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About ISEMA
ISEMA is a graduate journal founded by students in the Innovation, Science and Environment (ISE) stream that preceded the Sustainable Energy Policy (SEP) program of the School of Public Policy and Administration at Carleton University. The purpose of ISEMA is to showcase the best student work on ISE and Sustainable Energy (SE) policy issues, while providing students with a unique opportunity to experience the peer-review process. Articles are nominated by professors teaching courses in the SEP program and other courses focusing on ISE-related topics. Nominated papers are subjected to a double-blind peer review process by ISE alumni and other specialists in the field. The highest ranked papers then undergo an editorial process before publication. ISEMA also serves as a valuable resource for students and others wishing to learn more about the latest policy trends and issues emerging from this exciting area.

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ABOUT THIS EDITION

The ISEMA executive and editorial board have worked diligently over the past several months to put together the 13th volume of the journal. ISEMA Volume 13 received 11 papers from students in the School of Public Policy and Administration at Carleton University, all of which were excellent in their writing and persuasive in their arguments. Following a rigorous double-blind peer-review process, we have selected four exceptional papers for publication in this year’s edition. These papers takes a deep dive into topics within the energy, environment, and innovation sectors.

- John McNally conducts an analysis on deep decarbonization pathways in Canada in order to answer a captivating question: how can Canada successfully meet its 2050 target of 80 percent emissions reduction? McNally does so by exploring the aspects of a low-carbon transition in Canada, current climate policies, and recommended policies for adoption.

- Peter Whitred contextualizes building policy in Canada, and explores different policy instruments that would enable a reduction in greenhouse gas emissions from the sector. Whitred focuses on building codes, symbolic response and exhortation, and expenditure based approaches as key policy instruments in cultivating a strong foundation for sustainable building policy and effective climate change mitigation.
• With his second paper in this year’s edition, John McNally takes a deeper dive into decarbonisation pathways, this time homing in on the aviation sector. McNally acknowledges international aviation as a fundamental barrier to total economic decarbonisation, and analyses existing policies, technical solutions, and various policy levers that could clear the runway for emissions reductions in the aviation sector.

• Parisa Khosraviani explores the roll-out of 5G networks. In light of the emergence of this innovative technology, there have been health concerns from the public regarding the implementation of 5G infrastructure. Khosraviani analyses the issue by outlining the technical elements of 5G, conducting an examination of current literature on the subject, and analyzing how the precautionary principle can be considered in decision making in the face of scientific uncertainty.

The ISEMA executive and editorial board would like to extend its gratitude to all authors as well as participants in the external and internal review process for dedicating their time and effort in publishing this year’s edition of the journal. The executive and board would also like to thank the School of Public Policy and Administration at Carleton University for their continued support of ISEMA.
HOPE IS NOT A STRATEGY: NAVIGATING A COURSE TO DEEP DECARBONIZATION IN CANADA

Author: John McNally
Written for: The Science, Politics and Economics of Global Climate Change

INTRODUCTION
Canada's current approach to combating climate change relies upon meeting two targets: a 30% reduction in greenhouse gas (GHG) emissions below 2005 levels by 2030, and an 80% reduction in GHG emissions below 2005 levels by 2050 (Langlois-Bertrand, Mosseau, Beaumier, Bahn, & Vaillancourt, 2018). One is short-term and focuses entirely on taking steps to reduce emissions within the next decade. The other is longer-term, necessitates structural change, and is quickly becoming the elephant in the room for environmental policymakers in Canada and the world. As the Canadian political and social classes battle over climate policies deployed by the federal government to meet the nation’s 2030 GHG emissions reductions target, very little mainstream discussion is taking place about what is supposed to come next: an unprecedented increase in the ambition and scale of national decarbonization to a rate never before seen anywhere across the globe. It is becoming clear that the increasingly aspirational pace of emissions reductions required to meet targets in a post-2030 Canada cannot be driven using the same old approaches to climate action. With barriers to using today’s methods becoming ever clearer, the Canadian federal government can no longer simply hope systemic change occurs. Canada must set a new and more direct course if it is to safely reach its low-carbon economy of tomorrow.

This essay seeks to answer three broad questions: what does a low-carbon transition look like in Canada? How are
today’s climate policies supporting Canada in meeting its 2050 target? And what policies could be adopted to ensure Canada is successful in transitioning to a low-carbon economy before the benefits of climate action are outweighed by the looming costs of inaction?

This essay aims to answer these questions analytically. The first step will be conducting a review of low-carbon transitions literature in the Canadian context to examine the pathways to Canada becoming a low-carbon economy. Second, once these pathways are defined, this paper will use a low-carbon pathways framework to analyze the current suite of federal climate policies in the Pan-Canadian Framework on Clean Growth and Climate Change to identify which policies have the potential to accelerate Canadian decarbonization and which ones may inadvertently impede it. This paper will look to connect this theoretical framework to identified best practices in real-world climate policy design, emphasizing the importance of developing economic and political support for climate solutions that allow for the achievement of long-term climate targets. Finally, this essay will present recommendations for a restructuring of policy actions in order to develop momentum and support behind a low-carbon transition that will move at the pace required to meet Canada’s 2050 target.

What does Canada’s low-carbon future look like? 
Avoiding the iceberg

In 2018 the Intergovernmental Panel on Climate Change (IPCC), an international UN body, released a special report on the potential impacts of a changing climate. The report highlighted the urgent need for climate action by stating that unless global emissions are reduced by 25%-45% by 2030 and 70%-100% by 2050, there will be no possibility of keeping the global average temperature below the 1.5°C – 2°C target codified in the Paris Agreement (Intergovernmental Panel on Climate Change, 2018).
The Canadian government has readily endorsed this conclusion in its own pledges to combat climate change. The federal government has two emissions reductions targets that largely align with the pace of decarbonization called for by the international scientific community. The first is a 30% reduction in absolute GHG emissions below 2005 levels by 2030, and the second is a loftier pledge to reduce absolute emissions by 80% below 2005 levels by 2050 (Canada, 2016a). Currently, the 2030 target dominates the federal government’s agenda. This is emphasized by the deadline’s use in signature climate policy documents from the macro-level ‘Pan-Canadian Framework on Clean Growth and Climate Change’ to the more technical pledge to phase-out coal-fired electricity generation by 2030 (Canada, 2016b). However, these actions are not usually framed solely based on their potential to help Canada meet its 2030 target. Rather, they are framed politically as key steps towards a longer-term and more ambitious goal.

Political and policy documents that focus on combating climate change within Canada share a common theme: Each highlights the importance of transitioning the nation towards a ‘low-carbon economy’ (Canada, 2016b). This phrase has permeated the funding mechanisms, mandates and rhetoric of the current Liberal government over the last three years (Government of Canada, 2015; Government of Canada, 2017). What the term may lack in specificity, it makes up for in implied ambition. Canada’s publication of ‘The Mid-Century Long-Term Low-Greenhouse Gas Development Strategy’, or Mid-Century Strategy, submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in 2016 highlighted that the creation of a low-carbon economy in Canada depends entirely on the nation meeting its 2050 climate goal (Canada, 2016a). The report itself states “the Mid-Century Strategy is an essential first step to set the course towards a low-carbon economy” and reaffirms the 80% emission reductions target. This implies that the low-carbon economy envisioned for Canada by the Liberals can only exist if the nation meets its
2050 climate target (Canada, 2016a). This pledge, while non-binding, will guide the analysis in this paper moving forward. A transformation on the scale of economy-wide decarbonization of processes and services within the next 31 years requires enormously ambitious strategy and vision to achieve. It is essential to understand what that vision might entail by identifying what decarbonization in line with meeting the 2050 target looks like. This is an essential step that must be undertaken before an evaluation of Canada’s progress towards meeting its 2050 objective can take place.

**Understanding navigation to a low-carbon economy (LCE)**
Reducing emissions by 80% and fundamentally restructuring the national economy in a little over three decades is no simple task. The phenomenon of completely decoupling economic growth from emissions growth and developing a low-carbon economy is known as ‘deep decarbonization’ and the precise nature of how to actually achieve it has been a detailed area of collaborative study. Research focuses on two questions whose answers inform the development of each nation’s vision of their own low-carbon future: what does a low-carbon economy look like, and how do we get there (Sustainable Canada Dialogues, 2017)?

Before comparing existing visions for Canada’s low-carbon economy, it is important to understand the theoretical framing around these topics. Decarbonization discussions can be understood as a conversation about the ‘pathways’ that economies and societies can take to reach their low-carbon identities of the future. Each pathway is a combination of social, economic and technological factors that push progress in one direction, or trajectory, over another (Rosenbloom, 2017). In pathways literature, which can be viewed through a multi-level perspective approach, three concepts are important to understand: the landscape, the regime and the niche. The landscape is a term used to
describe the broader system; the set-up of actors, technologies and processes that make up the world being examined. The regime is a term used to define the actors, players or technologies who make up the status quo; in environmental terms, these actors would include the fossil fuel industry, mainstream political parties and the internal combustion engine (Meadowcroft, 2016). Niche actors are those looking to upend or disrupt the landscape. These include renewable electricity technologies and environmental activists. The interactions between regime and niche actors to date are one of the key factors that has shaped the current landscape. The success or failure of each party in maintaining or disrupting the status quo moving forward is what will lead to changes in the landscape of the future. The combined impacts of those social, economic and technological changes therefore make up the pathway that society is taking moving forward. Pathways are also directional and any one can be described as a ‘trajectory’; an economy moving away from fossil fuels can be described as having a lower-carbon trajectory than one that is not.

An additional element to highlight is that once a trajectory along a certain pathway is underway, it can be near impossible to change. This is known as ‘pathway dependence’ or ‘lock-in’ (Rosenbloom, 2017). Once a certain technology or approach has set in as the new regime, its adoption and uptake can create a ‘path-dependence’ that limits the ability of other niche actors to change the course of progress. This ‘lock-in’ to a certain system can set a trajectory for the years or decades to come. The path dependency phenomenon is often studied in climate change debate to frame how a landscape configured for the use of fossil fuels, through corporate economies of scale and widespread infrastructure, can actually structurally slow the uptake of lower-carbon technologies and processes (Unruh, 2000).

*A low-carbon future for Canada*
Scholars and groups have long used pathways frameworks to determine how the actions taken today shape the world of tomorrow. Specifically, researchers in recent years have been assessing how to create Canada’s low-carbon economy of the future by starting with a vision of 2050 and working backwards to figure out how to get there. This paper conducted a comparative analysis of three projects that produced reports detailing paths’ for a Canadian low-carbon transition: the Deep Decarbonization Pathways Project, the Trottier Energy Futures Project and the Sustainable Canada Dialogues. These initiatives were selected because they were not only specific to the Canadian context, but were explicitly highlighted in Canada’s Mid-Century Strategy. This matters because the Mid-Century Strategy is currently Canada’s only official public document that details what a low-carbon economy in 2050 could entail, which means any formal thinking done by the federal government about 2050 up to this point has yet to move beyond this level of detail. With that in mind, this paper must assume that any decarbonization pathway highlighted in this report has been heavily influential in shaping official thinking to date. This makes an analysis of these reports a valuable place to start when determining how discourse about Canadian decarbonization will be shaped in the coming decade.

The Mid-Century Strategy itself is not assessed because it is not technically a decarbonization pathways model. Rather, the strategy describes itself as “an opportunity to begin the conversation” and is therefore categorized as more of a discussion paper than a pathway to be analyzed in depth. Other reports highlighted in the Strategy were individually assessed and each was found to be more of a discussion paper than a formal model. This meant it was not possible to assess them using a formal pathways framework and they are therefore not included in this analysis.

It should be noted that this essay does not look to compare modelled quantitative pathways against each other. Even a
cursory analysis shows that comparing pathways between reports is near impossible because of three key differences: the scope of sectors analyzed within modelling, the differences in the authors’ categorization of sectors, and the differences in the assumptions made within each report. Certain reports, such as the Trottier Energy Futures Report, have assumed ambitious technological innovation rates and included the agricultural sector while excluding the waste sector from their emissions baselines (Trottier Family Foundation, The Canadian Academy of Engineering, & David Suzuki Foundation, 2016). Others have taken a fundamentally different approach, choosing to focus on industrial emissions while including waste sectors and modelling a different mix of technologies across sectors while defining innovation in a completely different manner (Bataille, Sawyer, & Melton, 2015). These two reports not only have different emissions levels set as their 2015 baselines, but also have drastically different conclusions regarding what is or is not economically feasible moving forward.

In short, a quantitative comparison of these reports is not possible. Therefore, this essay looks at the common elements and themes around what the generally agreed-upon approaches to decarbonizing Canada are and should be moving forward. This analysis allows for an understanding of which steps experts commonly agree are required for Canada to meet its deep decarbonization target, and can be used as a baseline when comparing against Canada’s current climate trajectory. A detailed comparative analysis of the themes present in these reports can be seen in Annex 1, with a summary compiled in Table 1 below.

Table 1: Elements that scholars agree are required for Canada’s transition to a low-carbon economy
This analysis illustrates that while uncertainty is abound regarding what technologies or systems will drive a low-carbon transition in Canada, all parties universally agree that deep decarbonization in Canada will involve the four following elements:

1. The removal of price-distorting fossil fuel subsidies and the pricing of carbon pollution;
2. Mass electrification of all systems in the residential, commercial and industrial sectors (when technically feasible);

This table summarizes the key elements:

<table>
<thead>
<tr>
<th>Enabling policies</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Developing and maintaining a carbon pricing scheme that increases in stringency over time</td>
</tr>
<tr>
<td>• Removing all fossil fuel subsidies</td>
</tr>
<tr>
<td>Alternative Fuels</td>
</tr>
<tr>
<td>• Total decarbonization of the electricity grid</td>
</tr>
<tr>
<td>• Electrification of processes and technologies across every sector*</td>
</tr>
<tr>
<td>Changes in consumption</td>
</tr>
<tr>
<td>• Large-scale investments and regulations to improve energy efficiency and conservation across all sectors</td>
</tr>
<tr>
<td>Structural shifts to the economy</td>
</tr>
<tr>
<td>• Phase out the extraction and export of fossil fuels within Canada</td>
</tr>
<tr>
<td>Major Challenges</td>
</tr>
<tr>
<td>• Decarbonizing heavy industry</td>
</tr>
<tr>
<td>• Adoption and dissemination of net negative-emissions technologies</td>
</tr>
</tbody>
</table>

*When technically feasible*
3. Substantial improvements in energy efficiency across every area of the Canadian economy; and
4. The phasing out of Canada’s fossil fuel extraction and refinement sector.

While the inclusion of each of these points in reports and pathways examining Canadian deep decarbonization is seemingly intuitive, it bears mentioning that many other potentially obvious solutions to reducing GHG emissions commonly discussed in climate policy circles were not highlighted as must-haves in every report. These include: Addressing direct and indirect land-use concerns; the deployment of ‘cleaner fuels’ such as biofuels or hydrogen; the need for investments in sustainable infrastructure; and improving the capture of industrial process emissions. Each of these four areas are commonly understood barriers to deep decarbonization and are readily discussed in both the Mid-Century Strategy and the Pan-Canadian Framework on Clean Growth and Climate Change (Government of Canada, 2016a; Government of Canada, 2016b). Their absence is therefore notable. It should be noted that each of these themes was individually mentioned in at least one report, but that consensus was not reached on their importance across all pathways. The reasons for their exclusion are not currently clear, but may be due to the need to scope analyses or differences in the perception of the feasibility or utility of any individual option.

Scholars and analysts widely agree that Canada’s low-carbon economy of the future will be electrically-powered, highly efficient and absent of fossil fuels, and that any decarbonization strategy should be centered around those principles. The question now turns to whether Canada’s current approach to combating climate change is getting the nation any closer to realizing those dreams.

**Getting from Point A to Point LCE**

*Canada in 2019: Causing Climate Change*
Understanding what Canada’s low-carbon economy of tomorrow will look like must begin with an understanding of where Canada’s economy is today. In 2016, the most recent year for which Canadian GHG emissions data exists, Canada’s absolute GHG emissions were 704 megatonnes of carbon dioxide equivalents (Mt/CO₂eq) (Canada, 2017b). The three largest emitting sectors in Canada are currently the oil and gas sector at 183 Mt CO₂eq/year, the personal and freight transport sectors at 173 Mt CO₂eq/year and the buildings sector at 81 MT CO₂eq/year (Canada, 2017b). An analysis of greenhouse gas emissions by economic sector for Canada can be seen in Figure 1 below (Canada, 2018e).

Figure 1: Canada's GHG Emissions by Sector, 2016 (Mt)

This analysis highlights that any strategy to decarbonize Canada’s current economy will need to be cross-sectoral and comprehensive to ensure emissions from upstream oil and gas production are dealt with alongside emissions from the agriculture and industrial manufacturing sectors. Any strategy developed that is in line with the theme of deep decarbonization must also include policies to transform sectors away from carbon-intensive processes, and to

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improve the efficiency of non-carbon intensive systems to reduce overall energy usage. Both latter points are central to any deep decarbonization pathway modelled in Canada, and should therefore be central to any government’s approach to decarbonizing sector-level emissions.

The current federal government has designed and implemented a broad range of climate policy instruments to tackle these issues. This policy bundle, primarily enveloped in a single overarching strategy called the Pan-Canadian Framework on Clean Growth and Climate Change, looks to holistically reduce emissions across sectors by 89 Mt/CO₂eq by 2030 (Government of Canada, 2016b; Government of Canada, 2018b). The Pan-Canadian Framework’s four pillars are pricing carbon pollution, mitigating emissions through complementary actions, adaptation and resilience, and investing in clean technology (Canada, 2016b). The Pan-Canadian Framework forms the backbone of climate policy in Canada and will be the main focus of this paper when assessing Canada’s long-term strategy to meet its 2050 climate targets.

Canada in 2019: Combating Climate Change
This section will analyze the mitigation actions in the Pan-Canadian Framework to detail how the policies being used today are shaping Canada’s decarbonization trajectory of tomorrow. However, before beginning, an additional factor must be added into the pathways framework outlined previously to ensure this analysis can generate meaningful insights into the impacts of real-world climate policies.

The development of pathways in academic literature is largely a definitional exercise, one focused on outlining how one might get from point A (high-carbon intensity associated with growth) to point B (low-to-no carbon intensity associated with growth) (Rosenbloom, 2017). However, this paper will seek to compare the decarbonization trajectory that experts say Canada should be on against the one it appears to be on today. This novel
application of comparing a theoretical pathways framework against a real-world suite of climate policy actions will aim to fill a gap currently present in the academic literature. This approach therefore necessitates the inclusion of an additional comparative factor.

This paper proposes to introduce a factor into an analysis of theoretical versus actual decarbonization pathways: how individual policies impact the overall rate of transformational change. This measure is one of “policy depth”, a best practice in climate policy design identified by the OECD in 2010 (Johnstone, Hascic & Kalamova, 2010). Policy depth is an evaluative criterion that identifies the extent to which a given policy incentivizes change sufficient to meet a desired outcome (Johnstone, Hascic & Kalamova, 2010). In climate policy terms, this measure can identify whether a given policy approach might support the achievement of an emissions reductions target. This is a relative measure, since climate targets can vary drastically in ambition and scope.

This paper is evaluating whether Canada’s current climate policies will support its efforts to meet its 2050 climate objective. Therefore, the inclusion of policy depth as a criterion allows individual policies to be evaluated based on whether they will help meet this 80% emissions reductions target. Policies will be placed in one of two categories: ‘radical’ or ‘incremental’. Radical policies are approaches that have transformational potential. They can be used at scale to transform industries at the speed required to meet Canada’s 2050 climate targets, or to accelerate the speed of current actions. Radical policies are therefore seen as having the depth required to support the country in meeting its long-term decarbonization target. Incremental policies, on the other hand, are approaches that are more focused on generating emissions reductions within the current landscape. They have relatively low transformational potential. While they may support meeting a 2030 target, they lack the ability to scale at the
speed required to stimulate decarbonization to the depth required to meet the 2050 climate target. Incremental policies are named as such because they are designed to offer marginal improvements on the systems and technologies we use today, even if those systems have no obvious place in the low-carbon landscape of the future.

The inclusion of policy depth as an evaluative criterion is especially important when viewed alongside the concept of lock-in to a carbon-intensive system. One example of this in real terms is the use of natural gas to generate electricity or power transport. Commonly deemed a ‘transition fuel’ and described as a stepping stone towards electrification or cleaner no-carbon fuels, investments in natural gas transmission and shipping infrastructure may help achieve emissions reductions broadly in line with 2030 climate targets (Jaffe & Ogden, 2018). But this may pose problems for achieving further reductions: one analysis showed that introducing natural gas could substantially delay the implementation of near-zero energy systems, and concluded that “the use of natural gas cannot directly result in emissions reductions of the magnitude (required to meet future international decarbonization targets)” (Jaffe & Ogden, 2018). This highlights that supporting a transition from energy sources such as coal or diesel fuel to natural gas is an ‘incremental’ policy: it results in substantive short-term investments and costs into infrastructure and systems that ultimately do not have the potential to support economy-wide deep decarbonization. This technology does not possess the ‘radical’ ability to scale because of its emissions profile and has no obvious place in the low-carbon Canada envisioned by experts above. This means it offers only short-term reductions and may even impede the transition to a low-carbon economy moving forward if it creates another barrier that must be overcome at a later date.

Measuring how “deep” Canada’s current deep decarbonization pathway is requires an evaluation of the
policy depth of current approaches. This novel categorization of policies will therefore be integrated into this analysis of the Pan-Canadian Framework, referred to as the PCF, alongside the elements required for Canadian decarbonization that have been previously identified in this essay.

**Getting our bearings: An analysis of the Pan-Canadian Framework**

Detailing the policy bundle contained the PCF provides insight into Canada’s plan to reduce emissions by 2030. To understand how effectively the PCF is being implemented and its goals being realized, one must read more recent reports than those published in 2016. This essay conducted an analysis of both the PCF and ‘the Second Annual Synthesis report on the status of implementation of the measures in the PCF’, a second publication that offered a progress report on realizing the PCF’s objectives in late 2018. The progress report contains names of programs, funding figures and outcome metrics that allow for deeper insight into how successful the Framework has actually been at meeting its objectives. A detailed summary of this analysis, alongside an application of the pathways framework, can be seen in Annex 2. A summary of this analysis can be seen in Figure 2 below:
This analysis highlights that the PCF includes both policies with the depth to radically accelerate Canadian decarbonization in line with 2050 targets, and policies more focused on incremental reductions geared towards meeting 2030 targets that may create challenges when decarbonizing long-term. This is discussed in greater detail below.

Wind in the sails: Policy as a driver to a low-carbon transition
First, Canada should be lauded for its leadership in taking actions today that aim to decarbonize, electrify and conserve energy tomorrow. There are numerous policies within the PCF that have the radical potential to transform the Canadian economy at the depth, scale and scope required to meet its 2050 target. The phase-out of coal-fired electricity generation will support Canada’s target of having 90% of all electricity generated from non-emitting sources
by 2030. Eliminating coal is a major step towards this target as coal in 2016 made up 72% of emissions from the electricity sector while only generating 9% of national electricity (Canada, 2018b). The gap in electricity supply that will exist following the phase-out in the four remaining coal-burning provinces (Alberta, Saskatchewan, Nova Scotia and New Brunswick) will be replaced through a combination of natural gas, renewable electricity and electricity shipped across provincial borders through new transmission lines (Government of Canada, 2018a; Government of Canada, 2018e). This highlights that both the phase-out of coal and construction of provincial electricity transmission interties are radical policies that will accelerate sector-wide decarbonization by enabling a faster wind-down of coal-burning electricity generation plants. An additional radical move was to say that in rural and Indigenous communities looking to reduce diesel consumption, only renewable and biomass projects would be eligible for funding support (Canada, 2017c). This will reduce the potential of communities installing natural gas as an electricity generation fuel, and will expedite the decarbonization of electricity in Canada on or off the grid.

Canada’s focus on improving energy efficiency standards for both new construction and retrofits is equally impressive. The traditional view of energy efficiency as a means to lower energy costs through replacing lightbulbs has drastically shifted in recent years with the rise of digitization and decentralization in the electricity sector. According to an analysis by Katherine Hamilton, Stephen Lacey and Jigar Shah, a group of US energy professionals, efficiency is now understood as “a critical path in regulating and modulating demand to fuel the decarbonization and transformation of the global electricity sector” (Lacey, Hamilton, & Shah, 2019). This means that policies aimed at reducing energy consumption across all sectors are now recognized for the important role they play in helping decarbonize the economy. Efficiency standards are radical policies given their ability to scale and transform
production processes; a 2018 report indicated a full implementation of the efficiency measures in the PCF had the potential to reduce Canada’s emissions by 52 Mt, which is equal to approximately 25% of Canada’s overall 2030 emissions reductions target (Clean Energy Canada & Dunsky Energy Consulting, 2018). One of these policies is a promise by the federal government to help provinces implement a ‘net-zero ready’ model building code for new construction by 2030, meaning all new construction will be designed to only use as much energy as it might be able to produce itself using renewable energy (Clean Energy Canada & Dunsky Energy Consulting, 2018). Updated energy efficiency regulations for industrial and commercial equipment, implemented alongside offerings for funding for a smarter electricity grid, will have positive long-term effects as well. These policies can help Canada overcome market barriers of split incentives and a lack of consumer awareness that a carbon price alone would be unable to address (The Atmospheric Fund & Dunsky Energy Consulting, 2017).

The final radical policy approaches outlined in the PCF are focused on transforming commercial and industrial processes towards lower-carbon alternatives. A national zero-emissions vehicle strategy will support the electrification and decarbonization of the transportation sector. Wood Mackenzie, an energy market intelligence firm, has calculated that the life-cycle emissions of battery electric vehicles are an average of 67% lower than a comparable internal combustion engine vehicle (Wood Mackenzie, 2018). Similarly, emissions assessments from wood-framed construction compared to concrete framing can offer emissions reductions benefits of 60-80% during the construction phase of new buildings (Borjesson & Gustavsson, 2000). Both shifts represent structural changes in economic processes towards lower-carbon alternatives, highlighting how investments into radical new processes may possess the depth to catalyze the shift needed in
Canadian industry to create the nation’s low-carbon economy of tomorrow.

**Dropping anchors: Policy as a barrier to a low-carbon transition**

Not all of the policies in the PCF are designed with an eye towards deeply decarbonizing Canada. This essay has repeatedly highlighted that climate policies aiming for incremental improvements might inadvertently ‘lock-in’ a set technology or process. If policies aimed at offering incremental emissions reductions decrease the uptake of more radical solutions, they might negatively impact the nations’ capacity to fully and rapidly decarbonize moving forward. A major element of every Canadian deep decarbonization pathway modelled above is that in order to meet 2050 climate targets, there must be a phase-out of Canada’s fossil fuel extraction and export industry. Yet while the PCF contains numerous policies that seek to reduce emissions from fossil fuel extraction and end-use, it may also be unwittingly lengthening the lifespan of the oil and gas sector by promoting investment into the fossil fuel technologies we use today.

This is where the carbon lock-in phenomenon becomes relevant. Cost-benefit analyses developed for individual regulations by the Government of Canada have highlighted that the PCF’s upstream methane regulations will have a forecasted cost of compliance of $2.5 billion to industry, and the new efficiency standards for heavy-duty diesel freight vehicles will have a cost of compliance of $5.1 billion to industry members over the next five years (Read & Kenyon, 2017; Canada, 2018). These figures represent capital investment into existing technologies that could lock-in a reliance on the fossil fuel-based systems we use today; that is because it is likely a sector that has just spent $5.1 billion over 5 years on diesel engine technologies will look to lengthen the lifespan of their investment in order to generate higher returns. Businesses are naturally risk-

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2 See Figure 1 and Annex 1 for details.
averse and have high costs associated with upgrading equipment and training staff about new processes and technologies (Unruh, 2000). That means that if policymakers approach the freight sector in 2025 with a plan to electrify all heavy-duty trucking by 2050, they may be forced to dilute their radical and transformative sector deep decarbonization plan and take more incremental steps to ensure the economic survival of a freight sector that just invested billions into a technology that is widely understood to have no place in Canada’s low-carbon future.

This is known as ‘technological trajectory lock-in’ and refers to the path dependency that occurs when investment and growth occur around one specific technology. This has spillover effects; dependence on diesel fuel means maintaining diesel fuelling infrastructure, which means supporting a fossil fuel sector that refines and extracts diesel for use in heavy-duty trucking. The impacts of this network quickly become obvious: forcing investment to incrementally improve the emissions performance of fossil fuel technologies today lessens the likelihood that more radical action can be taken to phase out the sector tomorrow (Klitkou, Bolwig, Hansen, & Wessberg, 2015).

The reasons outlined above are why setting efficiency standards in the freight sector, requiring investment to reduce methane leakage from upstream oil and gas and creating performance standards for natural gas combustion are all long-term risks. Incremental improvements today can limit the potential for ambitious transformation tomorrow. This is also why the upcoming Clean Fuel Standard poses a risk; economic modelling has forecasted the opportunity to create over 31,000 new jobs, attract $5.6 billion in investment in clean fuels and reduce the emissions intensity of liquid fuels by 11% by 2030 (Clean Energy Canada & Navius Research, 2017). These short-term benefits are undeniably attractive, but could also serve as a long-term challenge. A report by Clean Energy Canada highlights that biofuel facilities typically require long
operational lifespans to achieve profitability, and that a federal Clean Fuel Standard would provide a signal that Canada would be “a market for biofuels for years to come” (Clean Energy Canada & Navius Research, 2017). However, the use of and support for biofuels in Canada may prove a barrier to mass electrification of industry and transportation in the coming decades. This could lead to a scenario where, in 2040, biofuel refineries who have yet to turn a profit argue for an extension on the policy that creates the market demand for their products. This would slow both the rate of technological change and economy-wide decarbonization, and means that adopting a Clean Fuel Standard today may have a negative impact on Canada’s long-term ability to meet its 2050 targets.

One key element to note is that each of the standards outlined above is designed to be ‘technology-neutral’. This means that they do not mandate the use of any specific technology as a compliance pathway. In particular, the Clean Fuel Standard states that blending biofuels with fossil fuels, switching from fossil fuels to electricity or improving efficiency are all viable pathways to achieve regulatory compliance (Canada, 2018d). Therefore, it cannot be argued that all of these policies are guaranteed to have an inhibiting effect on the uptake of radical technologies and solutions. If regulated parties under the Clean Fuel Standard decide to comply by investing in more radical solutions, they could support the uptake of technologies with transformational potential and accelerate the depth of overall decarbonization. Nevertheless, the risk of lock-in remains high; it remains to be seen to what extent the performance and emissions intensity standards for fossil fuels introduced in the PCF will support or impede Canada’s future actions to decarbonize the economy.

For some policies contained in the PCF, it remains too soon to tell whether they have the potential to accelerate or slow a transition. Data gathering and sharing efforts between the federal and provincial government are currently focused on
the agriculture and aviation sectors, two areas that face significant barriers to decarbonization (Government of Canada, 2016a; Government of Canada, 2019). The Mid-Century Strategy acknowledges that greater research and focus are required to understand what technologies and processes can stimulate meaningful emissions reductions within those two areas. At this point in time, it remains too early to tell whether today’s actions to research those areas are supporting the development of policies with the necessary depth to reach 2050 targets.

**Left adrift: What policies are missing from Canada’s approach**

The PCF is forecasted to reduce 89 Mt of emissions by 2030, which is only 29% of the 302 Mt/CO₂eq GHG reductions required to meet Canada’s 2030 climate target. This indicates that the plan is not as holistic or ambitious as may be required (Canada, 2018f). When it comes to setting Canada up for a low-carbon transition, it lacks three major elements: a program for reducing emissions in hard-to-abate sectors, a strategy for developing net-negative emissions technologies, and a stated objective of phasing out Canada’s fossil fuel extraction and export sector. All three are common elements found in every deep decarbonization pathway modelled for Canada, and are therefore notable in their absence from current Canadian climate strategy.

First, Canada has no clear plan to address emissions from hard-to-abate sectors. The Energy Transitions Commission published a report in 2019 outlining decarbonization pathways for heavy-duty manufacturing and heavy-duty transport, two sectors that face singular challenges to reducing emissions. The report’s findings were that while decarbonization would be costly, commercially viable technologies to reduce sector emissions were available today (Energy Transitions Commission, 2019). Each of the six sub-sectors examined (cement manufacturing; steel manufacturing; plastics manufacturing; heavy-duty road
freight; marine shipping; and aviation) exists in Canada. Up to this point, Canada’s approach to reducing emissions from these sectors has been focused on reducing emissions intensity: reducing the sulfur content in bunker fuel for shipping, mandating efficiency improvements for domestic aviation and creating efficiency standards for heavy-duty freight are all incremental steps that fit in this category (Government of Canada, 2012; Government of Canada, 2016b). None of these actions indicate these issues are being examined strategically. Each of these approaches is separate and uncoordinated, with each detailed in a different document or plan and developed by a different federal department. These incremental and uncoordinated steps lack any sense of an overarching strategy towards addressing emissions from hard-to-abate sectors and are a notable gap that the Mid-Century Strategy highlights “remain(s) a challenge to reducing emissions (moving forward)” (Canada, 2016a).

Second, Canada has no stated strategy or approach towards supporting net-negative emissions solutions. Carbon capture and storage (CCS) and direct-air-capture (DAC) are examples of two innovative technologies that remove carbon dioxide from their environment and that the IPCC has indicated will be critical to maintaining global temperature levels below 1.5 degrees of warming (Government of Canada, 2016b; Intergovernmental Panel on Climate Change, 2018). However, they are little mentioned or discussed in the PCF (Canada, 2016b). This is despite the fact that Canadian companies sit at the forefront of innovation in both of these industries (Karstens-Smith, 2015). Canada also has no formal strategy or plan to encourage more natural methods of carbon sequestration such as afforestation. This represents a major gap in Canada’s approach to combating climate change, as it leaves no room for error in emissions mitigation. This additionally highlights that the Government is not currently working to develop Canadian industrial leadership in this technology space.
Finally, and somewhat controversially, Canada has not published a formal date to phase out its fossil fuel extraction and export sector. That is likely because the current federal government has doubled down on fossil fuel development, with the Prime Minister arguing that proceeds from the sale of resources can be directed towards funding a low-carbon transition (Dagg, 2018). Despite the federal government’s belief that one can both have and eat cake simultaneously, the truth remains that emissions from Canada’s oil and gas sector made up 26% of national emissions in 2016 (Dagg, 2018). Unless a magical solution is invented that allows oil and gas development to become completely carbon neutral in the next 31 years, it remains a problem that must be dealt with within the next generation for the country to have any hope of staying on its climate track.

**Abandon the life-raft, get on the speedboat**

In order to accelerate Canada’s transition to a low-carbon economy, Canada must commit to abandoning the incremental and dive into the radical depths. This means three things: first, Canada should invest money and focus into solutions that have the potential to radically accelerate its deep decarbonization trajectory. That means doubling down policy support for mass electrification, renewable electricity, and energy efficient buildings and equipment. Support for electrification should be scaled up with regulations and funding directed towards supporting the uptake of electrification technologies in home heating and cooling. Developing flexible energy efficiency policies that can be steadily increased over time will also be crucial. Sustained improvements in energy efficiency across all sectors should be mandated with policies directed towards lowering the barriers to adoption for new efficient processes and technologies. As the pace of adoption for each solution increases, the current $50/tonne ceiling of the national carbon pricing backstop that will be reached in 2022 should be reassessed to determine how a higher cost
per tonne might accelerate Canadian deep decarbonization (Canada, 2016b).

Designing and championing this suite of priorities will require careful coordination. To manage and oversee it, the federal government should form an arms-length Low-Carbon Transitions Institute to provide independent analysis and advice about how to best decarbonize Canada. This institute would work across federal departments to provide advice on policy design and identify best practices for implementation. This organization could additionally highlight the potential unintended consequences of certain emissions reduction approaches. The institute could also improve transparency into Canada’s climate progress by publishing annual pathways progress reports, and would help identify both the major barriers to decarbonization in Canada and how they could be overcome.

Third, Canada needs to address the gaps in its climate approach and look beyond 2030 and the PCF. The federal government should develop both a strategy to reduce emissions from hard-to-abate sectors and a separate strategy to support the growth of net-negative emissions technologies in Canada. Canada has the potential to set international standards for decarbonization and lead in the development of a sector that will be in high demand in years to come. This rare opportunity should be seized.

Finally, Canada should closely examine existing policies aimed at incrementally reducing emissions from technologies that have no obvious place in tomorrow’s low-carbon economy. Inadvertently stimulating investment into, and lengthening the lifespan of, fossil fuel technologies would be a regrettable and self-inflicted barrier to Canada’s low-carbon transition. But it must be acknowledged that it is currently politically non-viable for Canada to pledge to phase out its oil and gas extraction sector by a set date.
What Canada could opt to do instead is to tweak existing emissions standards to emphasize the need for continuous improvement. This would mean changing the way standards are developed away from setting absolute reduction targets towards mandating annual improvements by a set percentage. In practice, this would create policies that mandated ‘5% annual reduction in methane leakages from upstream oil and gas production in every year moving forward’ instead of a ‘40-45% reduction in methane emissions from upstream oil and gas by 2025’. This ‘continuous improvement’ approach was used to great effect in California. The state’s model building code, called Title 24, mandated the stringency of the code be tightened every three years if cost effective efficiency technologies existed (Harvey, Orvis, & Rissman, 2018). This code has gradually tightened over time and stimulated the energy efficiency market in California by creating a challenge that efficiency equipment manufacturers had to meet. In order to continue doing business in the state, innovation and investment was directed at creating cost-effective and scalable solutions that would result in the code being tightened and allow for demand for the sector’s products and services to increase over time. This has stimulated both emissions reductions and growth in the low-carbon economy in California over the last four decades.

Adopting a continuous improvement approach would offer the following for Canada: One, it would create a clear market signal to business about rising future costs. Two, it would allow for policy stringency to increase and keep pace with technology improvements. Three, it would clearly illustrate that if the oil and gas sector was unable to reduce methane or carbon dioxide emissions by 100% from their operations within 30 years, they would have no place in Canada’s low-carbon economy of the future. This would create an environment where investment decisions about the viability of oil and gas assets made by investors and insurers moving forward would have to take into account their potential to adapt and eventually reduce their
emissions to the levels required. In other words: a policy of continuous improvement would mean that the future viability of Canada’s oil and gas sector would be determined not by the government, but by a free market armed with the information needed to help make decisions about the investment viability of a shrinking industry in the decades to come.

**Conclusion**

A scope of political and policy ambition beyond anything seen up to this point will clearly be required to make all this happen. This may lead one to conclude upon reading this paper that Canada might very well not meet its 2050 climate objective. That will have consequences: a 2012 Navius research report highlighted that each time climate policy implementation was delayed between 2012 and 2020 in Canada, the delay in action increased overall abatement expenses by 27% (Melton, Bataille, & Goldberg, 2012). This has added a total of $87 billion to the cost of mitigation for future Canadian generations (Melton, Bataille, & Goldberg, 2012). It should be noted that this figure includes only the added cost of proactive abatement and does not include the much higher cost to future generations of reactively addressing climate disasters only after they’ve happened. This cost is forecasted to be between 5 – 20 times more expensive than simple mitigation to the global economy. A final note is that these cost estimates include only figures in dollars spent and do not include the very real added costs of lives being disrupted or lost.

Canada’s approach to climate policy has been largely centred upon meeting a 30% emissions reduction target by 2030. This approach fails to acknowledge that the actions taken today shape the decarbonization trajectory the nation will take tomorrow. Reducing carbon emissions to 80% below 2005 levels by 2050 requires a substantial acceleration to the pace of emissions reductions that have been seen in Canada to date. Even if one assumes that 2030 climate targets will be met, meeting the 2050 target means
the annual emissions reduction required in Canada from 2030 to 2050 will be approximately 18.7 Mt CO₂ eq/year. This means Canada will need reduce a volume of emissions equivalent to the entire PCF every four and a half years for two straight decades. This simply cannot be left to chance. The risks are too great and the volume of action required is too astronomical to believe an answer will simply appear. Depending on technological breakthroughs such as energy fusion is not a realistic solution either; hoping for a course correction or a miracle will only lead to stronger storms and shipwrecks. What Canada needs now is vision, ambition and a whole new level of depth if it is to rise to the challenge of tomorrow.

References


term_strategies/application/pdf/canadas_mid-century_long-term_strategy.pdf


**Annex 1: Comparison of low-carbon transition pathways models and papers for Canada**

Decarbonization Pathways examined in this paper:
3. Trottier Energy Futures, 2016. *Canada’s Challenge and Opportunity: Transformations for major reductions in GHG*
emissions. Referred to as 'Trottier Energy Futures'. (Trottier Family Foundation et al., 2016).

Table 2: Thematic analysis of Canadian decarbonization pathways literature

<table>
<thead>
<tr>
<th>Enabling Policies</th>
<th>DDPP Canada</th>
<th>Sustainable Canada Dialogues</th>
<th>Trottier Energy Futures</th>
<th>Alternative Fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Two-tier carbon price for heavy industry and consumers</td>
<td>- Carbon pricing scheme</td>
<td>- Carbon pricing scheme</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- GHG performance regulations for electricity grids</td>
<td>- Elimination of fossil fuel subsidies</td>
<td>- Support and subsidize electrification in all sectors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Removal of all fossil fuel subsidies</td>
<td>- Full integration of the fossil fuel sector into all climate policies</td>
<td>- Fund research and development into emerging technologies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Mandatory controls for all industrial and landfill methane emissions</td>
<td>- Develop inter-provincial electricity transmission infrastructure</td>
<td>- Reduce fugitive emissions from processes across all sectors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Regulations for use of carbon capture and storage (CCS)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| DDPP Canada | - Large-scale electrification and scale-up of decarbonized electricity  
- Decarbonize personal and industrial transportation through biofuels, electricity or hydrogen |
| Sustainable Canada Dialogues | - Scale up renewable electricity generation and support large-scale electrification of all sectors |
| Trottier Energy Futures | - Scale up of renewable electricity generation  
- Adoption of electricity and biofuels in personal transportation sectors  
- Electrification of residential heating and cooling systems |
| Changes in consumption | |
| DDPP Canada | - Improvements in energy efficiency in transport, industry and residential sectors |
| Sustainable Canada Dialogues | - Energy efficiency programs targeted at the building, industrial and commercial sectors  
- Direct stricter efficiency programs specifically in the extraction sector |
| Trottier Energy Futures | - Investment and adoption of significant energy efficiency and conservation measures for residential and commercial sectors |
| Structural shifts to the Economy | |
| DDPP Canada | Cap and find uses for GHG emissions from industrial processes and waste  
|            | - Diversification away from primary resource extraction and heavy industry towards low-carbon goods and services |
| Sustainable Canada Dialogues | - Incorporate sustainability principles into urban land-use planning and development  
|            | - Shift away from model of urban sprawl towards greater urbanization |
| Trottier Energy Futures | - Shift away from fossil fuel extraction and exports  
|            | - Phase out fossil fuel use entirely in sectors where possible |
| Major Challenges | |
| DDPP Canada | - Decarbonizing heavy industry and manufacturing  
|            | - Policy stringency of international economic competitors |
| Sustainable Canada Dialogues | - Regional differences in fuels/technologies may slow economy-wide adoption  
|            | - Integrating biodiversity and social equity concerns into a wider societal transition |
| Trottier Energy Futures | - Deployment of second-generation biofuels in heavy freight  
|            | - Lack of certainty around the use of net-negative emissions technologies (i.e. CCS) |
Annex 2: Evaluation of PCF Measures through analytical framework

Table 3: Analysis of domestic actions pledged and implemented in the Pan-Canadian Framework, analyzed through adapted pathways lens

<table>
<thead>
<tr>
<th>Sector</th>
<th>Actions</th>
<th>End Objective</th>
<th>Decarbonization potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-sectoral</td>
<td>Putting a price on carbon</td>
<td>Reducing market distortions</td>
<td>Radical</td>
</tr>
<tr>
<td>Electricity</td>
<td>Phase out of coal-fired electricity generation</td>
<td>Decarbonization of electricity sector</td>
<td>Radical</td>
</tr>
<tr>
<td></td>
<td>Performance standards for natural-gas combustion</td>
<td>Reducing emissions intensity of the electricity grid</td>
<td>Incremental</td>
</tr>
<tr>
<td></td>
<td>Create Canada's Regional Electricity Cooperation and Strategic Infrastructure Initiative (RECSI) to identify regional electricity</td>
<td>Decarbonization of the electricity sector, Electrification</td>
<td>Radical</td>
</tr>
<tr>
<td>Environment</td>
<td>Infrastructure projects</td>
<td>Effects</td>
<td>Type</td>
</tr>
<tr>
<td>-------------</td>
<td>------------------------</td>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>Launched Smart Grid program to fund demonstration and deployment projects</td>
<td>Electrification, Efficiency</td>
<td>Radical</td>
<td></td>
</tr>
<tr>
<td>Replacing diesel generation with clean energy in rural and Indigenous communities</td>
<td>Decarbonization of the electricity sector</td>
<td>Radical</td>
<td></td>
</tr>
<tr>
<td>Developing roadmap for deployment of small modular nuclear reactors in Canada</td>
<td>Decarbonization of the electricity sector</td>
<td>Radical</td>
<td></td>
</tr>
<tr>
<td>Built Environment</td>
<td>Launched National Housing Co-Investment Fund to support efficiency in residential construction</td>
<td>Efficiency</td>
<td>Radical</td>
</tr>
<tr>
<td>Initiative</td>
<td>Focus Area</td>
<td>Position</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
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<td></td>
</tr>
<tr>
<td>Launched Energy Efficient Buildings Program to support commercial building design and renovation</td>
<td>Efficiency</td>
<td>Radical</td>
<td></td>
</tr>
<tr>
<td>Development of tiered-net zero energy code for residential housing</td>
<td>Efficiency</td>
<td>Radical</td>
<td></td>
</tr>
<tr>
<td>Act upon and support existing federal-provincial-territorial strategies to set minimum performance standards for equipment and products</td>
<td>Efficiency</td>
<td>Radical</td>
<td></td>
</tr>
<tr>
<td>Updating Energy Efficiency Regulations for commercial and industrial sectors</td>
<td>Efficiency</td>
<td>Radical</td>
<td></td>
</tr>
<tr>
<td>Work with First Nations to develop/implement retrofit guidelines</td>
<td>Efficiency standards for diesel-operating heavy-duty and light-duty freight vehicles</td>
<td>Reducing emissions intensity of the freight sector</td>
<td>Incremental</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>------------------------------------------------------------------</td>
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<td>------------</td>
</tr>
<tr>
<td>Leading international team to reduce GHG emissions from international shipping</td>
<td>Reducing air pollutants from shipping sector</td>
<td>Incremental</td>
<td></td>
</tr>
<tr>
<td>Implementing domestic civil aviation action plan</td>
<td>Reducing emissions intensity of domestic aviation sector</td>
<td>Incremental</td>
<td></td>
</tr>
<tr>
<td>Development of Canadian Zero-Emissions Vehicle (ZEV) Strategy</td>
<td>Electrification, decarbonization of the transport sector</td>
<td>Radical</td>
<td></td>
</tr>
<tr>
<td>Development of electric vehicle and alternative fuel</td>
<td>Electrification, decarbonization of the transport sector</td>
<td>Radical</td>
<td></td>
</tr>
<tr>
<td><strong>infrastructure program</strong></td>
<td><strong>transport sector</strong></td>
<td><strong>Industry</strong></td>
<td></td>
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<tr>
<td>---------------------------</td>
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</tr>
<tr>
<td>Introduce Clean Fuel Standard to reduce emissions intensity of solid, liquid and gaseous fuels</td>
<td>Reduce emissions intensity of fuels across sectors</td>
<td>Incrementa1</td>
<td></td>
</tr>
<tr>
<td>New methane regulations to reduce methane emissions from upstream oil and gas</td>
<td>Reduce emissions intensity from oil and gas sector</td>
<td>Incrementa1</td>
<td></td>
</tr>
<tr>
<td>Development of new energy efficiency certifications for industrial manufacturing and supply chains</td>
<td>Efficiency</td>
<td>Radical</td>
<td></td>
</tr>
<tr>
<td>Invest in technologies to improve emissions profile of oil and gas extraction</td>
<td>Reduce emissions intensity from oil and gas sector</td>
<td>Incrementa1</td>
<td></td>
</tr>
<tr>
<td>Forestry, agriculture and waste</td>
<td>Launched Agricultural Partnership and Living Lab to fund research into sustainability in farming and natural systems processes</td>
<td>Collect data to inform decision-making on mitigation*</td>
<td>*Uncertain – dependant on future actions taken</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Launched GCWood to develop building designs using timber bridges and now recognize wood as a sustainable building material in government procurement</td>
<td>Improve emissions intensity of construction</td>
<td>Radical</td>
<td></td>
</tr>
<tr>
<td>Government leadership</td>
<td>Developed Greening Government Strategy to improve government sustainability</td>
<td>Efficiency, reducing emissions intensity of operations *</td>
<td>*Uncertain – will depend on actions taken</td>
</tr>
<tr>
<td>Created Centre for Greening Government</td>
<td>Efficiency, collect data to inform decision-making*</td>
<td>*Uncertain – will depend on actions taken</td>
<td></td>
</tr>
</tbody>
</table>

*I uncertain – will depend on actions taken.
International actions are not mapped, as they are not readily included as part of Canada’s deep decarbonization pathway domestically.
SETTING THE STAGE
Buildings in Canada are a significant source of greenhouse gas (GHG) emissions, contributing up to 17% of carbon emissions (Canada Green Building Council, 2019a). As a key component of the Pan-Canadian Framework on Clean Growth and Climate Change, the built environment has been specifically targeted to meet Canada’s goal of reducing GHG emissions 30% below 2005 levels by 2030 (Government of Canada, 2016). In order to meet this target, policy must be developed using instruments that will enable industry actors to reduce their buildings’ GHG emissions. Reducing the GHG emissions associated with the built environment could take Canada one step closer to meeting its international obligations associated with climate change (Environment and Climate Change Canada, 2015). This paper will identify and analyze three potential instruments associated with a policy designed to reduce the GHG emissions from Canada’s building sector by 30% from current levels. These potential instruments include: regulation, specifically building code; symbolic response and exhortation, with the specific example of the promotion of a voluntary sustainable building rating system; and an expenditure-based approach using subsidies or tax breaks. It will then conclude with an analysis of the policy drivers and a recommendation that while the regulation approach will likely have the single largest impact on reducing GHG emissions in Canada, a blended approach of all three policy implementation types will provide the most benefit for
future building policy to meet Canada’s climate change goals.

**Canada’s Built Environment**

Canada’s building sector is quite large, and includes three different types of structures: dwellings, commercial and institutional buildings, and industrial structures. With over 14,000,000 dwellings (Statistics Canada, 2017) in Canada, along with over 482,000 commercial and institutional buildings (Statistics Canada, 2016), making any significant changes to the building industry will require far-reaching policy that effects a majority of structures. According to Natural Resources Canada (NRCan), the built environment was responsible for 275.3 Mt eCO2 in 2016, which is 17% of Canada’s total GHG emissions (Natural Resources Canada, 2017). A 30% reduction from current GHG emission levels would be 61.4 Mt eCO2, which would be the goal of any policy developed to meet Canada’s GHG emissions reduction target.

**Policy Instruments**

In comparing different policy instruments that can be used to design a policy intended to reduce GHG emissions associated with the building sector in Canada, an analysis will be completed to identify the advantages and disadvantages of each approach. Before evaluating the approaches, however, criteria must first be developed to understand how they will be compared. The first criteria that will be used to compare the various approaches is the projected decrease in GHG emissions associated with each approach. This is because the reduction of GHG emissions is directly stipulated in Canada’s international agreements, and therefore of central importance. Although it may not be possible to accurately determine the specific amount that GHG emissions will be reduced, the general likelihood of the approach’s ability to reduce emissions will be approximated. The second criteria that will be used to

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1 Institutional buildings include municipalities, universities/colleges, schools, and hospitals (MUSH).
analyze the instrument approaches is the direct costs to the government associated with designing and implementing the policy. A reduced cost would be more advantageous than an increased cost, both in terms of capital and person-hours. While the industry wide cost effects of a policy instrument may not be able to be predicted, a comparison of the three options and their relative costs will be made. The final criteria that will be used to compare the different approaches is how quickly an instrument can be implemented. If a policy instrument takes a considerable amount of time to develop, it would detract from the likelihood that it can be introduced in time to meet Canada’s GHG reduction target.

Now that the evaluation criteria have been determined, we will turn to outlining which policy instruments will be evaluated as part of this paper. As mentioned in the introduction, there will be three separate instruments that will be reviewed in detail and compared against the evaluation criteria outlined above; GHG reductions, costs, and timeline. The first policy instrument is regulation or, in the case of the building sector, building code. Building code has been used in Canada since its founding to regulate the way in which structures are designed and constructed. It is a specific set of requirements that every building must meet in order to ensure the safety and security of building occupants, as well as the structural integrity and energy footprint of the buildings themselves. The second policy instrument that will be evaluated is symbolic response, or exhortation. More specifically, the government will advertise and persuade the industry to use voluntary building rating systems to design and construct sustainable buildings. The third instrument is the incentivization of the private sector to improve the performance of their buildings through either tax expenditures or public expenditures. This approach relies on the government giving either subsidies or tax breaks to participating firms, which in turn stimulates adoption of the policy. These options can be quite popular as individuals and corporations are motivated to reduce costs (lower taxes) or
increase revenue (grants/subsidies) (Dyck, Cochrane, & Blidook, 2017). Each of these policy instruments will motivate building sector stakeholders to varying degrees; it is important to determine their success relative to the three criteria to understand their potential to reduce Canada’s GHG emissions.

**Regulation**

Building code in Canada first started under the British North America Act during confederation in 1867. The responsibility for building code was, and continues to be, under the authority of the provinces and territories, although it was typically delegated to municipalities. However, in 1941 the federal government introduced the first National Building Code (NBC) which was available to be adopted by all provinces, in order to promote consistency across the country. This would allow businesses, such as manufacturers or contractors, to be able to work across regions without encountering wildly different requirements (National Research Council Canada, 2013). Currently there are five different types of building codes in Canada: the NBC, the National Fire Code, the National Plumbing Code, the National Energy Code for buildings (NECB), and the National Farm Building Code. In focusing on building code to target and reduce GHG emissions, the options would be to change the five existing codes or create a sixth code specific to GHGs. Currently there is no building code in Canada that is specifically devoted to measuring and reducing only GHG emissions. However, there are several codes, such as the BC Step Code2 (BC Housing, 2017) and the Toronto Green

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2The BC Step Code is an incremental standard that increases energy efficiency requirements over time. Unlike most codes, these steps are measurable, and performance based, rather than prescriptive in nature. The code is currently laid out until 2032, at which point buildings will be required to be net zero energy ready.
Standard3 (Chief Planner, Director, & Planning, 2017), that use GHG intensity (GHGI) along with other metrics to model building performance, typically alongside energy intensity targets. Using this example, the federal government could adapt the NECB to include specific performance targets, including GHGI, rather than prescriptive targets4, which has been the approach to date. By setting a specific GHG target within the NECB, it would ensure that all new buildings developed under that code would be designed to meet those targets. If not, the buildings would not receive a building permit, ensuring they could not be constructed. For example, if a building was designed within a province or territory that adopted an updated NECB standard it would be necessary to demonstrate, typically through energy modelling, that the GHG emissions due to the operation of the building are below the requirements. In the case where a building could not demonstrate that requirement, the municipality would not provide the developer with a building permit, and the structure could not be built until changes to the design were made. The regulation instrument approach is the most invasive of the three approaches that will be examined (Dyck et al., 2017), requiring specific actions by performed by relevant stakeholders.

For existing buildings, there is also the option of a retrofit standard, something that is being planned by the National

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3The Toronto Green Standard is similar in nature to the BC Step Code, with a series of tiers that become more stringent over time, with the ultimate goal of reducing GHG emissions 80% by 2050.

4Prescriptive targets refer to detailing exactly how something will be done, rather than performance targets, which are focussed solely on the outcome. For example, a prescriptive target would be to install an air-source heat pump, along with R-20 insulation and triple-pane windows. A performance target is to achieve an 80% reduction in GHG emissions within your building. The prescriptive approach requires the building owner to follow a set of requirements in order to meet the goal, rather than allowing them to decide for themselves how to achieve the end result.
Research Council (National Research Council Canada, 2018) after being detailed in the Pan-Canadian Framework on Clean Growth and Climate Change (PCF) (Government of Canada, 2016). Similar to code for new buildings, any existing building undertaking a retrofit would be required to meet specific targets. It is clear why existing buildings must be targeted; every new building added to the grid will only increase GHG emissions, or at best have no effect (if it is a zero-carbon building). While it is necessary to target new builds for GHG reduction targets, only targeting new buildings will not have enough of an impact to reduce GHG levels sufficiently to meet Canada’s targets (Heerema, Frappé-Sénéclauze, & Wu, 2017). By introducing GHGI targets into a code for existing buildings, governments can significantly reduce GHG emissions from the entire sector. Therefore, regulation for both new and existing buildings is required to meet Canada’s GHG targets for the built environment.

A significant benefit of regulation is the requirement to comply or face negative consequences (Pal, 2013), such as not receiving a building permit; thereby ensuring the intended behaviour is put into effect in most instances. In this case, by regulating the allowable GHGI for new and existing buildings, governments can be confident that GHG emissions will be reduced, which ties in to the first criteria used to evaluate the proposed policy implementation strategies, as discussed above. The amount that GHG emissions will be reduced depends on the targets built into the regulation. In other words, a very strict target will ensure a significant reduction, while a softer target may not allow Canada to meet its targets. While having a strict target allows for more confidence in the overall GHG emission reductions, the costs to builders related to training their staff on the use of new technologies will negatively affect their bottom line. Conversely, a softer target, while allowing builders to invest smaller amounts into their employees, will be less likely to meet the required GHG emission reduction targets.
One complicating factor to setting the appropriate targets is the complexity of the Canadian electricity grid. Currently, the emissions associated with electricity production are reported at a provincial level, with a significant difference between some provinces. In Quebec, for instance, the GHG emissions factor for electricity is 1.6 g/kWh (mostly from islanded grids in the North) and in Alberta the emissions factor is 960 g/kWh, due to their coal power plants (Environmental Protection Agency, 2018). This means that targets for provinces will need to be customized, if GHGI is the primary method of tracking GHG emissions. In other words, having one target for all of Canada would make GHGI targets extremely easy in provinces like Quebec, and potentially impossible in provinces like Alberta. This will affect how each province will view a GHG reduction regulation, whether business-as-usual, or a complete change in construction practices and techniques. With electricity accounting for 39% of energy use in commercial buildings and 25% of energy use in residential buildings, a major difference in GHG emissions associated with that fuel type would have significant impacts on similar projects in different locations (Natural Resources Canada, 2016). This added layer of customization adds time and cost to the process of designing regulation.

The main cost associated with this approach is the development of the regulation itself. The typical cycle for the various codes is five years, with voluntary standing committees being involved throughout that period to adjust the code as necessary (National Research Council, 2018). On top of the standing committees is the public review process which comprises two months every year. All this feedback must be evaluated by NRC staff and by the committees as necessary, which requires NRC staff time to complete. Within the five-year cycle associated with code development, the main cost is the salaries of staff working on the portfolio. However, when you factor in that this cycle would happen regardless of whether specific requirements
were implemented to reduce GHG emissions, the additional costs associated with this work, the opportunity costs, are quite low. Further to that, in terms of actual implementation, since municipalities currently regulate the building sector to ensure they meet code, there would be minimal additional costs, beyond some training for municipal building inspectors. There would, however, be some additional cost for the building industry which would likely lead to lobbying by industry representatives. Given that there is currently a shortage of skilled trades in the green building sector (Canada Green Building Council, 2019b), it is not possible to introduce strong reduction targets in the short term without contributing to the training of individuals throughout the industry. Otherwise, there will not be workers with sufficient skills to construct all the projects as designed. This training requires investment by various levels of government, as well as by private industry (Canada Green Building Council, 2019b). While some of the cost would be passed on to the private sector, government would need to take a leadership role to ensure appropriate training standards are in place. Considering the scope of the approach, and what it can achieve, all this cost is relatively small when compared to the other two options. Therefore, this approach scores well on the second criteria, the cost to design and implement the regulation policy instrument.

Although this process would not require a large amount of cost to design and implement, it does take a large amount of time. As the time required to implement the prospective policy instrument is one of the criteria introduced above, this will have an impact on how this option is evaluated. A five-year code cycle represents a significant portion of the time left available to reduce GHG emissions if Canada is to meet its 2030 target. There may not be enough time left to develop and implement this policy to reduce the built environment’s GHG emissions by 30% in the next ten years without setting extreme targets for the building sector. This could in turn lead to disruptions in the construction
industry and have an overall impact on the economy, given that the construction industry is the fourth largest contributor to GDP in Canada at close to 8% (Allen, 2019). As such, it may be necessary to concurrently develop policy that could be used in the near future to reduce GHG emissions while preparing industry for the change in regulation. In other words, while developing new building code, it would be beneficial to have short-term policies in place to reduce emissions as much as possible before the regulation would come into effect.

Overall, if the government chose to introduce a regulation to control GHG emissions through building codes, they could be more confident in the projected GHG emission reductions. Also, the costs associated with developing and implementing the regulation would be fairly small and spread over a long time. However, there is a significant timeline associated with this strategy. In other words, although this strategy meets the first and second evaluation criteria (GHG reduction and cost), it falls short on meeting the third (time).

**Symbolic Response and Exhortation**

The next policy implementation approach that will be examined is a combination of symbolic response and exhortation. Symbolic response is the act of issuing a statement or passively discussing a subject while exhortation takes this one step further and encourages the public to change its behaviour through voluntary compliance (Dyck et al., 2017). Both of these approaches are considered an information-based approach (Pal, 2013), and are some of the least intrusive policy instruments available. In this particular case, a clear statement or advertising campaign issued from the government encouraging the public to follow a voluntary building standard, such as the Leadership in Energy and Environmental Design (LEED) Rating System, will be analyzed. The symbolic response and exhortation approach is the least intrusive of the three
approaches examined (Dyck et al., 2017), as it does not require specific actions, only encourages certain behaviour.

LEED is a voluntary building rating system that creates a framework designed to encourage sustainable building development. Projects that pursue LEED certification are third-party verified to ensure that they meet the requirements of the program. LEED has been chosen for this example because it is the world’s most popular green building rating system with over 90,000 projects worldwide (US Green Building Council, 2019a). LEED began development in 1993 with the founding of the US Green Building Council (USGBC), was eventually released in 2000, and is mainly focused on commercial, residential, and institutional building types. However, LEED also certifies transit, communities, and cities around the world. In order to become certified, a project must meet a series of prerequisites and credits. Prerequisites are required to be met by every single project, while credits are met at the discretion of the applicant. Certification can only be achieved if a certain threshold of credits has been met. In the most current version, LEED v4.1, a project must achieve 40 out of a possible 110 points, along with all prerequisites, to be considered certified. Given that LEED has a market penetration in Canada of 22% of all new commercial projects, 30% of all new institutional buildings, and 11% of all new floor space overall, it is clear that it is a well-known standard in the Canadian building industry (Burns, 2016). As such, if the federal government were to recommend a voluntary building standard to be used in the Canadian marketplace, LEED would likely be their main choice. In fact, since 2005 the federal government has had a policy of having all new office building certified to LEED Gold standard (Canada Green Building Council, 2017).

By promoting a standard like LEED more broadly, the federal government has the opportunity to increase the use of an already popular product, which would lead to additional GHG emission reductions. LEED v4.1 has a GHG
emissions target for operational carbon, focusing on reducing the GHGs that a building emits through electricity use and fossil fuel combustion during operations. In the case of LEED v4.1, provincial emissions factors, as discussed in the previous section, are used. However, instead of calculating GHGI for a particular building and comparing to a regional target, LEED requires users to compare the design of their building to a baseline building built to code. So, the proposed building’s GHG emissions would be compared to the GHG emissions of the same building built to a minimum industry standard, in this case ASHRAE 90.1-2016, projected through an energy simulation (US Green Building Council, 2019b). Since the baseline building is in the same region as the proposed building, the same provincial emissions factors apply. In other words, a building in Alberta would be compared against a building in Alberta. Because of this approach, LEED is able to use a percentage reduction that would be consistent across all jurisdictions, rather than emissions reduction targets specific to each region.

Historically, LEED in Canada has had an impact on reducing GHG emissions. From 2005 until the end of 2016, LEED projects in Canada are estimated to have reduced GHG emissions by over 1.8 Mt of eCO2 (Canada Green Building Council, 2016). That being said, given the voluntary nature of the program, it is not possible for the government to be certain that this approach will meet the GHG reduction goals that Canada is targeting. With the requirement under LEED v4.1 to reduce operational GHG emissions by a minimum of 5% compared to the baseline building, with increasing points up to 100% GHG reduction, although new buildings will reduce their projected GHG emissions, overall emissions will continue to increase with each new building added to the grid that has not met the maximum 100% reduction target. As discussed earlier in this paper, new buildings are only part of the issue; existing buildings will also need to reduce operational carbon emissions. Given that the average lifespan of a commercial building in North
America is approximately 50 years, buildings that were designed and built 20 years ago will still be in operation in 2050 (O’connor, 2004). LEED v4.1 does provide pathways for major renovation projects, but with a minimum 2% GHG reduction target over the baseline building, and without knowing the historical GHG emissions for each building, it is not possible to determine the anticipated GHG emission reductions. While it is likely to reduce GHG emissions for the built environment, especially when compared to the ‘business as usual’ approach, the federal government can have little confidence in the total GHG reduction amounts associated with this strategy. On top of this, it is important to note the issue of attribution, which is the contribution of a given policy to resolving an issue (Pal, 2013). When using policy instruments that are less intrusive, it becomes even more difficult in practice to be able to quantify the impact that the policy has on the outcome. As such, although reasonable approximations can be used, it requires detailed analysis to be able to confirm results with any sort of confidence. As such, when evaluating this strategy based on the first criteria, it is not a strong approach. Although LEED is the most popular voluntary program available, it is still voluntary, and the emissions reductions associated with new and existing buildings when following the program can fluctuate from 2% reductions to 100% reductions, making the emissions decrease difficult to project. Overall, when comparing to the required 30% GHG savings by 2030 (61.4 Mt eCO2), the 1.8 Mt reduction associated with LEED adoption over 11 years is not enough to meet Canada’s target. Even if the popularity of the program doubled with the government’s approach, this would only lead to an additional 4 Mt eCO2 reduction by 2030, well below the target.

The cost associated with developing and implementing this policy instrument is more difficult to define. A good comparison is the short lived One-Tonne Challenge (OTC) implemented by the federal government in 2004. The OTC was an advertisement campaign developed by the
government to encourage Canadians to reduce their personal annual GHG emissions by one tonne. Using Rick Mercer as the spokesperson, it suggested several different techniques that could be used to accomplish its goal. Over the three years that this program ran, it cost an estimated $37M, or $12M annually (Environment Canada, 2006). If the government were to develop an exhortation approach of similar scope, including the design of the program, along with implementation in the form of advertising, this is a reasonable approximation of the expected costs. When comparing to the other approaches presented, this strategy falls squarely in the middle, not too expensive, but not too inexpensive either.

When considering the third criteria, the time taken to implement, this strategy ranks very highly. Using an existing green building rating standard, with industry support, means that the time to implement this strategy will be minimal. Once a consensus is reached on what system to use, a delivery methodology can be determined, programmed, and released. Again, comparisons can be made to the One-Tonne Challenge. Budget for the OTC program began in fiscal year 2003, and the campaign began less than a year later in March of 2004 (Environment Canada, 2006). Based on this example, the projected timeline for implementing this approach would be less than 20% of the regulation approach discussed earlier in the paper. As such, this approach could be very successful at minimizing the time to get to market.

Overall, if the government chose to introduce a symbolic response or exhortation approach to reduce GHG emissions through voluntary green building rating systems, there could be no guarantee that the emissions reductions would be sufficient to meet Canada’s targets. Although this approach is likely to reduce emissions overall, based on the information provided, it would comprise only a portion of what would be required. As such, it would not meet the primary goal of reducing the built environment’s emissions
30% by 2030. The costs associated with developing and implementing this approach would not be very large but would not be inconsequential either. However, the timeline for implementing this strategy would be quite small. In other words, this approach does not rank highly on the first and second evaluation criteria (GHG reduction and cost) but does excel at the third (time).

**Tax and Public Expenditures**
The final strategy that will be evaluated is using either the tax expenditure or public expenditure approach. Tax expenditures are tax credits or deductions that users can claim for behaving in a manner that the government would like to encourage (Dyck et al., 2017). An example of a tax expenditure is charitable donations, where someone that donates to a charity can claim the expense and not have to pay income tax on the amount. This equates to tax revenue that the government will no longer receive. Public expenditure is the act of a government providing money to individuals, corporations, non-governmental organizations (NGOs), or other governments to support their agenda. Examples of public expenditure include grants, subsidies, loans, and cash transfers (Pal, 2013). In terms of intrusiveness of policy instruments on the lives of Canadian citizens, the expenditure-based approaches are in the middle of the spectrum: less intrusive that the regulatory approach and more intrusive than the exhortation approach (Dyck et al., 2017). The goal of the expenditure-based policy instruments is to encourage individuals or organizations to make decisions that will support the goals of the governing body. In this case, by providing tax exemptions or grants directly related to GHG emission reductions in buildings, the federal or provincial governments can encourage the construction of low impact buildings, along with the retrofit of existing buildings to low GHG emitting alternatives.
An example of a subsidy approach designed to encourage energy efficiency is the ecoENERGY retrofit program. This four year, $160M program was developed primarily to provide grants to homeowners that were completing energy efficiency retrofits on their homes to help reduce high energy costs (Natural Resources Canada, 2007). Other objectives include reducing GHG emissions, and contribute to clean water, air, and energy (Natural Resources Canada, 2010). Throughout the lifetime of the program, there were approximately 250,000 registered homeowners that participated across Canada, meeting the overall goal (Natural Resources Canada, 2012). In terms of GHG emission reductions, the goal of the program was to reduce emissions by 0.4-0.5 Mt by 2011. When evaluated in early 2009 after less than half the timeline, the program achieved a 0.32 Mt reduction in GHG emissions, or 64%-80% (Natural Resources Canada, 2010). Although the final results of the program are not available, the projected GHG emission reductions are estimated to be greater than originally targeted.

Based on the example above, an expenditure-based approach can motivate the targeted audience to engage in the behaviour that the government is promoting. And, given their previous experience in similar programs, governments can use those findings to more accurately predict the GHG emission reduction outcomes. However, when comparing the results of a voluntary program like LEED, which resulted in 1.8 Mt of GHG emissions reductions over 11 years, the ecoENERGY for Homes program does not provide significant improvement, based on the results reported. Given the 0.32 Mt reduction over a two-year period, this projects out to a 1.8Mt reduction over 11 years, the same as the voluntary program. One large caveat in that approximation is that while LEED focuses on commercial, residential, and institutional, the ecoENERGY Homes programming was targeted exclusively at residential structures. It is likely that expanding the scope of the program to include commercial, institutional, and industrial
buildings would increase the GHG emission reductions. However, given that the number of residential structures far outweighs commercial, industrial, and institutional buildings, there is not a lot of room for the program to expand. Even assuming a large increase in the scope and popularity of the program as more and more homeowners and organizations become aware that it is available, it is unlikely that this option alone could achieve the 61.4 Mt eCO2 reduction target.

Potential costs associated with an expenditure-based program can vary widely depending on the scope of the initiative. For a fairly limited program, like the one described above focused solely on the retrofits of homes, the cost of the program in grants was $40M per year, as mentioned above. For a projected decrease of 0.16 Mt of eCO2 per year, this cost is quite high when compared to the other alternatives. Although homeowners benefited from lower energy costs and more comfortable homes after making the retrofits, the large price tag reduces the likelihood that this option meets the criteria. In comparing another program this trend continues. Under the recently announced climate action incentive program, residents in provinces without a carbon pricing program that are subject to a carbon tax will be able to claim the incentive on their tax returns (Government of Canada, 2019). In Ontario, for instance, a family of four will be able to claim $307 in 2019. Approximating this cost to the Federal government in tax expenditures, if we assume that Ontario is entirely made up of families of four, a total of $1.09B in government funds will be reimbursed to Ontario’s 14.2 million residents (Statistics Canada, 2018). That is obviously a very large cost to the federal government. Also, in terms of oversite, expenditure-based programs tend to require a lot of effort to effectively manage: “Expenditure instruments pose substantial management challenges in terms of ensuring that conditions are met and monies are spent appropriately” (pg. 143, Pal, 2013). This additional effort to manage the programs results in additional costs throughout
their lifetime. Based on the sample programs evaluated above, the direct costs to the government associated with the expenditure policy instrument approach are high. As such, this option does not rank highly when using the second evaluation criteria. One important note on this though is that by receiving subsidies through the ecoENERGY program, most homeowners completed more upgrades than they thought they would implement on their homes (Natural Resources Canada, 2010). This work will help stimulate the economy, increasing employment and generating additional tax revenue. However, the external effects associated with the strategies is outside the scope of this paper.

The development of an expenditure-based program can happen very quickly. Some programs are implemented within a few months of announcing the idea. For example, when instituting tax breaks for items such as the Children’s Fitness Tax Credit (CFTC), they can be introduced in the government’s budget and then available for claiming at the end of that fiscal year. The CFTC was first introduced in the 2006 federal budget, on May 2nd, and available for use by Canadians on January 1, 2007 (Leitch, 2006). That is an eight-month window from the time it was introduced until it was first claimed, which is a very short amount of time. Even when implementing potentially more complicated scenarios, like a tiered grant program, given the importance of the GHG emissions reduction issue to the federal government (“Climate change,” 2015) it is very likely that resources would be devoted to ensuring a timely delivery of service. As such, this approach tends to be quicker than some of the alternatives, such as the regulation instrument.

Overall, if the government chose to introduce an expenditure approach to reduce GHG emissions through tax breaks or subsidies, there could be no guarantee that the emissions reductions would be sufficient to meet Canada’s targets. Although this approach is likely to reduce emissions overall, based on the information provided, it would
comprise only a portion of what would be required. As such, it likely would not meet the primary goal of reducing the built environment’s emissions 30% by 2030. That being said, the GHG emission reductions that can be achieved by following this strategy would likely be higher than the exhortation policy instrument, based on the analysis above. The costs associated with developing and implementing this approach would likely be very large, even if they can be offset somewhat by increased tax revenues. However, the timeline for implementing this strategy would be quite small. In other words, this approach does not rank highly on the first evaluation criteria (GHG reduction), ranks quite low on the second evaluation criteria (cost), but does quite well at the third (time).

**Summary**
When a comparison is made between the three alternatives discussed above, the first option, the regulation approach, is the most likely to achieve the goal of GHG reduction, which is key to meeting Canada’s targets. When you factor in the additional advantage of a low cost, this strategy is the standout as the optimal solution. The major disadvantage, the time required to implement the regulation, will be a strong factor in determining how the policy will be shaped as it moves forward. For instance, due to the length of time required to create the regulation, the base requirements needed to meet Canada’s GHG reduction target will be that much higher, which will have an impact on the built environment. Some strategies, such as educating the market and preparing the industry actors for the change, can help to mitigate the negative impacts that the policy will have. Overall, however, due to the associated impact on GHG emissions and the low cost of implementation, the regulation approach is the ideal policy instrument to use for the building sector.

**Analysis**
When preparing any type of policy, several factors must be examined in greater detail. Although the information
presented above specifically details the implementation approaches possible, other key factors, including drivers and actors, will be briefly outlined to provide greater context. While this is not an exhaustive study, it provides further background for the conclusions presented below. Although there are numerous drivers for a federal policy designed to reduce GHG emissions in new and existing buildings, three of the primary factors include: 1) meeting Canada’s international obligations to reduce climate change impacts, such as the Paris Agreement (Environment and Climate Change Canada, 2015), 2) the health and well-being of Canada’s citizens, and 3) minimizing the large costs that will be associated with a changing climate. Each of these three factors tie into the criteria chosen to evaluate the implementation approaches; since the drivers are important to the federal government, it is essential that the rating criteria reflect them. These drivers provide the necessary motivation to devise a policy that minimizes the GHG emissions associated with the building sector.

It is also necessary to examine the key actors, both governmental and non-governmental, associated with any policy put into place by the federal government. Obviously, the federal government and its branches will be key stakeholders as they work to devise and implement the policy. Additionally, provincial governments will be partners in implementing any approach taken by the federal government, particularly in the case of building code, where provinces have regulatory oversight. Similar to the federal carbon pricing backstop, the implementation of any plan put into place by the federal government will be either strengthened or weakened based on the acceptance of the various provincial authorities. It will be essential to have provincial governments support any plan within their jurisdictions. And, finally, municipal governments will be involved in implementing policies at the city level and can support the policies put forward. Again, looking at the case of building code, municipalities are required to inspect and approve building design (as described earlier in this paper).
and will therefore be instrumental in enforcing the policy requirements.

Beyond the government actors are the non-governmental actors, particularly those that will either be for or against a sustainable building policy put forward by the federal government. Some of these actors were discussed earlier in this paper, such as the CaGBC and USGBC. However, other entities, like the Canadian Real Estate Association (CREA) will have wildly different viewpoints. There are also builder associations, such as the Canadian Construction Association (CCA) or the Canadian Home Builders’ Association (CHBA) that would need to work with the federal government to develop and support a policy that can be implemented. Part of that support could mean education for skilled trades, as discussed earlier, or building owners. Taking this into account, stakeholder consultation and engagement is a key aspect of developing a robust, comprehensive, and successful sustainable building policy.

With this greater context in mind, we shift the focus back to instruments. In comparing the three policy instrument approaches proposed above, some clear conclusions can be drawn. The first result, which is somewhat self-evident but bears stating, is that no single policy instrument approach is perfect. Each approach has advantages and disadvantages that must be examined and weighed against a standard set of criteria and viewed through the lens of the various actors that will be involved in implementing the policy. This was clearly demonstrated in the analysis done throughout this paper. Even the solution that meets the chosen criteria most consistently will have disadvantages that will need to be accounted for in some way. It is the responsibility of the policy creators to understand those disadvantages and take them into consideration when crafting the final policy.

Secondly, complex problems may require multiple instrument approaches to provide a policy that meets the primary goal to reduce GHG emissions. In the analysis
completed throughout this paper, the regulation approach was determined to be the optimal solution. However, due to the time involved, there is an opportunity to implement one, or both, of the alternative instruments to gain traction in the market during that downtime and prepare the industry for what is to come. By advertising sustainable buildings, educating the market through various actors, and providing financial incentives while the regulation is being developed, the industry would have a chance to change their current construction practices. In other words, strategies that were foreign or considered too difficult and expensive could become the norm, just in time for the regulation to enshrine those strategies as code.

And, thirdly, the policy instrument approach chosen must be adapted over time. The optimal strategy that is used at any time may no longer be the optimal strategy in the future. As such, policy instrument approaches should be revisited over time to confirm that the chosen solution is still ideal given the changing situation. Part of this process would involve re-examining the drivers affecting the policy and reaching out to the affected actors to determine whether changes are necessary. One past example of this is the privatization of Air Canada. Originally, Air Canada was a crown corporation, which means that the policy instrument used was public ownership. However, over time that model was reassessed as the Canadian market evolved, until eventually the Chretien government changed to a privatization instrument to more closely align with the neo-liberal approach of the time (Dyck et al., 2017). As the needs of society change, the policy instruments may need to change as well.

The analysis completed in this paper is only one part of the overall picture. Further study needs to be completed to determine the best way to more specifically identify key drivers and actors, to frame the policy to appeal to Canadian building owners, and to further identify the costs and benefits to the building industry due to the proposed
changes. With such an important target that affects so many Canadians, it is imperative that governments of all levels invest sufficient resources to tackle this problem before it becomes unmanageable.

**Conclusion**

Buildings within Canada are a significant source of GHGs, contributing up to 17% of our carbon emissions. As a key component of the PCF, the built environment must reduce its levels of GHG emissions 30% by 2030 to support Canada’s overall targets. After analysing and comparing three alternative policy instruments, regulation, exhortation, and expenditure, the regulation instrument approach is the most advantageous when considering the key criteria of efficacy, cost, and time to implement. Canadian institutions and associated actors must work together quickly to begin the process of updating Canada’s building code to require specific GHG emissions targets. In addition, other short-term strategies, such as encouraging industry to use voluntary sustainable building rating systems, educating the market, and providing incentives to reduce GHG emissions, must be adopted to prepare the build environment for the necessary change. The reduction of GHG emissions from the built sector is an important component of Canada’s overall strategy and necessary to meet its targets. By creating a strong foundation of sustainable building policy, this sector can be a leader in the fight against climate change.

**References**


Flying into turbulence: how governments can support decarbonisation pathways in the aviation sector

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Written for: Science and Technology Policies

INTRODUCTION
In 2015, governments of the world pledged to hold increases in the global average temperature to below 2°C above pre-industrial levels. This historic pledge was acknowledged as requiring coordination across all sectors of the global economy. Two sectors were excluded from inclusion within Nationally Determined Contribution agreements: international aviation and shipping (Conference of the Parties, 2015). A consequence of this non-inclusion within the Paris Agreement is that mitigation of carbon dioxide emissions (CO₂eq) from these sectors is not required. This is despite the fact that these two sectors currently makeup over 25% of global greenhouse gas (GHG) emissions from transportation and emissions from each are forecasted to grow by 2050 by a factor of 4.5 and 6 respectively (EEA, 2017; Director-General for Internal Policies, 2017; Dessens, Anger, Barker, & Pyle, 2014).

The international aviation sector poses a fundamental barrier to total economic decarbonisation due to its non-inclusion in the Paris Agreement, the complexity of emissions allocations, and the lack of options in appropriate decarbonized aircraft technologies that would fulfill the needs of airline operators (Murphy, 2016). Current solutions for mitigating emissions from this sector include the development of emissions trading schemes and fuel switching measures towards biofuels. From the current options, no solution offers the opportunity to decarbonize the sector at the ambitious rate required to meet international climate targets (Bows-Larkin, 2014).
Pursuance of only one technical emission mitigation pathway, if it turns out to be insufficient to meet environmental targets, also creates the potential for ‘lock-in’ within the existing technological regime that would slow technology diffusion and sector-wide decarbonisation.

This paper argues that it is essential that governments provide policy support to emerging technologies in the aviation sector. This paper examines and compares technical pathways for decarbonisation within the industry, concluding that liquefied hydrogen offers the most realistic technical option for the aviation sector to meet its environmental goals over the long-term. The following sections then outline how policy supports across the production and supply chain for hydrogen fuels could support their uptake within the sector to help address market barriers, de-risk investment and develop the technical expertise necessary to support low-carbon flight.

**The challenge of decarbonisation**
In 2015, the Conference of the Parties agreed in Paris to a historic pledge limiting global average temperature increases to below 2°C above pre-industrial levels, with an aspirational ambition of limiting warming to below 1.5°C above the 1990 emissions baseline (Conference of the Parties, 2015). The Paris Agreement, set to come into force post-2020, represents a historic acknowledgment of the urgency with which global decarbonisation is required (Conference of the Parties, 2015). The agreement requires state actors to develop mitigation pathways referred to as nationally determined contributions (NDCs) that allocate the responsibility of reductions to domestic governments (Directorate-General for Internal Policies, 2017). This structure of apportionment has the effect of excluding emissions that occur outside the scope of any one national economy, with two prominent sectors being notably excluded from the Paris Agreement: international maritime shipping and international aviation. Responsibility for mitigating emissions within each sector has been delegated...
to the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO), two representative governance bodies within the United Nations (COP, 2015).

Although both sectors should be examined in detail, this paper will choose to focus on international aviation. International aviation benefits from a more comprehensive framework for reducing emissions of the two, which includes a market-based approach and several environmental targets; however, scholars have noted that the approach outlined lacks integrity (Bows-Larkin, 2014; Roth, 2018; Dessens et al., 2014). This is a pressing issue in a sector whose technical challenges in shifting away from fossil fuels are seen as more complex than those of maritime shipping (Dessens et al., 2018). In addition, while the international maritime shipping sector does account for a more significant portion of overall global emissions, there is a range of short-to-medium term policy options available that have yet to be cohesively organized by IMO into a single approach (EEA, 2017). This means that although no current framework for reducing emissions in the shipping sector exists, one may very well come along tomorrow whose ambition and scope show preparation to meet the decarbonisation challenge. In international aviation, that day has come and it has been widely seen as insufficient. The next section will detail how the international aviation sector aims to reduce emissions and will explore why scholars think it would not be sufficient.

Current approaches
Existing policies
The aviation policy landscape is subject to oversight from multiple bodies. International aviation policy is governed by ICAO. ICAO’s members have committed to four policy initiatives to mitigate CO$_2$eq emissions within the sector: a global market-based mechanism called the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA); an energy efficiency standard for aircraft; a new
CO₂eq standard to apply to new airplanes post-2020; and a voluntary initiative to promote the use of carbon offsets by airline carriers (International Air Transport Association, 2018). Each of these approaches has been developed to support the international aviation sector’s environmental targets of “only carbon-neutral growth from the entire sector after 2020” and “a reduction of net aviation CO₂eq emissions of 50% below 2005 levels by 2050” (International Air Transport Association, 2018).

The first approach, CORSIA, is a sector-wide scheme operating similarly to a cap-and-trade market with a set emissions baseline of 2020 GHG levels (Gonçalves, 2017). CORSIA’s international market allows members of the aviation industry to purchase carbon offsets from other sectors. Although carbon markets are a common instrument for reducing emissions, CORSIA has been widely criticized due to its “compensation model”, wherein airline operators are only responsible for mitigating emissions that cannot be otherwise purchased through offsets (Gonçalves, 2017). This means there is no formal cap on the number of offsets that can be purchased, and that airline operators can choose to mitigate 0% of their emissions and offset 100% of their GHGs without consequences. This reduces the effectiveness of the policy in stimulating emissions reductions within the sector because the industry can choose to offset any level of emissions instead of being required to mitigate GHGs from their own operations.

CORSIA, alongside all other policies contained in the suite of proposed approaches, has been described by international policymakers and environmental groups as a “weak response by industry” that is “grossly insufficient to meet the objectives of the climate regime” (Gonçalves, 2017). Similar criticisms have been levied upon a set fuel efficiency improvement target of 2% annually and CO₂eq standard for new aircraft, which focus on emissions intensity reductions while placing no cap on overall emissions growth from the sector (Jungcurt, 2018). Scholars have also stated that
meeting targets within policy initiatives are technically possible simply through the modernization of existing fleets with more fuel-efficient aircraft; however, this strategy is not sufficient to meet the sector’s environmental targets over the long-term (Jungcurt, 2018). These critiques illustrate the widely-held view that ICAO’s current policy approach lacks ambition and potential.

Aviation is also subject to domestic policy. However, state-led initiatives to reduce emissions do not hold any additional promise. Domestic aviation emissions are included in the scope of NDCs, with some states additionally setting their sights on contributing to the reduction of international emissions as well. 109 states have developed action plans to reduce CO₂eq emissions from international aviation, as seen in Figure 1 below (International Civil Aviation Organization, 2018). Each action plan contains a baseline, an environmental target and selected measures to reach the target (International Civil Aviation Organization, 2018). There are no existing analyses conducted of state strategies to reduce emissions from international aviation, so this paper undertook a cursory analysis of five of these reports that were randomly selected from a mix of developed and developing nations. Results of this analysis can be seen in Appendix 1.

From these reports, the common practice appears to be a focus on optimization and efficiency, with only developed nations supporting pilot programs into alternative fuels and airplane designs (Federal Aviation Administration, 2015; Schaefer, 2016). Equally important was that each nation stressed that while the issue was one of pressing importance, each retained the right to implement measures voluntarily with no legal consequences for inaction (CAAPER, 2013; China, 2012; Fernandes, Toto & Rosa, 2016). This brief analysis offers two conclusions: first, domestic approaches do not offer the transformative potential necessary to rescue the international sector from the shortcomings of its policies. Second, the policies being
used by domestic and international communities are not going to allow them to meet their environmental targets. All policies focus on reducing the emissions intensity of processes through efficiency and optimization, while the targets set to outline the need to reduce GHG emissions in absolute terms. As previously mentioned, it is unclear how one might lead to the other.

Figure 1: Map of state action plans submitted by ICAO

As seen above, the majority of policy solutions developed internationally, and domestically have been accused of being diluted past the point of effectiveness in meeting climate targets. To meet ICAO’s environmental targets of only carbon-neutral growth from the entire sector after 2020 and a reduction of net aviation CO₂eq emissions of 50% by 2050, far greater ambition is required (International Air Transport Association, 2018). A 2018 presentation to the International Energy Agency’s aviation working group outlined that sector growth was outpacing efficiency gains and that a future emissions gap was very likely to occur if a full paradigm shift towards renewable energy carriers did not start before 2020 (Roth, 2018). This

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1International Civil Aviation Organization. (2018). Climate change: State action plans and assistance
lack of stringency in environmental policies, as previously stated, means pledged actions have little hope of reducing emissions to needed levels to meet climate targets. This means it is an issue of even greater importance that technical solutions to reducing emissions be adopted that offer the potential to scale and support the sector’s climate targets. Therefore, the pursuance of any technical pathway must be rigorously analyzed to ensure that it has the potential to drive the transformative change the sector has pledged to achieve.

**Technical solutions**

Before detailing the technical alternatives to petroleum-propellant fuelled jet engines, it is important to consider the specifications that any alternative fuel must meet to address the technical challenge of fuelling flight. Modern jet engines are widely used because of their light-weight, compactness and high power-to-weight ratios (Bahrami, 2017). The jet propulsion cycle that occurs in a jet engine requires fuels to meet specific standards for performance and safety under a range of conditions. This includes standards for energy density, thermal stability and combustion properties at different levels of atmospheric concentration (Richter, Braun-Unkhoff, Naumann, & Riedel, 2018). Within international aviation, the industry-standard variant of jet fuel is called Jet A-1 (Zhang, Hui, Lin, & Sung, 2016).

This illustrates that any potential low-carbon alternative to traditional jet fuel must be able to meet the complex requirements, safety and performance specifications needed while also offering a co-benefit of emissions reductions. Currently, the most common forms of lower-carbon fuel adopted by the market are derived from biomass feedstocks (referred to herein as biofuels). Biofuels are categorized based on their production process and feedstock sources.
There are two kinds of biofuels used in aviation: synthetic jet fuels and bio-jet fuels (Zhang et al., 2016). Synthetic jet fuels are derived by combusting fossil fuels, then converting the by-products into a synthetic hydrocarbon to blend into Jet A-1 (Zhang et al., 2016). Bio-jet fuels are derived by hydro-processing organic oils, meaning no fossil fuels are involved in the production process (Zhang et al., 2016). Figure 2 below compares the life-cycle emissions of Jet A-1 (kerosene derived fuel), synthetic fuels, and bio-jet fuels. The figure illustrates that without the use of carbon capture and storage technology (CCS), the only fuels that offer improvements environmental performance benefits are fuels developed through bio-jet fuel blending processes. Therefore, these are the ones that this paper details.

Figure 2: Life-cycle GHG emissions for conventional, synthetic and bio-jet fuels

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2 Baseline calculations of bio-jet fuels compare feedstocks undergoing ‘HRJ’, which is the hydro-processing conversion process outlined in the paragraph above.

Discussion of pathways to decarbonizing aviation does not end with biomass. Other fuel types are just as widely discussed but less widely deployed within the market today. The three most prominent non-biofuel low-carbon alternative fuels discussed are electricity, hydrogen and liquefied natural gas (LNG) (Roth, 2018).

Electricity’s use as an alternative to aviation fuel can take two forms. The first is a hybrid-engine that combines a fossil fuel engine with an electric motor (Henke et al., 2018). The second is an all-electric drive train. While these two designs remain entirely theoretically plausible, their current limited deployment is indicative of the significant technical and cost limitations seen in the market today. Powering flight with electricity remains largely commercially unfeasible due to the weight restrictions imposed by battery mass (Henke et al., 2018). According to a 2018 presentation to the IEA, the critical energy density required for a battery to power 80% of international air traffic is greater than 1 kWh/kg, with certain domestic flights requiring only 500 Wh/kg (Henke et al., 2018; Roth, 2018). Current battery densities sit at ranges between 250 to 320 Wh/kg, with the most recent estimates illustrating the 500 Wh/kg benchmark will not be reached until 2025 (Henke et al., 2018). This lack of existing technology readiness and uncertainty as to whether electricity can overcome its own limitations to power flight mean it likely will not have a substantial role in reducing sector emissions in the short-term. At a minimum, the adoption of pilot projects would not be viable until 2025, which does not align with the ICAOs 2020 environmental target of carbon-neutral sector growth (International Air Transport Association, 2018).

Hydrogen-powered aviation has a history of fuelling human flight, although modern engine designs that use H₂ fuels offer notable improvements over the balloon airship. Modern designs for hydrogen-powered aircraft typically use liquefied hydrogen (LH₂) fuel (Yilmaz, Ilbas, Tastan, & Tarhan, 2012). Technical designs do exist for solid
hydrogen fuel cell technologies, although recent technical analyses highlight that the technology is not yet developed enough to be deployed in the near future (Ronnebro, 2012; Adolf, Balzer, Louis, & Schabla, 2018). Technical designs for LH₂ aircraft differ in design from traditional jet engines, as LH₂ has different storage and combustion requirements than fossil fuel alternatives (Adolf, Balzer, Louis, & Schabla, 2018). Notably, LH₂ has a lower combustion temperature and requires vacuum-sealed storage containers (Adolf et al., 2018). Designs have shown that this lower combustion temperature offers efficiency gains within the combustion process, and academics and manufacturers have both cited that LH₂ aircraft designs would be lighter, more fuel-efficient and have longer lifespans than Jet A-1 powered alternatives (Adolf et al., 2018; Airbus, 2001). Concerns about the safety of hydrogen as a fuel have also been examined and studied by industry. Airbus, a manufacturer, identified that the perception that hydrogen fuels were not safe was untrue; every test noted that leaks from storage tanks would result in hydrogen entering the atmosphere without detonation (Airbus, 2001).

The environmental performance of LH₂ powered aircraft is dependent upon how the fuel itself is derived. Hydrogen is widely used in the economy today with over 97% of current supply being generated and captured through either fossil fuel combustion or the separation of water molecules using electricity, a process called electrolysis (Khandelwal, Karakurt, Sekaran, Sethi, & Singh, 2013). A 2012 analysis highlighted that of the two, the only hydrogen derived by electrolysis using electricity supplied from clean energy offered an improvement in environmental performance over Jet A-1 (Yilmaz et al., 2012). Although hydrogen combustion is not a 100% clean combustion process, as it yields both H₂O and NOx products, research has shown that it has the potential to offer a notable improvement in environmental performance over kerosene-derived alternatives.
Finally, liquefied natural gas (LNG) is often discussed as a fuel source for aviation alongside discussions of LH₂. Similar to LH₂, the use of LNG as a fuel source would require the adoption of different engine designs that could offer improvements in overall efficiency (Roth, 2018). However, assessments of LNG as a fuel source have found little to no potential for emissions reductions. A 2018 analysis of aviation fuel alternatives showed that the use of hybrid-electric drive trains, steam-methane reformed hydrogen fuel (hydrogen created through the combustion of natural gas) and LNG-powered planes offered little to no emissions improvements over traditional Jet A-1 fuel (Roth, 2018). This lack of potential to improve upon the environmental performance of existing designs disqualifies LNG as a low-carbon alternative to traditional Jet A-1.

With ICAOs environmental targets requiring steps be taken by 2020, the analysis conducted above shows that only bio-jet fuels and liquid hydrogen offer technical mitigation alternatives to traditional jet fuel that are technologically feasible today. Both have stated environmental benefits, but it is unclear to what extent the adoption of either solution increases ICAOs ability to meet their environmental targets over both the short and long term. If a technical solution does not have the potential to prevent the creation of the forecasted emissions gap within the sector, policies supporting that pathway should not be developed. Therefore, subsequent sections will look in-depth at bio-jet fuels and LH₂, comparing the two based on their ability to put the sector on a pathway that will help ICAO meet its environmental targets.

Choosing wisely
Overview of analytical framework
The effectiveness of a decarbonisation pathway can be examined using components of a multi-level perspective lens, a theoretical approach that examines change creation within a socio-technical system (Haley, Elgie, & McCarney,
The multi-level perspective (MLP) understands that economic change is defined by market and non-market forces, creating selection environments that enable certain technological pathways. The MLP explores the notion of path-dependency, illustrating that marginal changes and developments can evolve into structural configurations that restrict options for future change (Klitkou, Bolwig, Hansen, & Wessberg, 2015). Once a technology trajectory is selected, preconditions can emerge within the environment that create ‘lock-in’ mechanisms; this is conceptualized as frameworks that reinforce a certain pathway of technological or industrial development, leading to a structural path-dependency (Klitkou et al., 2015).

Application of a MLP lens, paired with the concept of ‘lock-in’ mechanisms, offer a useful frame through which to evaluate the short and long-term potential of bio-jet fuel and liquefied hydrogen technical pathways in meeting ICAO targets. This evaluative framework can be seen in Table 1 below. One assumption made in this paper is that regardless of the technical pathway chosen, economic performance will remain aligned with current growth forecasts in the coming years. This assumption allows for an analysis of technical feasibility to exclude any bias towards technologies that may offer current cost advantages at the expense of meeting long-term climate targets. Once the most viable technical decarbonisation pathway is selected, policy recommendations aimed at lowering the current barriers to adoption can be put forward to support cost reductions or adoption at accelerated rates.

It is also important to note that current fuel efficiency and optimization technologies are already capable of reducing sector-emissions by 1.5% annually (EEA, 2017). These efficiency gains will positively impact the sector’s ability to meet its short-term climate objectives. However, they will not be sufficient to meet long-term targets. A comparison of technical pathways must ensure that both short-term and long-term potential is evaluated. This is crucial, as even
when technological and operational improvements are factored in, GHG emissions from international aviation are projected to rise from 755Mt/CO₂eq/year in 2020 to 2.7 Gt/CO₂eq/year by 2050 (IRENA, 2017).

Table 1: Evaluation criteria for technical pathways

<table>
<thead>
<tr>
<th>Type of target</th>
<th>Target</th>
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<tbody>
<tr>
<td>ICAO Environmental</td>
<td>Fuel efficiency improvement of 2% annually post 2020</td>
</tr>
<tr>
<td>objective</td>
<td></td>
</tr>
<tr>
<td>ICAO Environmental</td>
<td>Cap in net aviation CO₂eq emissions from 2020 (carbon-neutral growth)</td>
</tr>
<tr>
<td>objective</td>
<td></td>
</tr>
<tr>
<td>ICAO Environmental</td>
<td>Reduction in net aviation CO₂eq emissions of 50% under 2005 levels by 2050</td>
</tr>
<tr>
<td>objective</td>
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Analysis of pathway: bio-jet fuels
In the short-term, biomass-derived fuels offer the most obvious and attractive pathway for incumbents to reduce CO₂eq emissions due to their use as a ‘drop-in fuel’; the asset intensive nature of the aviation sector limits the ready adoption of alternatives, and drop-in fuels are designed to be interchangeable and easy to mix with today’s propellant (Rye, Blakey, & Wilson, 2010). The adoption of biofuels has been championed by policymakers and airlines across the globe, with bio-jet use targets set by carriers and states such as Boeing, the United States, Australia, Germany, and Israel to name only a few (IRENA, 2017). Canada has even developed a nationwide challenge, called the ‘Sky’s the Limit Challenge’, to stimulate demand for greener aviation fuels with prize-money being allocated to bio-jet fuel solutions (Government of Canada, 2018b). Canadian cabinet ministers have identified this pathway as ‘a game-
changing transformation for the aviation industry” with the potential to “achieve a cleaner, more sustainable future” (Government of Canada, 2018b).

However, despite the rhetoric of policymakers and industry incumbents, biomass is not the panacea it may seem. Modelling conducted by the International Renewable Energy Association (IRENA) in 2017 indicates that meeting ICAOs environmental target of reducing total sector emissions by 50% by 2050 using only bio-fuels would require the international aviation sector to use 426 million tonnes of bio-jet fuels annually by 2050 or 504B litres/year (IRENA, 2017). This is equal to approximately 50% of the total estimated annual fuel used by the sector (IRENA, 2017). This number stands in contrast with the overall production targets of bio-jet fuel expected by the same date; an article published in 2016 that studied the future impacts of biofuel production out to 2050 estimates that based on current production trends, bio-jet production will be 6.7 exajoules in 2050, which is equal to 39.23B litres of bio-jet fuel (Hammond & Li, 2016). This falls short of what is required. In fact, an examination of the biomass sector as a whole makes this target seem even more far-fetched. A seminal 2011 report by the International Energy Agency outlines that the use of bio-fuels in transportation is expected to increase to 32 exajoules by 2050, roughly equal to 187.67B litres/year (International Energy Agency, 2011). This analysis shows two things: first, that the required demand for bio-jet fuel by 2050 to meet ICAOs targets would exceed forecasted production of bio-jet by 465B litres/year, a deficit of approximately 1285% of

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4 It is assumed that the molecular density of bio-jet is identical to that of Jet A-1. 1 metric tonne of Jet A-1 is equivalent to 1183 litres.

5 The conversion of exajoules of overall biofuel production were converted into litres of Jet A-1 equivalent fuel for this analysis. 1 exajoule of biofuels is equivalent to 5.855 billion litres of Jet A-1 equivalent.

6 The 165B litres/year figure is indicative of the global production capacity to supply a fuel whose molecular density would be sufficient for use in bio-jet, which requires greater supply within its production process than the production of other biomass-derived products.
production capacity. Second, that this demand for bio-jet fuel would exceed the total estimated global production capacity of all transportation bio-fuels by 2050 by 316.3B litres/year, a deficit of approximately 269% of required capacity. This analysis shows that the bio-jet technical mitigation pathway, even if all global transportation biofuel production were directed towards bio-jet production, would still fall short of supplying the required quantities needed to meet ICAOs environmental targets. Therefore, it can be reasonably concluded that the adoption of biofuels in the necessary quantities required to meet the decarbonisation targets of the aviation sector will not occur by 2050, an analysis that can be seen in Table 2 below.

Table 2: Technical potential of bio-jet fuel pathway

<table>
<thead>
<tr>
<th>Type of target</th>
<th>Target</th>
<th>Potential to meet target</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICAO Environmental objective</td>
<td>Fuel efficiency improvement of 2% annually post 2020</td>
<td>High; although no short-term bio-jet production targets have been met by parties thus far, existing efficiency measures will likely see most of this target met.</td>
</tr>
<tr>
<td>ICAO Environmental objective</td>
<td>Cap in net aviation CO\textsubscript{2}eq emissions from 2020 (carbon-neutral growth)</td>
<td>Low; Lack of bio-jet supply will limit access to the quantity needed to maintain carbon neutrality, resulting in existing assets compensating with kerosene-based</td>
</tr>
</tbody>
</table>
fuels and growing overall emissions.

| ICAO Environmental objective | Reduction in net aviation CO₂eq emissions of 50% under 2005 levels by 2050 | Low; Highly likely that necessary production volumes (426M tonnes/year) will not be reached to meet long-term decarbonisation objectives. |

This illustrates that pursuing this pathway has an effectiveness ceiling. It is unreasonable to assume that global bio-jet production, which is not deployed in any notable quantities in international commercial aviation beyond a few pilot projects, will grow from its current use in individual pilot programs to a production quantity that far exceeds the size of forecasted global transportation biofuel production in the next 30 years (IRENA, 2017). This is made even more likely by the fact that out of all the states and airlines mentioned above, no single party has been identified as being on track to meet their own bio-jet fuel use targets (IRENA, 2017).

Bio-jet’s long-term lack of ability to scale means it should not be regarded as a viable pathway for long-term decarbonisation of the aviation sector. However, there is potential for biofuels to play a role in supporting incremental emissions reductions in the short-term while investment is directed towards low-carbon solutions that have the potential to meet climate targets. If this were to occur, an important pre-condition to this pathway would
need to be that investment into biofuels was viewed as a compliment to investment into low-carbon alternatives instead of being viewed as a substitute. While this lens of complementarity is theoretically possible, it should be noted that no domestic or international strategy or policy to reduce emissions from aviation states that this is the case. As previously noted, policymakers have affirmed support for bio-jet fuels as a sustainable alternative to Jet A-1 without any indication of its limitations in reducing emissions long-term.

If policymakers do not meet this pre-condition of acknowledging complementarity, this pathway goes from being potentially useful to being an obstacle to meaningful climate action. It is understood that bio-jet’s capability to blend into existing fuels allows for incumbents to use existing technologies while improving their emissions intensity incrementally. When viewed alongside the lock-in principle outlined above, this highlights a hazard. The incremental approach of blending biofuels favoured by incumbents creates a risk of technology lock-in, through investments in infrastructure and production, towards a solution that has been identified as insufficient for meeting environmental objectives. This is because bio-jet offers the potential to help meet short-term efficiency targets, and ICAOs environmental policy approaches are designed in a manner that does not favour one technology over another. This neutrality increases the chance that the sector will invest in low-cost, short-term solutions instead of looking to shift to meet long-term objectives. Currently, the short-term solution that has been selected and supported by both the private and public sector is bio-jet. Over-emphasis by governments on this incremental innovation approach, and a failure to acknowledge the need to shift to lower-carbon alternatives eventually, will only lengthen the period of uncertainty that prohibits investment and the adoption of more radical innovations that may have more long-term potential. This would slow user and institutional learning and delay the development of the economies of scale.
necessary to commercialize high-cost technologies. Each of these mechanisms directly contributes to lock-in and should be immediately addressed if path dependency is to be avoided (Klitkou et al., 2015). This shows a risk that by the time the non-viability of this path is realized, it may be too late to mobilize system actors towards any other trajectory. As such, unless bio-jet is explicitly acknowledged as a solution that is only a first step towards a decarbonized future, investment into low-carbon solutions would be better directed towards fuels that offer the potential to more deeply decarbonize over time.

**Analysis of pathway: LH₂**
The second pathway this paper examines is LH₂. Hydrogen fuelled aircraft have largely fallen out of favour as a decarbonisation pathway within the aviation sector following some experimental developments in the mid-2000s (Airbus, 2001). The primary reasons for abandoning this pathway were the high energy costs required to produce and use hydrogen fuel, its associated carbon footprint and the high costs of sourcing hydrogen fuels (Fitzpatrick, 2010). However, the rationale underpinning these motivations have changed as technology has evolved. Hydrogen production is still energy-intensive, but renewable sources of electricity now operate for far smaller costs than they did in the mid-2000s. This has lowered the cost of hydrogen production on a per-energy-unit basis. While the overall costs of hydrogen production remain high, this is largely attributable to the small number of hydrogen production facilities that have yet to achieve the economies of scale necessary to reduce costs. Should this technical pathway be perceived as environmentally superior to others in helping ICAO achieve its goals, government policies directed at addressing those barriers could be seriously analyzed and discussed.

One area in which there has long been industry consensus is in the environmental and technical performance benefits associated with hydrogen-powered aircraft. LH₂ aircraft are
lighter, have longer lifespans and use less fuel than Jet A-1 powered counterparts. From the analysis conducted previously in this paper, it is also clear that renewably-derived LH₂-powered flight could potentially result in carbon-neutral aircraft and lead to long-term decarbonisation. An evaluation of hydrogen-based upon its ability to support the international aviation community meet its long-term environmental targets can therefore be seen in Table 3 below. The exact extent with which hydrogen could help meet environmental targets would largely be dependent upon the pace of technological adoption, as meeting sector targets would only be possible if a sufficient number of hydrogen aircraft were adopted as to reduce overall sector emissions by 50% by 2050. This is where the principle of lock-in mechanisms can be deployed to support this analysis. Installation of hydrogen production, transportation, and fuelling infrastructure would lower barriers to adoption of LH₂. As the use of LH₂ grows, so would user and institutional learning. This would allow incremental innovations to follow the adoption of more radical changes, leading to a cascading effect that would decrease cost and fuel sector growth to shape a technical pathway for years to come.

Table 3: Technical Potential of LH₂ fuel pathway

<table>
<thead>
<tr>
<th>Type of target</th>
<th>Target</th>
<th>Potential to meet target</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICAO Environmental objective</td>
<td>Fuel efficiency improvement of 2% annually post 2020</td>
<td>Mid; although LH₂ technologies will not be commercially viable, current efficiency improvements of 1.5% annually will likely see this target met.</td>
</tr>
<tr>
<td>ICAO Environmental objective</td>
<td>Cap in net aviation CO₂eq emissions from 2020 (carbon-neutral growth)</td>
<td>Unclear; Meeting criteria would depend upon the rate of adoption of LH₂ aircraft. Any adoption of LH₂ fuelled aircraft would dramatically lower emissions relative to Jet A-1 alternatives. If existing assets are readily phased out in the coming years and emissions are offset while this occurs, there is high potential to achieve carbon-neutral growth.</td>
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<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
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<tr>
<td>ICAO Environmental objective</td>
<td>Reduction in net aviation CO₂eq emissions of 50% under 2005 levels by 2050</td>
<td>High; reduction of GHG emissions of over 50% below 2005 levels is likely of LH₂ fuelled aircraft are widely adopted.</td>
</tr>
</tbody>
</table>

Within this analysis, it is apparent that adoption of LH₂ as a technical mitigation pathway would offer an opportunity to increase overall fuel efficiency and heavily decarbonize the sector. However, the potential success of this technical pathway would be entirely dependent on the rate of uptake of LH₂ aircraft. The adoption of LH₂ aircraft would also need to begin as soon as possible for it to play a role in meeting climate targets within the next decade. There are barriers to this: current projections estimate that LH₂ fuelled aviation may be technically viable by 2020, but will not
become commercially mainstream until 2040 (International Renewable Energy Agency, 2018). This timeline is too long to meet ICAO targets.

This is an area where government support for technologies can play a key role in meeting targets. As previously stated, bio-jet fuels may offer a solution to meeting climate targets in the near term but lack the potential to support sector-wide decarbonisation. LH₂ aircraft, a technology that is both viable today and can support meeting long-term climate targets, represent the only technical pathway where policies directed can begin to stimulate action and investment in the near term. Waiting for breakthroughs in solid-state fuel cells or batteries risks substantially delaying investment into the necessary infrastructure and supply chains required to scale solutions at speed. Without action today, sector emissions will have little chance of deviating from the set business-as-usual pathways described above. Understanding which policies could make the greatest impact in addressing barriers to adoption is therefore imperative, and subsequent sections will be dedicated to understanding how actions today can support the uptake of LH₂ aircraft and the achievement of climate objectives.

Clearing the skies
Targeting hydrogen: science or technology policy?
The mainstream commercial use of LH₂ and fuel cell technologies have long been assessed as financially unfeasible until sufficient scale is achieved that a 'hydrogen economy' develops. This is defined by the Hydrogen Council, an industry representative body, as the expansion of the use of hydrogen fuel in multiple sectors that would surpass a critical supply benchmark deemed at meeting approximately 18% of global energy demand (Hydrogen Council, 2017). However, this creates a stalemate for the market: the market will not reduce costs to competitive levels until there is sufficient adoption, but no adopter is willing to invest given the small market and high costs of
production. This is where government policy can have a catalyzing effect.

The overarching objective of policy supporting LH₂ aircraft should be directed at accelerating the pace of development and deployment of technologies to shorten the adoption timeline so that this occurs before 2040. Supporting this process of commercialization for LH₂ technologies requires governments not just to direct capital at manufacturers, but to take a system-wide lens and support the installation of framework conditions for growth or fostering desired links between actors (Lundvall & Borras, 2009). Facilitating systems-wide change is a product of market and non-market forces; therefore policy supporting technology diffusion in the hydrogen economy must examine not only challenges such as infrastructure development and the achievement of economies of scale, but also how to develop consumer trust and industry support for the fuel (Shakeel, Takala, & Lian-Dong, 2017). This paper will focus on examining which technology and innovation policy levers have the greatest potential in addressing the barriers to dissemination identified above.

**Recommended policy levers**

The major physical and market barriers preventing the adoption and commercialization of hydrogen-fuelled aircraft are the high cost of production and use, inadequate supporting infrastructure, and a lack of familiarity within the aviation sector of LH₂ technologies (Khandelwal et al., 2013; Richter et al., 2018; Adolf et al., 2018). Recommendations given in subsequent sections focus on technology and innovation policies that support the use of hydrogen derived through renewable energy, thereby allowing the fuel to maintain its environmental advantage relative to Jet A-1.

**Technology policy levers**

In the case of hydrogen, technology policies are defined as policies related specifically to expanding the development
and use of hydrogen technology. In 2015, the International Energy Agency (IEA) identified the largest physical barriers to the widespread adoption of hydrogen technologies within the transport sector were a lack of renewable hydrogen production facilities, the high costs of production components and insufficient distribution infrastructure (International Energy Agency, 2015). This has limited the growth of renewable hydrogen fuel in the last decade, with over 95% of industrial hydrogen manufactured being fossil-fuel derived (International Energy Agency, 2015). Governments can provide support to renewable hydrogen production through multiple avenues, including financial policies and regulation.

Financial policies can improve the investment climate in the sector and stimulate investment into the market today. Investment tax credits and long-term low interest loans to renewable hydrogen producers are examples of two financial policy tools that would support sector growth. A key example of a tax credit is the accelerated cost of capital allowance write-down that is available to energy projects in Canada as of Fall 2018 (Government of Canada, 2018a; International Energy Agency, 2015). An example of a policy that would support loans is to collaborate with financial institutions and guarantee a fixed portion of the commercial loans given to renewable hydrogen production facilities; this would serve to de-risk capital investment and lower the barriers to entry for firms seeking to enter the sector (The World Bank & Climate Investment Funds, 2016). Both of these policies would be aimed specifically at supporting the production of fuels and not funding pre-commercialization research. This change would de-risk investments for producers, thereby stimulating investment into production that would lead to the development of greater economies of scale and decrease the cost-per-unit of production at a faster rate than might other occur under a business-as-usual scenario (The World Bank & Climate Investment Funds, 2016).
A regulatory approach adopted in tandem with any financial tools would offer additional benefits. Regulations deployed that focused on the development of harmonized standards for hydrogen production and refuelling equipment would further increase investor certainty by ensuring that any projects could be designed to meet domestic standards and could, therefore, guarantee access to the domestic market (International Energy Agency, 2015). The development of common standards in the energy sector is widely regarded as an essential step to create market certainty and stimulate investment (International Energy Agency, 2015). As the international harmonization of safety and handling standards would remove barriers for sector growth across borders, a degree of international coordination in this exercise would be beneficial in supporting the sector as well. It is recommended that loan guarantee mechanisms and harmonized standards for equipment be developed to lower the barriers to growth and investment in the sector. Beyond supporting hydrogen production, it is equally important to develop standards and financing tools to support the distribution and transmission of fuels. An advantage for renewable hydrogen production is that production facilities can be anywhere, so long as there is access to sufficient water to undertake industrial electrolysis. Producing hydrogen in centralized facilities allows for cost reductions through the achievement of economies of scale, but creates a need to develop a transmission and distribution system to ship produced hydrogen. Policies that support the development of this distribution network are equally important to support the growth of the sector, as uncertainty around standards for emerging technologies is a key factor that holds back their adoption.

There are three approaches to distributing hydrogen fuels: pipelines, high-pressure tube trailers, and liquefied hydrogen tankers (International Renewable Energy Agency, 2018). While pipelines are the most financially and
environmentally sound distribution option long-term, the development of pipelines can have a high financial and political cost (Austen, 2018). Constructing infrastructure that will create a ‘lock-in’ mechanism to distribution is also unwise in the nascent days of a growing sector, as uncertainty surrounding new innovations will decrease the investment attractiveness of permanent infrastructure. Therefore, it is recommended that government support that aims to foster the development of infrastructure pre-2040 be directed towards liquefied cryo-cooled tankers to be distributed through existing rail and freight networks. Additionally, hydrogen’s low density and broad flammability range make the setting of regulatory standards critical to ensuring the growth of a distribution network. As noted above, standard setting is recommended to facilitate asset purchasing and lower investor uncertainty.

Supporting airports in constructing hydrogen fuelling and storage infrastructure is the last phase of the distribution network, but is another area where policy can play a crucial role. ICAO’s 2016 Annual Report collaborated with the Rocky Mountain Institute’s Carbon War Room and developed a best practices approach to growing the use of alternative sustainable fuels within the aviation sector (ICAO, 2017). The model prioritized an airport-first approach that facilitates infrastructure planning and encourages each individual airport to collaborate with national governments and national airline carriers to develop infrastructure (ICAO, 2017). This paper recommends the same model (a public-private partnership model between governments, airports and participating airlines) should be piloted in Canada to determine its use in helping to share costs and reduce the initial expense and complexity of procurement of hydrogen fuels. If successful, this will provide support to airports and aircraft whose unfamiliarity would be a major barrier to adoption that would slow technology uptake. This approach illustrates how government policies aimed at supporting the market
can also help overcome non-market barriers to adoption such as a lack of individual expertise, thereby removing additional barriers to investment today that financing may not target.

**Innovation policy levers**

Innovation policies are defined as policies whose aim is building connections between different actors within the hydrogen energy sector. Innovation policies can be deployed to work with industry to overcome market barriers and develop familiarity and expertise in the use of hydrogen fuel, both nationally and internationally. As discussed above, the airport-first model should pursue to support the development of hydrogen infrastructure. However, the lack of technical and operational knowledge within the aviation sector associated with the use of hydrogen fuels may slow adoption globally. It is recommended that ICAO and its industry equal, the International Air Transportation Association (IATA), collaborate to create a joint working group whose mandate will be to develop research and lend support to national governments in the development of their own hydrogen supply chains. As international bodies, research should emphasize how both developed and developing nations can adapt the airport-first model to their local contexts.

National governments can support local action through their domestic action plans to reduce aviation emissions. It is recommended that states, with a special focus on developed nations, form joint research and industry working groups with a mandate of investigating the viability and commercialization of hydrogen fuels. These working groups should have an aim of fostering collaboration to overcome market barriers to commercialization in the near future and include relevant local stakeholders such as aircraft manufacturers, airports, airlines, governments and hydrogen energy manufacturers.
Initiatives such as these offer opportunities to share knowledge and develop industry-led targets that fuel sector growth, such as the Fuel Cell and Joint Hydrogen Undertaking within the European Union and the H₂ USA program in the United States of America (International Energy Agency, 2015).

Conclusion
The development and diffusion of LH₂ technologies in aviation offers a long-term pathway to meeting climate targets that can be embarked upon today. Policies aimed at de-risking investment and supporting commercialization will help address market barriers and uncertainty around the fuel’s future, promoting investment and adoption in a timeline that will likely be swifter than a business-as-usual approach. Failing to support LH₂ aircraft by choosing instead to focus on the deployment of bio-jet, and emphasizing technological solutions that are not yet deployable, risks putting climate targets firmly out of reach. Aviation is widely understood to be a sector whose road to carbon neutrality will be arduous. Clear investment and declarations of support into a single solution today could offer a clear signal to markets and states about the pathway the sector will take moving forward. Failing to outline a commitment to decarbonisation firmly will only see the urgency and uncertainty around direction climb upwards alongside emissions projections.

The aviation sector’s exclusion from the Paris Agreement was not due to its lack of significance as a contributor to global emissions, but rather because its potential inclusion was a complex inter-jurisdictional affair that no government could be held accountable for solving. While some may view its exclusion as a worrisome example of private sector inaction, this paper argues it is an opportunity for governments to support market leadership. As states look long-term towards decarbonisation, they must accept the turbulence that a successful long-term transition will bring. Championing hydrogen fuels within
aviation offers the opportunity to commercialize a renewable solution described as “a potential holy grail in the environmental movement”; expertise built here can be cross-cutting and transferred into heavy industry, other forms of transportation and potentially address the environmental concerns associated with international maritime shipping (Adolf et al., 2018). The hydrogen energy sector is preparing for take-off; government action today will help it ensure it takes flight.

References


Civil Aviation Administration of China. (2012). China’s action plan to limit and reduce CO2 emissions from international


dasenergyandnaturalresourcesectorstheroleofp.pdf


opportunities of very light high-performance electric drives for aviation. Energies, 11(344).
https://doi.org/10.3390/en11020344


**Appendix 1: Comparison of state action plans to combat emissions from international civil aviation sector**

<table>
<thead>
<tr>
<th>Member State</th>
<th>Categorization</th>
<th>Stated Measures</th>
</tr>
</thead>
</table>
| Angola       | Developing     | • Improved air traffic management and infrastructure use  
• More efficient operations  
• Airport improvements |
| (Fernandes, Toto, & Rosa, 2016) |                |                 |
| China        | Developing     | • Energy efficiency measures for airports  
• Optimization of air space routes |
<p>| (Civil Aviation Administration of China, 2012) |                |                 |</p>
<table>
<thead>
<tr>
<th>Region</th>
<th>Status</th>
<th>Key Developments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>Developed</td>
<td></td>
</tr>
<tr>
<td>(Schaefer, 2016)</td>
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<tr>
<td>Central America*</td>
<td>Developing region</td>
<td></td>
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<tr>
<td>The Central American region, composing of six states, developed a common action plan</td>
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<td>(CAAPER, 2013)</td>
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<tr>
<td>United States</td>
<td>Developed</td>
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<tr>
<td>(Federal Aviation Administration, 2015)</td>
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</table>

**Germany**

Developed

- Supporting the growth of industry best practices
- Funded R&D and pilot programs for alternative fuels and designs
- Improved air traffic management

**Central America**

Developing region

- Air traffic management and flight path optimization
- Strengthen institutions to improve knowledge sharing
- Create new ‘spaces for investment’

**United States**

Developed

- Investment in alternative fuels and designs
- Air traffic management improvements
- Improvements in operational efficiency
Sending Mixed Signals: Radiofrequency Electromagnetic Radiation, 5G Networks, and the Precautionary Principle

Written by: Parisa Khosraviani
Written for: Science and Technology Policy

1.0 INTRODUCTION
In the age of the internet and open access sources of information, it can be difficult to navigate and arrive at the truth (Manjoo, 2016). In recent years, public concerns have been raised over the possible impacts on human health from exposure to radiofrequency electromagnetic radiation (RF-EMR). The concern has surrounded commonly used technologies such as cell phones, Wi-Fi, and most recently, the impending rollout of 5G wireless networks (Russell, 2018; Akdag et al., 2016). 5G networks are needed to enable new technologies that require sharing of massive amounts of data, such as autonomous vehicles and other technologies classified under the IoT (internet of things) umbrella (Russel, 2018). Much of the concern over radiofrequency (RF) emitting technologies, in particular 5G networks, stems from the lack of conclusive research regarding whether or not its implementation will lead to adverse health impacts. Since 5G will require the installation of more densely positioned network towers, some worry that the increased exposure to RF-EMR could cause cancer or skin and organ tissue damage (Rahhal, 2018; CBS News, 2018), yet to date there has been no thorough discourse or efforts on the part of governments or industry to address these public health risks.

A widespread heuristic for how policy makers should act in situations of uncertainty and risk is referred to as the precautionary principle. The precautionary principle encourages policy makers to take various courses of regulatory action when there is potential for certain
products and activities to have harmful effects on the environment or human health, even before conclusive scientific evidence provides proof of such harmful effects (Tosun, 2013). This paper's argument has two parts. First, it argues that uncertainty over the health impacts of 5G technology warrants the use of the precautionary principle by governments before widespread implementation is permitted. This uncertainty has arisen from a combination of public perception, lack of scientific research on 5G radiofrequency, conflicting conclusions on the health effects of radiofrequency in the scientific literature, and also from a lack of publicly available information on the issue. Second, the paper argues that governments and industry are unlikely to take any precautionary measures or address public concerns, as it does not serve their economic interests. Canada, the United States, the State of California and the European Union will be examined to demonstrate both overlapping and conflicting approaches to the implementation of 5G networks.

This paper will develop as follows. First, a technical backgrounder on radiofrequency technology and 5G networks will be provided, connected to a brief discussion on how these technologies could pose harm to human health. Second, evidence of public concern and uncertainty around the safety of radiofrequency, including 5G, will be presented. Subsequently, both governmental and peer-reviewed publications concerning radiofrequency impacts on human health will be examined. This section will demonstrate the communication of mixed messages by both governmental organizations and the scientific community to the general public, as well as point to conflicting conclusions apparent within the scientific community itself. Lastly, the precautionary principle will be considered to understand both how decision makers can react in the face of scientific uncertainty, and why this approach should be applied to the case of 5G. The paper will conclude with a discussion on the likelihood a precautionary approach will be used in this circumstance.
2.0 Background

**What is radiofrequency radiation?**

Broadly, radiation is the emission of energy from any source. Radiation exists across a spectrum from very high-energy (high-frequency) radiation to very low-energy (low-frequency) radiation: this is referred to as the electromagnetic spectrum. High-energy radiation, which includes x-rays and gamma rays, is also called ionizing radiation, which means there is enough energy to remove an electron from (or ionize) an atom or molecule. Ionization can damage the DNA inside of cells, which can potentially result in cancer. Radiofrequency radiation, which includes radio waves and microwaves, is at the low-energy end of the electromagnetic spectrum. It is a type of non-ionizing radiation. Non-ionizing radiation has enough energy to move atoms in a molecule around or cause them to vibrate, but not enough to cause ionization (American Cancer Society, 2018).

If RF radiation is absorbed in large enough amounts by materials containing water, such as food, fluids, and body tissues, it can produce heat. This heat can lead to burns and tissue damage. Although RF radiation does not cause cancer by damaging DNA in cells the way ionizing radiation does, there has been concern that some forms of non-ionizing radiation might have biological effects that could result in cancer in some circumstances (American Cancer Society, 2018). People are exposed to a complex mix of weak electric and magnetic fields from the generation and transmission of electricity, domestic appliances and industrial equipment, and telecommunications and broadcasting. According to the World Health Organization, the levels of radiofrequency fields to which people are normally exposed are lower than those needed to produce significant heating. To date, no adverse health effects from low level, long-term exposure to radiofrequency or power frequency fields have been confirmed, but scientists are actively continuing to research this area (WHO, 2018).
What is 5G?
5G is a type of wireless cellular service, similar to 4G. Compared to the existing 4G networks, 5G networks will allow for greater speed and volume of information transfer. 5G carries information wirelessly through the electromagnetic spectrum, specifically the radio spectrum. Within the radio spectrum are varying levels of frequency bands, some of which are used for 5G data. 4G networks use frequencies below 6 GHz; higher frequencies above 6 GHz are needed to meet the ultra-high broadband speeds envisioned for 5G. Currently, the 26 GHz / 28 GHz bands have the most international support in this range (Fleck, 2018; GSMA, 2019). Wavelength is inversely proportional to frequency, meaning the higher the frequency, the shorter the wavelength. 5G cell towers are much smaller than their 4G counterparts but will require an increased concentration of cell tower sites since the shorter wavelengths are more likely to be blocked by physical objects (Fisher, 2019). Specific development plans detailing the exact concentration have not yet been released by network providers, contributing further to the uncertainty factor (Fisher, 2019a, b).

3.0 Public perception and uncertainty
This section will provide evidence demonstrating the existence of public concern regarding health risks associated with the implementation of 5G networks, as well as with radiofrequency emitting technologies more generally. A media scan resulted in numerous articles discussing this concern and uncertainty expressed by everyday citizens. For example, CBSNews, an American news organization, published an online article in May 2018 titled “5G service is coming – and so are health concerns over the towers that support it”. The article interviews concerned citizens in Montgomery County, Maryland, where light poles were being proposed to be converted into 5G cell sites. Members of the neighbourhood echoed concern over the unknown health effects of the cell sites and
had been motivated enough by their concern to attend a
government hearing.

Canada’s *National Observer* published an article on their
website in August 2019, titled “Panicked Nuns’ Island
residents afraid of cell phone antennas fight to have them
removed”. Residents of a building on Nuns’ Island in
Montreal believe that cellular antennas on their rooftop are
making them sick, despite the fact that frequency levels are
within the parameters of Health Canada’s guidelines that
regulate electromagnetic frequencies. A building resident
and former Montreal city councilor Michelle Daines is
quoted as saying “I cannot sleep, I have a difficult time
working and I am afraid that I am dying. Slowly frying like a
lobster, irreversible hypersensitisation to [radio frequency]
radiation because I have been exposed for long durations,
all the while being told everything was below Safety Code
6”. The article highlights the tension between scientists and
health professionals who are dismissive of sensitivity to
electromagnetic radiation, and those who argue health
effects of wireless technology deserve further scrutiny
(Bramadat-Willcock, 2019).

Public concern over 5G has been also been observed in
California, and in some instances has seen paralleled
government action. The city council of Mill Valley, a small
town just north of San Francisco, voted unanimously to
effectively block deployments of 5G wireless towers in the
city’s residential areas, citing cancer concerns. In the past,
California’s Department of Public Health has also issued
warnings about potential health effects of personal cell
phone antennas (Crichton, 2018). Additionally, in 2017
Governor Jerry Brown vetoed a bill backed by the cellphone
industry that would have made it easier to install
microwave radiation antennas. Grass-roots activists and
scientists warned that if the bill became law, a projected
50,000 new cellular antennas would be installed on public
buildings and utility poles in California neighborhoods,
creating a risk to public health because of the dangers of
radiation and electromagnetic frequencies emitted by cell towers (Seipel, 2017).

4.0 The literature on 5G and other RF technologies: Mixed messages

Methodology

In order to assess the extent of uncertainty concerning the impacts of radiofrequency electromagnetic radiation on human health, a scan was performed for relevant publications. The literature examined included reports and communications from government and international agencies, and Carleton University Summon was used to perform a scan on the large body of peer-reviewed scientific publications on the topic. Because an initial scan zeroing in on 5G specifically resulted in too few publications for analysis, likely due to the technology’s novelty, the scan was expanded to include scientific studies that have been published on health impacts related to RF radiation more generally. Importantly, this section of the paper is not meant to present a comprehensive literature review on the topic of health impacts of 5G technology. Rather, this section will demonstrate how the lack of available information on 5G and conflicting conclusions regarding other RF-EMR technologies together merit application of the precautionary principle.

This section will first present findings released by accredited institutions and governments, to demonstrate how these communicate mixed messages to the public and in turn contribute to public doubt and concern over RF technologies. Subsequently, in an effort to summarize the findings of the vast number of academic publications on this topic and to allow for the reader to effectively understand how they present conflicting information, the various sources and their findings will be presented in a table. Note that the table is not a comprehensive representation of the academic literature on 5G, although an effort was made to search for and include a variety of conclusions in order to demonstrate the existence of 'mixed messages.'
4.1 Canadian Governments: Federal and provincial agencies

While federal and provincial governmental health agencies in Canada have released publicly accessible documents on the safety of radiofrequency, there have been no publications released since 2014, and no publications specifically discussing 5G. The Government of Canada has a publicly available web page titled “Wireless Communications and Health”, which assures citizens that exposure to cellphones and other radiofrequency fields are safe, and that the Government of Canada has set safe exposure limits (Government of Canada, 2012). Furthermore, according to Health Canada, the vast majority of scientific research to date does not support a link between RF energy exposure and human cancers. 5G networks in Canada will release millimetre wave (mmWave) spectrum in the 28 GHz, 37–40 GHz and 64–71 GHz frequency bands (Government of Canada, 2017). Health Canada’s Safety Code 6 (2015) provides guidelines on acceptable exposure thresholds for RF radiation, and references scientific literature published up to 2014. The Safety Code determines that a frequency range from 6 GHz to 300 GHz is safe for human exposure, which means that 5G fits within Health Canada’s safety guidelines (Government of Canada, 2018).

However, Health Canada is in agreement with both the World Health Organization and the International Agency for Research on Cancer (IARC) that additional research in this area is warranted (Health Canada, 2011). They state that at present, the evidence of a possible link between RF energy exposure and cancer risk is far from conclusive and that more research is needed to clarify this "possible" link. This sends a mixed message to the public. On one hand, the link between RF exposure and cancer is rather confidently rejected, yet on the other hand the call for more research casts doubt on the certainty of this conclusion.
Mixed messages have also been communicated by provincial agencies in Canada. In 2011, a report was released by the Ontario Agency for Health Protection and Promotion (OAHPP) on “Wireless Technology and Health Outcomes.” The report first presents information stating that the strength of RF emitted by Wi-Fi is below the safety limit and has no adverse health effects. However, the OAHPP report also presents conclusions from other agencies and scientific publications that conflict with this information, primarily the Bio-Initiatives Working Group’s “The BioInitiative Report: A Rationale for a Biologically-based Public Exposure Standard for Electromagnetic Fields.” The OAHPP describe the working group as “an ad-hoc group of scientists and public policy analysts” (Copes & Loh, 2011, p.4) and is critical of the working group’s methodology. The report does conclude that “research on potential health effects from exposure to RF energy is an active field of investigation” and that up-to-date literature reviews are useful in informing sound policy-making (p.7); however, no further publications have been released by the OAHPP since then.

4.2 The International Agency for Research on Cancer and the Scientific Community

The International Agency for Research on Cancer (IARC) is a branch of the United Nations with a mandate to conduct and coordinate research investigating the causes of cancer. In May 2011, the IARC evaluated cancer risks from radiofrequency radiation. RF radiation was classified as Group 2B, a possible human carcinogen, based on an increased risk for glioma, a malignant type of brain cancer, associated with wireless phone use. The 2B category is used for agents “for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity in experimental animals. It may also be used when there is inadequate evidence of carcinogenicity in humans but there is sufficient evidence of carcinogenicity in experimental animals” (IARC, 2011, p.1). The results section specifically stated:
“The evidence was reviewed critically, and overall evaluated as being limited among users of wireless telephones for glioma and acoustic neuroma, and inadequate to draw conclusions for other types of cancers. The evidence from the occupational and environmental exposures mentioned above was similarly judged inadequate. The Working Group did not quantitate the risk; however, one study of past cell phone use (up to the year 2004), showed a 40% increased risk for gliomas in the highest category of heavy users (reported average: 30 minutes per day over a 10-year period).” (IARC, 2011, p.2)

There have not been any updated publications on RF radiation from the IARC since 2011.

In an academic article published in 2018, Anthony Miller and colleagues provided a follow up to the 2011 IARC report. By reviewing and summarizing epidemiology studies published between 2011 and 2018, they concluded that the recent studies strengthened and supported the conclusion that RFR should be categorized as carcinogenic to humans, under the IARC Group 1 classification, rather than 2B. The review included numerous studies since the publication of IARC 2011 which provided evidence of increased risk of brain, vestibular nerve and salivary gland tumors associated with mobile phone use (Miller et al., 2018). Furthermore, an appeal for a moratorium on 5G has been signed by over 180 doctors, who argue that the technology could be a hazardous to human health. They argue that the implementation of 5G networks will substantially increase exposure to radiofrequency electromagnetic fields (RF-EMF), in addition to the 2G, 3G, 4G, and Wi-Fi infrastructure for telecommunications already in place (International Electromagnetics Field Alliance, 2017). This is another example of mixed messages being sent by the scientific community.
4.3 Conflicting conclusions in the academic literature on RF-EMR

This section will present the findings from a review of scientific publications on 5G and RF emitting technologies. The Conclusions column demonstrates how even within the scientific community there are conflicting findings and recommendations regarding the health impacts and safety of 5G and other RF emitting technologies. Uncertainty is also evident within individual studies which conclude that further research is required.

<table>
<thead>
<tr>
<th>Title, author, year, and publication type</th>
<th>Journal</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Towards 5G communication systems: Are there health implications? Di Ciula, A. 2018 Type: Literature review</td>
<td>International Journal of Hygiene and Environmental Health</td>
<td>· Preliminary observations showed that 5G MMW (millimeter wave) increase skin temperature, alter gene expression, promote cellular proliferation and synthesis of proteins linked with oxidative stress, inflammatory and metabolic processes, could generate ocular damages, affect neuro-muscular dynamics. · Further studies are needed to better and independently explore the health</td>
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ISEMA: Perspectives on Innovation, Science and Innovation
effects of RF-EMF in general and of MMW in particular.
- However, available findings seem sufficient to demonstrate the existence of biomedical effects, to invoke the precautionary principle, to define exposed subjects as potentially vulnerable and to revise existing limits

Summary: Enough evidence on 5G to invoke the precautionary principle; more research needed

<table>
<thead>
<tr>
<th>The link between radiofrequencies emitted from wireless technologies and oxidative stress</th>
<th>Dasdag, S. &amp; Akdag, M. 2016</th>
<th>Journal of Chemical Neuroanatomy</th>
</tr>
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<tbody>
<tr>
<td>Results of the studies reviewed indicated that mobile phones and similar equipment or radars can be thought as a factor which cause oxidative stress.</td>
<td></td>
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<tr>
<td>Some studies claimed that oxidative stress originated from radiofrequencies can be resulted with DNA damage.</td>
<td></td>
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</tr>
<tr>
<td>Study Title</td>
<td>Journal Title</td>
<td>Summary</td>
</tr>
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<td>----------------------------------------------------------------------------</td>
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<tr>
<td>Does prolonged radiofrequency radiation emitted from Wi-Fi devices induce DNA damage in various tissues of rats? Akdag, M. et al. 2016</td>
<td>Journal of Chemical Neuroanatomy</td>
<td>Summary: Mobile phones can cause oxidative stress which some studies say results in DNA damage. Long-term exposure to 2.4 GHz RF radiation (Wi-Fi) does not cause DNA damage of the organs investigated in this study except testes. The results of this study indicated that testes are more sensitive organ to RF radiation. Summary: RF had negative effect on rat testes but no other organs.</td>
</tr>
<tr>
<td>Acute Effects of Radiofrequency Electromagnetic Field Emitted by Mobile Phone on Brain Function Zhang, J., Sumich, A., &amp; Wang, G. 2017</td>
<td>Bioelectromagnetics</td>
<td>Summary: There is little evidence of the harmful nature of the effects of EMF exposure on brain function, and greater understanding is needed of their functional significance.</td>
</tr>
</tbody>
</table>
· To date, the crucial scientific question of the effect of longer-term mobile phone EMF exposure on brain function remains unanswered and essentially unaddressed.
· The potential health effects of mobile phone EMF exposure in children and adolescents have been identified by the World Health Organization (WHO) as a high priority research area, since they have longer lifetime exposure to mobile phones.
· Prior to establishing a clear picture of a cause-effect relationship on mobile phones, it is safer to minimize mobile phone use.

Summary: Little evidence of harm of EMF exposure to date, more research needed especially on exposure in children
<table>
<thead>
<tr>
<th>No Effects of Acute Exposure to Wi-Fi Electromagnetic Fields on Spontaneous EEG Activity and Psychomotor Vigilance in Healthy Human Volunteers</th>
<th><em>Zentai, N. et al.</em> 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type: Experiment</td>
<td></td>
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</table>

*Radiation Research*  
- Wi-Fi exposure under the conditions applied in the study had no measurable effects on neurocognitive function of the human brain.

*Foster and Moulder (2015) published in Radiation Research criticizing this experiment and the experiments it drew from as not having exposure limits that came close to what people are exposed to, thus portraying inaccurate/useless results that made it falsely seem RF from Wi-Fi was harmless.*
<table>
<thead>
<tr>
<th>5G wireless telecommunication s expansion: Public health and environmental implications</th>
<th>Environmental Research</th>
</tr>
</thead>
</table>
| *Russell, C.* 2018 | · Although 5G technology may have many unimagined uses and benefits, it is also increasingly clear that significant negative consequences to human health and ecosystems could occur if it is widely adopted. Current radiofrequency radiation wavelengths we are exposed to appear to act as a toxin to biological systems.  
· A moratorium on the deployment of 5G is warranted, along with development of independent health and environmental advisory boards that include independent scientists who research biological effects and exposure levels of radiofrequency radiation.  
· Sound regulatory policy regarding current and future telecommunication |
| Type: Literature review | |
s initiative will require more careful assessment of risks to human health, environmental health, public safety, privacy, security and social consequences.

- Public health regulations need to be updated to match appropriate independent science with the adoption of biologically based exposure standards prior to further deployment of 4G or 5G technology.

Summary: Evidence that 5G is harmful to health, regulatory policy required

5.0 The Precautionary Principle and Policy Making

Recommendations for greater precautionary measures came up several times in the literature review presented in the table above. The precautionary principle is essentially about expanding the scope of preventive action to situations with a level of uncertain risk (Tosun, 2013). The classic definition of ‘a precautionary approach’ comes from the 1992 Rio Declaration on Environment and Development, which states that "where there are threats of serious or irreversible damage, lack of full scientific
certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation” (United Nations, 1992).

However, the precautionary principle is not limited to the realm of environmental issues: it has been applied to a diverse range of fields, including health protection and emerging technologies (European Commission, 2017). Raffensperger and Tickner explain that “when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically” (1999, p.1). Precautionary measures can be applied in instances where incomplete information, inconclusive evidence, and/or public controversy can make it difficult to achieve consensus over the appropriate response to potentially hazardous substances or activities. In other words, a precautionary approach captures the idea that regulatory intervention may still be legitimate, even if the supporting evidence is incomplete or speculative and the economic costs of regulation are high (European Commission, 2017). The insufficient evidence, conflicting conclusions, as well as the numerous calls for precautionary measures in the reviewed academic literature, demonstrate that radiofrequency emitting technologies (and 5G networks in particular) are an area of risk where the precautionary approach could be applicable.

There are four general approaches to implementing the precautionary principle. The first approach involves non-preclusion measures, in which actions are taken to control risk-generating activities. The second approach involves the implementation of safety measures that establish certain cautious limits. The third approach involves prescribing criteria for activities or products. For example, governments might require using the “best available technology.” The fourth category concerns prohibitory measures, meaning that a presumably risky activity should not be undertaken unless there is no appreciable risk. The
selection of measure or measures is determined by state, national, or international governmental organizations (Tosun, 2013).

However, the precautionary principle is not without criticism. One critique of the principle is that it is “anti-scientific and stifles innovation” (European Commission, 2017, p.6). This argument is most commonly directed at strong interpretations of the principle, which may be understood as ruling out all developments that could have adverse health or environmental consequences. Another issue is that it is difficult to assess what degree of scientific uncertainty warrants application of precaution. The meaning of ‘uncertainty’ is more complex than might be apparent. Science and technology studies have shown that uncertainty can stem from more than a simple lack of data or inadequate models of risk assessment. Uncertainty might also exist in the form of indeterminacy (where not all the factors influencing the causal chains are known), ambiguity (where there are contradictory certainties), and ignorance (where “we don’t know what we don’t know”) (European Commission, 2017, p.5).

Despite these concerns, the precautionary principle can play an important role in addressing these layers of uncertainty. The source of uncertainty surrounding radiofrequency emitting technologies originates from the above-mentioned categories of ambiguity in addition to a lack of data (lack of studies specific to 5G networks). The development of evidence-based policy is challenged when confronted with this uncertainty (Stirling, 2016). Uggla and colleagues write that it is unrealistic to expect regulatory science to provide totally conclusive information to governments on public health or environmental issues, since some element of uncertainty is an unavoidable part of scientific inquiry. Therefore, it can be difficult to determine exactly when and how to act on potential risks (Uggla et al., 2012).
There have however been instances in the past where the precautionary principle was invoked to a detrimental effect. In 1998, British researcher Andrew Wakefield and 11 co-authors published an article in the journal *The Lancet* claiming that 12 children had experienced the onset of severe neurological disorders shortly after receiving the combined measles, mumps, and rubella vaccine. Wakefield’s paper sparked widespread hysteria about the possible connection between the vaccine and autism. Shortly after Wakefield’s article was released, the United States Public Health Service and the American Academy of Pediatrics issued a joint statement declaring that "thimerosal-containing vaccines should be removed as soon as possible" (Bailey, 2015). The statement noted that "there are no data or evidence of any harm" stemming from the minuscule amounts of thimerosal in the vaccines, but the authors nonetheless recommended removing the preservative "because any potential risk is of concern" (Bailey, 2015). The study was ultimately discredited and studies since have disproven links between vaccines and autism, yet distrust and fear of vaccines has persisted since then, resulting in lack of vaccination. This has led to recent outbreaks of diseases that were thought to be eliminated, such as measles (Hussain et al., 2018).

However, the case of the anti-vaccination movement is not comparable to that of radiofrequency radiation and should not be used as a case study to deter applying the precautionary principle to the case of 5G radiofrequency. If anything, the example of the anti-vaccination movement does a disservice to other cases where the precautionary principle ought to apply, and has led to a culture of condescension and dismissal of concern raised over scientific uncertainty. In debates surrounding the

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1 Thimerosal is a vaccine additive, added to some vaccines to prevent germs (like bacteria and fungi) from growing in them. It has not been used in children's vaccines since 2001, although there have been no reported adverse health effects (Centre for Disease Control and Prevention, 2015)
precautionary principle it is often claimed that widespread application of the principle will lead to a large number of regulatory false positives. Regulatory false positives refer to over-regulation of minor risks and regulation of non-existent risks, often due to unwarranted public fears. False negatives refer to instances where early warnings existed, but no preventive actions were taken. An analysis by Hansen and Tickner showed that fear of false positives is misplaced and should not be a rationale for avoiding precautionary actions where warranted, as false positives are few and far between as compared to false negatives (Hansen & Tickner, 2013). To put this in the context of 5G and the precautionary principle, a false positive would occur if after taking precautionary measures prior to implementation, scientific consensus determines that 5G networks are 100% safe to human health. The potential consequence of a false positive in the case of 5G is very different from the case of vaccines, as preventing the implementation of 5G networks would not pose any health risks. In the case of vaccines, the cost of precaution has been disease outbreaks.

Another reason to apply the precautionary principle to the case of 5G is the expressed concern by members of the general public about potential adverse health effects. An element of the precautionary principle implies that there is a duty to address public concern in the face of scientific uncertainty. This notion was introduced at a gathering of scientists, philosophers, lawyers and environmental activists who aimed to define the precautionary principle over the course of a three-day conference in Wisconsin in 1998. The resulting “Wingspread Conference Statement on the Precautionary Principle” states that the application of the precautionary principle should involve “open, informed and democratic processes”, and “must include potentially affected parties” (European Commission, 2017, p.7). In the specific case of 5G, an example of this open, informed and democratic process could involve government funded research on the health risks of 5G. If this research
concluded that 5G was safe, governments could then disseminate the information to assure the public there will be no adverse health impacts prior to widespread installation of 5G networks. Alternatively, the government could prohibit the rollout of 5G if it was determined to be unsafe. From a regulatory standpoint, this paper recommends that governments restrict widespread implementation of 5G until the aforementioned steps have been taken, to respect an open, informed and democratic process.

5.1 Likelihood of a precautionary approach to 5G
There is very little likelihood that any precautionary measures will be taken by Canada, the United States, and the European Union prior to widespread rollout of 5G networks. There is a strong focus on developing policies and strategies for implementing 5G, and it is seen as a key indicator of economic competitiveness. For example, the Canadian government estimates that 5G wireless technologies could be a C$40 billion industry in Canada by 2026 (Reuters, 2019). There is also a strong push from the industry players that will benefit from the development of 5G networks, such as telecommunication network and equipment providers (Jackson, 2019). In October 2018, the President of the United States Donald Trump signed a Presidential Memorandum to develop a national strategy for spectrum policy to advance the United States’ development of 5G. According to Deputy U.S. Chief Technology Officer “America cannot risk lagging behind other countries” and must ensure American leadership in 5G. The economic rationale is that wireless technology currently contributes $475 billion to the economy every year and supports nearly 4.7 million jobs in the United States. The same document states that 5G networks are needed to support improvements in cybersecurity, smart cities, and other digital infrastructure which could improve societal functions and further boost the economy (Kratsios, 2018). Furthermore, the Federal Communications Commission, an organization in the United States, is
committed to reducing regulatory impediments to the rapid deployment of 5G; in particular deploying the small-cell infrastructure needed for 5G (FCC, n.d.).

Europe is also attempting to position itself as the “global lead market for 5G”, while largely ignoring potential health risks (Horwitz, 2018). The Centre on Regulation in Europe published a document titled “Towards the successful deployment of 5G in Europe: What are the necessary policy and regulatory conditions?” In the entire 116-page document, potential health concerns are only addressed in one line on one page (CRRE, 2017, p.76). The remainder of the document focuses on the societal benefits of 5G and policy considerations to facilitate implementation. Working under the 5G Action Plan for a Digital Single Market, the European Commission has asked each member state to specify one city to be 5G-ready by 2020. By 2025, the goal is to ensure every European household has access to at least 100Mbps download speed, and that every urban area, major road, and railway will have uninterrupted 5G coverage. While Brussels would normally be Belgium's top choice, the city’s radiation standards are more restrictive than in neighboring cities, and 50 times more stringent than international standards set by the World Health Organization (Horwitz, 2018).

However, the Belgian Institute of Postal and Telecommunications Services (IBPT) is supporting a study stating that radiation standards in force in Brussels should be adapted to enable 5G deployment in the capital. Without relaxing the Brussels radiation standards, no new radio frequency can be brought into service. The study was produced at the request of the Minister for Telecommunications and the Brussels Minister for the Environment. The telecommunications regulator has not looked into environmental or public health issues (Andersen, 2018). This demonstrates that Belgium is moving away from their previous precautionary approach towards RF and towards the European Union’s push to be a
global competitor in the race to 5G. The most recent development in Belgium is that the Belgian government is aiming to hold 5G spectrum auctions (which essentially sell spectrum space to telecommunications providers) in late 2019 (Tomás, 2018).

Canada has already begun holding spectrum auctions for 5G, with another round scheduled for 2020 (Jackson, 2019). Meanwhile, there has been no acknowledgement of possible health effects of 5G from the Government of Canada. Technology companies such as Telus are in fact urging that 2020 is too late for Canada to wait, and that consumers will be at a disadvantage (Paddon, 2018). Despite resistance from California, other major governments such as Canada, the United States, and the European Union are committed to implementing 5G networks. These commitments are supported by the telecommunications industry who will profit from 5G spectrum contracts.

6.0 Conclusion
A review of scientific publications on the health effects of radiofrequency electromagnetic radiation from cellular networks and Wi-Fi has demonstrated that the results and conclusions presented vary, and that further research is often deemed warranted. There is a discord both within publications by government and international agencies on the health effects of RF-EMR, as well as discord amongst the scientific community. Furthermore, there is also a lack of scientific research on 5G in particular since it is such a new technology. In addition to the uncertainty in the scientific literature, there is also a significant level of public concern. Therefore, this paper argues that there is adequate scientific uncertainty and citizen concern for governments to invoke the precautionary principle prior to widespread implementation of 5G network technology. This would involve government-commissioned scientific research on the health safety of 5G, as well as the effective communication of its safety (if it is determined) to the general public. Although some jurisdictions, such as...
California, are opposing 5G due to health concerns, the overarching rhetoric from Canada, the United States, and the European Union is that 5G networks should be installed as soon as possible. As such, the policies and strategies being developed are focused on rapid implementation. Therefore, it is unlikely that precautionary measures will be taken by these governments.

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