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CHANGE AHEAD:

A CASE FOR INDEPENDENT EXPERT ANALYSIS AND ADVICE IN SUPPORT OF CLIMATE POLICY MAKING IN CANADA

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Background and acknowledgements

This report was initiated by the Ivey Foundation in December 2017 as a way to integrate the work of the authors with the discussions that occurred in a number of workshops over the past two years (see **Appendix 1**). The purpose of this report is to make recommendations on how to achieve the objectives laid out by Canada and the provinces in the **Pan-Canadian Framework on Clean Growth and Climate Change** [4].

The authors thank the Ivey Foundation for their support of, and assistance with, this work. We also appreciate the critical input and advice from the following reviewers: Ralph Torrie, Robert Hoffman, Lorne Johnson, Bruce Lourie, Katherine Wynne-Edwards and the staff at CESAR. DBL is grateful to the Edmonton Community Foundation, without whose support many of the ideas presented here would not have been developed. LB thanks the Trottier Family Foundation for supporting energy and climate change related initiatives that helped in the production of this report.

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About CESAR

CESAR (Canadian Energy Systems Analysis Research) is an initiative started at the University of Calgary in 2013 to understand energy systems in Canada, and develop new modelling, analysis and visualization tools that would support their transformation to sustainability (environmental, economic and social). By building data resources and visualization tools, analyzing past and present energy systems, and modelling energy futures, CESAR researchers work to inform policy and investment decisions guiding the next energy systems transformation.

In 2017, CESAR launched its **Pathways Project**, a novel, technology-rich, exploratory modelling effort to define and characterize credible, compelling pathways for Canada to meet the 2030 and 2050 climate change commitments it made in Paris in 2015. The CESAR website (www.cesarnet.ca) provides free access to information on the Pathways Project, technical details on possible pathways, and other data-rich visualizations on the energy systems of Canada. CESAR's research and communications activities are supported though grants, contracts and philanthropic donations.

About IET

The *Institut de l'énergie Trottier* (IET) was created in 2013 thanks to a generous donation from the Trottier Family Foundation. Its mission is to train a new generation of engineers and scientists with a systemic and trans-disciplinary understanding of energy issues, to support the search for sustainable solutions to help achieve the necessary transition, to disseminate knowledge, and to contribute to discussions of energy issues.

Based at Polytechnique Montréal, the IET team includes professor-researchers from HEC, Polytechnique and Université de Montréal. This diversity of expertise allows IET to assemble work teams that are trans-disciplinary, an aspect that is vital to a systemic understanding of energy issues in the context of combating climate change.

About the authors

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David Layzell is a Professor at the University of Calgary and Director of the Canadian Energy Systems Analysis Research (CESAR) Initiative. In CESAR, he studies the energy systems of Canada and models the costs, benefits and tradeoffs of technologies and policies driving energy systems transformation. Between 2008 and 2012, he was Executive Director of the Institute for Sustainable Energy, Environment and Economy (ISEEE), a cross-faculty, graduate research and training institute at the University of Calgary.

Before going to Calgary, Dr. Layzell was a professor at Queen's University (Kingston) and the Executive Director of BIOCAP Canada, a research foundation focused on biological solutions to climate change. While at Queen's, he founded an scientific instrumentation company called Qubit Systems Inc. and was elected 'Fellow of the Royal Society of Canada' (FRSC) for his research contributions.

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Graduated from Polytechnique Montréal, Louis Beaumier worked for many years in software development. He has been involved in various application domains, ranging from distributed immersive simulation systems to speech recognition interfaces. The experience he has acquired over the years in his various positions – from developer to R&D director – lead him to see that a misunderstood problem, like a poorly presented solution, is often the main source of difficulties in a project. After many years in product management, where he acted on both understanding the need and presenting the solution, came the opportunity to join the Institut de l'énergie Trottier at his alma mater, adding the sense of engagement that was missing from his previous duties.

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Abbreviations and Acronyms Used

C4G	Canadian Climate Change and Clean Growth Institute
CanESS	Canadian Energy Systems Simulator
CCC	Climate Change Committee (UK)
CEIO	Canadian Energy Information Organization
CERI	Canadian Energy Research institute
CESAR	Canadian Energy Systems Analysis Research Initiative
CIMS	Canadian Integrated Modelling System
CGE Models	Computable General Equilibrium Models

E3MC	Energy, Emissions and Economy Model for Canada
ECCC	Environment and Climate Change Canada
EIA	Energy Information Administration (US)
Ecofiscal	Canada's Ecofiscal Commission
ESMIA	Energy Super Modelers and International Analysts
ETSAP	Energy Technology Systems Analysis Program
GDP	Gross Domestic Product
GEEM	General Equilibrium Energy Model
GERAD	Group for Research in Decision Analysis
GHG(s)	Greenhouse Gas(es)
HEC	HEC Montréal (business school)
IEA	International Energy Agency
IET	Institut de l'énergie Trottier
IPCC	Intergovernmental Panel on Climate Change (United Nations)
LEAP	Long-Range Energy Alternative Planning system
LCC	Life Cycle Cost
m	Metres
MAPLE-C	Model for Analysis of Policies Linked to Energy-Canada
Mt CO2e/yr	Megatonnes of Carbon Dioxide (Equivalent) Per Year
NATEM	North American TIMES Energy Model
NEB	National Energy Board
NGO(s)	Non-governmental Organization(s)
NRCan	Natural Resources Canada
NSERC	Natural Sciences and Engineering Research Council of Canada
OPEC	Organization of Petroleum Exporting Countries
R&D	Research and Development
RD&D	Research and Development and Demonstration/ Deployment
SAIC	Science Applications International Corporation
SEI	Stockholm Environmental Institute
SFU	Simon Fraser University
SSHRC	Social Sciences and Humanities Research Council of Canada
TIM	The Infometrica Model
UA	University of Alberta
UC	University of Calgary
UM	Université de Montréal
WAIFM	Wharton Annual and Industry Forecasting Model
WholeSEM	Whole System Energy Modelling Consortia

Executive Summary

In support of the **Pan-Canadian Framework on Clean Growth and Climate Change** (the Framework), this document presents recommendations on how Canada can best engage with external experts to provide independent advice, informed by science and evidence, to First Ministers and decision makers.

Achieving the Framework's combined goals of economic prosperity and low greenhouse gas (GHG) emissions will require transformative – even disruptive – changes in the technologies, infrastructure and behaviours that define the anthropogenic systems impacting GHG emission. Consequently, the traditional climate change policy tools (carbon price, regulations and low-carbon incentives) may not be sufficient to meet the targets. In a world of rapid change, governments need to understand the implications of technology, business model or social innovation and consider the use of policy 'levers' that can encourage, nudge or direct these innovations in ways that will help to address societal goals including, but not limited to, GHG emission reduction.

Canada's research community can provide valuable, independent, expert advice through the development and use of powerful computer models of systems change, supported by access to high-quality data. Work in this area focuses around defining and critically assessing credible, compelling Pathways capable of achieving the targets of the Pan-Canadian Framework.

To realize this potential, the federal, provincial and territorial governments are encouraged to continue their efforts to improve the quality and accessibility of energy systems data in Canada. We also recommend the establishment of an Institute [Working title: **Canadian Climate Change and Clean Growth Institute (C4G Institute)**] with a mandate to build capacity across Canada for systems change modelling and analysis. It would provide governments (federal, provincial, territorial and municipal) with independent science- and evidence-based analysis, policy options and advice regarding how they could meet their Framework commitments related to climate change and clean growth.

The C4G Institute should be arm's length from government and have a long-term (10 year) funding commitment, ideally through an endowment created by contributions from federal and provincial governments. Governance should be via an independent board directed by experts rather than stakeholders. Openness, transparency, trustworthiness and credibility should define its values.

Activities of the **C4G Institute** would include:

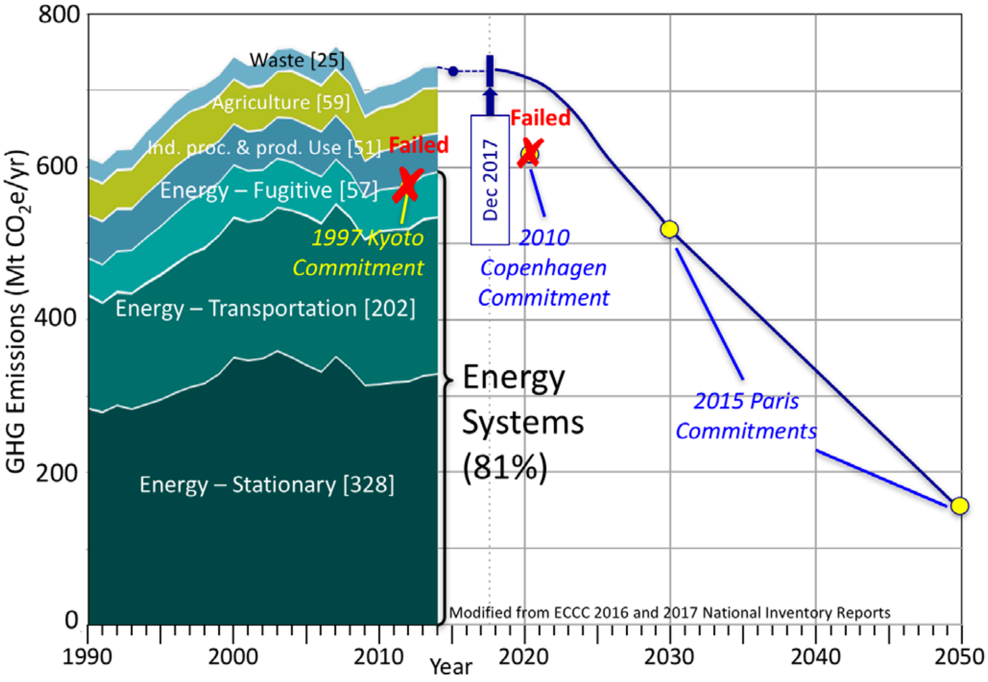
- Building human capacity for modelling and analysis of systems changes, with a particular focus on anthropogenic systems that give rise to Canada's GHG emissions;
- Coordinating and supporting the development, maintenance and use of a range of models capable of predicting or projecting future scenarios for Canada and its regions that include, but are not limited to, energy supply/demand and GHG emissions;
- Convening workshops, conferences, courses and committees, engaging experts, trainees and a wide range of stakeholders to assist in the work of the institute;
- Producing rigorous, evidence-based, policy-relevant insights and advice that is non-partisan and reflective of regional differences and similarities.
- Communicating its research, insights and advice in a full, timely and transparent manner to stakeholders and the public.

By supporting the objectives of the Pan-Canadian Framework, the **C4G Institute** will help all regions of Canada enhance their economic prosperity and competitiveness, while contributing meaningfully to a stable, sustainable climate for future generations.

1. Introduction

In the 2015 **Paris Climate Change Agreement** [1], Canada committed to a 30% reduction in 2005 levels of greenhouse gas (GHG) emissions by 2030, and to work with other nations to hold “the increase in … global average temperature to well below two degrees C above pre-industrial levels.” This latter commitment is widely thought to require an 80% reduction in the 2005 level of emissions by 2050 [2], as illustrated in **Figure 1**.

In 2016, the majority of Canada’s federal, provincial and territorial governments collaborated to develop a **Pan-Canadian Framework on Clean Growth and Climate Change** [4] (the Framework), a document that identifies several initiatives that will be used by the jurisdictions to significantly reduce Canada’s GHG emissions.



Modified from ECCC 2016 and 2017 National Inventory Reports

Figure 1. Canada’s greenhouse gas (GHG) emissions by IPCC sector and their projected decline for Canada to meet its 2015 Paris climate change commitments. The 1997 Kyoto commitment and 2010 Copenhagen commitments are also shown. The Auditor General of Canada has noted [3] that the nation has failed to meet both of these commitments; so the current focus of the government’s GHG aspirations is now the Paris 2030 commitment.

The Framework reflects a new perspective on the climate change challenge by explicitly connecting the goals of economic prosperity and low GHG emissions. The prospects for a low-GHG economy depend on a global transformation in the anthropogenic systems that give rise to these GHGs. Such a transformation will be driven by technological, social and business model innovations, and when successful, will redefine the pathways to economic prosperity and competiveness in the 21st century.

To achieve success, the Framework also commits federal, provincial, and territorial governments to "*engage with external experts to provide informed advice to First Ministers and decision makers; assess the effectiveness of measures, including through the use of modelling; and identify best practices. This will help ensure that actions identified in the Pan-Canadian Framework are open to external, independent review, and are transparent and informed by science and evidence.*"

This report builds on this commitment in the Framework by exploring how best to provide policy makers with external, independent analysis and expert advice regarding integrated strategies for climate change mitigation and economic prosperity. The goal of engaging experts is to inform and support decision-making across regions, governments and sectors in Canada.

"This report builds on ... the [Pan-Canadian] Framework by exploring how best to provide policy makers with external, independent analysis and expert advice regarding integrated strategies for climate change mitigation and economic prosperity."

The insights and recommendations presented here draw on the ideas and discussions that have taken place at numerous meetings (**Appendix 1**) held over the past two years.

All meetings were focused on strategies to enhance the role of data, science and evidence to inform decision making regarding how best to achieve the objectives of the Pan-Canadian Framework by advancing economic prosperity and meeting Canada's 2030 and 2050 climate change commitments. The meetings engaged governments, regulators, utilities, academics, modelling experts, industry and non-governmental organizations (NGOs) across Canada. Experts from the UK and USA also contributed by sharing their experiences in providing strong evidence-based support to policy makers.

In addition, many of the concepts presented here have come out of work that has been done at the Canadian Energy Systems Analysis Research (CESAR) Initiative at the University of Calgary or at the l'Institut de l'énergie Trottier (IET) at Polytechnique Montréal.

2. Key Ingredients for Independent Expert Analysis and Advice

Canada's previous, unsuccessful, climate change commitments (i.e. Kyoto and Copenhagen) required systems change capable of reducing emissions by about 9 Mt CO2e per year between the time of the commitment and the target date. In comparison, to meet Canada's Paris commitment for 2030 will require systems change capable of reducing emissions by about 14 to 15 Mt CO2e per year between 2016 and 2030 (**Figure 1**). Achieving this magnitude of emission reduction will require transformative – even disruptive – changes in the technologies, infrastructure and/or behaviours that define the anthropogenic systems impacting GHG emissions.

"Achieving this magnitude of emission reduction will require transformative – even disruptive – changes in the technologies, infrastructure or behaviours that define the anthropogenic systems impacting GHG emissions."

Twenty years of failed climate change strategies illustrate that the roadmap to success is not well defined, nor is it likely to be identical for all of Canada's diverse regions / economies. It is time to open up the discussion, more fully engage other levels of government, tap into the 'systems change' expertise that exists across Canada, and expand the scope of strategies that can be used to achieve the systems transition needed to meet the objectives of the Pan-Canadian Framework.

The critical characteristics of an independent expert engagement body include that it be:

- Science- and evidence-based;
- Independent from political influence;
- Transparent;

- Credible;
- Policy-relevant;
- Pan-Canadian.

Moreover, three ingredients are needed for independent expert analysis and advice:

A. Independent Experts. Specific expertise in the systems that are critical to both our economy and GHG emissions exists across Canada, both inside and outside of government. Many experts have a strong interest in improving these systems to better meet societal goals through policy, technology, social or business model innovation. Others have skills in building and using complex models capable of projecting and analyzing alternative futures based on a wide range of policies, technologies, infrastructures or human behaviours. Still others have the expertise to draw on the insights gained and formulate options for policy and investment decisions by government and industry players.

An integrated and coordinated effort is needed to bring these experts and knowledge-generating researchers together to focus on municipal, provincial/territorial and national strategies that will make it possible to meet the objectives of the Pan-Canadian Framework and support clean growth and competitiveness.

B. Accessible Models. Computer modelling of complex anthropogenic systems will provide a powerful tool to generate evidence-based insights regarding the challenges and opportunities for systems change that will be capable of realizing Canada’s decarbonization objectives.

Over the past 20+ years, policy makers charged with finding politically acceptable climate change solutions have primarily been responsible for defining the questions being asked of these models, as well as the assumptions that will be used as model inputs. However, experts within government and consultants working under government contract are often required to use specific assumptions when doing their modelling and analytical work, thereby avoiding ‘tough’ or ‘unpopular-but-nonetheless-realistic’ assumptions that should be put on the table if we are to move forward.

If these models were made accessible to independent, arm’s-length researchers, they would be empowered to identify new and different questions and approaches for GHG management. This will independently identify facts for public discussion that governments would otherwise find challenging to raise for political reasons. It would be better for all concerned if these matters were identified outside of government.

So what should these models address? Since the production and use of fuels and electricity account for about 81% of Canada's GHG emissions (**Figure 1**), 'energy systems' are the most important anthropogenic systems in need of transparent models that will predict or project the socio-economic and environmental implications of alternative energy futures.

Models are also needed for anthropogenic systems associated with the production, use and disposal of food and fibre. These parts of the economy contribute another 12% of GHG emissions. Also, agriculture and forestry are able to remove carbon from the atmosphere through the creation of bio-based carbon 'sinks' (essentially negative emissions) and are rarely incorporated in current modelling efforts.

Finally, models need to incorporate the technologies that are used to recover, process and produce non-energy products (e.g. cement, steel, fertilizer, chemicals, etc.), which give rise to the remaining 7% of Canada's emissions, typically referred to as 'process GHG emissions.'

Key ingredients needed "for independent expert analysis and advice:

A. Independent Experts...

B. Accessible Models...

C. High Quality Data..."

Subsequent sections of this report will consider the questions being asked of the models (**Section 3**), the Energy Systems models currently being used in Canada (**Section 4**) and the need for transparency, documentation and open access in the models that are used (**Section 5.4**).

C. High-Quality Data. Reliable, high-quality data is the basis on which evidence is built to support the science and analyses needed to find solutions to the challenges identified in the Pan-Canadian Framework. This is especially important when considering energy systems because all sectors of the economy consume energy, and data is needed regarding the factors (e.g. infrastructure and activities) defining that demand, and the fuels or electricity used to meet that demand.

Unfortunately, Canadian energy data, even if all sources could be combined, is incomplete, varies in quality, lacks consistency, and is not widely or easily accessible, even to the federal government [5]. Over the past few years, the Canadian Energy Research Institute (CERI) has played a central role in working with others (including the Ivey and Trottier Foundations) to highlight the shortcomings in Canadian energy data, and to make recommendations regarding how these could be addressed. This work supports similar efforts inside government notably at Natural Resources Canada and Statistics Canada. They are working with industry groups and other Ministries in the federal and provincial governments to resolve this issue.

Appendix 2 describes some of the challenges and requirements for improved quality, quantity and access to energy data in Canada.

3. Framing the Climate Change Challenge: Defining the Questions

Models – especially models of highly complex, interconnected systems – are built to answer questions, especially 'what if' questions about the future. In the realm of GHG management/ climate change policy, the questions asked of the models can be broadly grouped into two categories that reflect different 'framings' for defining the scope of the climate change challenge.

3.1. Questions Related to the Implications of Climate Change Policies

To date, most climate change policies have focused on the impacts of:

1. Putting a price on GHG emissions (e.g. carbon taxes, cap-and-trade systems);
2. Implementing new regulations (e.g. building or fuel standards, off-coal policies, etc.); or
3. Incentivizing lower GHG solutions (home renovation credits, electric vehicle subsidies, deployment of renewables), to improve efficiency or shift sectors to lower carbon energy sources.

To inform decision makers designing and assessing climate change policies, systems modellers (especially energy systems modellers) have been challenged to answer questions similar to those presented in **Box 1**, below.

Over the past 20-30 years, a number of powerful models have been developed and used to meet this challenge and these models have played a major role in climate change policy over this time. It is worth noting that the questions posed in **Box 1** are primarily focused on finding 'least-cost' or most 'publicly acceptable' strategies to reduce GHG emissions. This is both a strength and a weakness of historical policy formulation to address climate change.

It is a strength because the identification of 'least-cost,' publicly acceptable strategies for achieving policy objectives is an admirable goal. However, it is a weakness because **Box 1** questions do not consider the possibility that significant GHG emission reductions may be achievable in response to alternative drivers for systems change. That constrains the scope of climate change instruments available to policy makers with a real potential to increase the cost.

> *"... Box 1 questions do not consider the possibility that significant GHG emission reductions may be achievable in response to alternative drivers for systems change. That constrains the scope of climate change instruments available to policy makers with a real potential to increase the cost."*

The Pan-Canadian Framework has explicitly connected the goals of economic prosperity and low GHG emissions, making the limitations of the questions posed in **Box 1** even more apparent. The Framework challenges decision makers – and by extension, the systems modelling and analysis community – to explore future scenarios that will

Box 1: Questions Related to the Implications of Climate Change Policies

- What impact would policy tool 'X' have on energy use and GHG emissions in sector 'Y'? Also, what impact would there be on the economy, competitiveness, jobs?
- What policy tool(s) would work best to achieve significant GHG reductions in sector 'Y,' and what would be the associated costs, benefits and tradeoffs?
- What is the projected future demand for fuels and electricity (domestic and international), assuming futures with various combinations of economic or regulatory instruments? What implications would there be on the regional and national economies, jobs or GHG emissions?
- Which sectors and regions are most – and least – capable of systems change at a scale needed to meet GHG objectives and help position Canada to succeed in globalized energy service and technology markets?

simultaneously enhance both the economy and the environment. This challenge has identified a new suite of questions and a new modelling approach to address those questions.

3.2. Questions Related to Understanding and 'Directing' Systems Changes that are Occurring for Reasons other than Climate Change Mitigation

We live in a time of rapid change, driven in large part by rapid technological innovation that can give rise to major changes in society (social innovation) or in the business models that are used to deliver services. Over the past century, the rate of these changes has been rapidly increasing for household technologies (**Figure 2**).

Over the past 25 years, innovations in digital technologies have disrupted major industries including photography, music, video/movie, books, media, telecommunications, retail and banking. Few, if any, of these innovations were introduced to address climate change concerns / GHG emissions, but many have had a major impact (positive or negative) on energy or material demands and therefore on GHG emissions.

Looking forward to the next 30+ years of systems change, it is imperative to understand the implications of new technology, business model or social innovation, and consider the use of policy 'levers'

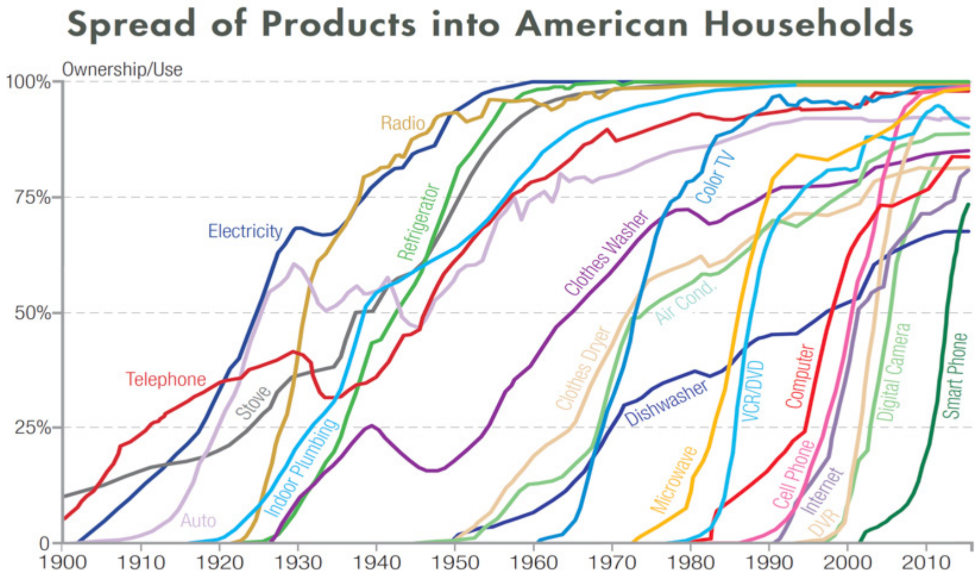


Figure 2. The introduction and spread of household technologies over the past 115 years. Note that the rate of market share penetration has increased over the past few decades. From Cox and Alm, 2016 [6].

that can encourage, 'nudge' or 'direct' these innovations in ways that will address societal goals, including but not limited to GHG management.

Technologies or business model innovations that are too recent to be shown in **Figure 2**, but now promise to disrupt anthropogenic systems include electric and autonomous vehicles, car sharing, LED lighting, the internet of things, e-commerce, solar photovoltaic systems, prosumers (producers and consumers of electricity), microgrids and many others just emerging.

Technology-rich, systems-level modelling is needed to explore the energy and environmental implications of transformative or disruptive innovation while addressing policy-relevant questions such as those identified in **Box 2**.

> *"...it is imperative to understand the implications of new technology, business model or social innovation, and consider the use of policy 'levers' that can encourage, 'nudge' or 'direct' these innovations in ways that will address societal goals, including but not limited to GHG management."*

Box 2: Questions Related to Understanding and 'Directing' Systems Changes that are Occurring for Reasons other than Climate Change Mitigation

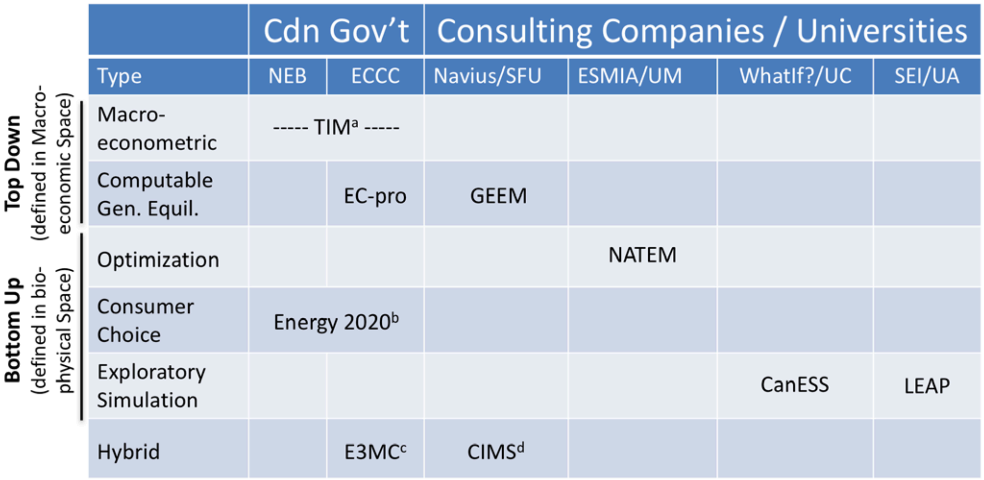
- What are the challenges and unintended consequences of our existing 'anthropogenic systems'? Where do these challenges align with or have the potential to align with the Framework objectives (GHG reductions and economic growth)?
- How could transformative or even disruptive technological, business or social innovation be directed to address societal goals (including, but not limited to GHGs)?
- How rapidly could/should these changes be implemented, and what would be the costs, benefits and tradeoffs?
- Given the global nature of the energy transition and the quest for decarbonization, what Canadian innovations offer the greatest potential to succeed in globally?
- What combination of pathways is most likely to achieve climate change targets at the lowest economic and political cost in each province of Canada?
- Where should RD&D investments be made to address those sectors where GHG management seems to be most challenging?
- What policy or investment instruments would be most appropriate to achieve the desired objectives?

4. An Overview of Energy Systems Models in Canada

Thirty to 40 years ago, some of the first models of Canada's energy systems were built to address concerns and provide policy advice regarding energy cost, supply and security in the wake of the OPEC oil crisis. Over the past 20-30 years, these 'energy security' models have been repurposed, with limited success, to address the climate change challenge and the desire to design and implement a sustainable, low-carbon energy system.

As shown in **Table 1**, the models are typically classified as **Top Down** (i.e. defined in macro-economic space) or **Bottom up** (i.e. defined in bio-physical space), and most, if not all, of them are not fully transparent. Instead, models are either owned by the government or by private consulting companies that use them to deliver policy-relevant insights to governments. **Appendix 3** provides

Table 1. Models of Canadian energy systems currently in use. Abbreviations: **CanESS**, Canadian Energy Systems Simulator; **CIMS**, Canadian Integrated Modelling System; **ECCC**, Environment and Climate Change Canada; **ESMIA**, Energy Super Modelers and International Analysts; **GEEM**, General Equilibrium Energy Model; **LEAP**, Long Range Energy Alternative Planning System; **NEB**, National Energy Board; **NATEM**, North American TIMES Energy Model; **NRCan**, Natural Resources Canada; **SEI**, Stockholm Environmental Institute; **SFU**, Simon Fraser University; **TIM**, The Infometrica Model; **UA**, Univ of Alberta; **UC**, Univ of Calgary; **UM**, Univ of Montreal. This table was adapted from reference [7].



		Cdn Gov't		Consulting Companies / Universities			
	Type	NEB	ECCC	Navius/SFU	ESMIA/UM	WhatIf?/UC	SEI/UA
Top Down (defined in Macro-economic Space)	Macro-econometric	----- TIM[a] -----					
	Computable Gen. Equil.		EC-pro	GEEM			
Bottom Up (defined in bio-physical Space)	Optimization				NATEM		
	Consumer Choice	Energy 2020[b]					
	Exploratory Simulation					CanESS	LEAP
	Hybrid		E3MC[c]	CIMS[d]			

[a] TIM is being redeveloped for ECCC by PolicyModels Corp

[b] Developed and supported for Canada by Systematic Solutions Inc. (USA)

[c] CIMS is a partial equilibrium model consisting of energy supply and demand, consumer choice and macro-economy components;

[d] E3MC (Energy, Emissions and Economy Model for Canada) computationally links Energy 2020 to TIM for work within ECCC.

additional details on the history of these models. While each has its own strengths and weaknesses, it is not the purpose of this report to itemize these.

Suffice it to say that no one model is capable of answering all the questions posed in **Boxes 1 and 2**, above. The 'Top Down' models and the Optimization, Consumer Choice and Hybrid models tend to be used to address the kinds of questions presented in **Box 1**, while the Exploratory Simulation models tend to be better suited to address the questions summarized in **Box 2**. Addressing all questions of interest to decision makers will require both kinds of models, and it is likely that new modelling tools will need to be developed.

5. The Analysis and Modelling of Systems Change

To identify, and ultimately answer, questions such as those posed above, experts drawn from government, industry, academia, and non-governmental organizations, participated in a number of workshops as summarized in **Appendix 1**.

These meetings resulted in a consensus that **an Initiative was needed to support Independent Expert Analysis and Advice regarding policies to achieve the objectives of the Pan-Canadian Framework**. We have compiled here some guiding principles that we perceive as most important for the success of this initiative.

5.1. The Importance of Defining Credible, Compelling Pathways to the Target

We have long known the kind of changes that are needed within our anthropogenic systems to make them more sustainable from a climate change perspective (see **Box 3**). However, credible policies and programs capable of meeting Canada's climate change objectives will require much more specificity and must include integrated sector and region-specific details of '**Low-Carbon Pathway(s)**' to achieve climate targets while addressing economic growth and competitiveness.

In this report, a 'Low-Carbon Pathway' refers to the sequence and the magnitude of specific technology, infrastructure and behavioural

Box 3: Towards Sustainable Anthropogenic Systems

The high-level objectives for systems change, in approximate order of priority, by workshop attendees:

- Energy efficiency;
- Electrification (transport, home heating, industrial processes);
- Decarbonizing electricity supply;
- Low-carbon / alternative fuels;
- Behaviour changes;
- Reduction of fugitive, process and agricultural emissions;
- Carbon capture and storage.

changes that are capable of transitioning our anthropogenic systems to achieve major proportional GHG emission reductions.

Figure 3 shows the structure of energy systems and provides examples of two systems capable of delivering the necessary tools for individual mobility and workplace access. In this case, a Low-Carbon Pathway would define the transformation from one energy system to the other energy system.

There are two different ways, or strategies to define such pathways, one as an *output*, and the other as an *input* into the systems modelling process. In the former strategy (typically used to answer questions such as those defined in **Box 1**, above), model inputs may be policy levers (e.g. regulations, carbon pricing, incentive mechanisms, etc.) targeted to achieve systems change, and the model should be able to generate possible low-carbon pathway(s).

In the latter strategy, which is better aligned to the questions posed in **Box 2** above, low-carbon pathways are defined exogenously, drawing on existing or new technology, social or business model innovations that have the potential to transform anthropogenic systems. The process used to define these pathways includes:

- An understanding of the techno-economic and environmental characteristics of the current system, including its unintended consequences;
- The creation of a detailed mathematically-based computer model of that system;
- A vision for an alternative low-carbon system that also addresses the unintended consequences of the existing system,

with reasonable, evidence-based estimates of its cost, benefits and trade-offs;

- An evidence-based argument for the timing and degree of technology, infrastructure and behavioural changes (i.e. the Pathway) needed to make the transition;
- The conversion of the Pathway narrative, or description, into quantifiable 'levers' that can be applied to the computer model of the current system to simulate its transition to the low-carbon system;
- The assessment of the model results, and an adjustment of the pathway, if needed;
- The identification and assessment of policy instruments that could be used to encourage and direct the deployment of the desired Pathway.

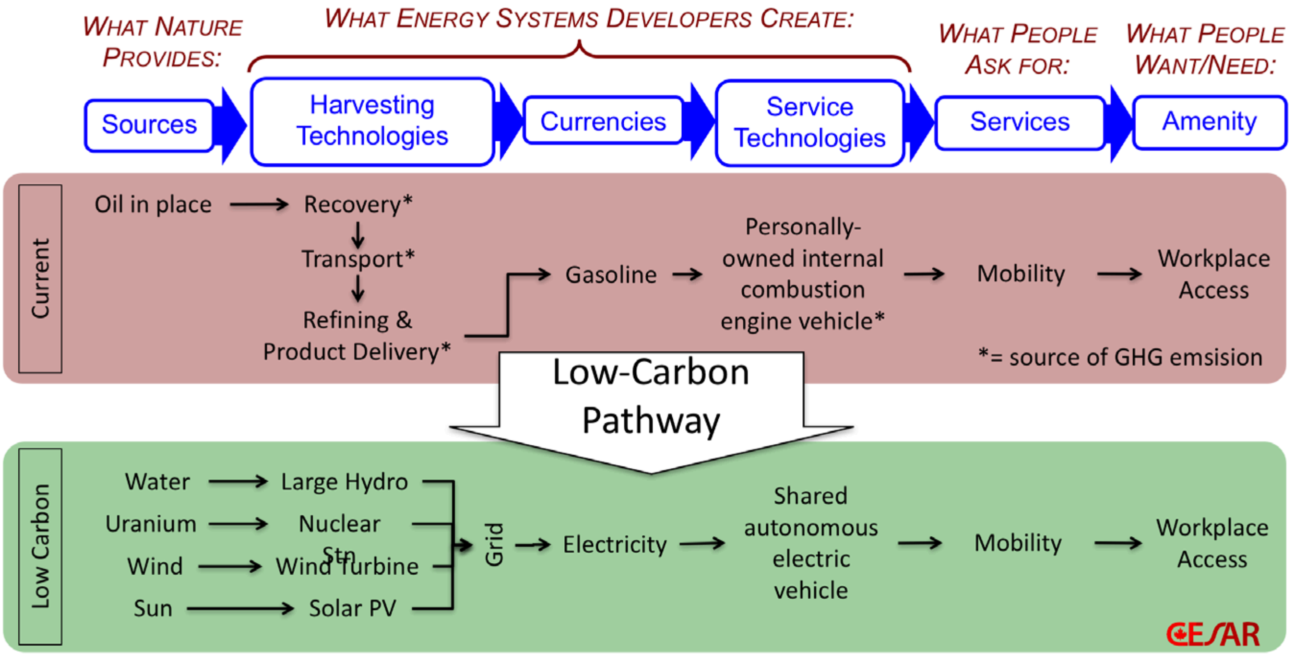


Figure 3. The structure of energy systems with two examples of energy flows capable of meeting a need for personal mobility and workplace access. A Low-Carbon Pathway would define the sequence and timing of the specific technology, infrastructure and behavioural changes capable of transforming the current to the low-carbon energy system. Of course, there may be a number of different pathways capable of achieving the desired transition.

Whether pathways are the modelled output of policy inputs to answer **Box 1** questions, or the input to exploratory models that generate policy options to address **Box 2** questions, pathways are important for the following reasons:

- They define the necessary timing and conditions for implementation of policy instruments;
- They identify potential winners and losers of systems change, allowing decision makers to build in response strategies ahead of time;
- They provide metrics to assess societal progress towards the goal; and
- They can engage the broader public in a positive, collective vision for a better future.

"We cannot predict the future, but we can invent it."

–Dennis Gabor, Nobel Prize Winner (Physics, 1971)

Assessing Low-Carbon Pathways

Regardless of how they were generated, not all pathways are created equal. We provide here three criteria that should be used by innovators, modellers, analysts and policy makers to assess proposed pathways and determine whether they should be supported and/or are worthy of public or private investment:

A. Is the Pathway Credible?

To have any reasonable potential for deployment, pathways need to be credible from a variety of perspectives, including:

- **Technologically.** Do the technologies exist or are they likely to exist by the time they are projected to take market share? What evidence is there to support this projection?
- **Economically.** Is the projected future price of the new technology / energy resource / service reasonable? What evidence is there to support this assessment?
- **Logistically.** Could a new industry/ technology grow and take market share as rapidly as projected? What evidence do we have from past transformations?
- **Socially.** Will society accept this technology, infrastructure or behavioural change at the projected rate? Who will be the 'early adopters' and the 'laggards,' and why?

- **Politically.** Will the projected policy levers needed to affect systems change be acceptable to the public and policy decision makers? Is there any evidence for this?

B. Is the Pathway Compelling?

In a democracy, public support is necessary for systems change. Pathways, therefore, need to be compelling / attractive, or at least the projected future that the pathway is working towards needs to be compelling to stakeholders. For example:

- **Convenience.** Will the envisaged systems change be more convenient?
- **Comfort / pleasure.** Will it enhance the comfort or the pleasure of key stakeholder?
- **Community.** Will it enhance the community in which key stakeholders live or work?
- **Financial return.** Will it save money or even generate financial return to the individual, family, community or company impacted?
- **Social status.** Will it enhance (or at least sustain) the social status of key stakeholders?

C. Does the Pathway take Canada towards its Target?

The reason for defining, characterizing and then working to realize a pathway is to achieve the goals of the Pan-Canadian Framework for economic prosperity while delivering on climate change commitments.

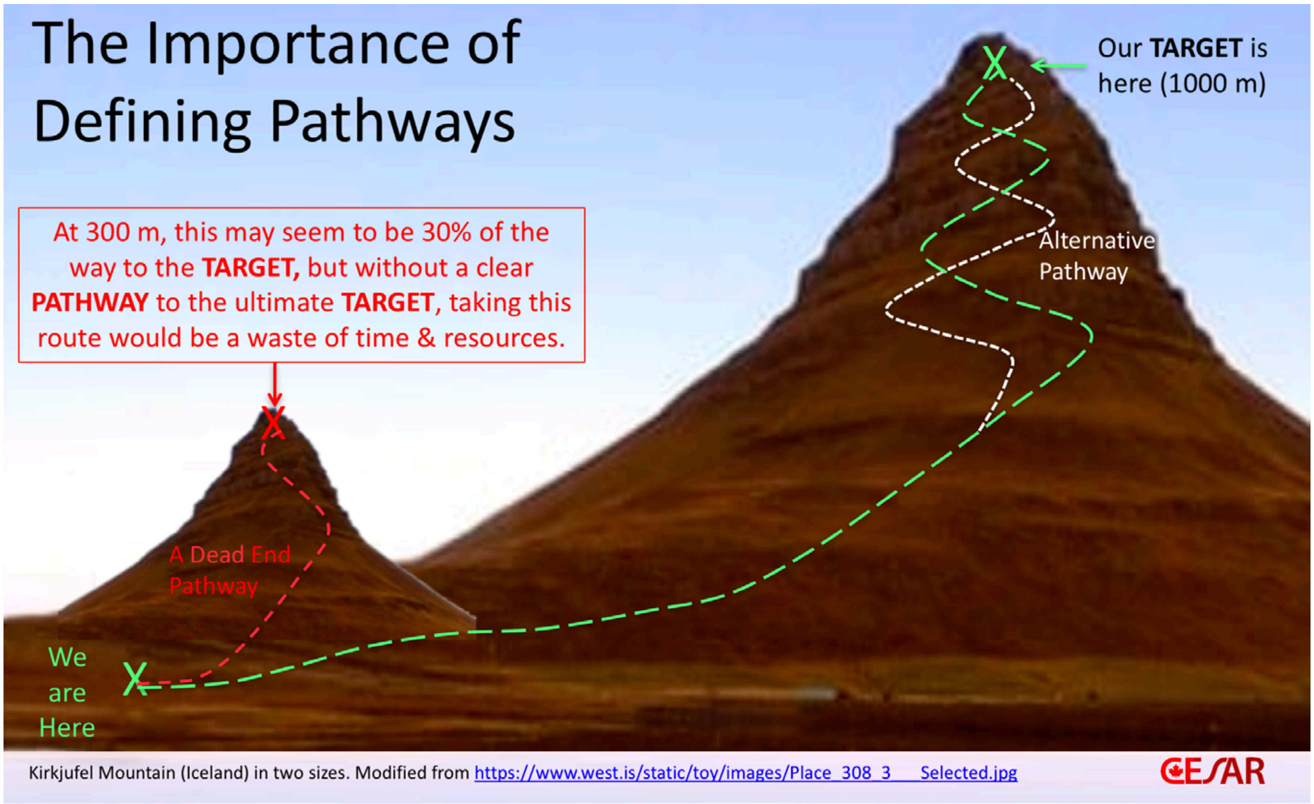
Hence it is critical to ensure that any chosen pathways are actually going to help Canada achieve its climate change targets. One could envisage a credible, compelling pathway that might realize some economic and/or environmental benefits, but which has no potential for contributing to the longer-term objectives of the Pan-Canadian Framework. Policy and financial investments in such a ‘dead-end pathway’ would be a waste of time and resources and might result in a failure to reach the actual target.

Figure 4 illustrates this point by envisaging the target as the need to climb a 1000-metre peak of a large mountain. Climbing a nearby 300-m peak might seem to be 30% of the way to the target, but since there is no ridge to the original target, one would need to return to the valley again, before taking another pathway up the larger mountain.

When promoting new technology, social or business model innovations, proponents often highlight the apparent environmental and economic benefits, but fail to identify where their innovation fits within a low-carbon pathway to the long-term target. For this reason, policy makers need to be cautious about setting criteria for investing in low carbon technologies based solely on achieving an incremental emission reduction. An additional criterion should be how the innovation fits within a broader pathway to sustainability.

> *"...an ideal low-carbon pathway to address the goals of the ... Pan-Canadian Framework will be credible, compelling and take the nation towards its target."*

In summary, an ideal low-carbon pathway to address the goals of the Pan-Canadian Framework will be credible, compelling and take the nation towards its target.



Kirkjufel Mountain (Iceland) in two sizes. Modified from https://www.west.is/static/toy/images/Place_308_3___Selected.jpg

Figure 4. In this illustration, Canada's GHG reduction targets are represented as the need to climb a mountain to a height of 1000 m. Although climbing a smaller hill could allow one to achieve a 300-m elevation, it would not be on a route to the ultimate destination, and therefore likely to be a waste of time and resources.

5.2. Enlarging the Toolbox for 'Systems Change'

Achieving the targets in the Pan-Canadian Framework will require transformative change in anthropogenic systems. However, as noted previously (**Section 3.1**), it is extremely difficult – if not impossible – to achieve such changes solely with conventional GHG management tools. We need to enlarge the toolbox that is used to realize systems change and then ensure that the changes that do occur are aligned with societal objectives, including but not limited to GHG management.

Fortunately, many other tools exist since our anthropogenic systems are far from perfect. Some of our existing systems are dangerous, while others are inefficient, overly expensive, undermine social cohesion or are bad for our health/happiness.

By addressing these shortcomings, innovators and policy makers can initiate urgently needed changes in anthropogenic systems that can be 'nudged' or 'directed' to achieve other societal objectives such as GHG management. Society may not only "get two 'outs' with one pitch," but there may be greater public support and economic viability for these changes than for policy tools implemented solely from the perspective of GHG management.

An example of this opportunity can be seen in the North American system for personal mobility. Light duty vehicle use in Canada has large GHG emissions (82 Mt CO2e/yr in 2015) that have been resistant to policy tools such as vehicle efficiency standards, clean fuel requirements, fuel carbon taxes and major investments in public transit. Between 1990 and 2015, per capita GHG emissions from light duty vehicles have declined by only 9.5% and total emissions have risen by 17% [8]. Clearly, using GHG management tools to drive for systems change in this sector has not achieved the magnitude of emission reductions needed to meet past targets (**Figure 1**) .

> *"We need to enlarge the toolbox that is used to realize systems change and then ensure that the changes that do occur are aligned with societal objectives, including but not limited to GHG management."*

However, Canada's road transportation and personal mobility systems have other problems than GHG emissions, that could each justify substantive systems change. These include vehicle accidents (90+% human caused) [9], congestion and long commuting distances (lost productivity) [10], value for money (personally owned vehicles used only about 4% of the time) [10], parking (expensive and adversely impacts urban design) and air pollution (adverse health impacts) [11].

Many of the world's largest companies recognize the shortcomings of our current personal mobility system and are investing billions of dollars into the development of new technologies like vehicle automation, car sharing and vehicle electrification. How these technologies are deployed will determine which of the above problems are addressed and may either help or hinder Canada's attainment of its GHG commitments [12, 13].

> *"Understanding and modelling transformative ...changes will provide policy makers with new tools for ... 'directing' systems change to meet the economic and environmental targets within the Pan-Canadian Framework."*

Understanding and modelling transformative and disruptive changes will provide policy makers with new tools for 'nudging' or 'directing' systems change to meet the economic and environmental targets within the Pan-Canadian Framework.

5.3. Closing the Capacity Gap

In a world of rapid change, Canada's competitiveness will depend on the ability of our governments and industries to understand the nature of these changes before they occur, and then make the policy and investment decisions that are in the best interest of Canada and Canadians. Systems change modelling and subsequent analyses will be valuable in providing these critical, evidence-based insights for decision makers.

While some modelling expertise in systems change is found at universities and consulting companies across Canada, the national capacity is not very high, and there is little if any interaction among the various research teams. When companies or government departments hire policy analysts, few, if any, have training in the modelling of systems change.

This capacity gap needs to be addressed. Canada should be training more graduate students in systems change in disciplines that range from economics and engineering to business, the natural sciences and the social sciences. These degree programs would be an excellent opportunity for students to work in collaboration with industry and governments to do research on real-world issues.

We also need better models. As discussed previously (**Section 3, 4**), most energy systems models were first built to address energy security concerns and are focused on the questions defined in **Box 1**, while few are able to fully address questions such as those posed in **Box 2**. Moreover, all models need to be updated continuously to take into account additional historical data, or myriad new technologies, infrastructure, behaviours and business models that are shaping our anthropogenic systems.

In Canada, energy resource development is a provincial responsibility, so a strong case can be made that energy systems change modelling needs be carried out for each province, and for each of the territories. While the federal government could take on a more active role in setting standards and incentivizing systems change on the demand side, the diversity, particularities and realities of Canada's various regions make a one-size-fits-all solution unrealistic. Diversified and distributed modelling expertise is even more important as each region has specific challenges and opportunities.

There was general agreement at the workshops (**Appendix 1**) that Canada needs a vibrant community of systems change modellers and analysts, the work of whom is continuously being tested, challenged and improved. To create this community, universities need to know that this is a priority research area, and grant funding must be available to support the research.

"Canada needs a vibrant community of systems change modellers and analysts, the work of whom is continuously being tested, challenged and improved."

This concept of a permanent, independent institution to provide evidence-based advice to federal, provincial and territorial governments is consistent with the recommendations in a recent report from the Mowat Centre at the University of Toronto [14].

We also must ensure that the researchers not only interact with each other, but with relevant government and industry stakeholders and the interested public through:

- Workshops and conferences

- National, regional or sectoral committees to identify R&D priorities and coordinate efforts
- Expert panels to provide advice to government (e.g. as in the UK CCC [19])
- Training courses for graduate students, bureaucrats
- Transparent, publicly accessible websites to provide access to resources and the outputs of research
- Discussion papers, reports and peer-reviewed publications.

A networked community similar to the UK's Whole System Energy Modelling Consortia [15] would be well worth exploring as a possible organization to emulate.

5.4. Mending the Model Gap

As noted previously (**Section 4**), virtually all energy systems models built for Canada are owned by governments or the private sector. And while the government departments may own their models, they often use the private sector to support model development. Moreover, most of the models that were developed at universities (typically using public research funding) have now been moved into consulting companies and are therefore not transparent, or open, to be improved by others.

Also, government departments have neither the mandates nor the resources to support open access to their models by researchers outside of government. Private sector companies must provide access on a fee-for-service basis to clients who may not choose to make results public, thereby limiting access to the results of model runs.

This means that relatively few researchers use any given model, more work is done in competition than in collaboration, and it is very difficult to carry out a critical, balanced assessment of the strengths and weaknesses of any given model. [It is interesting to note that there has been recent media attention around similar problems with the energy systems models in Australia [16])

The lack of open-access, open-source models creates a barrier to new researchers moving into the field of systems change modelling and analysis. It also means that the models that do exist are not as good as they could be.

Systems models are complex, constantly needing improvements to keep up with the latest data as well as new technologies, infrastructure, business models and human behaviours. Up to date models also need to be challenged with new policy alternatives or new ideas for pathways for systems change. Work of this nature can provide an excellent environment for graduate student training at universities, but the students will want to know that they will have full access to the model(s) they learn how to work with when they leave to take a job in government, industry or at another university.

In an ideal world, the Canadian research community would have access to a number of different open-access models capable of exploring systems change. They would be owned, or at least managed, by a non-profit 'Organization' with a mandate to:

- Ensure the models are well documented / transparent, and open to be modified and improved (i.e. open source) by qualified individuals. (Each model could be managed by a committee of highly engaged and competent individuals using a set of principles and policies defined by the Organization.
- Encourage the research, consulting and policy communities to use their model(s) and contribute to enhance their further development under appropriate licensing agreements such as those define by the creative commons [17]. With such a structure, the learnings or enhancements from one research group will be made available to other research teams operating across Canada.

> *"In an ideal world, the Canadian research community would have access to a number of different open-access models capable of exploring systems change."*

- Coordinate and provide support for comparative studies where multiple models (both inside and outside the Organization) are challenged to answer a given question (similar to the Energy Modelling Forum that runs out of Stanford University [18]). Subsequent inter-model comparisons would help to inform policy makers regarding the level of robustness of the model predictions/projections, and to show how underlying model structures and assumptions impact the results.
- Provide partial or full funding to peer-reviewed research to model and analyze questions generated by the researchers themselves, or by stakeholders from government or industry

groups. Funding for such projects would also require an appropriate licensing arrangement [17].

- Build a vibrant community of systems-based modellers and analysts with activities such as those proposed in **Section 5.3**.

The funding for this work would need to come from the Organization, and for university-based researchers it may be possible to partner with NSERC and/or SSHRC to deliver top-quality peer review. However, it will be important for the Organization to work with accredited not-for-profit organizations and also consulting companies to deliver on its mandate.

It is worth noting that there are also advantages to having systems models remain in the private sector, as they then have a clear owner who will take the responsibility to give their model the attention and care it needs. One challenge that the Organization would need to address is what kinds of models are most appropriate to be either acquired, or built.

The UK's Climate Change Committee (CCC) [18] has been a successful energy systems modelling initiative supporting policy making in the UK. The CCC was set up as an act of parliament and has an explicit mandate from government to provide arm's length input and advice. It has focused its research on **Box 1** type of questions, and has policies that include (a) Full transparency over assumptions and results, (b) Disagreements between models must be documented and explained. The CCC also has a close relationship with the government on analytical work, with whom they work to either minimize disagreement regarding some issues or to consciously and transparently disagree on other issues that the researchers see as important. Canada needs something similar.

6. Recommendations

In bringing together the combined goals for economic prosperity and major reductions in GHG emissions, the Pan-Canadian Framework [4] identified the importance of "*engag[ing] with external experts to provide.. independent advice,*" *informed by* "*science and evidence*" *to* "*First Ministers and decision makers.*"

This document reports on the deliberations coming out of a number of workshops (**Appendix 1**) to explore how the Canadian research community could support federal, provincial and territorial governments of Canada by providing independent expert advice to achieve the objectives of the Pan-Canadian Framework.

Recommendations from this work include:

1. Ongoing efforts by government departments to improve the quality, quantity and accessibility of energy systems data should be commended and supported.

2. The Federal government should take the lead in establishing a new, independent, arm's length organization [Working title: **Canadian Climate Change and Clean Growth Institute (C4G Institute)**] having a mandate to build capacity across Canada for systems change modelling and analysis. It would provide governments (federal, provincial, territorial and municipal) with independent science and evidence-based analysis, policy options and advice regarding how they could meet their Framework commitments related to climate change and clean growth.

3. The **C4G Institute** should be arm's length from government and have a long-term (10 year) funding commitment, ideally through an endowment created by contributions from federal and provincial governments. Governance should be via an independent board directed by experts rather than stakeholders. Openness, transparency, trustworthiness and credibility should define its values.

4. Activities of the **C4G Institute** would include:
   - Building human capacity for modelling and analysis of systems changes, with a particular focus on anthropogenic systems that give rise to Canada's GHG emissions;
   - Coordinating and supporting the development, maintenance and use of a range of models capable of predicting or

projecting future scenarios for Canada and its regions that include, but are not limited to, energy supply/demand and GHG emissions;

- Convening workshops, conferences, courses and committees, engaging experts, trainees, and a wide range of stakeholders to assist in the work of the institute;
- Producing rigorous, evidence-based, policy-relevant insights and advice that is non-partisan and reflective of regional differences and similarities;
- Communicating its research, insights and advice in a full, timely and transparent manner to stakeholders and the public.

5. The policy-relevant insights would include:
   - Energy and GHG projections in light of current policies and commitments;
   - Additional policies that might be needed to close the gap between existing policies and our targets, as well as their costs, benefits and trade-offs;
   - The likelihood of proposed and existing policies to meet specific defined outcomes/targets.

By supporting the objectives of the Pan-Canadian Framework, the **C4G Institute** will help all regions of Canada enhance their economic prosperity and competitiveness, and contribute meaningfully to a stable, sustainable climate for future generations.

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APPENDICES

Appendix 1: Summary of Initiatives that Provided Input to this Report

The initiatives listed below have benefited from the financial and logistical support of a number of organisations: Clean Economy Fund, Conference Board of Canada, Edmonton Community Foundation, Energy Future Laboratory, Ivey Foundation, National Energy Board, Natural Resources Canada and Trottier Family Foundation.

April 5, 2016, Montréal

Trottier Energy Futures Project Results Presentation

Host: Institut de l'énergie Trottier

Summary: The Trottier Energy Futures Project is a comprehensive engineering analysis of Canada's future energy systems, with the goal of achieving an 80 per cent reduction in GHGs by 2050, relative to 1990 levels. The study is based on two detailed quantitative models for combustion emissions that have been calibrated using historical data.

Link: http://iet.polymtl.ca/tefp/

May 12, 2016, Ottawa

Informing Canadian Policies on Canadian Greenhouse Gas Emissions Reduction Through Modelling Workshop

Host: Conference Board of Canada

Summary: During this full day, by-invitation workshop presenters and participants met to share insights and better understand how models and scenarios can be used to inform policy analysis. Topics discussed: models, modelling approaches, model results and policy support.

Link: http://www.Ivey.org

August 2016

Interviews with key actors in Climate Change Mitigation

Interviewer: Ken Ogilvie

Summary: Interviews to explore institutional options for creating a National Advisory Committee in Canada similar in mandate and structure to leading greenhouse gas mitigation (and adaptation) bodies in other countries addressing the challenge of climate change.

Emphasis was placed on institutions relevant to the Canadian federal/provincial/territorial governance framework. Examples include the U.K. Committee on Climate Change, the California Air Resources Board, and the Connecticut Governor's Council on Climate Change.

Link: http://www.Ivey.org

December 2016, Calgary

Scenarios for Alberta's Energy Future

Hosts: Canadian Energy Systems Analysis Research (CESAR) Initiative, University of Calgary

Summary: A poster session and reception for about 170 participants, highlighting CESAR's previous year's work to explore technology rich pathways for the energy system's transition;

Link: http://www.cesarnet.ca/publications/posters

January 2017, Montreal & February 2017, Calgary

Canadian Energy Information Organisation Design Charrettes

Hosts: Institut de l'énergie Trottier (IET), Chair in Energy Sector Management at HEC Montreal, Canadian Energy Research Institute (CERI)

Summary: Those two charrettes gathered a broad range of energy stakeholders and government organizations to co-construct a proposition for a new energy data initiative. See Appendix 2 for the main outcomes of those two full day, by invitation sessions.

Link: http://www.ceri.ca/ceio

September 12, 2017, Ottawa

The Pathways, Forecasting and Energy Data Experts Workshop

(Generation Energy)

Hosts: Ivey Foundation and Natural Resources Canada

Summary: This by-invitation workshop included presentations by energy data and modelling experts to illustrate what energy models currently are saying about Canada's energy future, the range and limitations of energy modelling in Canada, the current state of energy data in Canada, and the future challenges both face.

Link: http://www.ivey.org

October 12, 2017, Winnipeg

Just the Facts: Evidence Based Energy Strategies (Generation Energy Forum Concurrent Session)

Hosts: Natural Resources Canada

Summary: A panel and workshop that explored the importance of transparent and accurate data and modelling to support evidence-based decisions about Canada's energy future.

Link: http://www.nrcan.gc.ca/20093

December 2017, Montreal

The role of universities in the strategy for energy transition (Public Consultation Brief)

Author: Institut de l'énergie Trottier (IET)

Summary: Brief submitted to *Transition énergétique Québec*'s public consultation on the elaboration of its first master plan. The brief advocates the role the academic world can play in the energy transition, as independent expert capable of defining and evaluating pathways among other things.

Link: http://iet.polymtl.ca/en/publications/role-universities-strategy-energy-transition/

December 2017, Calgary

Pathways to Sustainability: Canada's Energy Future

Host: Canadian Energy Systems Analysis Research (CESAR) Initiative, University of Calgary

Summary: A poster session and reception for about 160 participants, highlighting CESAR's previous year's work to explore technology rich pathways for the energy system's transition;

Link: http://www.cesarnet.ca/publications/posters

Appendix 2: The need for an Canadian Energy Information Organization

In recent years, there has been an increase in the number of researchers and analysts striving to understand energy systems, predict or project energy futures and either assess or formulate policy options for greenhouse gas (GHG) management

The lack of key historical data for Canada and its provinces, or its poor quality have been frustrating for the researchers and analysts, generating many comparisons with the impressive US Energy Information Administration (EIA, [22]). This has led to calls for a **Canadian Energy Information Organization (CEIO)** that would take a lead role providing high quality data about Canada's energy systems.

The **Canadian Energy Research Institute (CERI)** [23] has taken a lead role in working to understand and characterize the energy data problem in Canada, and to build a national consensus regarding the need for a CEIO. This appendix attempts to summarize the insights generated and the recommendations that have been put forward as a result of a series of the workshops and consultations that were held on this topic.

A2.1 Energy Data Issues

- **Lack of data.** Problems areas identified at the meetings included: Data on newer technologies, cogeneration, renewables, energy transportation infrastructure, energy storage potential
- **Incoherent data.** Challenges include: There are multiple data providers (municipal, provincial and federal departments, industry associations, etc.) that use different definitions for the same terms, different methodologies for collecting and managing data, different time periods for reporting and even different regions / sectors for reporting. For example, there are more than 10 different definitions for sector GHG emissions, the meaning of final consumption vs end use consumption is confusing, as is the difference between 'energy balance' and 'energy accounts' by different data providers
- **Inconsistent data.** We often have "Competing Facts" that result from errors in moving from primary to secondary sources; different sources of data where the organizations

collecting the data use different collection methods. Of 26 indicators assessed from different sources by one major data user, 42% differed in value by more than 10%.

- **Lack of confidence in data.** Key energy data users, many of which participated in the Ivey-coordinated meetings, had limited confidence in the data, presumably as a result of issues mentioned above
- **Data were not timely.** Of data assessed and used in 2016, 61% was from 2016, 9% was 2015, 30% was 2014. Moreover, most data is available only on an annual basis. To generate a complete set of data requires review of up to 20 sources of major and minor publications from various sources.
- **Confidentiality.** There are fundamental confidentiality issues that create challenges with the dissemination of energy data. In many cases the reasons for confidentiality seem arbitrary, and release of the data would not compromise industry competitiveness.

In late 2016 early 2017, CERI teamed up with the Institut de l'énergie Trottier (IET) and the Chair in Energy Sector Management to organize two design charrettes to co-construct a proposition on what mandate a CEIO should have in Canada.

The charrettes, held in Montreal and Calgary, brought together a wide range of energy sector stakeholders representing from the private and public sector as well as the civil society. Those two full day working sessions made it possible to reach a consensus on certain observations on the current state of affairs with respect to energy data, as summarized below.

A2.2 Finding and Observations

- A substantial amount of energy data is already collected, analyzed and communicated by governments, energy regulators, industry associations, and think tanks and other non-governmental organizations, but **there is no single repository or data** centre where these organizations and the public can access free, open-access, quality energy data for a wide range of purposes.
- Federal, provincial and territorial governments recognize **the need to improve** the quality and coherence of energy information. The need for improved energy data is also widely supported by user groups across Canada.

- There is a **broad recognition** that existing data do not adequately meet the need for comprehensive, timely, and coherent information.
- **New data sources are emerging** that challenge traditional ways of collecting and disseminating energy information. They also present new opportunities for data acquisition, analysis and communication.
- **Enhancing public and stakeholder trust** in energy information and related policy decisions is a critical issue. Data transparency, governance, financing model, expert-based non-partisan service, federal and provincial government support – all can serve as source for trust.
- The US Energy Information Administration (EIA) and the International Energy Agency (IEA) could serve as trusted role-models of a **one-stop agency in Canada**.

Based on this common understanding of the energy data situation, proposed elements of what should be the CEIO were drafted.

> **Mission Statement:**
> “*To provide unbiased, transparent, quality data and analysis on energy supply and use, to support informed discussion on public policy with respect to energy and its related impacts (environment, economic, social).*”

A2.3 Main Functions and Services

- Provide a central repository for energy data – This is to avoid information publication and coordinate information collection, but also to simplify information access;
- Facilitate access to traceable, high quality data – It is important that data can be traced back all the way through its source, and that its generation and collection process be documented;
- Identify and fill data gaps – Data gaps can either be identified in-house or in existing data agencies and organizations;
- Advocate and lead collaboration on standards and guidelines for energy data collection – There is a need to standardize many energy indicators (e.g. there are currently more than 10 different ways to calculate GHG emissions);
- Mediation to address data confidentiality issues – Work with energy producers to mitigate competitiveness issues related to data dissemination;

- Do quality control to improve data consistency and coherence;
- Perform historical data analysis and trends identification;
- Explore new and innovative data sources in a rapidly changing world;
- Turn data into information – aggregate indicators which would describe the trends and changes (e.g. energy usage per square metre/individual or similar);
- Contribute quality data/information to regulatory processes and to public debates.

A2.4 Key Design Features

- It must be widely supported by federal, provincial and territorial governments, and closely linked to existing energy data collection organizations to avoid duplication of effort and ensure timely sharing of data. Models for data sharing include the Canadian Institute for Health Information (a separate agency that has the cooperation of all the provinces); Justice Statistics; and the former Greenhouse Gas Voluntary Challenge and Registry;
- It should have a governance structure that ensures political independence and impartiality for its core data service functions;
- It should have diversified stakeholders represented in the advisory board to survive political cycle (similar to Ecofiscal, UK Climate Change Committee, Petrinex), it should be depoliticised;
- It should be viewed as a public good for all Canadians. Hence, it should have significant federal government funding in addition to provincial/territorial funding. Fully federal funding might be easier at initial steps. Provinces can get on board financial gradually. CEIO establishment should not dependent on “the last” province/territory commitment to fund;

A2.5 Issues still to be resolved

- Harmonizing data collection methods to enhance comparability and use in energy policy analysis;
- Mandatory data collection versus voluntary data sharing;

- Balancing data collection, confidentiality, privacy and open access;
- Linking data and policy analysis and modelling (e.g., as is done in Sweden, the U.K., and California);
- Independence of the CEIO while ensuring financial accountability and sustainable funding support over time;
- Accessing new data sources in the emerging ‘prosumer’ world.

Appendix 3: Overview of Canadian Energy Systems Models

This Appendix was prepared by Robert Hoffman, President of WhatIf? Technologies Inc. (Developer and Owner of the CanESS model) using, where possible, the wording that is provided by each of the models in their respective web pages or in publications. It provides a history of the energy systems models in Canada, including some details on the modelling approach used for each.

Presented in alphabetical order, some of the models described here are no longer in use.

A3.1 CanESS (Canadian Energy Systems Simulator)

The Canadian Energy Systems Simulator (CanESS) was developed by whatIf Technologies Inc., an Ottawa-based company founded in 1989 by Robert Hoffman and Bert McInnis, to develop custom simulation models using the whatIf suite of modelling tools. CanESS had its origins in the socio-economic resource modelling program at Statistics Canada, the development of energy end-use data bases for Natural Resources Canada, and the development of custom energy systems models for the National Energy Board, Natural Resources Canada, and Transport Canada.

CanESS became operational in 2004 and has been used by clients for a wide range of scenario analyses including the Trottier Energy Futures Project and the CESAR Pathways Project at the University of Calgary. whatIf? Technologies and the Canadian Energy Systems Analysis Research (CESAR) group at the University of Calgary are partners in the continuing development of CanESS since 2013.

CanESS is an exploratory systems model designed to simulate stock/flow consistent technology-rich trajectories for the energy and materials transformation processes of Canada and the provinces. In CanESS, the marginal share and life table parameters that determine the structure of the Canadian economy are user supplied. In this way the model can be used to explore a wide range of pathways including those that meet targets for greenhouse gas emissions. CanESS does not represent the behaviour of the economic agents who deploy new technologies as this behaviour is often assumed to be, at least in part, cost-minimizing. It is the objective of policy makers to change the behaviour of agents in such a way that societal goals for economic prosperity, ecological robustness and climate change can be met. Taxes and incentives that influence prices and costs are instruments that may be used to effect the behavioural change needed to meet those goals.

The current versions of CanESS focus on the representation of the technologies that are or can be deployed to transform energy from sources (both fossil and renewable) into energy carriers that are used to meet the economies' needs for mechanical energy, heat, and light. The model accounts for supply of energy from domestic production and imports and the disposition of energy for use in Canadian households and for export. CanESS can be extended to address the dynamics of structural change within a framework that is coherent with respect to the supply and disposition of materials as well as energy.

Insofar as technologies are embedded in stocks, the time horizon of the model is distant enough to accommodate at least one and preferably two stock turnovers. Accordingly, CanESS runs in annual time steps over periods of up to 100 years.

A3.2 CIMS (Canadian Integrated Modelling System)

The CIMS model has been developed at the Energy and Materials Research Group of Simon Fraser University over the past three decades under the direction of Dr. Mark Jaccard. CIMS is intended as a tool for energy and emissions policy analysis and supports the policy research program of the Group. Use of CIMS by third parties is commercially supported by Navius Research Inc.

CIMS is described as a hybrid model that incorporates bottom-up elements that are technologically explicit and top-down macro-economic elements. As a policy model, it is intended to be both technologically explicit and behaviourally realistic. It is an integrated, energy–economy equilibrium model that simulates the interaction of energy supply demand and the macro-economic performance of key sectors of the economy, including trade effects.

As a technology vintage model, CIMS simulates the evolution of capital stocks over time through retirements, retrofits, and new purchases, in which consumers and businesses make sequential acquisitions with limited foresight. The model calculates energy costs (and emissions) at each energy service demand node in the economy. In each time period, capital stocks are retired according to an age-dependent function, and demand for new stocks grows or declines depending on the initial exogenous forecast of economic output, and then the subsequent interplay of energy supply and demand and the macro-economic feedbacks between the energy sector and the rest of the economy. A model simulation iterates between energy supply and energy demand until energy price changes fall below a threshold value, and repeats this convergence procedure in each subsequent 5-year period of a complete run, which usually extends 30–35 years. A similar iterative convergence procedure is followed to equilibrate the markets for goods and services.

CIMS simulates the competition of technologies at each energy service node in the economy based on a comparison of their life cycle cost (LCC) mediated by some technology-specific controls, such as a maximum market share limit in the cases where a technology is constrained by physical, technical, or regulatory means from capturing all of a market. Instead of basing its simulation of technology choices only on financial costs and social discount rates, CIMS applies a formula for LCC that allows for divergence from that of conventional bottom-up analysis by including intangible costs that reflect revealed and stated consumer and business preferences with respect to specific technologies and time.

A3.3 Energy 2020

ENERGY 2020 is a system dynamics model developed by George Backus and Jeff Amlin that became operational in 1981. It had its origins in the work of the Dartmouth Systems Dynamics Group as the focus for energy policy was shifting from Washington to the state and company level. It combined the detailed supply model known as Fossil2 and a similarly detailed energy demand model, DEMAND81.

In 1985, ENERGY 2020 became the property of Systematic Solutions Inc., an Ohio-based company. Under the direction of Jeff Amlin, SSI performed forecasting, simulation, and policy analysis in over 30 states and provinces in North America as well as state, provincial, and national governments and energy companies in a dozen countries.

ENERGY 2020 is now an integrated multi-region energy model that provides a detailed simulation of supply and demand sectors for all types of fuels. It is used to analyze and forecast the impacts of a variety of policy considerations on the energy market and resulting emissions. When integrated with a macroeconomic model, ENERGY 2020 is used for estimating the impacts of energy policy on the economy as a whole.

ENERGY 2020 is parameterized with local data for each region, state, or province as well as all the associated energy suppliers it simulates. This allows the model to capture the unique characteristics (physical, institutional and cultural) that affect how people make choices and use energy. Model inputs and assumptions can be customized by the user in order to scale the model to their desired level of analysis.

Both the National Energy Board and Environment and Climate Change Canada have implemented versions of ENERGY 2020 and have resources dedicated to support the preparation of energy outlooks and policy analyses using ENERGY 2020 often in conjunction with The Informetrica Model (TIM) or other economy-wide models.

A3.4 GEEM and EC-Pro

Both GEEM and EC-Pro are computable general equilibrium (CGE) models. GEEM, General Equilibrium Energy Model, has been implemented for Canada by Navius Research. EC-Pro has been implemented by ECCC as one of the suite of models for internal departmental use.

CGE models are used to simulate how all sectors of the economy may evolve under different economic conditions and to provide insight into how energy and climate policies affect a number of variables, such as: economic activity (GDP), energy consumption, greenhouse gas emissions, trade of goods and services between regions, and the competitiveness of different sectors.

In CGE models, each sector is characterized by what it produces (e.g. electricity) and the inputs required in production (i.e., capital, labour, energy and materials). Commodities that are produced can then be sold to other producers (as intermediate inputs), to households (the final consumers of goods produced in the economy), or to other regions and the rest of the world as exports. Commodities can also be imported from other regions or the rest of the world. As the model steps through time, it ensures that markets clear for all commodities and factors by adjusting prices. GEEM explicitly accounts for how policies or different economic conditions alter the structure and growth of the economy. For example, a policy such as a carbon tax may increase the cost of producing energy-intensive goods and services. As a result, energy-intensive sectors such as paper manufacturing may experience a loss of competitiveness. Lower output of paper will reduce the inputs required by that sector, such as electricity and pulp. As a result, capital and labour are reallocated throughout the economy resulting in growth in other sectors or regions.

The fundamental elements of computable general equilibrium models are an input-output table or social accounting matrix for a single year and a set of elasticities that indicate how markets respond to changes in the costs of inputs and how they respond to changes in demand for the goods and services that they produce– all subject to budgetary constraints.

A3.5 LEAP (Long-range Energy Alternatives Planning system) - Canada

LEAP, the Long-range Energy Alternatives Planning System, was developed at the Stockholm Environment Institute as a software tool for energy policy analysis and climate change mitigation assessment. LEAP is a software platform upon which models of different energy systems at regional, national and international scales can be implemented. LEAP supports a wide range of different modelling methodologies such that models can be implemented in countries with limited data resources. Since its launch in the early 1990s, LEAP has become the platform of choice for many countries in meeting obligations under the UN Framework Convention on Climate Change.

A LEAP model for Canada was developed as a Masters degree project [19] under the direction of Dr. Amit Kumar, Professor of Mechanical Engineering at the University of Alberta.

The most recent release (LEAP2018) [20] includes new analytical capabilities for assessing the avoided health (mortality), ecosystem (crop loss) and climate (temperature change) impacts of climate mitigation scenarios, as well as new capabilities for land-use change and forestry modelling.

A3.6 MAPLE-C

MAPLE-C, Model for Analysis of Policies Linked to Energy – Canada, is a Canadian version of the US National Energy Modelling System (NEMS) developed for Natural Resources Canada in the period 2000 to 2010 by Science Applications International Corporation (SAIC), based in Reston, Virginia. SAIC is a premier technology integrator in the technical, engineering, intelligence, and enterprise information technology markets. It was the developer of the NEM for the US Energy Information Agency.

MAPLE-C uses a market-based approach to energy analysis. For each fuel and consuming sector, MAPLE-C balances energy supply and demand, accounting for economic competition among the various energy sources. It reflects the Canadian economy as well as its provincial components.

The projections published in 2006 in Canada's Fourth National Report on Climate Change were based on the use of MAPLE-C.

NRCAN no longer supports MAPLE-C. After the expenditure of several millions on the SAIC contract and in-house staff, the project was abandoned.

A3.7 NATEM (North American TIMES Energy Model)

The North American TIMES Energy Model, NATEM, is an optimization energy systems model for North America implemented by ESMIA Consultants Inc., a Montreal-based company, whose principal is Kathleen Vaillancourt, that had its origins in the work of Group for Research in Decision Analysis (GERAD) at HEC Montréal, Polytechnique Montréal, McGill University and Université du Québec à Montréal .

NATEM makes use of The Integrated MARKAL-EFOM System (TIMES) model generator, developed and distributed by the Energy Technology Systems Analysis Program (ETSAP) of the International Energy Agency (IEA). The MARKAL-TIMES model generators are generic models tailored by the input data to represent the evolution over a period of usually 40 to 50 years of a specific energy system at the national, regional, state or province, or community level. The number of users of the MARKAL family of models has multiplied to 77 institutions in 37 countries.

NATEM is used to find least cost pathways from the energy system as it currently exists to an energy system that is subject to constraints on the emissions of greenhouse gases. It encompasses 23 regions, including 13 Canadian regions, nine American regions, and one Mexican region.

Optimizing models make use of mathematical programming techniques. They have their origins in the activity analysis of Koopmans, Leontief, Dorfman, Samuelson and Solow, and Dantzig. Optimization involves finding the maximum (or minimum) value of a weighted combination of variables whose values are subject to constraints. The paradigmatic optimization problem is to minimize costs in a system consisting of production activities subject to input-output constraints, product supply disposition constraints, and non-negativity constraints on activity levels. There is no reference to time; neither to a starting time; nor to a time path; nor to time subscripts on any of the variables or parameters. Implicit in optimization problems is a single agent who has control of all the activities in the system. The mode of analysis is comparative statics.

For the application of mathematical programming techniques to modelling energy systems, it was necessary to find ways to recognize the concept of time path or trajectory and to bind the system in time, i.e. to recognize that existing stocks of facilities are sunk costs. The concept of pathway or time dynamic is usually incorporated by introducing the concept of 'time periods' and treating each successive time period as an optimization problem, on the grounds that finding optimal solutions in each time period will produce the optimal solution over all time periods. Constraints are used to represent the concept of stocks of productive assets that may survive from time period to time period and to recognize that there may stocks in place at the starting point of the first time period.

The early formulations dating from the energy crises of the 1970s focused on the supply side: minimize the cost of producing an array of energy carriers given world prices for oil. When the issue of climate change emerged in the 1980s, it was recognized that the burden of meeting emissions targets falls upon energy consumers as well as energy producers. It was then necessary to expand the scope of the activity space to include consumers as well as producers of energy carriers. Consumers require end-use services including lighting, space heating and cooling, high temperature process heat, stationary mechanical energy, and mobile mechanical energy and these end-uses may be obtained by the use of energy carriers. For at least some of the end-use services, substitution possibilities exist among energy carriers, and consumers will choose the facilities that transform energy carriers into end-use services that minimize cost. Consumers are also assumed to respond to the prices of energy carriers through an own-price elasticity.

A3.8 TIM (The Informetrica Model)

The Informetrica Model, TIM, is a macro-econometric model for Canada, originally developed as the Candide model at the Economic Council of Canada in the period 1965 to 1972. Candide took its inspiration from Lawrence Klein and the Wharton Annual and Industry Forecasting Model [WAIFM] at the University of Pennsylvania. A macro econometric model is set of stochastic equations with definitional and institutional relationships denoting the behaviour of economic agents. The parameters of the model are based upon correlations among time series variables drawn primarily from the system of national accounts. Input-output accounts provide industrial detail and are integrated within the structure of a macro-econometric model. Informetrica Ltd., an Ottawa-based company founded in 1972, maintained and developed what became the TIM model and provided forecasting services based on the model. When Informetrica ceased operations in 2013, Environment Canada, a user of TIM in conjunction with their version of Energy 2020, acquired the rights to TIM.