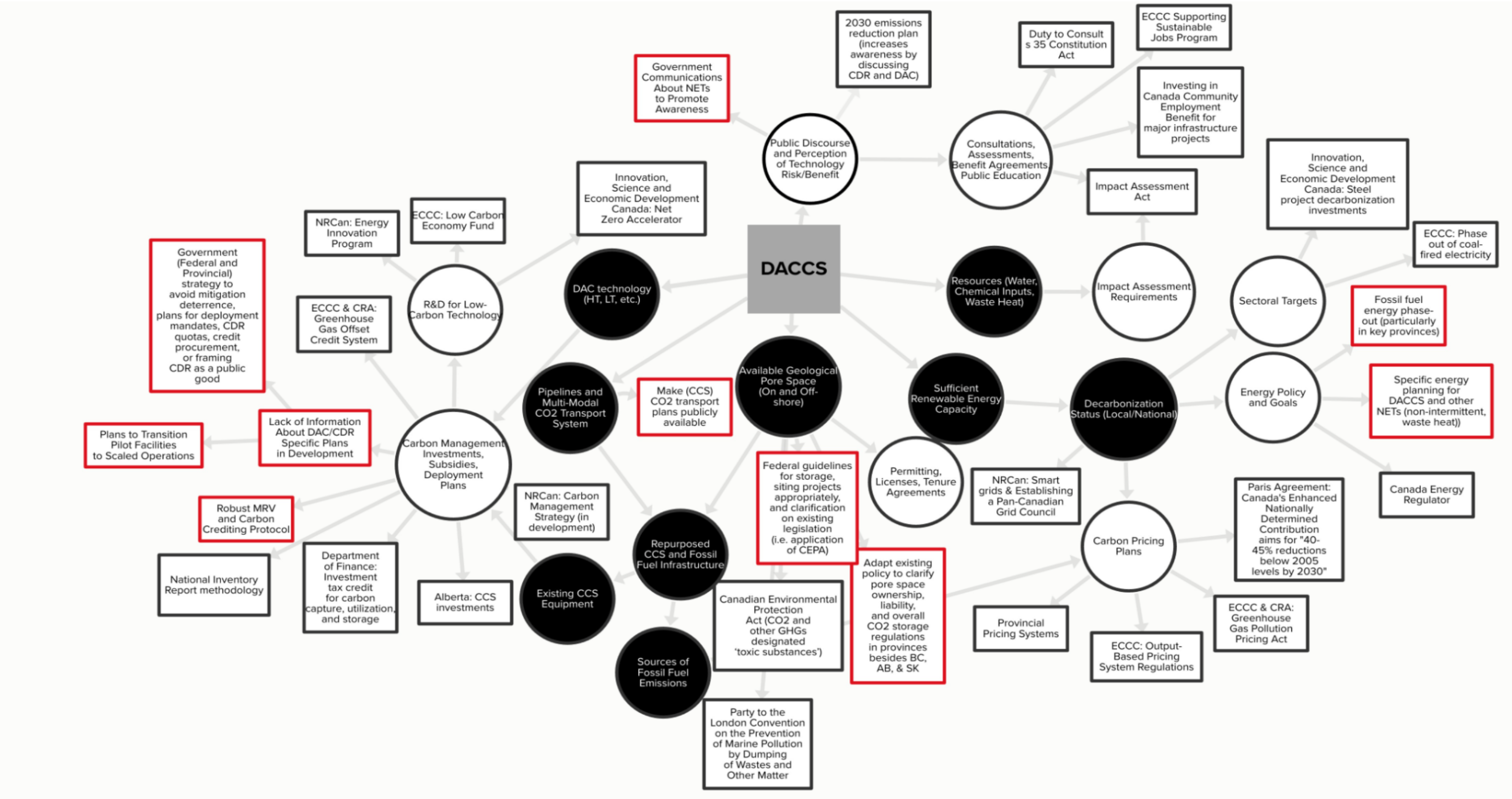
The DACCS Sub-System



Upon examining these objectives and insights, the MLP has allowed me to observe and model some key components of the regime and gaps in the DACCS sub-system in Canada (see Figure 8). Importantly, the MLP provides a framework for understanding what the regime looks like. The current regime as a whole includes the infrastructure and technologies of a fossil fuel-intensive economy, from pipelines and wells to gas-powered cars and all of the resources that support Canada's fossil fuel export economy; entire industrial networks are centred around extracting and transporting Canadian oil and natural gas (Canada Energy Regulator, 2022a). Replacing this economy and repurposing existing infrastructure will be an important part of easing this transition. However, the process of creating a DACCS sub-system within the larger Canadian socio-technical system is congruent with that objective because, for the purposes of carbon storage and transport, DACCS and other NETs can make use of some existing pipelines and depleted oil wells. Low-carbon technologies and NETs can also provide jobs to workers as Canada's oil and gas sector scales down and, as the policy examples in the first section of the Results table evidence, Canada has a number of programs in place to support this low-carbon job transition. Moreover, targetted financial support (per examples in the second section of the Results table) for research and development helps to generate techno-scientific knowledge and, therefore, niche development and integration into the regime's array of technologies. These are

Figure 8

Final System Visualization



Legend

● Physical system component

○ System policy component

▫ Policy example (non-exhaustive)

🟥 Gap

leverage points in the system because they reorient its goals so that the incumbent regime is not only working to reinforce itself but rather is actively introducing incremental changes while also retaining the utility of current infrastructure and worker competencies. By introducing new ‘rules’ to the system through incentives and regulations, regulators can help niche technologies both enter the regime and actually fulfill a necessary role in the transition. Other technological niches will also help to leverage change and successfully implement DACCS while maximizing the efficiency of project sites (e.g. via utilization). My assessment has revealed that the current regime largely lacks sectoral policies that are specific to DACCS and CDR, which are necessary to establish a functional DACCS system (see Figure 6 which identifies the system changes need to be implemented in the socio-technical regime to scale up DACCS successfully). The absence of policy is obvious enough given the newness of DAC and other NETs. However, this analysis has also highlighted the importance of observing the policies and infrastructure that are precursors to more specific policies and niche development. Coordinated regime changes, at each of the seven levels in the model, will work to adjust infrastructure and attitudes around these technologies to weaken path-dependencies and diffuse the cost of restructuring the system and introducing new network technologies. Policies that support niche carbon utilization opportunities in the near term, for example, will influence the availability of mature utilization technologies by mid-to-late century, therefore affecting the commercial viability of DAC and opportunities to further reduce removal costs once the technologies have begun to scale. The development of a carbon utilization marker will, depending on transport and energy infrastructure, also eventually influence where DACCS and CCS projects are sited, as well as more targetted regime policies on regional and national levels.

Landscape conditions in the system also impact this process. The current landscape includes exogenous pressures like climate change and rising energy costs due to international conflicts (another reason to decrease fossil fuel dependence). However, it also includes international climate agreements and a burgeoning CDR industry led by DAC companies like Climeworks and the coalitions they are establishing to support their expansion (Climeworks, 2022). While physical parts of the landscape in Canada (like eligible geological pore space) will not change, it is possible that developments at the regime level in regulation and policy will make new areas eligible for storage (i.e. offshore mineralization by amending legislation). In the future, the landscape will also involve the status of decarbonization in the regimes of other states, technological development, knowledge production, technology deployment, and establishing shared international carbon management practices (crediting, tracking, accounting).

Over the course of the climate crisis, landscape conditions or shocks (e.g. climate-related weather events) will influence how much and how fast DACCS gets deployed; more extreme weather caused by climate change will likely increase demand for CDR (i.e. producing co-benefits, utilizing a surplus of appropriate renewable energy in a region), which means that NETs will have a better chance of receiving support from the regime, joining the regime, and scaling up.

To directly answer the research question at the centre of this thesis, scaling up the DACCS system in Canada is contingent on early incentives and regulatory changes to enable facilities to be built at scale by mid-century (despite the delays associated with coordinating and building capacity for parts of the process, especially storage). The IEA has noted that while facilities in CO_2 capture projects (CCS or DAC) themselves take 3-5 years to build, assessing and developing storage typically takes much longer (together taking over a decade) (IEA, 2022). Although appropriate changes in energy policy are underway, financial and regulatory changes are progressing, and government plans will (to some extent) ensure that the public's needs are met in the transition process, the DACCS system is still far from being complete.

The scale-up of DACCS will occur in the context of regime change and a low-carbon system transition. However, unlike historical cases of technology that have featured in large-scale socio-technical transitions (e.g. the impact of the internal combustion engine on transportation, the physical design of urban spaces, and social perceptions of space and time), DAC is not replacing a previous technology and taking on its role in the regime. As Geels (2011) notes, sustainability transitions are purposive, in contrast to transitions driven by commercial opportunities. Rather, DACCS is a technology that fulfills a service that was not previously necessary to maintain a stable regime but became necessary due to landscape conditions. DACCS is a technology complementary to the major renewable energy and energy storage technologies that will enable large-scale emissions reductions. Though it necessitates a complex system of its own, it is not the central technology of the low-carbon socio-technical transition. The ideal regime would help DAC to co-evolve with renewable energy capacity by having the government invest in DACCS early and site it in proximity to renewables from the beginning so as to avoid any path dependencies caused by relying on fossil fuel energy or less-than-optimal storage sites (Creutzig et al., 2019).

DACCS will, in other words, become a network technology within the regime in Canada rather than a technology introduced mid-century to mitigate overshoot.[12] If energy infrastructure

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[12] Particularly, if the government plans to achieve net-negative emissions if and when the net-zero target is met.

planning decisions remain separate from discussions of where to site DAC and coordinating carbon transport and storage networks, the risk of technology lock-in in Canada will increase, since pipelines and energy infrastructure are capital-intensive, long-term infrastructures. This, in turn, factors into a firm's selection criteria when deciding where to site their facilities; in energy-intensive industries, for example, firms would be most willing to site facilities where they would be able to access a cheap supply of energy. One of the key takeaways of this study is that many of the types of policy actions that the government should undertake do not belong to a single theme category or sector despite being sorted as such. Rather, the objectives DACCS system policies must fulfill extend to multiple parts of the system, which requires cooperation between different actors and coordination across government institutions. For example, clarifying carbon storage regulations not only enables developers to design transport and storage infrastructure, it also reduces uncertainty for investors, which helps DAC projects secure funding; with effective public communication, these clarifications can also promote social acceptability in Canada. Though not a subsidy or investment, this is a means for the government to change incentives in the system and reduce barriers to deployment. Those objectives that transcend categories further emphasize the need to have DACCS and NET-specific policies and integrate them into the existing system and policy framework in the system.

This chapter has exposed gaps in the policy categories I have explained thus far. However, my description and analysis have not necessarily included specific critiques of the policy framework or helped explain why particular gaps persist in Canada. This includes commentary on parts of the system that fulfill particular policy objectives for DACCS governance but still need improvement to support the system more effectively. For example, while some policies support social acceptability and public interests, they do not necessarily guarantee best practices will be followed in all relevant activities and consultation processes or will even apply to all related projects. The Impact Assessment Act supports this policy category but only applies to projects on federal lands, while the duty to consult is a Crown obligation specifically. The limitations of these key policies could enable major infrastructure projects to evade adequate public consultations. Although they are policies that have similar impacts on the provincial and municipal levels that cover some of these gaps–for example, the CBA requirements in Toronto and Vancouver (as observed in the table). This gap exists, in part, due to the division of powers between the federal and provincial levels of government in Canada.

The same friction exists with regard to local energy and resource policy. Although the federal and provincial governments alike have established ambitious energy system decarbonization goals, as well as incentives and programs to support the transition, provincial control over energy production within provincial borders and ownership over electrical utilities via Crown corporations, in addition to municipal zoning bylaws, all complicate the process. Given the different energy resource profiles of Canadian provinces and their associated economic and political interests associated with these resources, the transition will continue to happen at different rates across the country. Geological carbon storage regimes will also similarly vary in their development. Since the broader socio-technical system operates through different levels of bureaucracy in government and the private sector, the inertia that already exists in the system will influence the rollout of new incentives, technologies, and infrastructure. Moreover, large-scale change may result in contention over the legitimacy of CDR in the climate strategy. The federal benchmark for carbon pricing has already been subject to pushback from some provinces, which resulted in legal challenges against the constitutionality of the Greenhouse Gas Pollution Pricing Act, which the Supreme Court of Canada upheld (ECCC, 2021). Whether the policy tools that are currently in development will be sufficient or well-received depends on whether policymakers can effectively communicate how important DACCS is to achieving the goals of the system. It will also depend on whether changes to the regime are able to progress as planned (i.e. whether the years-long processes for securing carbon storage permits are successful will determine if projects can move forward as planned). Even if a project developer locates an ideal project site, the outcomes of these procedures may halt activity and waste a significant amount of pre-development effort to coordinate an appropriate energy supply. Long project timelines, delays, and uncertainties will likely remain obstacles to DACCS development despite efforts to minimize them and clarify regulations. Still, good DACCS policies in Canada will anticipate these delays and conflicts and help to streamline the process of moving from pilot-scale development to large-scale deployment. Since choosing a location for the capture, transport, and storage stages of the sequestration process are contingent on each other as well as energy and resource availability, funding and siting niche technologies and infrastructure should be strategic to ensure technologies make optimal use of a region; therefore, policymakers should be apart of this process so as to clarify relevant regulations and barriers as soon as possible. As emphasized by various DACCS and CDR-focussed studies, reducing uncertainty around the niche technology is key to eliminating social, political/institutional, and economic barriers such as these (Buylova et al., 2021; Erans et al., 2022; Fuss et al., 2018; Lackner & Azarabadi, 2021; Minx et al., 2018; Nemet et al., 2018; Realmonte et al., 2019).

5.8 Contributions

After completing my research and reflecting on the results, I have identified several contributions to the literature, including novel applications of the theory and methods, my research findings, as well as the DACCS system assessment tool derived from it, and the integration of detailed policy examples into a system framework and visualization. The main contribution to theory is my application of the MLP to explain the role and pathways for DACCS in the socio-technical transition. Though Schenuit et al. (2021) previously combined CDR and the MLP in their study of policy in OECD countries, my research had a more specific focus on DACCS and applied theory differently. For each country, Schenuit et al. (2021) identified policy instruments, CDR niches, CDR accounting and methods, and the position of domestic expert bodies. In contrast, I primarily looked at domestic policy and reports to compile information on the different parts of the socio-technical system that would need to adapt to support DACCS scale-up. My approach was action-oriented and considered the seven different regime components that Geels identified. Other studies have used the MLP to explain complex systems and systemigrams to visualize the system. However, none used the theory to map the system itself by integrating a large volume of policies. This level of attention to individual policies is often missing from similar social science research, even though applying theory to policy to assist policy decisions is a shared goal between these studies.

The narrow focus of this study builds on the literature by providing a first in-depth analysis of DACCS and the policies that are needed to scale the technology in the context of a country-level case study. Studies of CDR that contextualize the role of NETs in the low-carbon transition and propose rational pathways to build upon existing policies will be especially important to understanding which technologies can be deployed where, how to reduce technology costs, and which kinds of policies are especially important in a particular context. Studies like Honegger et al. (2021) and Nemet et al. (2018) laid the foundation for understanding the key stages of upscaling and technology development which will be relevant to NETs and CDR efforts. Such studies also did a good job of making general observations about the challenges associated with the technologies at the global level. However, different NETs do not have the same needs as each other, especially at the state level, which demands further case studies similar to what has been presented in this thesis. Conversely, technology-specific studies, such as McQueen et al. (2021) and Lackner & Azarabadi (2022), have tended to focus on technology costs and innovation without discussing the broader spectrum of climate and environmental policies, social pressures, and infrastructure that could enable or impede development. By emphasizing the policy structures (and associated path-dependencies) already in place in Canada, my study identifies the real challenges and policy gaps that policymakers will need to address to achieve the necessary level of CDR.

Another contribution this thesis makes is methodological. Though the investigation began as a framework and document analysis, my research yielded a gap analysis tool by collecting policy objectives and converting them into questions to help understand how 'complete' the country's DACCS policies are. Moreover, by combining system mapping techniques with the underlying framework analysis and the MLP theoretical framework, I designed a unique methodological approach tailored to answer my research question sufficiently.

Lastly are the findings of my research itself, which identified the areas of Canada's policy and physical system for DACCS that require action from policymakers. Not all of these gaps were unique to my findings or unidentifiable through other methods or reports–instead, there were many similarities between Canada's system gaps and other countries. However, the systemic way I recorded the gaps allowed me to describe the origin of the gaps and how they might be resolved.

6. Conclusion

This research aimed to identify the policies that are needed to scale up DACCS in Canada and overcome the sociopolitical, economic, and techno-infrastructural barriers that impede that process. Since DACCS development will happen concurrently with decarbonization in the context of a low-carbon transition, this thesis sought to investigate the co-requisite features of a DACCS system that policymakers need to focus on to facilitate this transition in near to medium-term policymaking. Based on a qualitative analysis of climate-related policies in Canada using a set of policy recommendations derived from the literature on CDR policy, this study has located several key gaps in the DACCS system, both in physical infrastructure and policy. This chapter will conclude the thesis by outlining its main findings, outcomes relative to my research questions, any auxiliary findings, and areas for further research.

My research questions prompted me to investigate the literature and the scope of policies that will be relevant to DACCS in Canada. My first set of questions reads:

1. What policies are required to build and expand the infrastructure, economic incentives, regulatory regimes, and protected niche markets needed to support the large-scale development of direct air carbon capture and storage technologies in a manner conducive to a just, low-carbon socio-technical transition in Canada?
    a. Do existing policies that serve these functions? How do they do this? What are they?

These directed me to examine the Canadian Climate Institute's database of climate mitigation policies in Canada (Bryan et al., 2022). After sorting relevant policies into six thematic areas–social acceptability and public interest; policy for financing scale-up and supporting innovation; general environmental policy and climate mitigation strategy; carbon capture and removal technology and regulation; energy policy and local resource constraints; carbon transport and storage regulation–I was able to locate policies that already fulfill some important objectives that policies in an ideal DACCS 'system' need to fulfill, including carbon pricing and pore space regulations. Using the MLP conception of socio-technical systems and transitions, I was able to understand how systems change, which would later help me to explain how niche technologies like DAC can scale up with the support of regime-level interventions in the system and exogenous landscape influences. Across the study, I used system visualizations to develop an understanding of its constituent parts and the relationships between them.

Whereas my first research question sought to define the current system in Canada, my second set of questions prompted me to define what an ideal system looks like and speculate on how the current system might transform into the ideal.

2. What are the gaps in the system supporting DACCS?
    a. What kinds of policies will the government need to implement to address these gaps?

Using framework analysis as the basis of my methodology, I extracted key objectives from the literature and created a table of questions that served as criteria for an effective DACCS system. Then, using the policy database, I was able to assess Canada's policies based on those criteria and systematically identify policy gaps. The MLP, as my theoretical framework, allowed me to analyze the gaps and draw conclusions from that analysis.

One of the main findings of this study is that different policy areas (across sectors) will need to incorporate NETs and DAC into planning and infrastructural decisions. Renewable energy capacity, CO_2 storage, and pipeline accessibility are key considerations for siting DACCS facilities, and there will need to be government guidelines for doing so. Simultaneously, the government will need to ensure that, as they integrate DACCS into the climate strategy and increase policy incentives accordingly, they communicate with the public about the purpose, risks, and benefits of the technology. Moreover, the government should introduce policies to ensure that project developers engage with local communities at project sites, assess the feasibility of deployment, and confer benefits to the community, especially if existing legislation is insufficient for ensuring a particular community receives adequate protection and input. Since the government is in the process of developing new policies and accounting protocols to accommodate the scale-up of DACCS removals, it is imperative that policymakers at the federal and provincial levels clarify uncertainty around the role of DACCS in Canada's transition, as well as updating existing legislation to resolve uncertainty around on and offshore carbon storage regulations, the distinction between emissions reductions and removals, the possibility for cross-border transport, storage, and hubs, and release timelines for implementation and technology deployment at scale.

Though not as specific to my research questions and discussion chapter, I also noted the limited availability of studies focused on indigenous rights and perspectives on NETs, both in Canada and in the literature as a whole. More detailed policy objectives in this area would benefit future research and are essential in ensuring that the processes of NET deployment and decarbonization are just, respect land rights, and manage environmental and social risks. There was a similar deficit in policy recommendations around pipeline management (repurposing and constructing new ones); some of this information may be explored in greater depth in some of the CCS literature not explored in my literature review and was also excluded from the CDR-specific documents I used to collect criteria. However, there is likely a need to expand research into the different implications of pipelines built for DAC-associated storage and CCS pipelines, particularly regarding infrastructural lock-in.

Given the time constraints of a Master's research project, I was also not left with enough time to complete an in-depth comparative analysis of the DACCS system in Canada and another country. Since a few of the articles included in my sample were case studies in other regions, I was still able to comment on the similarities and differences between the strengths and weaknesses of the policy and physical systems of different countries in my discussion based on the criteria I had collected. Future research should develop a more complete analysis of these other systems using my assessment questions. Time constraints also limited the extent to which I could record the nuance and detail of each province's policy and infrastructure. At that level of abstraction, I would have also been able to discuss the suitability of DACCS in different provinces, drawing on statistical tools and quantitative data on energy and resources within a province relative to other regions (e.g. another province or a U.S. state making progress on CCS and DACCS).

Nevertheless, I have contributed to the growing body of literature on DACCS and CDR policy by performing a system-level analysis focused on a single country and technology case study. Much of the literature addresses an array of technologies at a more aggregated level without connecting specific policies to technology demands. By contrast, the more narrow focus of this research allowed me to suggest observations and policy recommendations that address the complexities of the Canadian context. Further research should explore additional methods, like interviews and quantitative analysis, to provide more detailed insight into future policy pathways for DACCS. Additionally, given that relevant policies and plans are likely to be released in the next year or two, an updated assessment would also be a valuable research opportunity. Moreover, a study that explores pathways within one of the provinces that already has DAC and CCS-specific policies would similarly benefit this research area.

The demand for CDR amidst the climate crisis will grow over the coming decades, along with the demand for NET-focused policy research. This study has addressed the system demands and barriers associated with deploying DACCS in Canada, a technology that is one of the climate intervention strategies with the most carbon removal potential. By highlighting policy gaps and establishing a set of criteria for deploying DACCS effectively, this research has begun to address important state-level policy considerations relevant to the role of NETs in the transition process.

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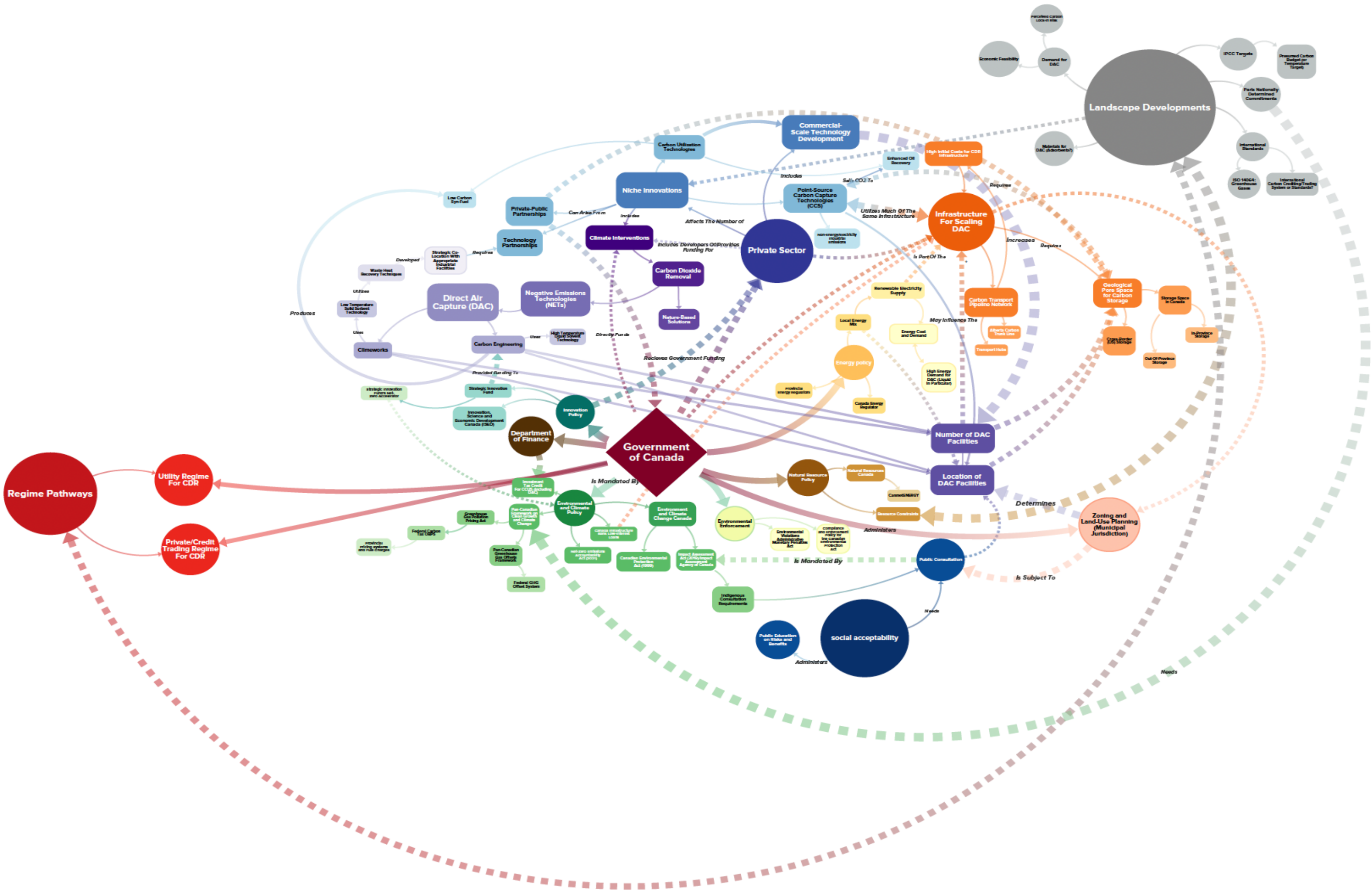
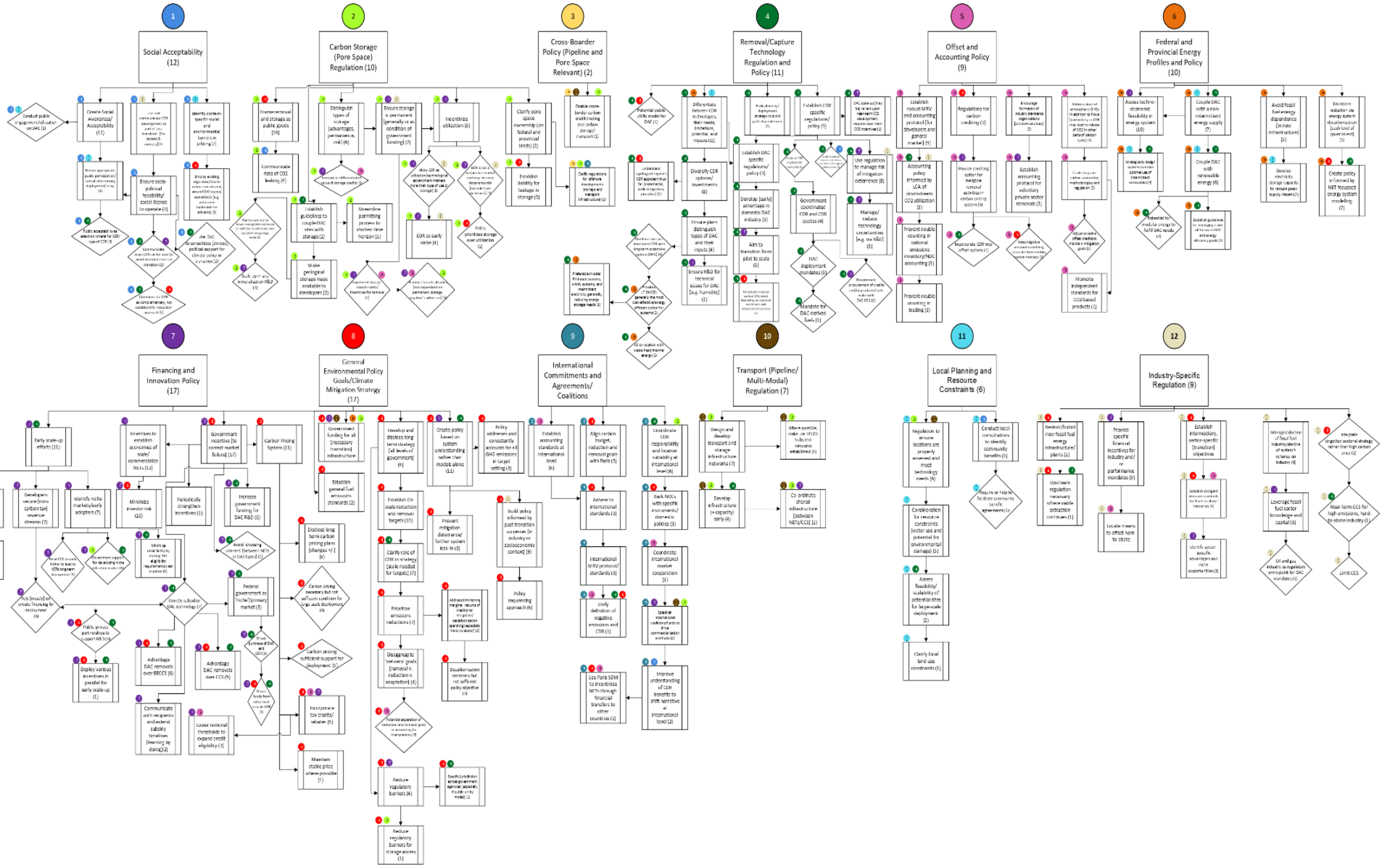
Appendix A.

Initial systemigram/mind mapping



Appendix B.

Policy objectives codes chart



Appendix C.

Criteria:	**Identifying Relevant Articles and Establishing Selection Criteria**	(Sources should check the first grey column, at minimum. If only that column is checked, the paper must be a highly cited work on a relevant policy area. Expert and think tank reports that have no citation listing but satisfy two or more criteria–particularly those that discuss Canada since there are few–will be included)			
	Policy Recommendation Citations:	*Approximate number of citations (from Google Scholar):*	*Discusses negative emissions, NETs, or CDR policy/includes system relevant insight (including info from the energy sector and CCS development):*	*Specifically mentions Canadian policy:*	*Specifically discusses DACCS+T at some point:*
1.	Williams, E. (2022). The Economics of Direct Air Carbon Capture and Storage. *Global CCS Institute.* 1-26. https://www.globalccsinstitute.com/resources/publications-reports-research/the-economics-of-direct-air-carbon-capture-and-storage/	N/A	√	- (one mention of Canada as example, not subject of paper)	√
2.	Hodgson, G. & Hodgson, D. (2022). Federal Purchases of Direct Air Capture Would Help Build a Viable Market. *C.D. Howe Institute.* https://www.cdhowe.org/intelligence-memos/hodgson-hodgson-federal-purchases-direct-air-capture-would-help-build-viable	N/A	√	√	√
3.	McLaren, D. P., Tyfield, D. P., Willis, R., Szerszynski, B., & Markusson, N. O. (2019). Beyond “net-zero”: A case for separate targets for emissions reduction and negative emissions. Frontiers in Climate, 1. https://doi.org/10.3389/fclim.2019.00004	105	√	-	√
4.	Larsen, J., Herndon, W., Grant, M., & Marsters, P. (2019). Capturing leadership: Policies for the US to advance direct air capture technology. New York, NY: Rhodium Group. Available online at: https://rhg.	18	√	-	√

	com/wp-content/uploads/2019/05/Rhodium_CapturingLeadership_May2019-1. pdf (accessed April 02, 2021).				
5.	Fajardy, M., Patrizio, P., Daggash, H. A., & mac Dowell, N. (2019). Negative Emissions: Priorities for Research and Policy Design. Frontiers in Climate, 1. https://doi.org/10.3389/fclim.2019.00006	32	√	-	√
6.	Peters, G. P., & Geden, O. (2017). Catalysing a political shift from low to negative carbon. Nature Climate Change, 7(9), 619-621.	143	√	-	-
7.	Lehtveer, M., & Emanuelsson, A. (2021). BECCS and DACCS as negative emission providers in an intermittent electricity system: why levelized cost of carbon may be a misleading measure for policy decisions. Frontiers in Climate, 3, 647276.	12	√	-	√
8.	Erans, M., Sanz-Pérez, E. S., Hanak, D. P., Clulow, Z., Reiner, D. M., & Mutch, G. A. (2022). Direct air capture: process technology, techno-economic and socio-political challenges. Energy & Environmental Science, 15(4), 1360-1405.	34	√	-	√
9.	Meckling, J., & Biber, E. (2021). A policy roadmap for negative emissions using direct air capture. Nature communications, 12(1), 1-6.	17	√	-	√
10.	Nemet, G. F., Callaghan, M. W., Creutzig, F., Fuss, S., Hartmann, J., Hilaire, J., ... & Smith, P. (2018). Negative emissions—Part 3: Innovation and upscaling. Environmental Research Letters, 13(6), 063003.	254	√	-	√
11.	Honegger, M., Poralla, M., Michaelowa, A., & Ahonen, H.-M. (2021). Who is paying for carbon dioxide removal? Designing policy instruments for mobilizing negative emissions technologies.	20	√	-	√

	Frontiers in Climate, 3. https://doi.org/10.3389/fclim.2021.672996				
12.	Schenuit, F., Colvin, R., Fridahl, M., McMullin, B., Reisinger, A., Sanchez, D. L., Smith, S. M., Torvanger, A., Wreford, A., & Geden, O. (2021). Carbon dioxide removal policy in the making: Assessing developments in 9 OECD cases. Frontiers in Climate, 3. https://doi.org/10.3389/fclim.2021.638805	47	√	-	√
13.	Valiaho, B. H. (2020, July 14). Importance of CCS hubs. International CCS Knowledge Centre. Retrieved July 30, 2022, from https://ccsknowledge.com/blog/importance-of-ccs-hubs	N/A	√	√	-
14.	Asayama, S. (2022). The Oxymoron of Carbon Dioxide Removal: Escaping Carbon Lock-In and yet Perpetuating the Fossil Status Quo?. Governing Carbon Dioxide Removal.	7	√	-	√
15.	Beuttler, C., Charles, L., & Wurzbacher, J. (2019). The role of direct air capture in mitigation of anthropogenic greenhouse gas emissions. Frontiers in Climate, 1, 10.	97	√	-	√
16.	Creutzig, F., Breyer, C., Hilaire, J., Minx, J., Peters, G. P., & Socolow, R. (2019). The mutual dependence of negative emission technologies and energy systems. Energy & Environmental Science, 12(6), 1805-1817.	125	√	-	√
17.	Rueda, O., Mogollón, J. M., Tukker, A., & Scherer, L. (2021). Negative-emissions technology portfolios to meet the 1.5° C target. Global Environmental Change, 67, 102238.	30	√	-	√
18.	Fuss, S., Lamb, W. F., Callaghan, M. W., Hilaire, J., Creutzig, F., Amann, T., ... & Minx, J. C. (2018). Negative emissions—Part 2: Costs, potentials and side effects. Environmental	792	√	-	√

	Research Letters, 13(6), 063002.				
19.	Marcucci, A., Kypreos, S., & Panos, E. (2017). The road to achieving the long-term Paris targets: energy transition and the role of direct air capture. Climatic Change, 144(2), 181-193.	96	√	-	√
20.	Cox, E., & Edwards, N. R. (2019). Beyond carbon pricing: policy levers for negative emissions technologies. Climate policy, 19(9), 1144-1156.	41	√	- (some brief, not especially notable examples of Canadian funding programs and pore space ownership in AB, out of date)	√
21.	Craik, N., Hubert, A. M., & Daku, C. (2022). The Legal Framework for Carbon Dioxide Removal in Canada. Alta. L. Rev., 59, 833.	-	√	√	√
22.	Lomax, G., Lenton, T. M., Adeosun, A., & Workman, M. (2015). Investing in negative emissions. Nature Climate Change, 5(6), 498-500.	87	√	-	-
23.	Haszeldine, R. S., Flude, S., Johnson, G., & Scott, V. (2018). Negative emissions technologies and carbon capture and storage to achieve the Paris Agreement commitments. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 376(2119), 20160447.	227	√	-	√

Appendix D.

Connections between the physical system and system policies