EnergyExchange
Powering Conversation
Creating Opportunities

Pollution Probe
CLEAN AIR. CLEAN WATER.

PRIMER ON

ENERGY SYSTEMS IN CANADA

SECOND EDITION, MARCH 2016

POLLUTION PROBE is a non-profit charitable organization that works in partnership with all sectors of society to protect health by promoting clean air and clean water. Its approach is to define environmental problems through research, to promote understanding through education and to press for practical solutions through advocacy. Its objective is to advance public policy that results in positive and tangible environmental change.

Pollution Probe was established in 1969 following a gathering of 240 students and professors at the University of Toronto to discuss a series of disquieting pesticide-related stories that had appeared in the media. Early issues tackled by Pollution Probe included urging the Canadian government to ban DDT for almost all uses, to eliminate the use of phosphates in detergent and to reduce acid rain – causing emissions from base metal smelting operations. During the 1980s, Pollution Probe encouraged curbside recycling in 140 Ontario communities and supported the development of the Blue Box program. Pollution Probe has issued a wide range of books and other publications, including *Profit from Pollution Prevention, The Canadian Green Consumer Guide* (of which more than 225,000 copies were sold across Canada) and *Additive Alert.*

Pollution Probe continues to play an instrumental role in the development and implementation of practical solutions and public policy in Canada. Recent achievements include the development of resources and tools to inform decision-making on alternative modes of transportation and advocating for regulations that limit emissions from energy-intensive industries, sulphur levels in fuel, and emissions from vehicles (including greenhouse gases from passenger cars and light trucks). To address issues related to human and environmental health at the community level, Pollution Probe recently launched its Healthy Communities Campaign, which engages and works with communities to come up with tailor-made local solutions to local problems.

Pollution Probe currently has standing programs on air pollution, water pollution, waste management and human health, as well as special issue programs that focus on transportation, energy systems, human health, climate change and environmental toxins. In the development of innovative and practical solutions, Pollution Probe draws on sound science and technology, mobilizes scientists and other experts, and builds partnerships with industry, government and communities.

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ENERGY EXCHANGE, an operating division of Pollution Probe, is Canada's centre for energy learning. Its mission is to measurably increase energy literacy levels among Canadians through knowledge mobilization techniques developed and implemented in collaboration with a network of experts on energy systems and learning. Taking a technology-neutral approach, it promotes broad-based energy literacy on all forms of energy.

Canada's energy resources can be a source of employment, prosperity and opportunity for the country. The cumulative impacts of low energy literacy are significant: fragmented energy leadership, unrealized economic gains, diminished energy conservation and less-than-optimized energy efficiency. At the same time, we are faced with the challenge of addressing accelerating climate change, which requires a strategic evolution of our energy systems. If energy is the currency of Canada's future, then energy literacy is the key to its realization.

Building energy literacy in Canada means building a common language for the citizens of an energy nation. Canada's citizens are diverse, but their futures are joined by shared responsibilities: to thoughtfully steward Canada's vast and diverse energy resources; to demonstrate global leadership in the responsible development, distribution and productive use of Canada's energy; and to innovate best practices and technology that conserve Canada's energy wealth and the environment for the benefit of future generations.

Energy literacy helps us to deliver on these responsibilities. It is a way for people in Canada to unite in shared recognition of their energy prosperity. Energy Exchange establishes the critical, national capacity to engage multiple audiences (opinion leaders, policy-makers, the media and the general public) to accelerate progress on energy literacy.

Working outside the formal education system, Energy Exchange engages with priority audiences, using a range of innovative learning experiences that leverage interactive tools as well as other more traditional techniques, such as forums, publications and courses. It targets energy influencers and decision-makers, energy literacy providers and the general public post K to 12. Measuring and reporting the impacts to investors is part of Energy Exchange's market-driven approach to fostering leading-edge advances in the field of energy literacy.

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POLLUTION PROBE'S PRIMER SERIES

POLLUTION PROBE'S series of educational primers on environmental topics is intended to inform Canadians about current environmental issues. The primers set out the scientific basis for concern, potential solutions and the policy tools available. Each primer focuses on what is being done and what more can be done by governments, businesses and individuals on the issue in question. The primers are researched and written under the direction of Pollution Probe's Chief Executive Officer and are reviewed before publication by scientists, non-governmental organizations, industry experts, policy-makers and others who have technical expertise in the subject area.

For information on Pollution Probe's primers and other publications, visit our website at **www.pollutionprobe.org/Publications**.

Primer on Toxic Substances (2012) summarizes the current understanding of toxic substances, how they are identified, their potential effects on human health and the environment, and possible sources of exposure.

Primer on Automobile Fuel Efficiency and Emissions (2009) explains energy use in the modern automobile, the environmental impacts and the technologies to minimize both.

The Acid Rain Primer (2006) contains an in-depth discussion of the science of acid rain and the policy and regulatory history of this fascinating environmental and health issue.

A Guide to Climate Change for Small- to Medium-sized Enterprises (2006) explains how businesses can take action to reduce their greenhouse gases and lower their energy costs, as well as managing the risks and opportunities associated with climate change.

Primer on Volatile Organic Compounds (2005) focuses on major VOC sources that are harmful to human health, explains how they are controlled and highlights government and industry action to reduce the level of VOCs in the atmosphere.

Child Health and the Environment – A Primer (2005) provides an introduction to what constitutes a healthy environment for children, explains why children are more vulnerable than adults to environmental impacts and examines health effects and exposures of concern for children.

Primer on Bioproducts (2004) provides an overview of the ways bioproducts are made and highlights some of the issues that bioproduct technologies raise for Canadians.

Primer on Climate Change and Human Health (2004) describes the ways in which a more variable climate may impact Canadians' health, reviews actions taken by governments and industries, and examines what individuals can do to reduce greenhouse gas emissions.

The Source Water Protection Primer (2004) explains the water cycle, identifies threats to water sources, focuses on watersheds as the ideal management unit and identifies steps to consider when developing local source water protection plans.

Emissions Trading Primer (2003) explains the concepts behind emissions trading, describes the ways in which it works and provides examples and case studies.

Primer on the Technologies of Renewable Energy (2003) explains the concept of renewable energy and the rationale for shifting energy generation towards cleaner and less greenhouse gas intensive sources.

Mercury in the Environment: A Primer (2003) provides an overview of the mercury cycle, releases to the environment, transportation and deposition around the world and the uptake and accumulation of mercury in the food chain.

The Drinking Water Primer (2002) examines the two sources of drinking water – groundwater and surface water – and the extent to which Canadians depend on them.

The Smog Primer (2002) explains what smog and the pollutants that create it are and highlights the major source of these pollutants: the burning of fossil fuels for transportation and energy.

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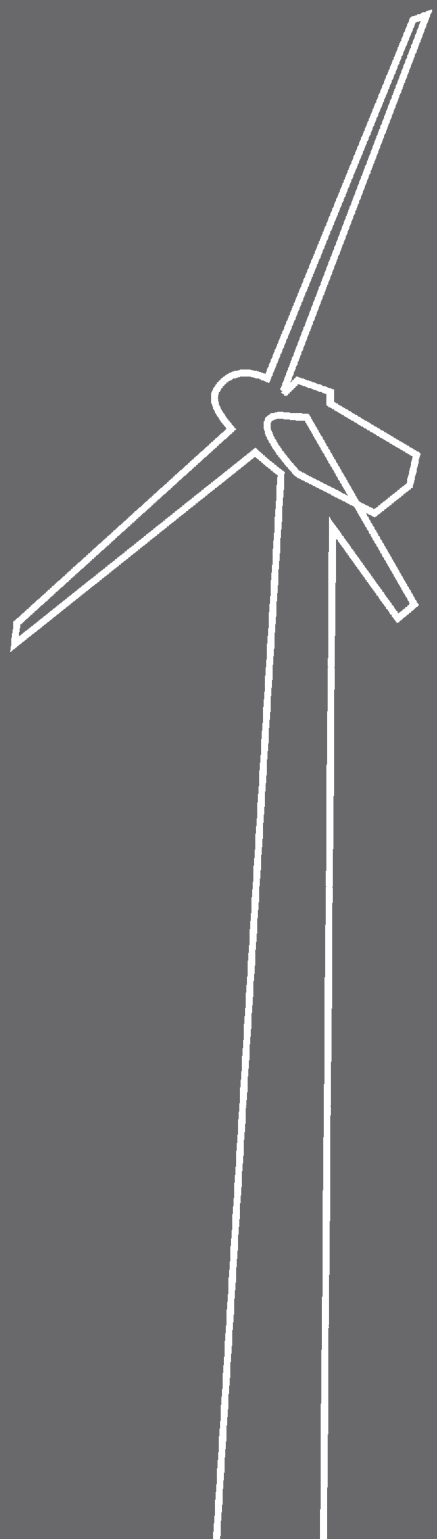


FOREWORD

POLLUTION PROBE and ENERGY EXCHANGE are pleased to introduce the second edition of the *Primer on Energy Systems in Canada*. Over the past decade, energy has been a dominant theme in the national discourse. Issues such as energy price fluctuations, infrastructure projects and environmental impacts, notably climate change, have thrust energy to the forefront of policy debate in Canada. At times, this debate has divided stakeholders and the general public along economic, environmental and social lines. As a result, a degree of national discord on energy policy has emerged. Different groups and governments across the country have different ideas about how Canada should develop its energy resources, in what energy technologies we should invest and what kind of energy future we wish to create for ourselves.

Unfortunately, such discussion often occurs in narrow contexts, in which the relative merits of choices presented as mutually exclusive options define the debate. In reality, the production and use of energy are both elements of interconnected systems of technology and distribution infrastructure that respond to our demand for the services made possible by the supply of energy. To recognize the most effective options for addressing the impacts of energy development and use in Canada, as well as the potential benefits, we need to consider the implications of change from a systems perspective.

That is the reason for this primer: to orient the reader to energy systems in Canada and promote a more sophisticated level of energy awareness and literacy among the public, industry stakeholders and government officials. Canada is endowed with a diverse wealth of energy resources and of expertise in the technologies that put energy to work for us. Understanding how these pieces fit together is the first step towards a productive dialogue about how we can build sustainable energy systems – now and in the future.

We hope that you enjoy this edition of our *Primer on Energy Systems in Canada* and that you discuss it with your community!

Steven Pacifico

Director
ENERGY EXCHANGE

March 2016

INTRODUCTION

Why You Should Read This Primer

The production, distribution and use of energy pervade every aspect of our society. Energy is needed to move, to harvest, to build, to mine, to manufacture, to heat, to chill, to illuminate. Everything that makes up our modern society is facilitated, in some way, by the provision of energy.

And our demand for energy is growing. As population increases and economies develop, demand for energy sources, commodities and services expands. Markets for energy products have evolved in response to this demand. We have tapped energy sources ranging from wind to coal to water to natural gas, to serve these markets. But while the markets are global, the supplies are often locally concentrated.

Around these concentrations of supply and around their distribution, industries have developed, attracting and generating wealth. Around these industrial activities, communities have developed. And within the communities, human culture continues to evolve.

Canada possesses a wide array of energy sources, and their development is part of the unfolding history of the nation. Whether it is oil in Alberta, natural gas deposits off Nova Scotia's coast, hydro dams in Quebec or nuclear power in Ontario, the choices that we have made in developing and managing our energy sources have become part of each region's culture and, therefore, its politics.

What is an energy system?

Though energy production has developed in distinctly different ways from province to province, reliance on energy is remarkably consistent across the country. We all travel to work, to shop and to meet with friends and family. We all light and heat our homes. We all have electric appliances. Because of this, we all use transportation fuels and electricity, and most of us rely on natural gas in one form or another. There is, therefore, an extensive network of pipelines and wires across the country, which connects us to the sources of the energy that we demand. The interconnections between energy sources, distribution networks and people constitute Canada's energy systems.

These energy systems have produced significant economic benefits for Canada, but they also contribute to significant environmental problems, such as air pollution, water pollution and climate change.

Governments, industry and civil society groups are promoting wide-ranging solutions to reconcile the economic and environmental aspects of energy production, distribution and use. Economic incentives to produce renewable energies, regulations to increase energy efficiency and the pricing of carbon dioxide emissions to reduce the combustion of fossil fuels are just a few examples of these initiatives. However, these measures are generally not applied consistently across Canada. They are implemented in some regions but not in others, and the objectives are often narrow, focusing on specific opportunities or impacts associated with a given energy source or technology. Though well-intentioned (and sometimes effective in bringing about real change at a regional level), such measures constitute a fragmented approach to change – fragmentation that reflects the lack of national integration in our energy systems.

Why are Canada's energy systems unique?

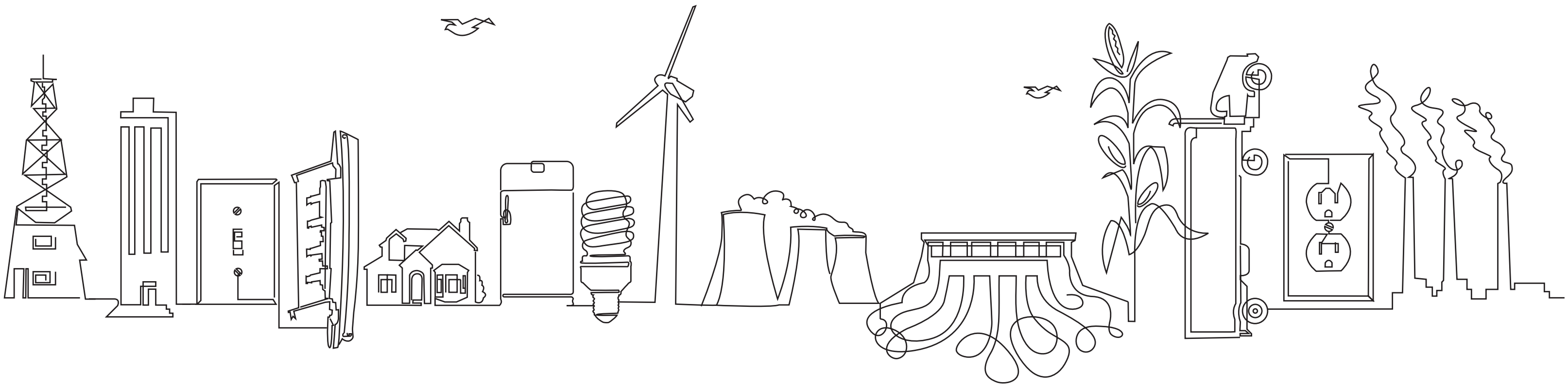
Canada is rare among nations in that it has an unusually wide range of energy options. Our large land mass and coastlines encompass globally significant levels of hydropower, oil, coal, natural gas, biomass, wind, uranium for nuclear power, ground heat, and the list goes on. We also have the world-leading expertise and innovative capacities in technology development necessary to make more productive use of our energy resources. Unlike many other countries, we have a multitude of pathways toward an energy future that is clean, safe and affordable.

Where do we stand now?

There is an urgent need to address the energy issue. Much of Canada's energy infrastructure is aging and in need of upgrades and replacement. Moreover, global patterns of energy use and demand are changing. The energy systems that we choose to build in the coming decade will determine, in part, the future of this country, its people, its prosperity, its international relevance and its culture.

To identify the opportunities for improving the way that we produce, distribute and use energy, we need to understand how all of the elements of Canada's energy systems currently tie together. Equipped with a whole-systems perspective, we can better consider the implications of change.

That is what this primer is all about. It provides a baseline description of the elements of Canada's energy systems and demonstrates how these systems have evolved to respond to the demand for energy arising from the choices that individuals – all of us – make every day. We are part of those energy systems, and changing the systems means changing ourselves.



PRIMER OVERVIEW

The primer begins with us, the end-users. What are we doing that requires energy? How does this give rise to the broader patterns of energy use in Canada? Then, step by step and chapter by chapter, we will work our way through the systems of energy supply that respond to our demand.

Chapter One describes the concept of energy systems and provides insight into why Canada's energy systems are unique. In this context, it explains why looking at energy from a systems perspective is crucial to understanding the energy choices before us.

Chapter Two explores the relationship between the amenities that we demand and the energy systems that provide those amenities. It shows how technology and infrastructure are critical to energy systems – the former, by upgrading energy sources to commodities and services, and the latter, by delivering to us the amenities that we demand. The chapter uses examples of energy pathways to illustrate how the choices that we make are ultimately the drivers of Canada's energy systems. The chapter also provides an overview of the impact that efficiency and conservation can have in minimizing our draw on energy sources, thereby reducing the environmental impacts of energy use without sacrificing access to amenities.

Chapter Three describes the major energy services in Canada – heating and cooling, lighting and appliances, and transportation – and reviews the primary technologies used to provide them. It demonstrates how, within each of these energy services, some technologies are more efficient or effective than others. The chapter showcases how the individual choices we make about those technologies affect our demand for energy commodities and, therefore, our impact on energy sources. To put this analysis in a broader economic perspective, the chapter also looks briefly at energy use in the industrial sector.

Chapter Four outlines the major energy commodities in use in Canada – fossil fuels, biofuels and electricity – and discusses the energy sources from which they are derived, the technologies used to derive them and the infrastructure used to deliver them to us, the end-users.

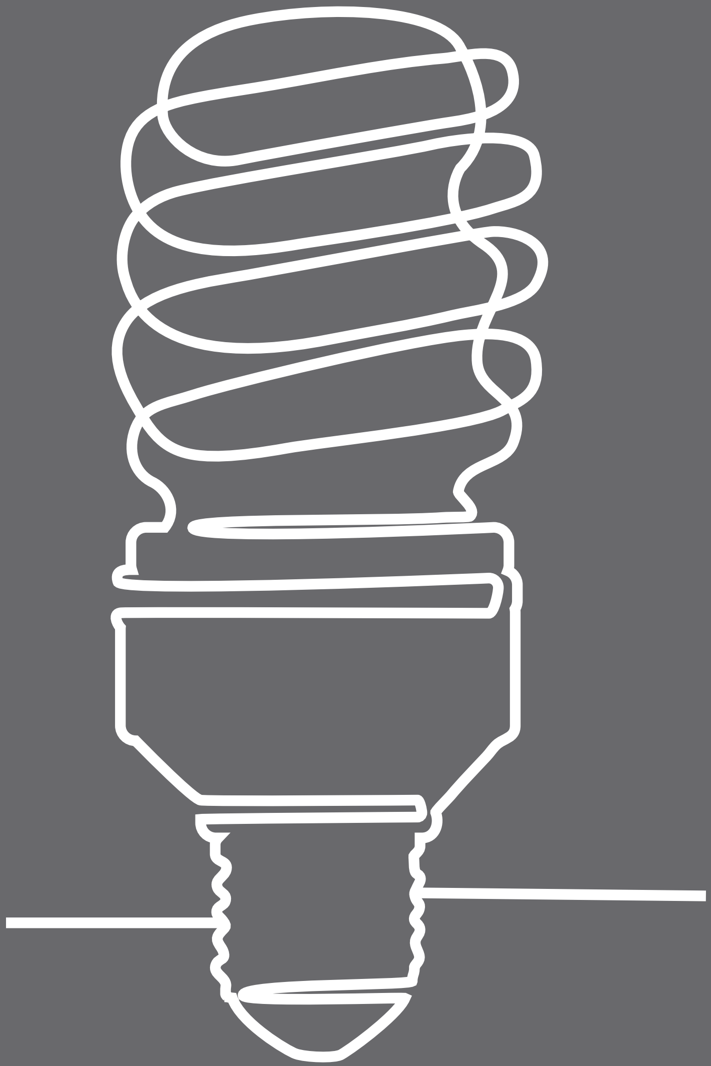
Chapter Five describes the complex array of factors that influence the pricing of energy commodities and services in Canada. Discussions on energy pricing too often take a one-dimensional approach that does a disservice to the energy system as a whole. This chapter takes a comprehensive approach to placing the financial dimensions of energy in their proper context.

Chapter Six provides an overview of the energy systems of each province and territory in Canada. Focusing on energy commodity extraction, trade and use, as well as modes of electricity generation, this chapter is intended to offer readers insights into how and why energy systems differ across the country.

Chapter Seven looks ahead to how the broad range of energy options available in Canada may shape the country's response to a rapidly changing global energy culture. The chapter identifies growing demand, environmental concerns and aging infrastructure as key factors making change both inevitable and urgent. It describes who is in charge of the various components of energy systems in Canada and looks at how the lack of national integration in energy policy and jurisdiction may affect Canada's ability to meet its future energy challenges effectively and efficiently. The primer closes with a summary of what the systems approach can offer us as a means of meeting these challenges and looks at some promising initiatives to put this approach into practice.

DRIVERS & IMPACTS: ENVIRONMENT, ECONOMY AND SOCIETY

Throughout this primer, DRIVERS & IMPACTS boxes describe the drivers influencing Canada's energy systems, as well as the impacts of those energy systems on the environment, the economy and society. These drivers and impacts are complex − sometimes they reinforce one another; sometimes they oppose each other. They are constantly changing, just as our natural environment, global economy and social structures are changing. DRIVERS & IMPACTS provide an introduction to some of the more complex subjects beyond the scope of this primer



CHAPTER ONE

Energy Systems How They Work

This chapter describes the concept of energy systems and provides insight into why Canada's energy systems are unique. It explains why looking at energy from a systems perspective is crucial to understanding the energy choices before us.

What is Energy?

Energy is something real that we all experience daily, but it can be defined only conceptually. Energy is not something that we can see or touch. Rather, energy describes the capacity of any person, thing, particle or system to do physical work, such as moving, lifting, lighting, heating, stopping, pushing or pulling.

What is not Energy?

Oil is not in itself energy. It is a potential source of energy. The heat generated when oil is burned can be harnessed to do work. Similarly, natural gas is not energy. Neither is wood nor water nor wind. But different technologies allow us to exploit the potential of all of these sources of energy to do work.

In the same way, we do not consume energy. We consume the energy source. For example, the process of combustion converts oil into water and carbon dioxide, while producing heat that can be used to warm a building or to power an engine. The conversion process depletes the energy source – the oil – and we use the energy produced by the process.

Technologies and infrastructure transform energy sources and commodities into what we really want: access, convenience, comfort, enjoyment and other amenities.

EXPLAINING ENERGY SYSTEMS

Energy systems can be thought of as the interconnected elements of technology and infrastructure that transform natural sources of energy into useful services that deliver access, convenience, comfort and other amenities.

Flicking a switch — *Flicking a switch is easy, but it activates a complex energy system in place to provide you with electricity on demand.*

Reading at night is an energy amenity
You could read at night by candlelight, but it is safer and more convenient to use electric lighting, which taps into an energy system. As a result, reading by electric light is considered an energy amenity.

When you flick the switch on your wall, it completes a circuit that allows electricity to flow through the light bulb, providing light.

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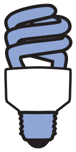

Lighting is an energy service
There are different types of light bulbs, but all of them convert electrical energy into light and heat.

Some light bulbs, such as compact fluorescents and LEDs, produce more light using less electricity.

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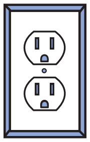

Electricity is an energy commodity
Electricity is a useful form of energy that powers light bulbs and most other appliances.

Electricity can be generated using a variety of technologies. In Canada, most of our electricity is generated from hydro-power.

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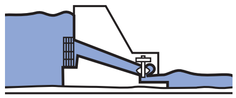
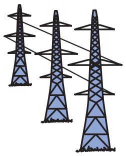


Water reservoirs are an energy source
When water is stored in a reservoir, its potential energy can be released, pushing down on turbine blades and making them spin.

When the spinning turbines are connected to an electric generator containing magnets and coiled wire, electricity is generated.

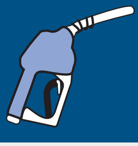
SUPPLY

Electricity needs to be used up as soon as it is generated, so transmission and distribution lines are built to connect hydropower plants, often in remote locations, to towns and businesses that use electricity.



Thousands of kilometres of transmission and distribution lines criss-cross Canada's landscape, bringing electricity that is generated far away to cities, farms and industrial facilities, where the energy is put to work.

When we use an energy service by flicking a light switch or squeezing a gas pump, we activate an energy system.



Squeezing the pump — *Like flicking a switch, squeezing the pump seems simple, but it too activates a complex energy system, in this case providing fuel based on your demand.*

Access to shopping is an energy amenity
Even when you can walk to a grocery store, you may choose to take your car so that you can carry everything home. Your car taps into an energy system to provide you with access and convenience, both of which are energy amenities.

When you squeeze the pump to fuel your car, gasoline is pumped up from large tanks under the service station into your fuel tank.

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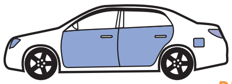

Transportation is an energy service
Automobiles use engines that convert some of the heat energy released in the combustion of gasoline into mechanical motion to drive the wheels.

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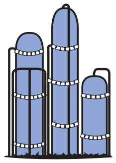

Gasoline is an energy commodity
The gasoline that fuels our cars is a petroleum product, made from crude oil in large oil refineries.

Gasoline is the fuel used in virtually all cars in Canada.

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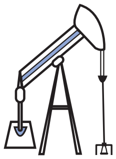
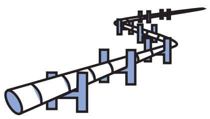


Crude oil (petroleum) is an energy source
Conventional crude oil is produced by drilling and pumping the liquid from the ground.

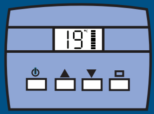
Oil is also produced from non-conventional sources such as oil sands and offshore drilling.

← ***SUPPLY***

Fuel is delivered from the refineries and storage terminals to gas stations by a pipeline and railway distribution system and by truck.



Pipelines bring crude oil and petroleum products (e.g., gasoline) from producing areas to refineries and storage terminals.



Adjusting the thermostat — *Another seemingly simple, everyday action, adjusting the thermostat also activates a complex energy system designed to provide natural gas for heating on demand.*

Having a comfortable home is an energy amenity

In Canada, especially during winter, we heat our homes to keep indoor temperatures at healthy and comfortable levels.

When you adjust the thermostat, it signals the furnace to turn on and heat the home to the desired temperature.

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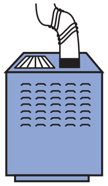

Heating is an energy service

All heating technologies convert an energy commodity into hot air or hot water that can be used for space heating.

Many of us rely on furnaces that burn natural gas to provide heat for our homes.

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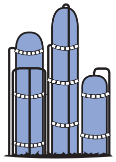

Natural gas is an energy commodity

Natural gas is a widely used fuel in much of Canada.

It is commonly used for heating homes and buildings, but it is also used in various industrial processes and as the raw material for many plastics, pharmaceuticals, fertilizers and other products.

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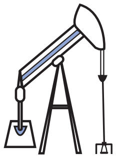


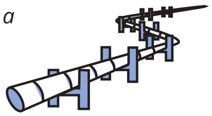
Raw natural gas is an energy source

Raw natural gas is found underground and beneath the sea floor in various parts of Canada.

The raw natural gas is under pressure, and when a drill breaks through the layer of rock above it, the gas naturally rises up the well to the surface, where it can be cleaned and processed for use.

SUPPLY

Natural gas is delivered to homes and buildings in a community by a pressurized pipeline distribution system.



Pipelines bring the raw natural gas from producing areas to natural gas processing plants.

Taking an Energy Systems Approach

The electric lighting, transportation and natural gas heating examples shown on pages 20 to 21 represent energy systems that most Canadians draw on in their everyday lives. These examples provide a "line of sight" between the actions we take to satisfy our demand for energy amenities and the energy systems that are activated to supply that demand. We can look at our demand for all energy amenities in this way. Viewing energy use in this manner is called taking an *energy systems approach*.

A system describes a set of interconnected pieces. Systems thinking, or taking a systems approach, means looking at the entire set of interconnected pieces that make up a system as a whole. Just like any system, energy systems consist of interconnected parts that transform raw energy sources into more useful energy commodities that provide us with energy services. Those energy services provide the amenities that we really want: access, convenience, comfort and enjoyment.

Energy Flow in Canada

You might recall from high school physics class a lesson on the laws of thermodynamics. These laws tell us that energy cannot be created or destroyed; it can only be changed from one form to another. For example, when fuel is burned, the chemical energy in the fuel is converted into heat.

If some of that heat is used to power an engine, we say that it performed "work;" in other words, it performed a useful service. The portion of the heat that did not contribute to the work is wasted; this wasted energy is referred to as conversion losses.

Figure 1-1 is a representation of the flow of energy through Canada's energy systems, from raw energy sources at the bottom through to useful energy services at the top. The figure reveals some key characteristics of how we produce and use energy – and how efficiently we do it.

Energy Flow in Canada

Overall Energy System Efficiency
Roughly two-thirds of the energy sources and commodities we use to provide energy services are wasted, mostly as heat – this is shown on Figure 1-1 as conversion losses. The remaining third of the energy sources and commodities we use provide useful energy services.

Energy Services
Energy services include heating, cooling and powering appliances in homes and buildings, powering industrial processes and enabling motive power for transportation. These services are grouped in the figure according to the main energy end-use sectors of the economy – homes and buildings, industry and transportation. Each of these sectors draws on diverse energy sources and commodities, except for transportation, which relies almost exclusively on crude oil and petroleum products.

The non-energy ("NE") products shown on the right in Figure 1-1 are products most of us use every day, such as plastics, that are made from energy sources and commodities but are not used to deliver energy services.

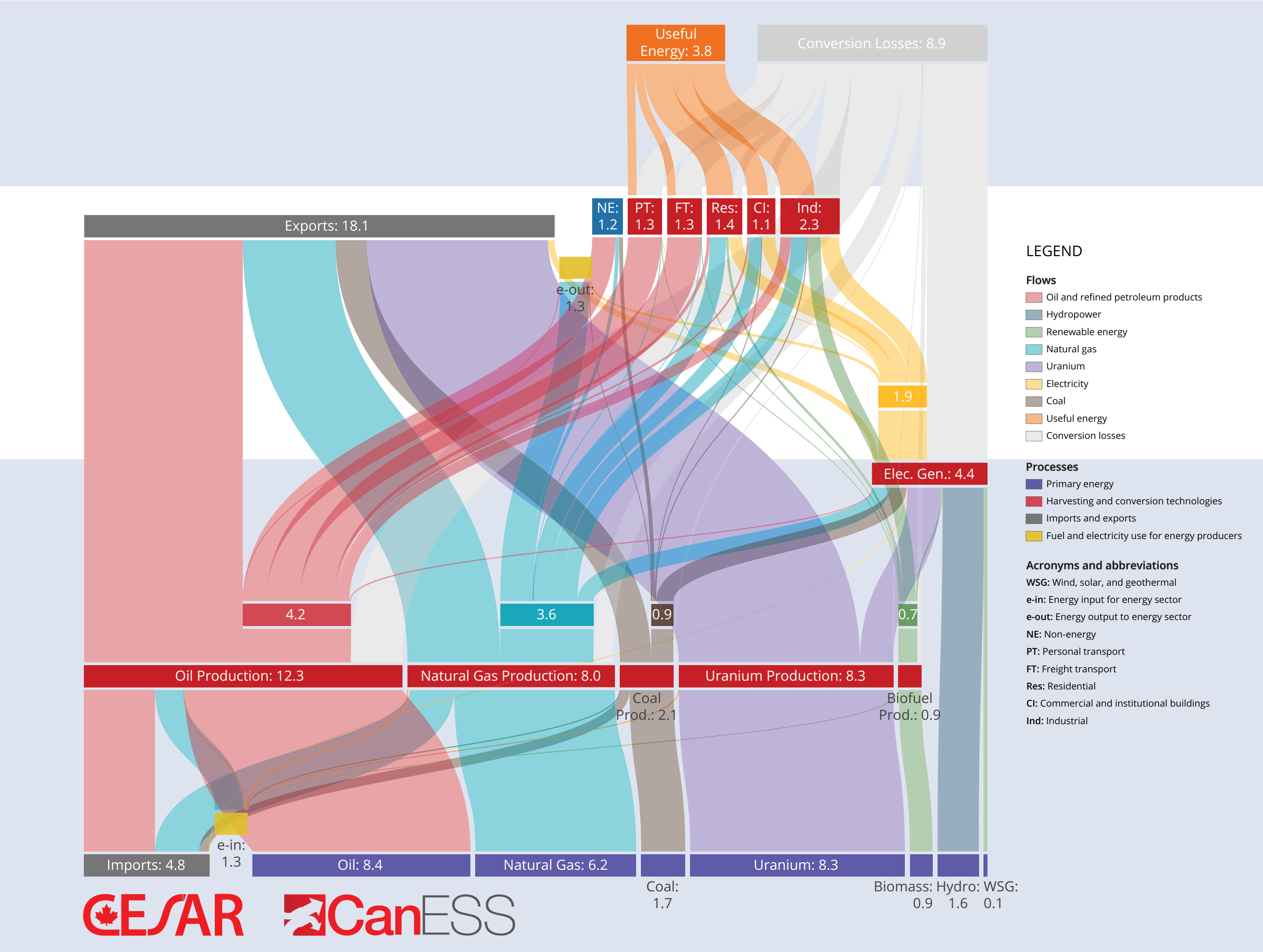
Energy Sources and Commodities
The energy services needed to heat and power homes and building systems, to support industrial processes and to power transportation depend on energy sources and commodities.

Electricity is a widely used commodity, providing energy services in homes and buildings as well as industry, with negligible use in transportation. All energy sources in Canada are used in the generation of electricity, with most of it coming from hydropower, nuclear and natural gas. Wind and solar are quickly growing in terms of their contribution to Canada's electricity generation but are still small compared to other sources.

Coal, natural gas, biomass and crude oil are energy sources that are used for purposes beyond electricity generation, primarily to heat homes and buildings and power industrial processes and transportation. These sources are used to meet the majority of Canada's demand for energy services.

The majority of the energy sources used in Canada are produced domestically, but Canada also imports energy sources as well as commodities, such as petroleum products, from the United States and other international producers.

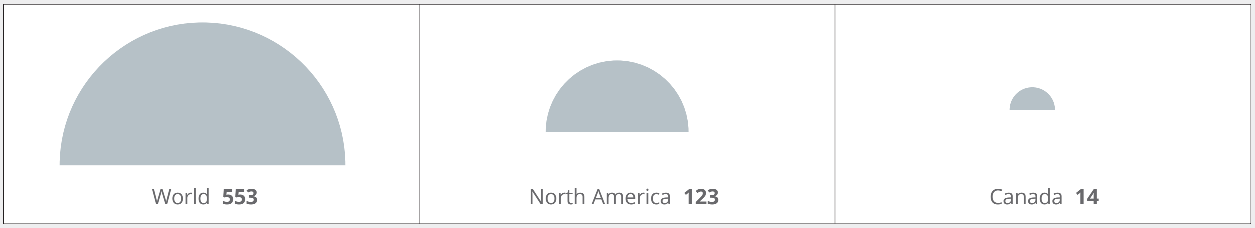
Figure 1-1: **Canada's Energy Flow, 2012** (exajoules; values are approximate)



ENERGY USE INTENSITY IN CANADA

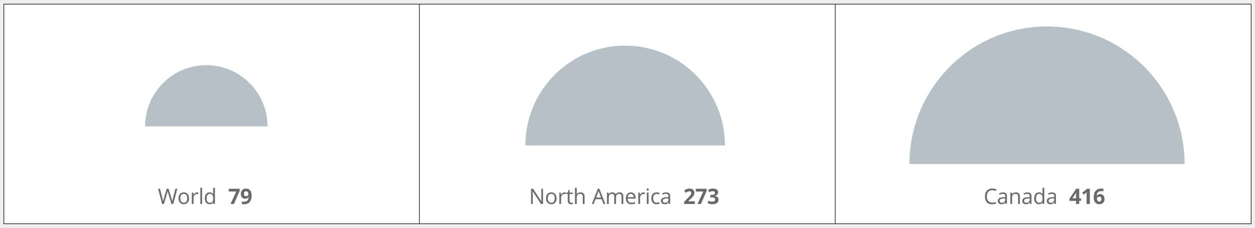
It is possible to add up all of the energy used by individuals, households and industry to compare the energy used by different countries. In Figure 1-2, we look at the total energy used in Canada in 2012, compared to North America and the world. The quantities shown here are the total sources of energy.

Figure 1-2: **2012 Total Energy Consumption for the World, North America and Canada**
(exajoules)



Canada's population is not big. We make up only about 0.44% of the world's population, yet we use a lot of energy per person – over five times the global per capita average. As Figure 1-3 shows, Canadians have the highest energy use per person even by North American standards.

Figure 1-3: **2011 Per Capita Energy Consumption for the World, North America and Canada**
(gigajoules)



Why Do Canadians Use So Much Energy Compared to the World Average?

Living standards – on average, Canadians enjoy a very high standard of living. Historically, there has been a correlation between a country's living standards – that is, how wealthy a country's citizens are on average – and its energy consumption per capita. Residents of higher-income, more industrialized societies like Canada drive cars, own larger houses and use more energy-consuming devices at work and at play.

Price – Canada has an abundant supply of inexpensive energy resources. While some lower-income Canadians do spend a disproportionate share of their income on energy, on the whole Canadians pay a lot less for electricity, natural gas and gasoline than most other people around the globe.

Heavy industry – we make lots of stuff. Heavy industries that extract natural resources, and manufacturing facilities that process raw materials into value-added products, require significant energy inputs. Because of its rich natural resources, Canada has a highly developed resource sector, including oil and gas extraction, mining and forestry, as well as manufacturing sectors, such as petroleum refining, pulp and paper mills, and metal foundries.

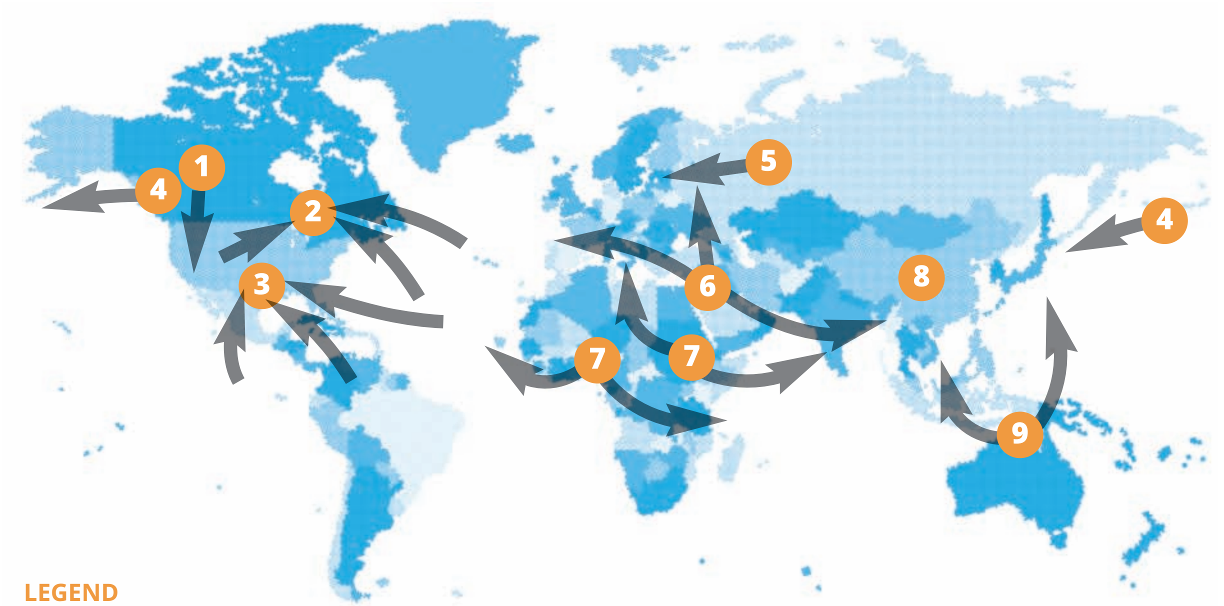
Geography and climate – Canada is big and cold. The second largest country in the world by land area, Canada is subject to some of the coldest temperatures of any inhabited area on Earth. Our cities and towns are far apart, and there are many rural and isolated communities across the country. Greater distances mean more energy is used to transport people and goods, and cold winters mean more heating energy is used to keep indoor temperatures comfortable.

These factors help to explain why Canadians consume so much energy, and they also provide insight into why Canada's energy systems have developed as they have.

Global Demand for Canada's Energy Sources

Global energy demand is another factor driving the development of Canada's energy systems. Canada is a large energy exporter, one of a very small group of higher-income nations that produce more energy sources than they consume domestically. Much of Canada's economy is driven by and depends on the export of energy sources and commodities, most of which go to the United States. Canada is by far the United States' biggest trading partner in energy commodities. Beyond the North American market, Canada is part of an international market in which energy sources and commodities are traded daily, with the United States and China being the world's largest consumers. The decisions we make about managing Canada's energy systems and energy future have implications well beyond our borders.

Figure 1-4: **Key International Energy Trade Flows**



LEGEND

1 — *Canada is the largest exporter of oil, natural gas and electricity to the U.S.*

2 — *Canada also imports oil and petroleum products from the U.S. and internationally (e.g., from Algeria).*

3 — *The U.S. imports oil from a variety of other countries, including Mexico, Venezuela, Saudi Arabia and Nigeria.*

4 — *Canada exports coal to Asian markets, including Japan and South Korea.*

5 — *Russia is a large supplier of natural gas and crude oil to European markets.*

6 — *Saudi Arabia and other Persian Gulf states are large suppliers of crude oil to American, European and Asian markets.*

7 — *Several African countries, including Nigeria, Angola and Sudan, are increasing their output of oil and exporting it to Asian, American and European markets.*

8 — *In 2015, China surpassed the U.S. as the world's largest importer of crude oil, bringing in most of its supplies from the Persian Gulf region and African states.*

9 — *Australia and Indonesia are the world's largest exporters of coal, supplying China, India and other Asian countries with fuel used for electricity generation.*

DRIVERS & IMPACTS: ENERGY IS INEXPENSIVE IN CANADA

Price is a major driver of energy use – and energy conservation. Energy prices vary from region to region, depending on local demand, infrastructure and supply, but on the whole, energy is relatively inexpensive in Canada. Figures 1-5 and 1-6 show price differences between representative jurisdictions (excluding delivery fees, administrative charges and other costs that can vary considerably by jurisdiction). As the charts show, electricity and gasoline prices are cheaper in Canada than in most other higher-income countries.

Electricity prices are generally cheaper in Canadian jurisdictions with large hydropower plants, such as Quebec, Manitoba and British Columbia. Hydropower plants usually have very high capital costs, but over the long term, they can generate power at a relatively low cost.

Average Canadian gasoline prices are substantially lower than those in Europe, where taxes are highest. Gasoline prices in Canada are about 50% higher than those in the United States, primarily as a result of provincial and federal gas taxes.

Figure 1-5: **2014 Average Electricity Prices**
(cents/kilowatt hour)

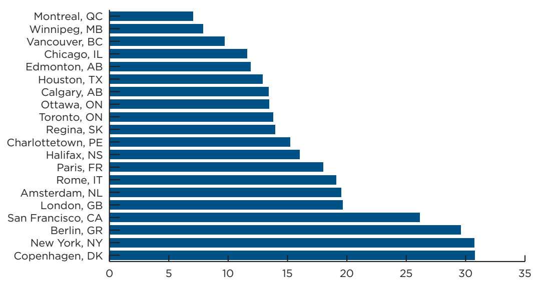
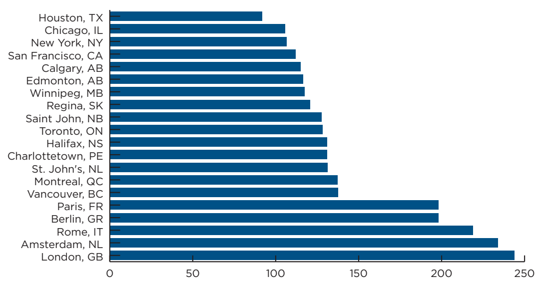


Figure 1-6: **2014 Average Gasoline Prices**
(cents/litre)



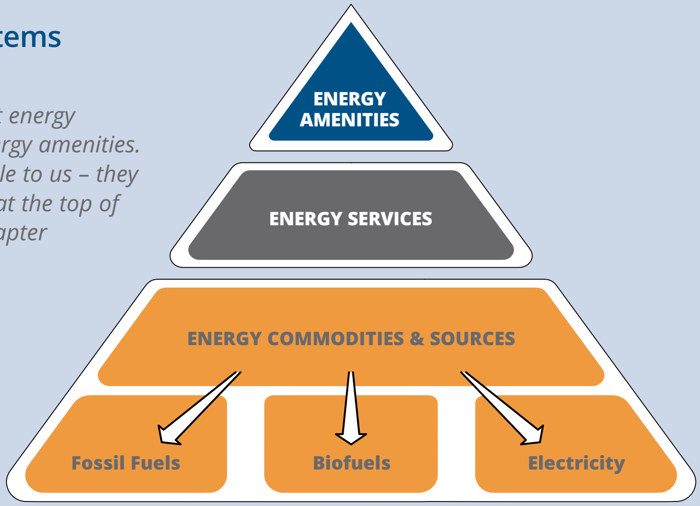
The Energy Systems Pyramid

Faced with the challenges of environmental improvement and shifting patterns of global energy use in the 21st century, Canada's energy systems will have to change substantially if they are to continue to contribute to the high living standards and economic opportunity they have historically supported. By taking a systems approach, in which we recognize how all of the elements of Canada's energy systems are interconnected, we can make the most of our opportunities and determine the optimal responses to the challenges that face us. Figure 1-7 is a representation of Canada's energy systems in the form of a pyramid. It is also a map of this primer. In the following chapters, we will walk through these energy systems, beginning with our demand for energy amenities. We then progress chapter by chapter, through the energy systems that respond to our demand.

As an example of this progression, we can look again at the basic demand for illumination: suppose you want to read a book at night. This convenience, which we call an energy amenity (Chapter 2), can be enabled through the use of a light bulb, which is a technology that provides lighting – we call this an energy service (Chapter 3). This energy service is made possible by electricity, an energy commodity produced by the conversion of an energy source, such as wind or uranium (Chapter 4).

Figure 1-7: **Canada's Energy Systems**

The energy systems pyramid illustrates that energy systems exist to satisfy our demand for energy amenities. It is these energy amenities that are valuable to us – they are what we really want – and so they are at the top of the pyramid and the subject of the next chapter



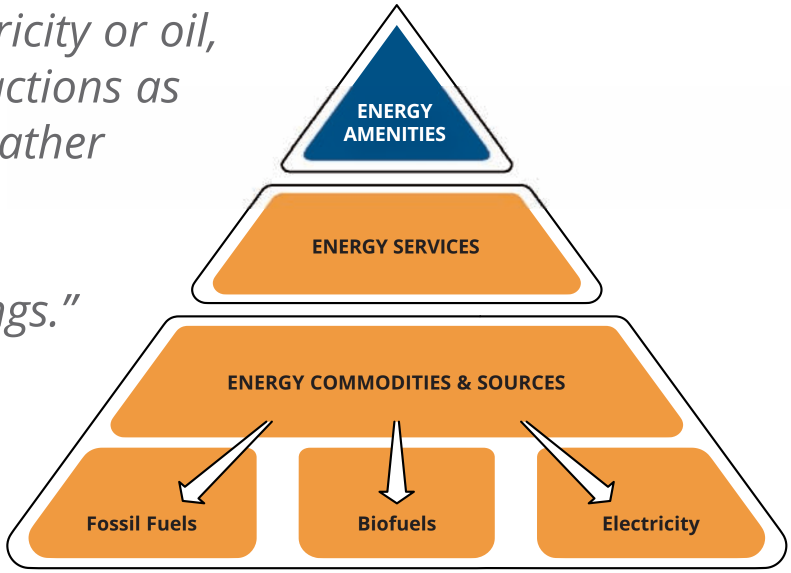
CHAPTER TWO

Energy Amenities What We Really Want

In the previous chapter, we learned about energy systems, the basic elements of which are depicted in the energy pyramid. In this chapter, we will focus on energy amenities, found at the top of the energy pyramid. What are energy amenities? Why are they important? And how do our decisions regarding our amenities affect our energy systems?

"People do not want electricity or oil, nor such economic abstractions as 'residential services', but rather comfortable rooms, light, vehicular motion, food, tables, and other real things."

– *AMORY LOVINS*



In many ways, the energy sources and commodities that we all know – natural gas, electricity and gasoline – are like money. Often, we think that we want money, but we actually want what money can buy: a home, a car or maybe a vacation. But even the things that we buy are the means to an end: homes bring comfort, cars provide access, and a vacation brings relaxation and personal enjoyment. These "ends" are what we really want.

What Are Energy Amenities?

Just like money, energy commodities are the means to an end. Energy sources and commodities are useless unless they power technology that provides the things that we really want – energy amenities. So, what are those things, what are the ends we seek? Access to and choices about amenities vary from person to person, but the following amenities, in large part, are drivers of Canada's energy systems.

Comfort. Having a safe, warm place to rest and to feel at home is a luxury for some, even in a wealthy country such as Canada. Like most amenities, comfort is personal; everyone has his or her own idea of what comfort feels like. Winter in Canada is especially cold, and being warm enough in our homes is an amenity that most Canadians want and need. How we heat our homes and buildings makes up a large part of Canada's energy systems. Increasingly, how we cool our homes in the summer is also becoming a driver of Canada's energy systems.

Convenience. Modern Canadian lifestyles are built for convenience. Everything from cars and household appliances to drive-throughs and disposable coffee cups demonstrates the degree to which our choices are based on convenience. While convenience is not in itself a bad thing, it draws heavily, and often wastefully, on the energy sources and commodities that enable it.

Access. Everybody wants access to people, places and opportunities. How people obtain access through lifestyle and transportation choices has a big impact on energy patterns. We can drive to the mall, we can walk to the corner store or we can shop online. All three provide access, with big differences in the energy used in the process.

Enjoyment. Enjoyment is subjective – different people like different things. How we use our home entertainment systems, what vehicles we use to get to summer cottages or camps and what watercraft we use when we get there, and what kind of vacations we take are all examples of how our energy systems are driven, in part, by the demand for enjoyment.

Energy as a Means to the Ends. Energy is the means to get the things we really want: the "ends" or amenities. We can still get what we want while drawing on fewer energy services, using fewer energy commodities and thereby consuming fewer energy sources. For example, suppose there are two refrigerators that will keep your food cold and safe. One uses half the electricity of the other. Which would you choose for your home?

We usually focus on where our energy comes from, how much it costs or how abundant the supplies are. It is important to remember that what we are really interested in is what energy can do for us.

Choosing the Means

Technology and infrastructure are in place to transform energy sources into useful commodities and to deliver them for use. But as energy is converted from one form to another, and as energy sources and commodities are transported, some of the original energy is lost. Technology and infrastructure are not perfect - their use results in energy losses.

Technology

Various technologies are used at each stage in an energy system. Some technologies are employed to extract and harness natural energy sources. Other technologies are used to convert energy sources into useful energy commodities. And technologies deliver the energy services that use those commodities. Natural gas furnaces and internal combustion engines, transformer substations and pipelines, wind turbines and oil wells are all examples of technologies that make up our energy systems.

Infrastructure

To be useful, energy must be available at the point where it is needed. Infrastructure is required to deliver the energy commodities to the point of use. Infrastructure is a critical part of Canada's energy systems. It connects the end-users of heat, electricity, natural gas and petroleum products with the ultimate sources of energy. Infrastructure is what gets the energy to us, the consumers – to our homes, to our vehicles, to our schools.

Energy Pathways

We pay for energy losses both financially and environmentally because we pay for the quantity of energy commodities used, not necessarily for the energy service delivered. We can meet our demand for energy amenities using various means, or energy pathways, some of which are more efficient and less disruptive than others. Choosing more wasteful energy pathways increases the monetary cost of our energy amenities and results in greater environmental impacts, such as damaging emissions to the atmosphere, including greenhouse gases and, more locally, land use changes and other social impacts.

Understanding energy losses, and how we pay for them financially and environmentally, can help us determine optimal energy pathways – the best choice of means – to obtain our energy amenities. The following example about home heating illustrates how this works.

Figure 2-1: **Home Heating Pathways**

Natural Gas Heating Pathway

Deposits of raw natural gas (an energy source) can be extracted and converted into high-grade natural gas (an energy commodity).

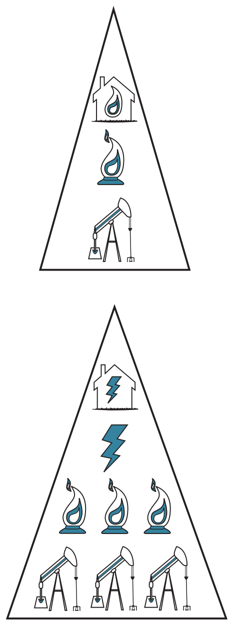
This natural gas can be distributed by using a relatively small amount of energy to pump the gas through pipelines and deliver it to the end-user's home.

There, it can be burned in a high-efficiency furnace to produce heat (the energy service), providing the end-user with comfort on a cold night (the energy amenity).

Electricity Heating Pathway

Another energy pathway to the same amenity is to pump the high-grade natural gas to a power plant, where it is burned to generate electricity – a process in which about one-third of the energy in the natural gas is converted into electricity, with two-thirds rejected through the power plant stack as unused heat (lost energy).

The electricity is then transmitted through power lines (where more of the energy is lost because of resistance in the wires) to the end-user's home. There, it is finally converted by an electric furnace or baseboard heater back into heat that provides comfort.



In both energy pathways, the gas deposit is used to provide comfort through heating, but the second pathway is more wasteful, burning more natural gas to provide the same energy value and resulting in higher costs to the end-user and more greenhouse gas emissions. This represents a less sustainable use of the natural gas deposit and a less economically productive means of satisfying the demand for heating for comfort.

Comparing energy pathways is sometimes more complex than it appears at face value. Some energy pathways are more energy intensive than others, but some are more versatile. In the example above, using natural gas to generate electricity is more energy intensive, but it does produce a form of energy – electricity – that can be used for more than just heating. Looking at energy pathways in this way is a form of life cycle analysis, in which cumulative impacts are considered.

Energy losses are an inevitable part of using energy services. Making choices that minimize energy losses through better design, conservation and efficiency can have a significant impact on how Canada's energy future unfolds.

Better by Design

The degree to which a home or building requires heating and cooling to keep things at a comfortable temperature depends on how well the building is designed. Buildings that are poorly insulated and that have leaky windows and doors let heat escape during the winter and enter during the summer. This leakage increases the demand for energy commodities to provide heating and cooling at the desired levels.

What it takes to heat or cool a building is one example of the impact of design. The same is true on a larger scale in our cities: the way they are designed in large part determines, for example, what transportation choices we make to gain access to people and places.

Conservation and Efficiency

Because energy systems introduce losses whenever energy sources are converted to commodities and whenever these commodities are delivered for our use, a small reduction in the demand for energy services multiplies into much bigger reductions in the energy commodities that we use. This *multiplier effect* is one of the most compelling reasons why conservation and efficiency measures are often the best way to ensure that energy amenities are provided with the least economic, social and environmental cost.

Conservation (Use Less)

In its purest form, conservation means not using energy services and, therefore, not drawing on energy systems. For example, turning off the lights when you leave a room is a simple way to conserve energy. Or, to take another example, if I decide to cut my showering time to 5 minutes instead of 10, I get half the showering time, but I reduce my energy demand for hot water by half as well. Not using energy in the first place, or using less energy, is usually the cheapest, most environmentally benign and least socially disruptive method of ensuring energy supply.

DRIVERS & IMPACTS: REDUCING ENERGY USE

For some, the very word "conservation" conjures up images of shivering in the dark with the furnace turned off.

The good news is that the notion of shivering with the lights and the heat off to save energy is outdated. Today, houses with better insulation and more efficient heating technologies can provide the same level of comfort and use half or a third less electricity and natural gas than houses built around the Second World War. And lighter, more efficient cars can provide the same access to family, friends or groceries, using a fraction of the gasoline that heavier, more powerful vehicles use. It is possible to implement conservation and efficiency measures that reduce unwanted environmental impacts and save money too, without sacrificing the comfort and convenience we want from our energy systems.

Efficiency (Use Better)

Efficiency means that we use energy services to provide the amenities we want, but we do so using better technologies that draw less on energy systems. It means having access to the same level of energy service, but using less energy. If you inflate your car tires properly, your car uses less energy to travel a given distance than it would with flat or partially deflated tires. The same energy service is being provided (driving the vehicle a certain distance), but less energy is being consumed.

Efficiency measures reduce the negative impacts of energy use by providing the same services while using fewer energy commodities and sources.

Thinking about conservation and efficiency as energy sources can make economic sense; it can often be more cost-effective to satisfy the demand for additional energy amenities without developing and delivering new energy supply. To meet the growing demand for energy, some Canadian provinces and American states are adopting aggressive programs to maximize conservation and efficiency.

In parts of Canada and the United States, energy conservation and efficiency measures are considered the "first fuel" for meeting the demand for energy amenities.

DRIVERS & IMPACTS: MEASURING CONSERVATION AND EFFICIENCY

Assessing the cost of generating more electricity to meet increased demand is relatively easy. But how do you quantify the absence of demand, and how do you value it? Assessing the impact of conservation and efficiency programs requires comprehensive and accurate evaluation, measurement and verification protocols.

In the absence of such protocols, we face challenges in realizing the potential for more efficient technologies and changes in behaviour to meet the demand for energy amenities – and to deliver compelling economic benefits.

Summary

In this chapter, we learned that what we really want are energy amenities, such as comfort, access, convenience and enjoyment. These amenities drive our demand for energy and activate our energy systems. In this sense, energy is the means to an end – obtaining amenities – and we have choices to make about the means we use to achieve this end. Because of the multiplier effect, reducing our draw on energy services can reduce our consumption of energy sources manyfold. We can reduce our energy demand by seeking and supporting better design of energy technologies and infrastructure, and we can apply energy conservation and efficiency measures in our everyday lives. The next chapter provides a context for making these choices by describing the major energy services in Canada and the technologies used to provide them.

ENERGY STORY NO. 1 JASON AND SHANNON RENOVATE THEIR HOME

Jason and Shannon moved to Saskatoon from Winnipeg with their two young children in the summer of 2013 so that Jason could pursue a new job at a software start-up company. They immediately fell in love with and bought an old, converted farmhouse on the edge of town.

After living there through the fall, they quickly learned that the house needed a lot of work. The furnace was nearly 20 years old and needed replacing, and they could feel drafts from some of the doors and windows. They were spending more on natural gas than they wanted to, and it wasn't even winter.

Jason started looking into replacing the furnace and putting in some new insulation to keep the heat in. Shannon called up a certified energy adviser, who came by to do an audit of the home to determine where energy was being wasted. After conducting an inspection of the home, including the furnace, attic, exterior walls and windows, and testing for air leaks, the adviser presented Jason and Shannon with a list of renovations that they could do to conserve energy and reduce their energy costs.

With the help of their energy adviser, Jason and Shannon estimated that these retrofit projects would reduce their natural gas consumption by half and, as a result, cut their energy costs from an estimated $1,600 a year to $800, for an annual savings of $800.

Retrofit Project	Estimated Cost
Replace old furnace with high-efficiency furnace	$5,500
Insulate attic and basement	$1,500
Seal doorways and windows	$350
TOTAL COST	***$7,350***

Jason did a quick payback calculation to see how long it would take for the annual savings to pay off the costs of the retrofits.

It would take approximately 9.2 years for the investment to pay off. But if natural gas prices were to increase, the savings would come even faster.

$$\textit{Payback Period (Years)} = \frac{\text{COST OF PROJECT}}{\text{ANNUAL SAVINGS}} = \frac{\$7{,}350}{\$800}$$

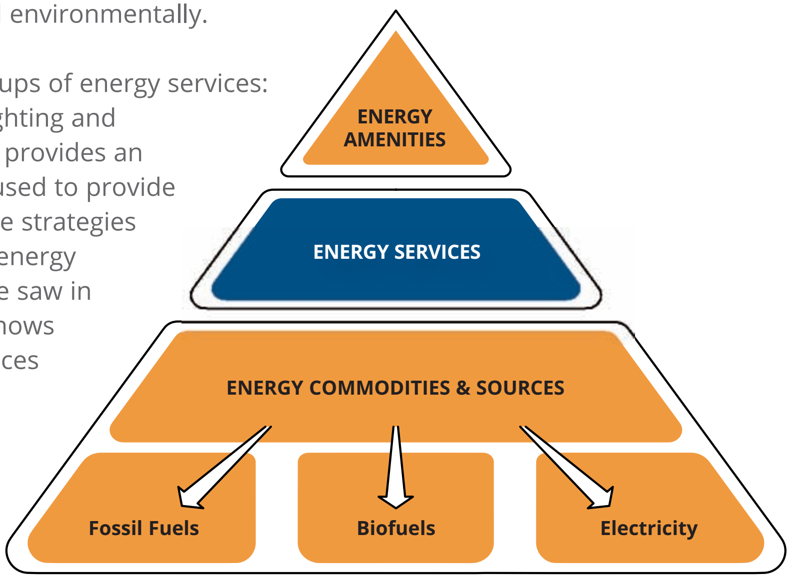
There are other factors to consider, of course. Jason and Shannon would have had to replace their old furnace at some point anyway. Also note that this is a simple payback calculation; it ignores the cost of borrowing money and the relative benefit of using the money for other purposes (opportunity cost).

CHAPTER THREE

Energy Services
Energy in our Everyday Lives

Every day, Canadians satisfy their desire for energy amenities – comfort, convenience, access and enjoyment – by drawing on energy services. Energy services, the next tier in the energy pyramid, include heating and cooling technologies that keep homes and buildings comfortable; lighting and appliances that help us work and play, even at night; and transportation technologies that provide access to people and places. Understanding energy services helps us understand that different technologies place different demands on energy systems. The type of furnace we choose to heat our home or the type of car we use to get to work does matter because some technologies place a greater demand on energy commodities and sources. The greater the demand, the greater the cost to us and to Canada's energy systems – economically and environmentally.

This chapter looks at each of these main groups of energy services: space heating, water heating, and cooling; lighting and appliances; and transportation. Each section provides an overview of some of the basic technologies used to provide these services and then points to some of the strategies that we can all use to meet our demand for energy amenities in ways that use less energy. As we saw in chapter 2, factoring in the multiplier effect shows just how much impact individual energy choices can have.



Industrial use of energy is not a focus of this primer, but this chapter also touches on some of the energy commodities and services used by Canada's industrial sector to produce goods and services, and how these industrial energy uses affect the larger picture of Canada's energy systems.

Energy Demand and Energy Efficiency

Residential energy use in Canada has risen in recent years, and explaining that rise highlights some of the pressures on the country's energy systems. While the energy efficiency of nearly all heating technologies and appliances has increased, there are more homes now than ever before, and we are using more, and more varied, appliances.

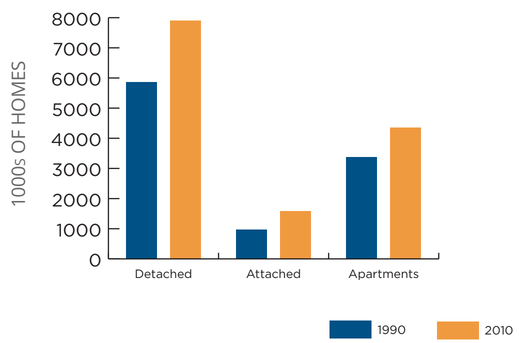
More Houses, Bigger Houses

Newer homes are usually better insulated than older ones, helping to reduce heat loss to the outside. And newer heating equipment is more efficient, so less energy is required to deliver heating services. But these gains are offset by the increased number of houses and the size of newer homes. The number of Canadian households increased about 50% more than the population between 1990 and 2010. This is partly explained by the rapid urbanization of rural areas and the continued dominance of single-family, detached dwellings. At the same time, the average floor space of a house increased by over 40% – bigger houses mean that more energy is required for space heating and cooling.

Figure 3-1: **Number of Canadian Households by Dwelling Type, 1990 and 2010**

About 56% of Canadian homes are detached. Detached homes are exposed on all sides to the outside environment, allowing more heat to escape out through the walls.

Detached homes use more energy for heating than houses attached on one side (semi-detached) or on both sides (row houses or townhouses), and more still than an apartment or a condominium.



More Appliances

The energy efficiency of most household appliances has improved substantially over the last 20 years. Dishwashers use a third of the electricity for a load of dishes, and modern refrigerators use half as much electricity annually as models from the 1980s.

But while appliances use less energy, we have introduced new devices and more appliances into our homes. The use of smaller appliances, including televisions, digital video players, radios and computers, has more than doubled since 1990.

Understanding how we can best minimize or manage our demand for energy while at the same time taking advantage of advances in energy-efficient technologies is key to determining what we can do to reduce demand on Canada's energy systems.

Heating and Cooling Services Provide Comfort

The easiest form of energy for most of us to understand is heat. Heat comes from the sun, from the decomposition of organic matter, and even from geothermal heat stored deep underground. While plentiful, these naturally occurring heat sources are not always conveniently located and are not necessarily available at the right temperature or the right time for our use. As a result, early on in human history, people learned to play with fire, by burning different materials to produce heat when and where it was convenient.

Canadians depend on heating and cooling technologies to keep their homes comfortable. But heat is also crucial to the operation of our energy systems. Some provinces rely heavily on electricity generation technologies that use heat to produce steam or hot combustion gases to drive turbines. Even a car's internal combustion engine relies on heat and pressure from burning fuel to drive pistons inside the engine that turn the wheels.

Almost all energy technologies used in Canada and worldwide involve producing, storing or manipulating heat.

Space and Water Heating

Canada's 35 million people live in more than 13 million households spread from coast to coast to coast. More than 60% of the energy used in Canadian homes is for space heating and cooling to keep our homes at a comfortable temperature year-round. Another 20% of residential energy is used to heat water for cooking and cleaning.

In Canada's commercial and institutional buildings, including warehouses, retail stores, schools, universities and government buildings, heating and cooling takes up a slightly smaller share of energy use – about 50% of the energy used in such buildings is for space heating and nearly 10% is for water heating.

Most of the energy used in buildings in Canada is for space and water heating.

Canadians heat their homes and buildings and their hot water supplies using a variety of technologies.

Furnaces, Fans and Ducts

Just over half of Canadian homes use a central furnace for space heating. Furnaces are usually located in a basement or utility room and circulate hot air throughout the house using ductwork. The majority (90%) of furnaces in Canada generate heat by burning a fuel such as natural gas. Ten per cent of furnaces do not burn fuel but use electricity instead to generate heat (mostly in Quebec and British Columbia).

Fuel Combustion

Canadians use natural gas, heating oil, propane, wood and other fuels in furnaces and stoves. These fuels consist mostly of carbon and hydrogen atoms. When these fuels are mixed with oxygen and ignited, they combust (burn), releasing the chemical energy stored in the carbon and hydrogen molecules as heat energy.

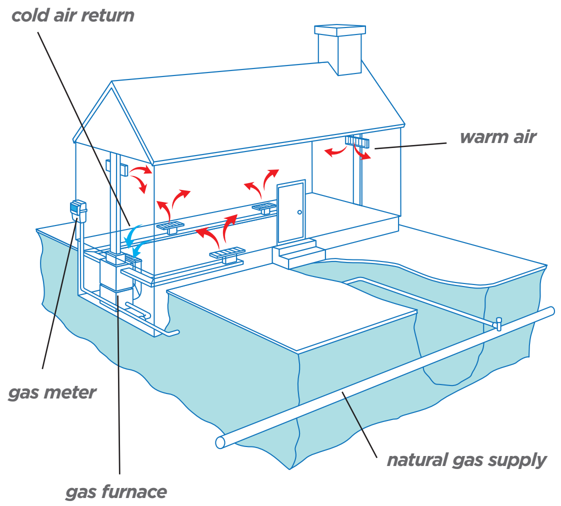
In addition to heat, the products of combustion are water, carbon dioxide and numerous other compounds that can pollute the air and affect human health. These products of combustion, or flue gases, are released to the atmosphere through chimney stacks.

Fuel + Air = Heat, Water, Carbon Dioxide and Other Compounds

Figure 3-2: **High-Efficiency Furnaces**

Furnaces draw in fresh, cold air from outside a house or building. This cold air is put in contact with hot combustion gases through the use of a heat exchanger.

The heated air is then circulated to other rooms in the house using a powerful fan that blows the warm air through ducts and vents. This heating system is called forced air because of the force of the fan used to circulate the warm air through the house. When used with a programmable thermostat, it can automatically turn on and off to maintain the desired temperature at different times of day.



Electric Heating

Electric furnaces do not burn fuel. They generate heat through resistive heating. Electric current naturally generates heat as it flows through wires and conductors. In electric furnaces, current flows through coiled wire, heating it up. This heat is transferred to the air that passes through the furnace, and the heated air is circulated throughout the building. Resistive heating is also how electric stoves and incandescent light bulbs generate heat and light.

It is also how electric baseboard heaters work. These are self-contained units that radiate heat from electrical and ceramic coils. A home heated exclusively with baseboard heaters typically requires several units, depending on the number and configuration of the rooms in the house. About one-quarter of Canadian households use electric baseboard heaters as their principal heating source, and many more homes have portable electric heaters that are used on occasion.

Because there is no flame, electric furnaces and baseboard heaters are suited to applications where fire hazards pose a safety risk. They produce no direct emissions, although emissions can occur at the power station supplying the electricity. There are also financial advantages for consumers using electric heat in jurisdictions where electricity costs are low. For example, two-thirds of the heating in Quebec is provided by electric baseboard heaters. Quebec generates most of its electricity from hydropower, which it sells at low prices to its domestic customers.

Other Space and Water Heating Technologies

Several hundred thousand Canadian households rely on fireplaces and wood stoves for their space heating. Wood and coal stoves provided all space and water heating in North America until the early 20th century, and they are still the primary heating technology used in lower-income countries.

About one in ten households in Canada uses a boiler for space and water heating. Boilers heat up water and distribute it through pipes to hot water radiators that transfer the heat to the surrounding air, thus heating the space.

Boilers are also used to generate steam in various industrial applications and to produce electricity using steam turbines. Most of the world gets its electricity using boilers and steam turbine technologies.

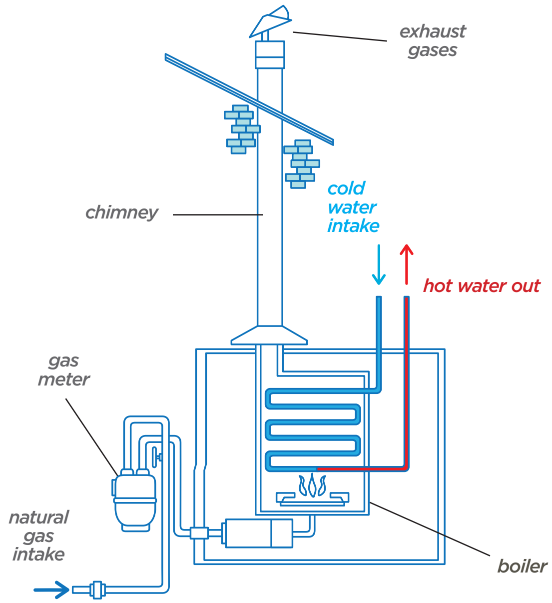
Figure 3-3: **Boiler Configuration**

Boilers

Just like furnaces, boilers generate heat by burning fuel or through resistive heating.

In combustion boilers, heat from the burning of fuel is transferred to water in a vessel. As with a furnace, the products of combustion are exhausted through a chimney stack.

Electric boilers use resistive heating to heat water in a vessel in much the same way that an electric kettle works.



Boilers always heat water (or other liquids), while furnaces heat air.

Water Heating

Twenty per cent of residential energy and 10% of commercial and institutional energy is used for water heating.

Hot Water Tanks and Alternatives

For cooking, bathing and other hot water services, about 90% of Canadians have an electric or natural gas–fired hot water tank, which is really a vessel of water that is kept hot at all times. When you turn on your hot water, it runs from the tank through plumbing to your tap. Boilers can be used for water heating as well as space heating.

There are other technologies that use less energy than hot water heaters, such as tankless (instantaneous) water heaters that heat water by applying a concentrated heat source just as you turn on the hot water tap. These systems use less energy because they heat water only on demand (i.e., only when we need it), rather than consuming electricity or burning natural gas to keep a tank of water hot at all times.

ENERGY STORY NO. 2 COMPARING HOUSEHOLD ENERGY USE

Individual Canadians use different amounts of energy for different purposes and in different forms. While we are, to some degree, constrained in our choices by our local natural and built environments, our energy use is very much determined by our individual lifestyle choices.

Not every joule of energy has equal impacts.

The amount of energy each Canadian uses can be quantified as a number of joules. But the way that those joules are provided, and where they ultimately come from, can result in different financial, social and environmental costs. To illustrate how different lifestyles affect these costs, let us take a look at four representative Canadians and the energy use, energy costs and greenhouse gas emissions associated with their lifestyles.

FOUR CANADIANS

Jon

lives in Halifax, Nova Scotia, and is attending law school at Dalhousie University.

Lives with his partner in a small bungalow

Michelle

is a pharmacist in Rimouski, Quebec.

Lives in a large apartment with electric heating

Leanne

was born in rural Ontario but moved to Toronto, where she works at a bank.

Lives in an old, three-bedroom house

Geoff

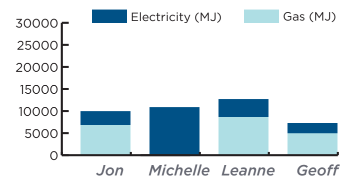
is from St. John's, Newfoundland, but lives in Fort McMurray, Alberta, where he works as a welder for an oil company.

Lives in a small apartment

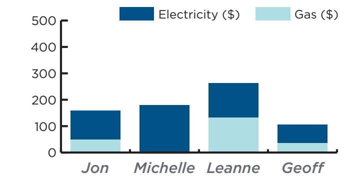
Figure 3-4: **Comparing Household Energy Use**

Energy Use (megajoules): *Jon, Leanne and Geoff all use a combination of natural gas and electricity to meet household energy needs, while all of the energy Michelle consumes at home is supplied by electricity. Leanne's three-bedroom house consumes the most energy, nearly twice as much as Geoff's small bachelor apartment.*

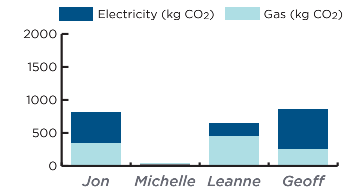
Data have been compiled from a number of sources and are representative of different dwelling types and locations.



Cost ($): *Jon's, Leanne's and Geoff's monthly electricity bills are higher than their natural gas bills, even though they get more energy per month from natural gas than electricity. While Michelle gets all of her energy services from electricity, her bill is not higher than the others' because electricity costs less in Quebec than in Ontario, Alberta and Nova Scotia.*



Greenhouse Gases (kg CO_2e): *The difference here results from using different energy sources to generate electricity. Alberta's electricity comes mostly from fossil fuels, which produce significant greenhouse gas emissions, whereas almost all Quebec's electricity is from hydropower, which produces virtually none. Ontario and Nova Scotia generate electricity from a mix of sources that vary by season and time of day. Some, such as hydropower and wind, are non-emitting, while others, such as coal, result in greenhouse gas emissions.*



Greenhouse gases can be represented by kg CO_2e, or kilograms of carbon dioxide equivalent, which is a way of equalizing the different global warming potential (GWP) of various gases (this allows for an "apples to apples" comparison of different greenhouse gases). Carbon dioxide equivalents are calculated using a relative scale that compares the GWP of emissions to that of carbon dioxide, the most prevalent greenhouse gas.

DRIVERS & IMPACTS: GREENHOUSE GASES DO NOT RESPECT BORDERS

As the greenhouse gas emissions chart above shows, heating a home in Quebec using electricity results in virtually no greenhouse gas emissions. At first glance, this suggests that Quebecers can use as much electricity as they want. But Quebec's electricity system is interconnected with the electricity systems in Ontario, New Brunswick, New York and Vermont, all of which otherwise rely on higher greenhouse gas emitting power generation systems. So, conservation matters just as much in Quebec as elsewhere because the export of its surplus electricity to these neighbouring jurisdictions helps to keep their collective emissions lower than would otherwise be the case.

Cooling

Residential as well as commercial and institutional cooling services are provided using air conditioners running on electricity.

Just over half of Canadian households – nearly seven million households – have an air conditioning unit. Of these, two-thirds have a central air conditioning unit located just outside the house. These units use a large fan to push the cooled air through the same ductwork and vents used by a central furnace. The remaining third of households with air conditioning have wall- or window-mounted units that provide cooling to a single room or section of the dwelling.

How Air Conditioners Work

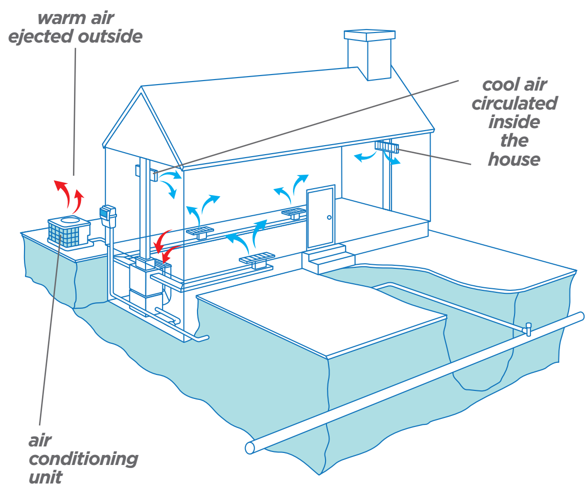
Central air conditioners, just like refrigerators, use energy to move heat out of an enclosed space. Most air conditioners work by circulating a special fluid called a refrigerant that changes back and forth from a liquid to a vapour as it absorbs heat from inside a room and releases it outside.

Figure 3-5: **Central Air Conditioning**

Inside the home, the refrigerant is pumped through an evaporator coil. This is the stage where the refrigerant changes to a vapour, absorbing heat from inside the room.

The refrigerant is then pumped outside the home and through a condenser, where the refrigerant changes back to a liquid and releases heat to the outside environment.

Central air conditioners (and refrigerators) use a compressor to pump the refrigerant through this cycle. It is the compressors inside these devices that use so much electricity.



Only about 2% of the energy used in homes, and 7% in commercial and institutional buildings, is for cooling services. These numbers may not seem high, but the energy used to provide cooling services is growing faster than that used for any other residential or commercial and institutional service, more than doubling between 1990 and 2010. And our increasing demand for cooling services is having a disproportionate impact on the reliability, cost and environmental performance of many provincial electricity systems.

DRIVERS & IMPACTS: AIR CONDITIONING, PEAK ELECTRICITY AND SMOG DAYS

Virtually all of the electricity used to provide cooling services is concentrated on the few hottest days of the summer. For example, Ontario used to see its highest demand for electricity – the peak demand – on cold winter days. But since 2005, peak demand has been occurring on hot summer days, when the demand for electricity for air conditioners and industrial chillers spikes. Up to a third of Ontario's peak summer electricity demand is now used for cooling.

This is significant for several reasons. First, the high demand puts stress on the electricity transmission and distribution system, increasing the potential for brownouts. Brownouts and power disruptions are most dangerous during very hot and very cold periods, so this introduces a public safety and health issue. Second, in jurisdictions that burn fossil fuels to generate electricity, such as Alberta, Saskatchewan, Nova Scotia and Ontario, the growing use of air conditioners increases the burning of these fossil fuels. And when it is hot and humid, this additional fuel combustion can be a significant contributor to smog, which is associated with respiratory and cardiovascular problems.

Heating and Cooling with the Sun and the Earth

We can also provide heating and cooling services in our homes using the natural heat from the sun and the Earth. Heat collectors, heat pumps and heat exchangers are all technologies that can exploit the sun's radiation and natural temperature differences in the ground. These technologies can play a significant role in helping us reduce the impacts of our energy demands.

Solar Heating

The simplest and most cost-effective way to use the sun's energy is for light and heat. Many modern buildings take advantage of this freely available energy by integrating passive solar systems into their designs. Passive solar design refers to the use of the sun's energy for the heating and cooling of buildings. In this approach, a building or one of its elements is designed to take advantage of exposure to the sun, absorbing or reflecting the sun's energy as needed. Various technologies, collectively termed solar thermal, work by absorbing solar radiation and transferring this energy to heat water, air or other materials.

Figure 3-6: **Solar Thermal Systems**

Solar collectors absorb and transfer the sun's radiation (a form of energy) to heat up a liquid or air. Some solar hot water systems circulate water through the collectors directly to your hot water tank or tap. Other systems circulate an intermediary fluid, such as glycol, through a closed loop system where it transfers heat to a tank of water. Both types of systems can significantly reduce the reliance on conventional furnaces and boilers to reach temperatures needed for space heating and hot water.

Collectors are often identifiable as dark panels or tubes mounted on the roofs of buildings and angled towards the sun.

Many houses in the Middle East and the Southern Hemisphere use solar thermal to heat water for bathing and cooking to reduce the need for fuels, which can be expensive.

Geoexchange (Ground Source Heat Pumps)

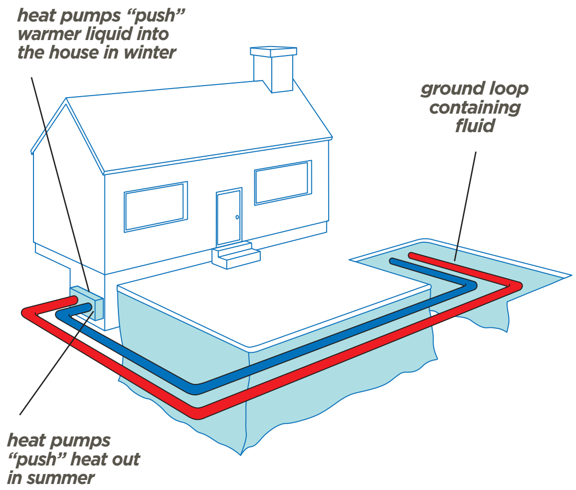
Even in the winter, when the air temperature can easily drop below –20 °C, temperatures several metres below the surface of the Earth stay relatively constant. From the surface down to a depth of about 500 metres, the temperature of the ground generally ranges from 7 to 15 °C.

Ground source heat pumps are essentially large, underground heat exchangers that use the temperatures beneath the surface of the Earth to provide heating or cooling to houses and other buildings. These systems include underground pipes or coiled wire filled with a fluid containing water and antifreeze.

Figure 3-7: **Geoexchange Systems**

In Winter
Circulating fluid is heated by warmer temperatures underground. Heat pumps and exchangers are used to heat air or water inside a building or a house.

In Summer
Pumps and exchangers push heat out of the house, exchanging it with the cooler liquid from underground.



Because these systems must be buried deep underground or over a wide area, ground source heat pumps can be expensive to install. They require deep or broad excavation, which can be costly for an existing structure. Costs can be reduced if geoexchange systems are installed along with other infra-structure, such as water and sewage lines, when a building's foundations are being laid.

Heat Pumps

Heat pumps are used to move heat between objects or fluids. They can be designed for both heating and cooling applications.

In heating applications, a heat pump is used to move heat from a high-temperature source to a lower-temperature sink. Refrigerators also use heat pumps, but they operate in the opposite direction, removing the heat from inside the refrigerator and ejecting this heat energy into the kitchen.

Just like other types of pumps, heat pumps need energy to perform work. Most heat pumps used in fridges and heating systems have a small motor and operate mechanically. In Canada, they are almost always electrically powered.

Heat Exchangers

Heat exchangers are used to increase the rate at which heat transfers from one object or fluid to another. Because the amount of heat transferred increases with the surface area in contact, heat exchangers are often made of looped coils containing air, water or another fluid. Using looped coils increases the surface area across which heat can transfer, thus increasing the ease of exchange between source and sink.

The back of your refrigerator is a heat exchanger. A heat pump moves the heat out of the inside of the fridge and into the coils on the back, where it accumulates and then dissipates to the surrounding air – which is why it is so hot back there.

Geothermal Power versus Ground Source Heat Pumps

There are two very different ways of putting the heat in the ground to use.

Ground source heat pumps or geoexchange systems make use of relatively constant temperatures several metres beneath the Earth’s surface to provide heating in the winter and cooling in the summer.

Geothermal power plants generate electricity from naturally occurring steam created by underground sources of extreme heat. Some countries, such as Iceland, have excellent geothermal electric power plants. Canada does not currently generate any commercial-scale electricity from geothermal power, although several demonstration projects have been launched in recent years.

Thermal Energy Storage

Energy can also be stored as heat. Copper is an excellent conductor of heat (and electricity), which means that it heats up very quickly when exposed to a heat source. But as a good conductor, it also dissipates its heat very quickly to other objects around it. Other materials, such as a clay pot, are slower to absorb heat, but they hold the heat in longer. Clay, brick and ceramic are poor conductors of heat energy, but once they have heated up, they store that heat for a long time.

Thermal Mass — Storing Heat Energy during the Day

The concept of storing heat energy is quite simple and has been used for thousands of years in building design. A south-facing interior wall in a home is constructed of a thick layer of brick or stone, called a thermal mass.

The thermal mass heats up gradually over the course of the day, as sunlight hits its surface. As night sets in, the temperature drops, and the heat stored in the thermal mass slowly dissipates, heating the air inside the home.

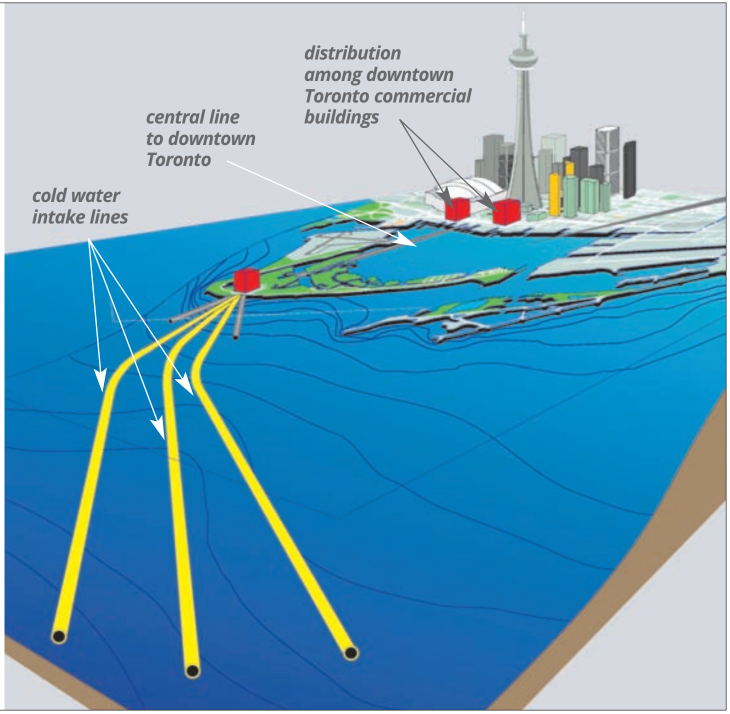
Cool Storage

Just as heat can be stored in a thermal mass, it is possible to store fluids that are cooler than ambient temperatures and use these chilled fluids to cool building interiors. These systems can reduce the energy demand for cooling services in the summer.

Figure 3-8: **Enwave Deep Water Cooling Project**

Geoexchange systems provide cooling by making use of lower temperatures underground during the summer. The Earth is essentially a thermal mass below the ground that is cooler than the air temperature above the ground.

Other systems use deep lake water to provide cooling services. Enwave's Deep Lake Water Cooling uses the much lower temperatures of water deep in Lake Ontario to provide cooling services to large commercial and institutional users in Toronto's downtown, reducing the demand for electricity.



District Heating and Cooling

In district heating and cooling systems, the types of systems designed to heat or cool homes are scaled up to serve a city block, industrial park, hospital or university campus.

In a district heating system, a large, centralized heating system distributes hot water, steam or chilled water to an entire community. Each household has access to the same heating and cooling services, but the use of a centralized source means that each house does not require its own furnace or air conditioner.

District heating is more efficient than heating houses with individual systems, and if the conditions are right, it can reduce costs because the central heating or cooling facility can purchase fuel in bulk, and maintenance costs on one large unit can be lower than for multiple smaller units.

DRIVERS & IMPACTS: DISTRICT HEATING SYSTEMS AND URBAN DENSITY

Heat can dissipate quickly, so the shorter the distance between the sources of heat (a furnace or central heating plant) and where the heat is needed, the fewer the energy commodities required to achieve the desired heating service. As a result, district heating systems work best when neighbourhoods are more concentrated. When they are too spread out, district heating systems become less economical because too much of the heat dissipates before it can reach its intended destinations.

Most Canadians live in lower-density neighbourhoods. Even most of our urban areas are quite spread out, compared to cities in Europe and Asia that are much older. The low density of our urban areas is one of the main reasons why district heating systems are rare in Canada, and why they are much more common in urban areas of Scandinavia, where district heating is part of community planning and design.

PUTTING THE MULTIPLIER EFFECT TO WORK

What We Can Do to Reduce Energy Use for Space and Water Heating

Most of the energy used in the home is for space heating and water heating (60% and 20%, respectively). Reducing the need for space and water heating is one of the easiest ways to reduce overall energy use in the home.

SPACE HEATING

Insulate —
Homes that have a properly designed building envelope, an air barrier to keep wind from blowing through, insulation such as fibreglass or mineral wool to limit heat flow, and a vapour barrier to prevent moisture from getting in are more comfortable and can save you money on your heating bill. R values (or RSI values) are a way of measuring how effective insulation is at limiting heat flow. A higher R value or RSI value means that the insulation is more effective.

Replace drafty doors and windows —
If your doors and windows are drafty, heat will take the path of least resistance and escape – and the same goes for moisture and cold air coming into your house. Make sure that your doors and windows are properly installed and sealed. When you are replacing them, look for doors and windows that are ENERGY STAR® rated. ENERGY STAR® is a labelling system used to rate the energy efficiency of various appliances as well as other products used both at home and at work. The program is voluntary and helps consumers identify appliances that maximize energy efficiency without compromising the technical specifications or performance of the product.

Use your windows to your advantage —
Windows can be a powerful heating tool. During a Canadian winter, south-facing windows receive high levels of solar radiation, which can be used to heat your home. By taking advantage of this natural heating source, you can decrease your requirement for space heating energy.

Replace old furnaces —
Condensing gas furnaces are the most energy-efficient furnaces available to consumers today. They are the perfect choice for a new or replacement furnace in almost any home. These furnaces can be a third more efficient at generating heat, using the same amount of fuel, as an old furnace, reducing emissions associated with fossil fuel combustion and saving you money over the long term.

Try a heat pump —
Heat pumps extract heat from one place and move it into another, the same way that an air conditioner or a refrigerator works. Applications for residential homes include ground source or air source heat pumps used in tandem with solar collectors. The payback period for these systems ranges considerably but can be as little as a few years in some applications.

WATER HEATING

Use less hot water —
The easiest way to reduce your water heating bill is to use less hot water – by taking shorter showers, washing clothes in cold or warm water instead of hot or using water-saving appliances and showerheads. Using less water has far wider implications than reducing your home's energy use. Your municipality uses large amounts of electricity to pump that water to your home, so by reducing your water consumption, you are not only saving on your own energy use but also the energy that your municipality uses.

Switch to a tankless water heater —
Making the change to a tankless water heater is an effective way of reducing the energy demand associated with heating water in conventional water heaters. By heating water only when it is needed, tankless water heaters eliminate the energy demand for keeping water hot at all times. Tankless systems also have a longer lifespan than traditional systems, which are susceptible to rust and corrosion.

Lighting and Appliances Provide Comfort and Convenience

Space and water heating, as well as cooling services, make up the bulk of residential as well as commercial and institutional energy use. But homes and businesses also use energy to operate lighting and appliances. During the day, when the sun is shining, a window and an open shade are often all that is needed to light up a room. But at night, and especially during long winter evenings, people have turned to technologies to provide the convenience of safe, reliable lighting, and the widespread availability of electricity has led to a proliferation of devices and appliances for convenience and enjoyment.

The energy used for lighting and appliances, almost all of it powered by electricity, accounted for 3.5% and 12%, respectively, of residential energy use in 2012.

In the commercial and institutional sector, lighting made up 12% and appliances 20% of energy use in 2012. This sector uses a greater share of its energy on lighting and appliances because large office buildings require more light and use considerable amounts of energy to operate office equipment.

Appliances and Electricity

The electrical power demand of lighting, appliances and other devices that run on electricity is rated in watts (W), while the electrical energy that they use over a given time is rated in kilowatt hours (kWh). Watts are the units used to measure power – energy transfer measured in joules per second. Power is calculated in watts by multiplying volts (V) – used to measure potential electrical energy – by amperes (A or amps) – used to measure the flow of electric charge.

To help visualize the relationship between amperes, volts and watts, try comparing electricity flowing through a wire to water flowing through a hose. In this analogy, the amount of water (electricity) flowing through the hose depends on the hose's diameter (by analogy, amperes – the flow rate of an electric current). The water pressure depends on how far open the hose's faucet is (by analogy, volts – the potential energy of an electric current). The total amount of energy in the hose's water (by analogy, watts) depends on both the volume and the pressure of water. So, the wattage of a current is determined by multiplying its amperes by its volts. For example, a standard 15 ampere, 120 volt electrical outlet can deliver up to 1,800 watts of power. The examples and charts below illustrate the difference between power demand and electricity use over one year for some appliances.

A ceiling fan with a power rating of 50 watts uses about 145 kilowatt hours of electricity per year if left on an average of eight hours a day. A standard modern fridge consumes about 450 kilowatt hours of electricity per year. If, as is usually the case, the fridge stays plugged in the whole year, that works out to an average power demand of about 50 watts. That is the same average power consumption as the fan. The fridge is always working, so it consumes more electricity over the year than the fan, which might stay on only a third of each day. The difference for the dishwasher is even more striking: when it is on, it uses a lot of power – about 1,300 watts, over 25 times as much power as a fridge. But because most people use their dishwasher only about an hour a day, the electricity used by the fridge and the dishwasher work out to be about the same over the year.

Figure 3-9: **Average Power Rating by Appliance**

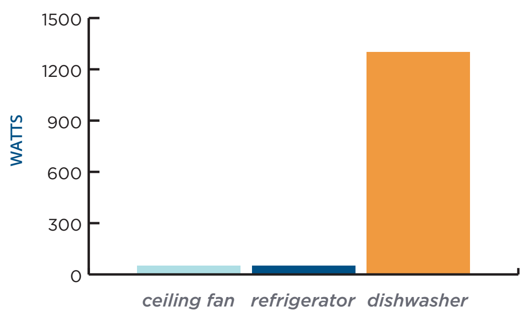


Figure 3-10: **Annual Electricity Use by Appliance**

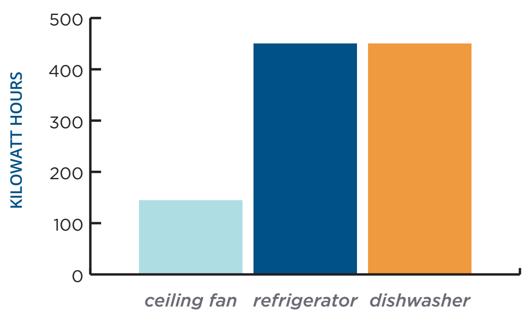
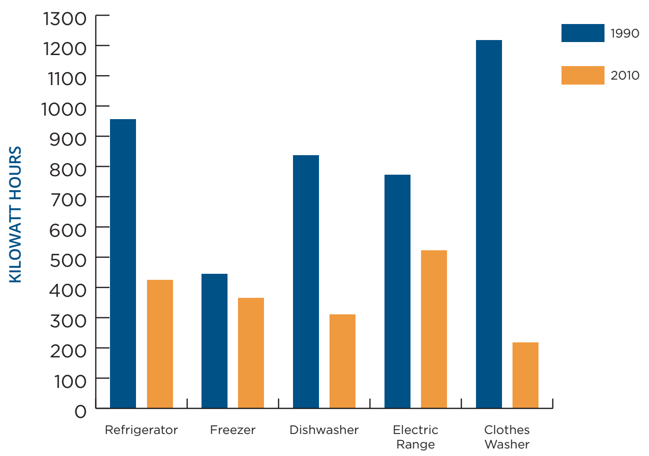


Figure 3-11: **Annual Electricity Use by Appliance, 1990 and 2010**



DRIVERS & IMPACTS: STANDBY AND PHANTOM LOADS

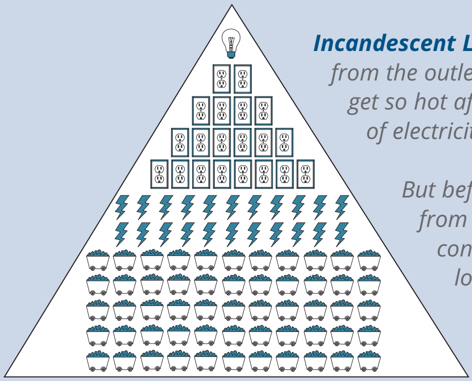
Refrigerators and clocks are left plugged in and running all the time, so they are always using electricity. You might think that your TV stops using electricity when you turn it off. But it does not. Neither does your DVD player, cable box, PVR, stereo or most other electronic equipment. A television or stereo can draw as much as 12 watts of power in standby mode. Each of those devices on its own may use a small amount of electricity, but taken together, they can use twice as much energy as a fridge over a year.

Lighting Technologies

The choices we make about lighting and how we use it can also have a significant impact on our energy use. Let us assume that we want one "unit" of light so that we can read a book at night (the energy amenity). Most Canadians can simply turn on a lamp (the energy service), which requires electricity (an energy commodity). But the type of bulb we use to light that lamp is a key factor in determining our energy demand for that amenity.

Different lighting technologies use varying quantities of electricity.

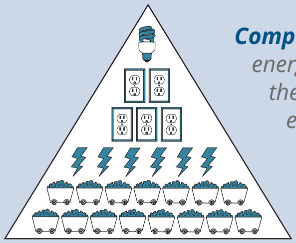
Figure 3-12: **Energy Pathways from a Coal-Fired Power Plant to Incandescent and Compact Fluorescent Lighting**



Incandescent Lighting Pathway *An incandescent bulb converts only about 5% of the electricity from the outlet in the house into light. The rest is converted into heat (which is why light bulbs get so hot after they are in use for a while). So, to produce one unit of light, we need 20 units of electricity.*

But before the electricity is available through the outlet in the house, it needs to travel from the power station through transmission lines. Transmission lines are good conductors, but there is some resistance to the flow of electricity, resulting in energy losses of about 10% (in other words, transmission efficiency is about 90%). So, to make 20 units of electricity at your home, 22 units of electricity are needed before transmission.

If the electricity is generated in a typical coal-fired power plant, the efficiency of conversion is about 40%. That means that to produce 22 units of electricity, 55 units of energy from burning coal are needed.



Compact Fluorescent Lighting Pathway *Now let us assume that we want one unit of light energy by which to read, using a compact fluorescent light (CFL). CFLs convert about 20% of the electricity from the outlet into light. So, to produce one unit of light, we need 5 units of electricity.*

Factoring in losses of about 10% from transmission lines, 6 units of electricity are needed before transmission to make 5 units of electricity for lighting in the house.

If the electricity is generated in a typical coal-fired power plant, the efficiency of conversion is about 40%. That means that to produce 6 units of electricity, 15 units of coal are needed.

Of course, if we turn off the light or read by natural light, there are no efficiencies to consider and no losses either – the energy systems are not activated to provide the service, so no electricity or coal is needed at all. Ideal, but not always possible.

PUTTING THE MULTIPLIER EFFECT TO WORK

What We Can Do to Reduce Energy Use for Lighting and Appliances

Choose ENERGY STAR® appliances and use their energy-saving features
When you are buying new appliances, look for the ENERGY STAR® symbol. ENERGY STAR® is a labelling system used to rate the energy efficiency of various appliances as well as other products used both at home and at work. The program is voluntary and helps consumers identify appliances that maximize energy efficiency without compromising the technical specifications or performance of the product.

Turn off the lights
Typical Canadian households have 20 light bulbs that consume roughly $200 worth of electricity each year. To reduce this, you can use windows and skylights for natural lighting, turn lights off when they are not in use, and use dimmer switches to reduce lighting intensity. If you are redecorating, remember that light-coloured walls reflect up to 80% of incident light, reducing the intensity and number of lights needed to illuminate a space.

Reduce standby loads
Purchasing ENERGY STAR® appliances is also a good way to reduce standby loads because appliances must have low levels of standby electricity consumption to qualify for ENERGY STAR® rating. Another option is to plug electronic equipment into a power bar that shuts off automatically or can be turned off when the equipment is not in use.

Switch to compact fluorescent lamps (CFLs) and light-emitting diodes (LEDs)
Switching to CFLs and LEDs is an excellent option to save electricity in your home. CFLs use 75% less electricity than traditional incandescent bulbs and the reduction with LED lights is even greater. Both last several times longer than incandescent bulbs, saving you money over the long term.

Just by using ENERGY STAR® appliances and switching from inefficient, incandescent bulbs, you can reduce your home's non-heating electricity demand by half. And it can save money – hundreds of dollars a year.

Managing Peak Demand

Having electricity widely available at costs that most consumers can afford has provided Canadians with unprecedented convenience – to read at night or to do laundry or run the dishwasher whenever they want, for example. But this convenience comes at a cost to Canada's energy systems. Not every joule of electricity has equal impacts, and the time at which electricity is used is very important. The biggest impacts – environmental, social and economic – occur during peak times of the day and year, when electricity demand is highest.

In Canada and most other higher-income countries, enough power plants are built to have the capacity to meet peak demand. The construction of new power plants often sparks community opposition, based on a mix of concerns over local air quality, increasing electricity prices, land use impacts, health and safety concerns, property values and aesthetics.

Reducing peak demand by even a few percentage points can eliminate the need to construct a new power plant.

Electricity systems rely on peaker plants to ensure that capacity can be ramped up to meet increasing demand and turned down when demand decreases. Because it has to be available on demand, electricity generated from peaker plants is typically the most expensive. A disproportionate share of energy costs goes towards covering electricity generated at peak times.

Reducing peak demand by a few percentage points can result in big savings for a community's collective energy costs.

Most peaker plants run on fossil fuels, which means that emissions of greenhouse gases and other air pollutants are higher when electricity is generated during peak demand periods. In many Canadian cities, electricity demand is at its highest on hot, humid days in the summer. The higher emissions, combined with the heat and sun, lead to the formation of smog, a toxic mix of gases.

Reducing peak demand by a few percentage points can result in large reductions in greenhouse gas emissions and air pollutants.

Peak electricity demand in Canadian jurisdictions occurs on weekdays, starting around 7 a.m. and lasting until 10 p.m. In most populated areas of Canada, the highest demand is registered during the winter when electric heating and lighting demand is highest, but Ontario's peak occurs on the hottest days of the summer, when air conditioners are on. Individual choices about how and when we use energy, and how we weigh convenience for ourselves against fluctuating demands on energy systems, can have a significant impact on energy costs – to us, the economy and the environment.

PUTTING THE MULTIPLIER EFFECT TO WORK

What We Can Do to Reduce Peak Demand

Reduce your electricity use at peak times —
You can help to reduce peak demand by reducing your energy use during the peak hours of the day. Restricting your peak-time use of appliances such as air conditioners, clothes dryers and electric stoves – appliances that are big consumers of electricity – is particularly effective. But every electricity-consuming device matters – using any of the lights, electronic devices or appliances in your home contributes to peak electricity demand. In Chapter 4, we will look at some of the strategies, such as time-of-use pricing, that utilities are using to encourage off-peak use.

Transportation Enables Access

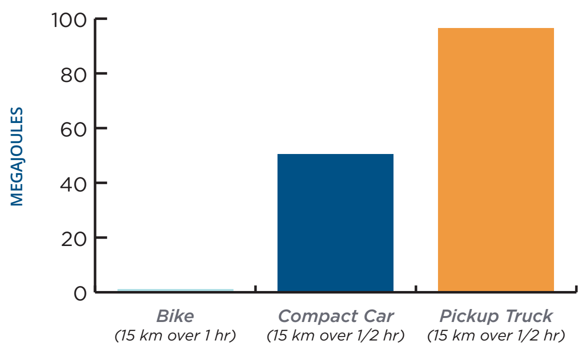
In addition to providing for heating, cooling, lighting and appliance services, energy is used to move people and goods, using automobiles, trains, planes and marine freighters.

Fossil fuel–based transportation fuels, mainly gasoline, diesel and aviation fuel, make up over 99% of the energy used in internal combustion engines (ICEs) in all types of vehicles. These fuels are so dominant because they have high energy densities, are easy to store and have historically been relatively affordable.

The majority of passenger cars and light trucks in Canada use an internal combustion engine that burns gasoline. A smaller share of Canadian cars burn diesel, and less than 1% of vehicles burn propane or use an electric motor. In heavy freight transportation, most trucks and locomotives burn diesel, while marine freighters use a mix of diesel and heavy residual fuels.

The transportation sector is special because of the dominant role that liquid fossil fuels play in supplying energy: no other sector is so reliant on one energy source.

Figure 3-13: **Energy Used by Transportation Mode to Travel 15 kilometres**



Transportation and Energy Use

When you go for a walk or ride your bike, your body is doing work – more work than it would be doing if it were at rest. Your body does this work by converting chemical energy into mechanical motion.

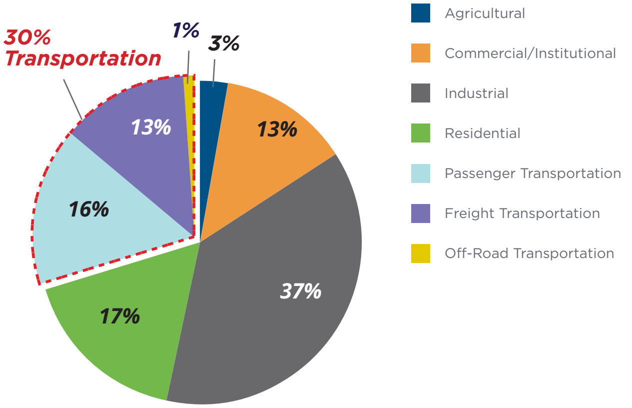
A 70 kilogram person riding her bike at 15 kilometres per hour for a whole hour consumes about 1.26 megajoules (1,260,000 joules) of energy.

A small, ICE-powered car consumes nearly 50 times that energy to travel the same distance, while a heavier pickup truck with a larger internal combustion engine will consume twice as much energy as the smaller car and almost 100 times more energy than the cyclist. Of course, pickup trucks are designed to haul heavy loads, not to provide individual mobility services.

Getting Around (Automobiles, Trains and Planes)

Moving tens of millions of people every day, and shipping all of the goods that they produce and consume, takes a lot of energy. Transportation is the second-largest energy end-use sector in Canada after industry, accounting for nearly one-third of the energy commodities used by Canadians in 2011 (see Figure 3-14). The transportation sector has also seen the largest growth in energy use, increasing 41% between 1990 and 2011 – double the population growth of 20% over the same time frame.

Figure 3-14: **Energy Used in Transportation Compared to Other Sectors, 2011**



**Off-road vehicles are vehicles not registered for travel on roads. ATVs, snowmobiles, golf carts and some military vehicles are examples of off-road vehicles.*

Moving People (Personal Transportation)

Personal transportation is responsible for just over half of total transportation energy use in Canada. Seventy-eight per cent of personal transportation energy is provided by gasoline for cars and light passenger trucks, and nearly 18% by aviation fuel for air travel. Diesel for cars, trucks and buses, along with a small amount of electricity used to power urban transit and commuter rail services, make up the remaining share.

Moving Goods (Freight Transportation)

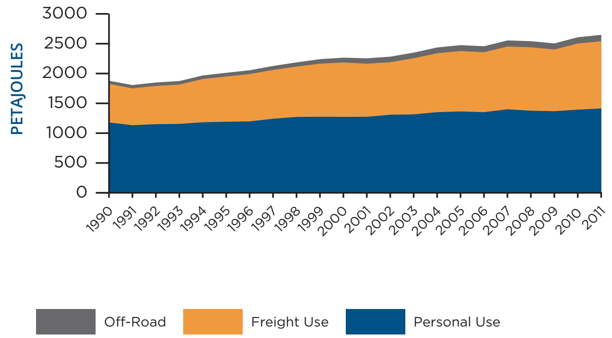
Canadians are consuming more goods and transporting more raw materials destined for manufacturing and export. Those goods and materials are increasingly being transported by trucks using diesel. Higher-valued, manufactured goods and materials (e.g., consumer products) are most often shipped by trucks using diesel, whereas lower-valued, raw materials (e.g., ore, coal) are most often shipped in bulk by rail, which also relies on diesel. Freight transportation accounted for 43% of total transportation energy use in 2011.

Figure 3-15: **Transportation Energy Use, 1990-2011**

Energy Use for Transportation Is Increasing

The increase in transportation energy use has been driven by the increased movement of goods and people.

Energy used in freight transportation increased 75% between 1990 and 2011. We are consuming and exporting more goods, and those goods are travelling longer distances, increasingly by truck (although rail has recently increased its share of consumer product shipments using intermodal containers).



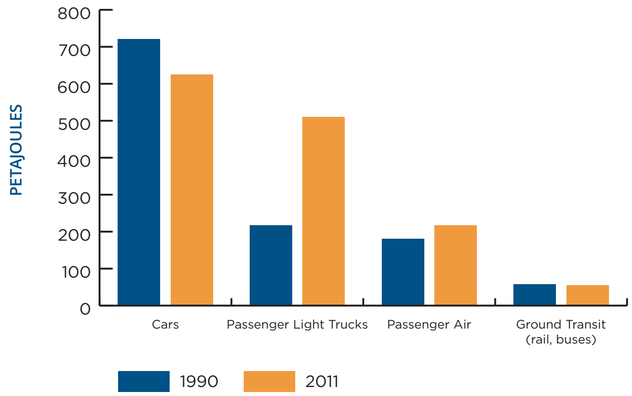
The growth in personal transportation energy use is less steep than for freight transportation, but it is still significant at 20%. Most of this growth is the result of the use of heavier, more powerful vehicles and an overall increase in personal vehicle use for commuting and for daily necessities in suburban areas where there are fewer effective transportation options. The lack of improvement over the last two decades in the fuel efficiency of new cars and light trucks has not helped to mitigate this increase.

For more information, see Pollution Probe's
Primer on Automobile Fuel Efficiency and Emissions.

Moving People

Canadians increased by 41% the amount of energy they used to get around between 1990 and 2011.

Figure 3-16: **Energy Use by Personal Transportation Mode, 1990 and 2011**



Passenger Cars

The amount of energy used to drive cars decreased by 13% between 1990 and 2011.

Light Trucks

Over the same period, the energy used to drive passenger light trucks more than doubled, for a 135% increase. Light trucks are a classification of passenger vehicles that includes pickup trucks, sport utility vehicles (SUVs), minivans and crossovers. These vehicles use more energy for each kilometre travelled because they are heavier, and they tend to have larger engines than cars.

Aircraft

Energy use for air travel increased by 20% during this period.

Personal transportation energy use has been increasing because more Canadians are driving longer distances and because they are driving in heavier, more powerful vehicles.

Figure 3-17:
Passenger Kilometres Travelled

Longer Distances

Canadians increased their kilometres travelled by road by 39% between 1990 and 2010.

We are flying more too, with over twice as many kilometres travelled by air over the same period.

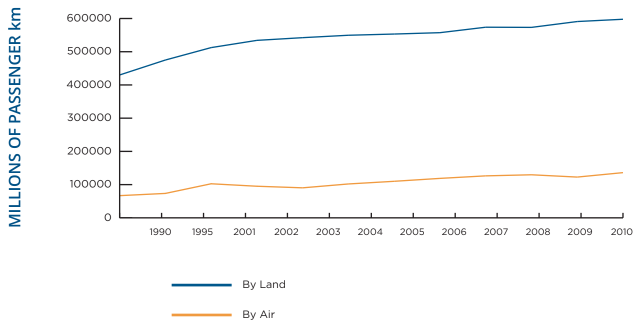
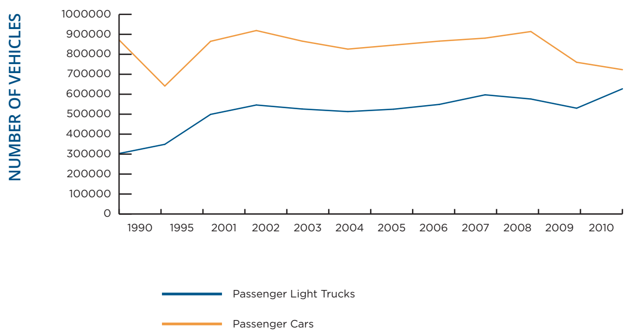


Figure 3-18:
Personal Vehicle Sales

More and Bigger Vehicles

The number of light trucks sold annually more than doubled between 1990 and 2010, whereas the number of cars sold in 2010 was down 17% from 1990.



Generally speaking, larger vehicles with more powerful engines use more gasoline. When more of these larger vehicles are used for more of the kilometres travelled, total energy use goes up.

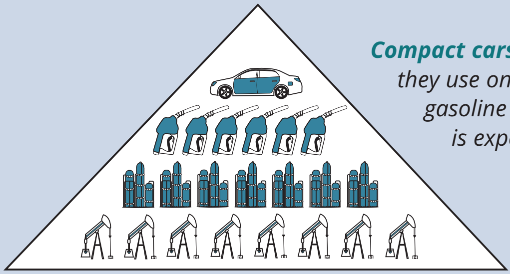
Comparing Transportation Technologies

Remember that energy is defined as the ability to do work. For cars and other vehicles, the "work" is turning the wheels to move along the road.

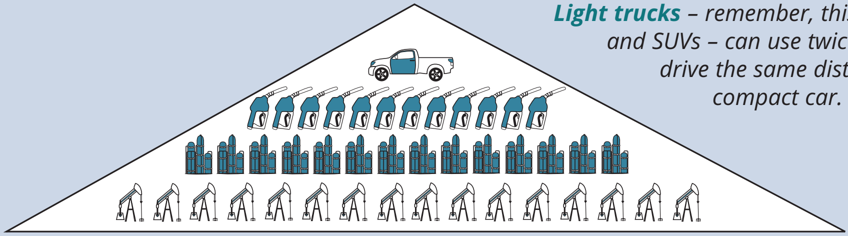
The fuel supplied to any vehicle represents 100% of the energy available for conversion into motion at the wheels; there is no other source of energy available. However, only a fraction of the energy in the fuel is used to move the automobile.

We can compare the energy pathways for two vehicles commonly seen on the road in Canada.

Figure 3-19: **Personal Transportation Energy Pathways**



Compact cars *are usually a fuel-efficient option. But they use only about one-sixth of the energy in the gasoline to move people. The remaining energy is expelled as waste heat.*



Light trucks *– remember, this includes pickup trucks and SUVs – can use twice as much gasoline to drive the same distance as a smaller, compact car.*

In a typical gasoline-powered vehicle used for urban driving, only about 13% of the fuel energy that is delivered to the engine actually makes it to the wheels to move the vehicle.

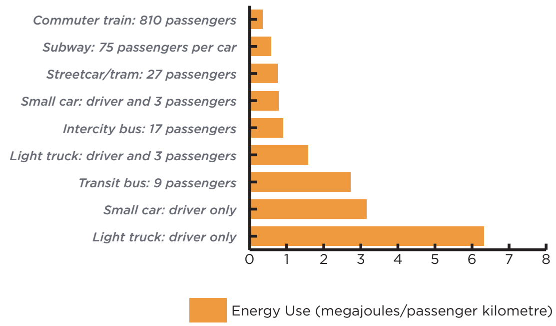
Figure 3-20: **Energy Use per Passenger Kilometre by Transportation Mode**

Urban and Intercity Transit

There are other transportation technologies besides cars and trucks.

Trains, buses and streetcars together make up less than 4% of the total personal transportation energy use in Canada. This is partly because these transportation modes service limited areas in urban regions, and because they tend to use less energy per kilometre travelled per passenger.

It is important to keep in mind that energy used is shown here as per kilometre travelled per person. If you are the only person on the bus besides the driver, the energy used per person can be higher than for a typical car or light truck.



Data have been compiled from a number of sources and are representative of the general magnitude of energy use per passenger kilometre travelled.

When energy is supplied by gasoline and other fossil fuels, lower energy use means lower greenhouse gas emissions and air pollutants.

DRIVERS & IMPACTS: PHEVS, HEVS AND BEVS

Plug-in hybrid electric vehicles, or PHEVs, have relatively small batteries that, when charged, can power vehicles for short distances – in the range of 20 to 60 kilometres. When the batteries are depleted, the vehicles switch over to gasoline power. PHEVs can charge their batteries using the same charging infrastructure as BEVs.

Hybrid electric vehicles, or HEVs, are powered only by gasoline and are not plugged in to recharge. They can offer improved fuel economy and reductions in air pollution and greenhouse gas emissions because, in addition to internal combustion engines, HEVs have electric propulsion systems that can yield up to 20 kilometres of range when fully charged. HEVs typically use regenerative braking to recharge their batteries. Some models use their internal combustion engines to generate electricity by spinning an electrical generator to either recharge their batteries or directly power electric drive motors.

Battery electric vehicles (BEVs, or simply EVs) are powered solely by electricity for a range of 100 to 400 kilometres and require regular charging because they have no gasoline engine. Most current BEV models use lithium-ion batteries with capacities ranging from 16 to 85 kilowatt hours.

PUTTING THE MULTIPLIER EFFECT TO WORK

What We Can Do to Reduce Energy Use for Personal Transportation

Depending on where you live and how you choose to get around, your transportation habits can easily make up the bulk of your energy use. So what can you do to help?

Walk, run, cycle

Any time you choose to use your own muscles to get around by walking or biking, you are displacing the fossil fuels that you would use if you were driving. Compared to driving a compact car, each 10 kilometres you walk or bike can reduce your personal greenhouse gas emissions by up to 2.5 kilograms. Compared to driving a light passenger truck, the reduction would be 5 kilograms of greenhouse gases. And you get the benefit of the exercise too.

Telecommute and teleconference

Telecommuting instead of driving, even for just part of the work week, or making use of increasingly sophisticated and inexpensive online teleconferencing services instead of flying to a distant meeting can dramatically reduce your energy use.

Use public transportation

If you have access to public transportation, use it. You contribute to these services through your property taxes or rent, so why not use them? Public transportation – commuter trains, subways, streetcars, buses – can be a great way to reduce your personal energy use and greenhouse gas emissions, and it can also save you money on gas and time spent in gridlock. You can relax, read or catch up on sleep instead of having to drive. If you are not used to taking public transportation, try it out once a week for a few months. You might well find it a welcome change in your lifestyle.

Carpool

Sharing a ride with another person cuts energy use in half, if the alternative is both of you driving separate vehicles. If driving is unavoidable, carpooling is an excellent option for lowering demand for fossil fuels and reducing greenhouse gas emissions. The more participants the better – getting three or more people in the car multiplies the reductions in energy use and greenhouse gas emissions.

Choose a fuel-efficient vehicle that meets your needs

Make fuel efficiency a priority in your next car purchase. Switching to a fuel-efficient car does not mean buying a car that is too small or otherwise unsuited to your needs – there are highly fuel-efficient models available in all classes of vehicles. Checking fuel consumption ratings is easy to do online, and your car dealer can help too.

Minimize engine idling

A car engine at idle produces emissions unnecessarily – it is a waste of both fuel and money.

Moving Goods

The share of energy used for shipping freight increased significantly between 1990 and 2010, primarily as a result of the increased use of heavy trucks for transporting goods.

Figure 3-21: **Freight Transport Modes, 1990 versus 2010**

Heavy Trucks

This mode of transportation can be seen at work on every major highway in the country. The use of the tractor-trailer, or "semi," has grown considerably, and energy use by these powerful vehicles grew nearly 160% between 1990 and 2010.

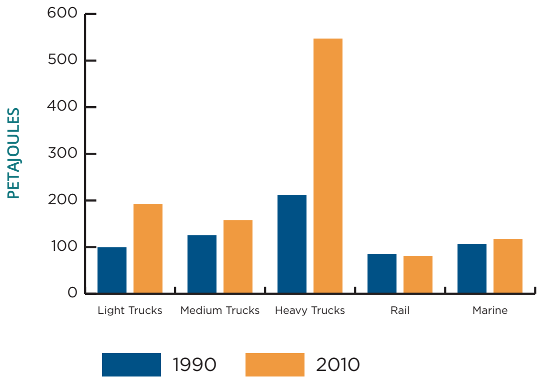
Other Trucks

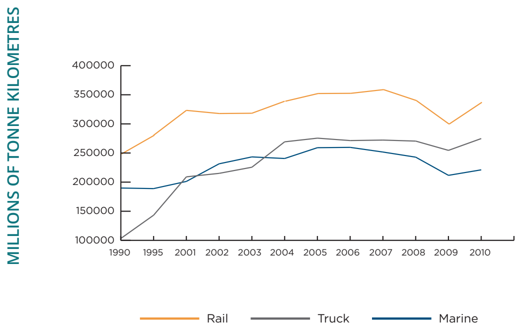
The energy used by all types of trucks has increased substantially since 1990. Trucking is responsible for nearly all of the growth in the transportation sector.

Even though trucks use more energy than other modes of freight transportation, rail is responsible for the shipping of more goods over longer distances.

International freight is shipped almost entirely using large marine cargo ships. On land, rail is primarily used for the transportation of large, heavy goods, such as lumber, coal and rolled metal products, that tend to be priced lower than manufactured goods.

Canadians are transporting more goods over longer distances by all freight modes, but the highest growth has been in freight movement by truck.





DRIVERS & IMPACTS: THE CONVENIENT TRUCK

When it comes to transporting goods, the trends are clear: more of the goods Canadians consume at home and export to the United States are shipped by truck, and increasingly by large tractor-trailers. Energy used to transport freight by trucks of all sizes doubled between 1990 and 2010, and the energy used for trucking goods now accounts for a full third of total transportation energy use.

Goods are increasingly being transported by truck because of the advantages trucks offer over other freight transportation modes, such as rail. Freight transportation by truck is more expensive than rail, but it offers superior convenience and flexibility and can meet the demand for faster delivery of higher-valued products, such as pharmaceuticals, food and other perishable goods, shipped over longer distances.

The widespread road networks in North America also contribute to the convenience and accessibility of truck transportation.

Powering Industry

Industry accounted for 38% of Canada's total energy end use in 2011, the largest of the major economic sectors. Industry uses energy for the extraction of natural resources and the manufacture of goods. Some of these resources and products are used domestically, but Canada is a large exporter of a wide range of products, most of which are destined for the United States.

Figure 3-22: **Energy Used in Industry Compared to Other Sectors, 2011**

Manufacturing (68% of industrial energy)

Canada has a strong manufacturing sector that produces a wide variety of goods, such as cement, iron and steel, and petroleum products. Canada's manufacturing sector used over twice as much energy as the resource extraction sector in 2011.

Resources (32% of industrial energy)

The main industries in this sector include mining, oil, natural gas and coal extraction, and forestry.

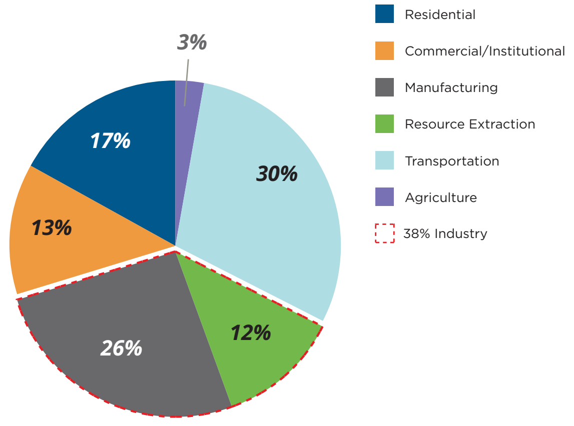
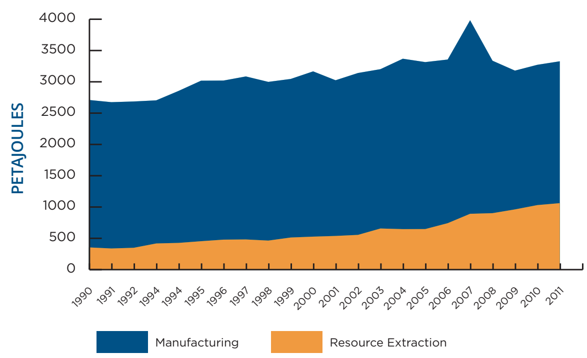


Figure 3-23: **Trends in Industrial Energy Use, 1990-2011**

Growing Energy Use for Resources

The manufacturing sector accounted for nearly 90% of total industrial energy use in 1990, but by 2011, this share had declined to 68%.

Over the same time, energy used in resource extraction rose by nearly 300%.



All of these sectors use energy principally to generate heat. Melting iron to produce steel, boiling and breaking crude oil into various petroleum products, and reducing trees to pulp require a tremendous amount of heat energy.

DRIVERS & IMPACTS: SMOG, TOXICS AND AIR QUALITY

Smog is a noxious mixture of vapours, gases and particles that often appears as a yellowish-brown haze in the air, lingering until it is dispersed by the wind or a change in the weather. It is formed in the lower atmosphere, just above the Earth's surface, when a variety of sources release smog-forming pollutants into the air. These pollutants are usually warmer than the surrounding air and tend to rise. Heat and sunlight cause chemical reactions to occur between them, forming ground-level ozone. Particulate matter is also released into the air or is formed later within the atmosphere through chemical reactions. These particles, together with ground-level ozone, are the main components of smog.

Smog pollutants can be generated by naturally occurring processes and by human activities. Natural sources of pollutants include forest fires and volcanoes, which add particles and gases to the air; trees, which emit volatile organic compounds; soil erosion, which produces dust; and biological processes in soil that create nitrogen oxides. The largest source of air pollution affecting human health and the environment, however, is human activity, primarily the combustion of fossil fuels (i.e., petroleum products, natural gas and coal) to transport people and goods, heat and cool buildings, generate electricity and power industry.

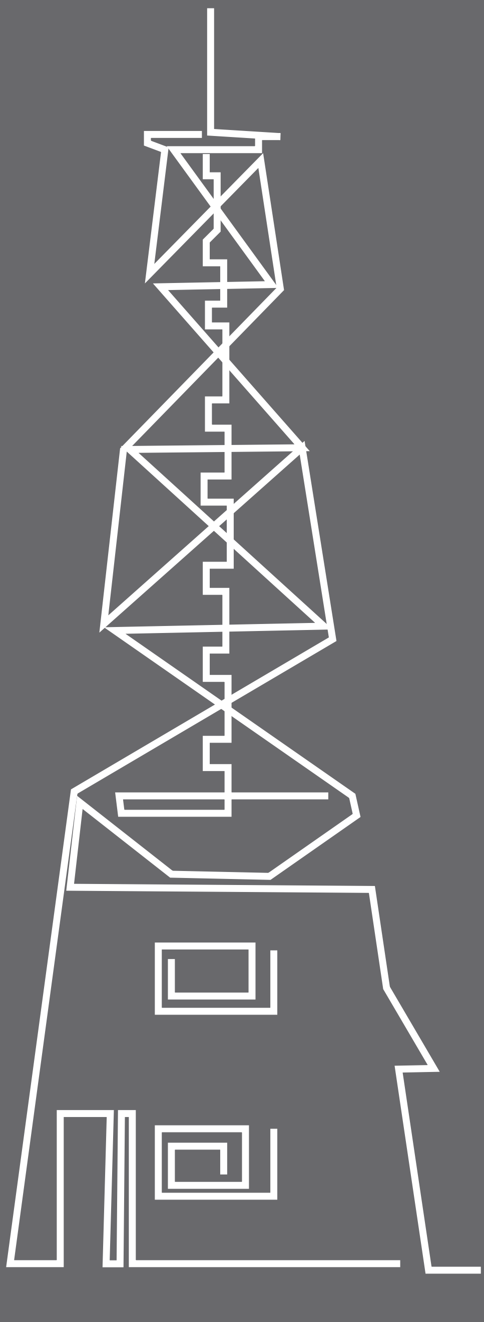
Transportation is the largest single human-produced source of outdoor air pollution in Canada. On average, each vehicle registered across the country emits approximately five tonnes of air pollutants and gases annually, mainly carbon monoxide, nitrogen oxides, volatile organic compounds and carbon dioxide. The introduction of the catalytic converter to automobiles over 30 years ago, along with better fuel efficiency, resulted in a dramatic drop in smog-related emissions from cars. However, while cars are becoming more fuel efficient and less polluting on an individual basis, the growing number of vehicles on the roads offsets some of the benefits of improved automotive technologies.

All fossil fuel–based electricity-generating facilities produce carbon dioxide, and coal-fired electricity generating stations are leading contributors of human-sourced sulphur dioxide and nitrogen dioxide, as well as mercury. Two-thirds of global electricity is generated through the combustion of fossil fuels, and about 60% of the fossil fuels burned are coal.

For more information, see Pollution Probe's ***Smog Primer.***

Summary

In this chapter, we have learned that our energy amenities – comfort, convenience, access and enjoyment – are supplied by energy services: heating and cooling, lighting and appliances, and transportation. Different technologies make these energy services possible, and some technologies are more efficient and effective at supplying services than others. Our choices about the means by which we obtain energy services affect the demand for energy commodities and energy sources. By just how much is explored in the next chapter.

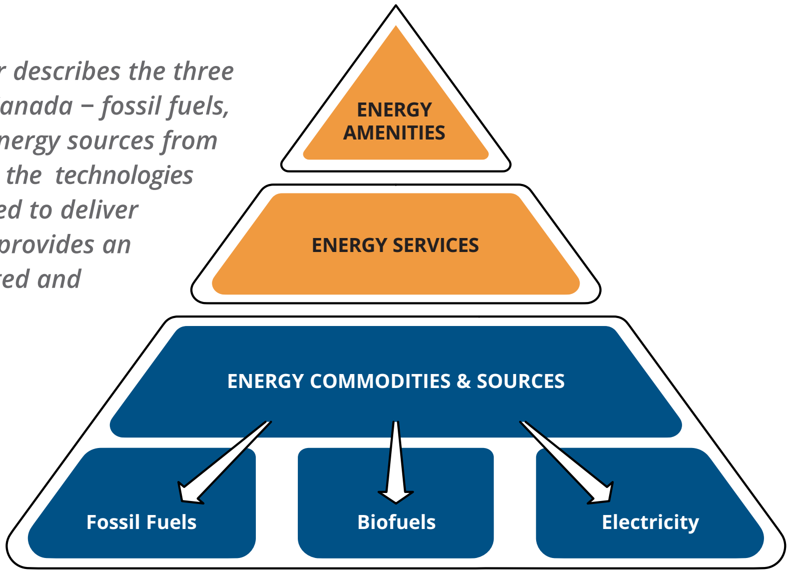


CHAPTER FOUR

Useful Forms of Energy
Energy Commodities and Sources

We have now worked our way from the top of the energy pyramid to the third and final tier. In chapter 2, we explored energy amenities, the things we really want – comfort, convenience, access and enjoyment. In the third chapter, we looked at how we obtain comfort, convenience, access and enjoyment through energy services such as heating and cooling, lighting and appliances, and transportation. Energy commodities are used to power the technologies that provide these energy services, and energy commodities are produced from energy sources. Viewing energy commodities and energy sources as part of energy systems allows us to better understand how our choices – in energy amenities and energy services – form part of the pathways that make up our energy systems.

As the energy pyramid indicates, this chapter describes the three major categories of energy commodities in Canada − fossil fuels, biofuels and electricity – and discusses the energy sources from which these energy commodities are derived, the technologies used to derive them and the infrastructure used to deliver them to us, the end-users. This chapter also provides an overview of how energy sources are distributed and used across the country.



What Are Energy Commodities and Energy Sources?

Energy commodities power the technologies that we use in our homes and businesses. In this primer, energy commodities are defined as finished products − for example, the gasoline in our cars or the natural gas burned in our home furnaces.

Most energy commodities are derived from a particular energy source. For instance, gasoline and other petroleum products (energy commodities) are produced from crude oil (an energy source). And natural gas (an energy commodity) is produced from raw natural gas (an energy source).

The three main categories of energy commodities – fossil fuels, biofuels and electricity – are used to power a variety of technologies that we depend on for heating and cooling, lighting and appliances, and transportation. We start this chapter by taking a look at fossil fuels because these are Canada's – and the world's − predominant energy commodities.

FOSSIL FUELS

Fossil fuels are hydrocarbon-based energy commodities that can take solid, liquid and gaseous forms. They consist of dead plant and animal matter compacted by millions of years of sedimentation and subjected to high levels of pressure. There are three main categories of fossil fuels: coal, petroleum products and natural gas.

The Benefits of Using Fossil Fuels

Most fossil fuels were easily accessible and relatively inexpensive until the latter part of the 20th century. As a result, Canadians and citizens of other higher-income countries became accustomed to fairly stable prices for gasoline and diesel for cars and trucks, and coal was available as a low-cost way to supply the growing demand for electricity. With access to abundant energy sources, Canada became a major producer of fossil fuels, some of it for export abroad, mainly to the United States – one of the world's largest fossil fuel consumers.

Fossil fuels possess properties that make them consummate energy commodities. They are relatively easy and safe to store and transport, which makes them ideal for providing transportation services. Fossil fuels also have high energy densities, which means that when a kilogram of coal or a litre of diesel is combusted, it releases more heat than burning a kilogram of wood or a litre of ethanol.

The energy density of a fuel is the amount of energy released per unit amount of that fuel combusted. For fossil fuels, such as gasoline and diesel, the energy density is determined by the fractions of carbon and hydrogen in each hydrocarbon fuel. Fuels with higher carbon content typically have higher energy densities but also release higher levels of greenhouse gases.

The Problems with Using Fossil Fuels

Fossil fuels are so useful, and historically have been so abundant, that we use a lot of them. This causes a number of problems. When they are combusted, fossil fuels produce air pollutants that contribute to smog, and they are the primary human-based source of greenhouse gas emissions.

Air pollutants associated with fossil fuel use can increase the number of cases and the severity of a variety of cardiovascular and respiratory diseases and infections in humans.

Leaving aside the environmental impacts of fossil fuels, a major concern with regard to their continued use is the simple fact that they are non-renewable. Most of the world's fossil fuels began forming over 300 million years ago, and the current rate of human consumption far surpasses the rate at which they are being formed.

Fossil fuel extraction invariably causes harm to local ecosystems through the alteration of the natural landscape. Extraction and distribution can also lead to direct releases of fossil fuels and associated chemicals into the environment. Such releases can result from pipeline leaks, train, tanker and oil rig accidents, improperly sealed wells, tailings pond breaches, mine flooding, and seepage into groundwater from non-conventional extraction methods such as hydraulic fracturing and steam-assisted gravity drainage (SAGD).

Certain forms of fossil fuel extraction require massive volumes of fresh water and natural gas to help bring oil and gas to the surface. In much the same way that fossil fuel usage adversely affects human health, it also adversely affects the health of other organisms by reducing air quality, causing acid rain and ocean acidification, and warming the global climate through the greenhouse effect.

The scale of the environmental and human health problems attributable to the use of fossil fuels means that the true costs of using them (often referred to as "externalities") are not captured in their price. Indeed, in many parts of the world, including Canada, it is often possible to purchase a litre of gasoline or diesel for less than the cost of a litre of bottled water. Many governments still subsidize the production of fossil fuels in the hope that their use will lead to a more prosperous economy and lower transportation and energy costs. This trend is beginning to shift, however, in part due to the recognition of the staggering costs of externalities associated with fossil fuel use. An increasing number of governments are now choosing to eliminate fossil fuel subsidies and implement carbon pricing schemes that tax fossil fuel users, both to discourage the use of these non-renewable fuels and as a way to generate revenue to pay for environmental and human health impacts related to their use – impacts that burden society as a whole.

Different forms of electricity generation have different impacts on greenhouse gas emissions into the Earth's atmosphere. As Figure 4-1 illustrates, these differences can be vast. While no form of electricity generation is completely free of negative environmental impacts, some forms clearly have less impact than others.

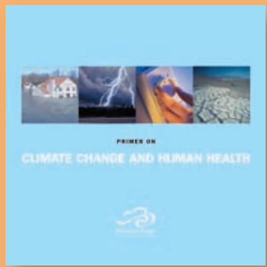
Figure 4-1:
Greenhouse Gas Emissions Intensity of Common Forms of Electricity Generation

Emissions Intensity (g CO_2e/kWh)	
Coal	1001
Oil	840
Natural Gas	469
Solar PV	46
Geothermal	45
Biomass	18
Nuclear	16
Wind	12
Ocean	8
Hydro	4

DRIVERS & IMPACTS: FOSSIL FUELS, GREENHOUSE GASES AND CLIMATE CHANGE

Energy from the sun drives the Earth's climate. As the sun's energy reaches the Earth's surface, some of it is reflected back and some of it is absorbed. The absorbed energy warms the Earth and is then radiated back out towards space as infrared energy. Certain chemical compounds in the Earth's atmosphere act as "greenhouse gases," absorbing the radiated infrared energy and thereby trapping some of the heat in the atmosphere, warming the Earth's surface to an average of 14 °C. This phenomenon, the "natural greenhouse effect," keeps the Earth in a temperature range that allows life on this planet to thrive. Without it, the sun's heat would escape and the average temperature of the Earth would drop to −19 °C.

Any changes in atmospheric greenhouse gas concentrations, therefore, affect the amount of energy stored in the atmosphere. For example, when the amount of carbon dioxide – a major greenhouse gas – is increased, more heat is trapped in the atmosphere. This "enhanced greenhouse effect" causes the Earth's surface temperature to rise. Since the beginning of the industrial revolution in the mid-18th century, the concentration of all major greenhouse gases in the atmosphere has increased, contributing to the changes in climate that the world is currently experiencing. Leading scientists around the world have predicted that increasing temperatures will lead to changes in many aspects of weather, such as wind patterns, precipitation, and the severity and frequency of extreme weather. A report released in 2007 from the Intergovernmental Panel on Climate Change (IPCC) declared, "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level."



*For more information, see Pollution Probe's **Primer on Climate Change and Human Health.***

Our collective emissions of greenhouse gases have been rising steadily since the Industrial Revolution, and the concentration of greenhouse gases in the atmosphere continues to increase. Burning fossil fuels for transportation, heating services and electricity generation is responsible for about 80% of worldwide human emissions of greenhouse gases.

Figure 4-2:
Atmospheric Concentrations of Common Anthropogenic Greenhouse Gases from 1750 to 2013

Year	Carbon Dioxide (CO_2)	Nitrous Oxide (N_2O)	Methane (CH_4)
	ppm	ppb	ppb
1750	278.0	270.0	700.0
1800	282.9	273.0	741.6
1850	284.7	275.4	791.6
1900	295.8	279.8	879.4
1920	303.0	282.9	978.1
1940	310.4	286.7	1088.9
1950	310.7	289.0	1147.5
1960	316.9	291.4	1247.5
1970	325.0	294.9	1386.0
1980	338.7	300.6	1547.1
1990	353.7	308.8	1709.3
2000	368.9	315.8	1774.4
2005	379.0	319.2	1774.6
2010	388.7	322.9	1810.5
2013	395.5	325.7	1813.9

Greenhouse gas concentrations are typically measured in parts per million (ppm) or parts per billion (ppb), which represent the concentration of a given greenhouse gas molecule within every million or billion molecules that make up the air in the Earth's lower atmosphere.

Coal

In its natural state, coal is a black or brownish rock consisting mostly of carbon. As an energy commodity, it is a solid fuel produced from coal deposits, the energy source, located beneath the Earth's surface. Coal is largely burned to produce steam for electricity generation.

As a solid, coal is easy to store and transport. It is rich in carbon, with a high energy density, and so it releases a lot of heat and greenhouse gases when burned. Sources of coal are abundant in North America, and the commodity is relatively inexpensive as a fuel.

TYPES OF COAL

Coals are ranked based on their carbon content.

Higher-carbon coals have higher energy densities. They burn hotter, releasing more energy and less particulate matter.

Anthracite *(over 87% carbon) has the highest carbon content and energy density. It is the most expensive type of coal, used for residential and industrial heating.*

Bituminous *coal (77 to 87% carbon) contains bitumen – the hydrocarbons that make up Canada's oil sands. Certain types of bituminous coal are used to make coke for steelmaking and other industrial uses.*

Sub-bituminous *coal (71 to 77% carbon) has properties somewhere between bituminous and lignite coals. This type of coal is commonly used for electricity generation.*

Lignite *(60 to 70% carbon) has the lowest carbon content and is the least costly type of coal. It is most commonly used for electricity generation.*

Canadian Coal Production

Canada is the 14th largest producer of coal in the world. All four types of coal are found in Canada, though only three are mined here, the exception being lignite. Active mining takes place in British Columbia, Alberta, Saskatchewan and New Brunswick.

Canada exports about 40% of the coal it extracts. Japan, China and South Korea are Canada's largest export markets for coal.

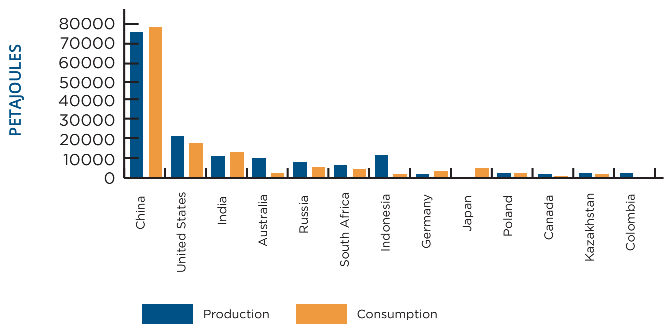
Figure 4-3: **Canada's Coal Deposits**

Global Coal

Global coal production and consumption are dominated by three countries. China, the United States and India rely on coal for much of their electricity generation (63, 40 and 59%, respectively). All three countries also use smaller amounts of coal to make steel and cement. China is the world's largest steelmaker.

China and India are planning to build more coal-fired power plants to keep up with their rapid economic growth and increasing demand for electricity, but they are also making significant investments in renewable energy options.

Figure 4-4: **Global Coal Production and Consumption, 2012**



Coal Processing

Coal is mined like other minerals and metals. It is extracted from the ground by underground mining or open-pit surface mining, depending on the geology of the deposit. Once mined from surface or underground sources, coal is processed to make it more suitable for combustion and other uses. Chunks of coal are commonly washed or cleaned to remove contaminants and then crushed before shipping. Large machines pulverize coal chunks into a powder that allows for more complete fuel combustion.

DRIVERS & IMPACTS: COAL MINING

Ash, soot and other emissions from coal extraction and processing affect local air quality and ecosystems. Mining processes also release acids that can contaminate groundwater and thereby jeopardize drinking water and irrigation sources. In addition, surface mining drastically alters landscapes.

Coal mine safety is an ongoing concern. Accidents have occurred from time to time, in which miners have been trapped underground in collapsed tunnels, beyond rescue.

Coal Transportation and Storage

Coal is typically shipped by rail. A train that is 125 cars long can handle over 13,000 tonnes of coal per trip. Coal from British Columbia and Alberta is sent to Japan, China and South Korea, Canada's largest coal importers, on large, seagoing cargo ships.

Coal is relatively non-reactive and stores well, even when exposed to the weather. It is usually stored outside, and large piles of it can be seen at most coal-fired power plants in Canada.

Using Coal: Electricity and Canadian Coal-Fired Power Plants

Thermal coal is combusted in power plants to produce electricity. Over 90% of the coal used in Canada is used for electricity generation. The other 10% is metallurgical coal, used to make steel.

In 2014, nearly 9% of Canada's electricity was generated from coal, using steam turbines. There are coal-fired power plants in Alberta, Saskatchewan, Nova Scotia, and New Brunswick. In 2003, Ontario was home to over 7.5 gigawatts of coal-fired electricity generation, which represented 24% of the province's electricity and over a third of all coal-fired generation in the country. By 2014, Ontario had successfully completed a phase-out of all of its coal plants, as part of an aggressive provincial energy policy driven by concerns related to climate change and human health. As a result of the closure of its coal plants, Ontario's greenhouse gas emissions from the electricity sector decreased by roughly 75%.

What is Carbon Capture and Storage?

Carbon capture and storage (CCS) technologies cool and condense carbon dioxide emissions into a liquid and then pump the liquid underground to be stored in saltwater aquifers, coal beds (where it can stimulate production of natural gas or oil) and natural gas fields (where the carbon dioxide can be used to increase a well's output).

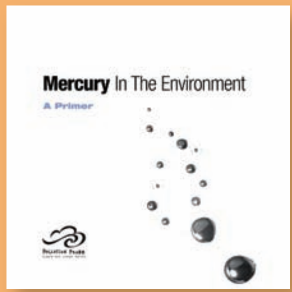
Some view CCS as a possible way to prolong the lives of coal-fired power plants. The Governments of Alberta and Canada are investing billions of dollars in CCS research to investigate its economic and technical feasibility.

But CCS is energy intensive. The process of liquefying the hot carbon dioxide exhaust gases produced during fuel combustion uses a lot of energy, which is supplied by burning even more coal. This increased fuel use makes the process expensive.

There are also other emissions from coal combustion that are of serious concern and that are not addressed by CCS. Mercury is one.

DRIVERS & IMPACTS: MERCURY

Coal-fired power plants are the biggest source of global mercury emissions. Small concentrations of mercury are embedded in the coal and are difficult to isolate. When the coal is burned, the mercury is vaporized and released. In Canada, coal-fired power plants accounted for approximately 25% of all mercury emissions in 2012. Once in the atmosphere, mercury can travel long distances, eventually being deposited onto land and water through rain and snow. As the mercury enters lakes, rivers and streams, it can transform into methylmercury, which readily bioaccumulates in fish and other aquatic organisms. The mercury is then passed on to us when we eat contaminated fish. Mercury is a harmful neurotoxin that can interfere with the development of the brain and the nervous system.



*For more information, see Pollution Probe's **Mercury In The Environment – A Primer**.*

Petroleum Products

Petroleum products are liquid hydrocarbons. As liquids, they can be transported relatively easily via pipelines and in large tanks on board trucks, railway cars or on ships. Petroleum products are derived from crude oil.

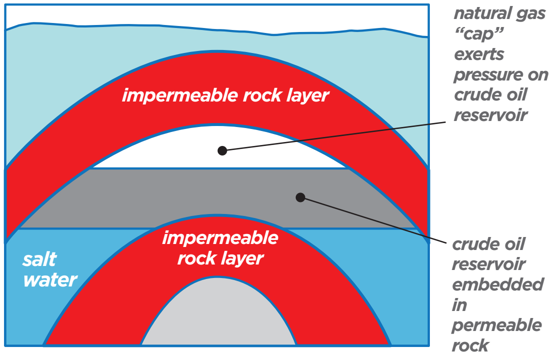
Crude Oil (Petroleum)

Crude oil, or petroleum, is a black, brownish or amber liquid that is a complex mixture of hydrocarbons. It is valued as the raw material used to produce a variety of petroleum products, primarily gasoline and diesel. Crude oil is found in deposits of varying size throughout the world and can be located near the Earth's surface or kilometres underground, as well as beneath the ocean or sea floor. Crude oil can be described as conventional or non-conventional; its quality and quantity vary considerably from deposit to deposit.

Conventional Crude Oil

Conventional deposits contain crude oil that can flow relatively easily through pipes and drilling wells. Conventional deposits are found trapped between layers of salt water and raw natural gas. It is this "cap" of raw natural gas that exerts pressure on the crude oil reservoir, forcing the liquid to gush out when a well is initially drilled.

Figure 4-5:
Conventional Crude Oil Deposits



Non-Conventional Crude Oil

Non-conventional deposits contain extra heavy (dense) crude oil that is thick and viscous. In its natural state, non-conventional crude oil does not flow through wells and pipes. It must be heated or diluted to be pumped up from the ground and transported through pipelines. Where these deposits have been exposed to air or bacteria, the lighter hydrocarbons have evaporated or been consumed, leaving the heavier hydrocarbons in the deposit. The oil sands in Alberta and Saskatchewan are a large source of non-conventional crude oil. Heavier oils have higher energy densities and, therefore, release more heat when combusted, as well as more greenhouse gases.

Canadian Crude Oil Production

Canada has been producing conventional crude oil for over a hundred years, mostly in Alberta, Saskatchewan and offshore Newfoundland, with smaller production in other provinces. Overall production of conventional crude oil has remained fairly consistent since the early 1990s.

Production from Canada's non-conventional sources began in the latter half of the 20th century, and output has been increasing rapidly.

Figure 4-6: **Conventional and Non-Conventional Oil Production, 1990-2011**

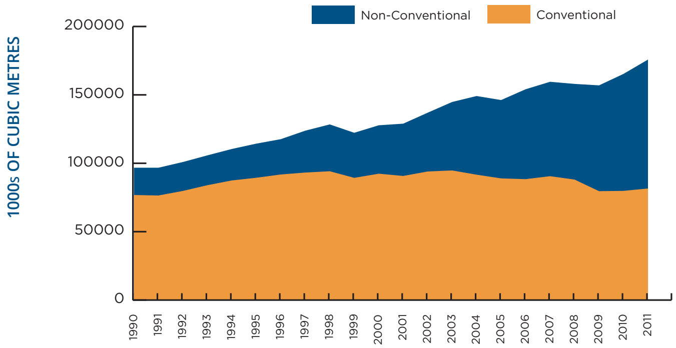


Figure 4-7: **Canada's Crude Oil Deposits**

The Western Canadian Sedimentary Basin

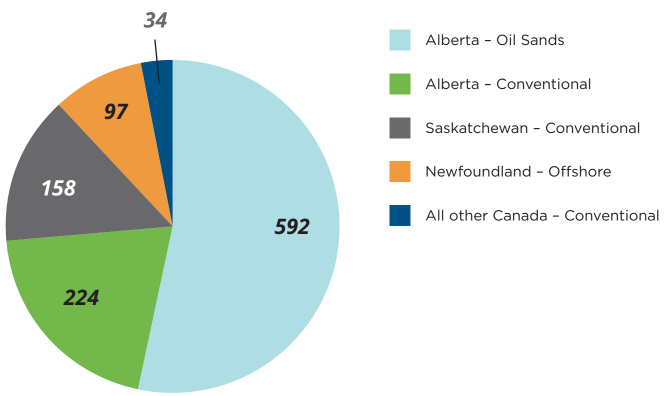
The Western Canadian Sedimentary Basin (WCSB) is a large geological formation covering most of Alberta and smaller portions of Saskatchewan and British Columbia.

Most of Canada's crude oil deposits, both conventional and non-conventional, are located in the WCSB, along with large coal and raw natural gas deposits.

Crude oil from the WCSB accounted for nearly 90% of all Canadian crude oil production in 2011. The only other significant source of crude oil in Canada is offshore Newfoundland.

The oil sands accounted for over half of total Canadian crude oil production in 2011. Production from the oil sands is projected to make up the bulk of future increases in Canadian crude oil production.

Figure 4-8: **Canada's Oil Production by Region and Type, 2011** (millions of barrels)



ALBERTA OIL SANDS

The Alberta oil sands contain the largest reserves of economically extractable crude oil outside of Venezuela and Saudi Arabia, representing roughly 11% of global reserves. The oil sands underlie tens of thousands of square kilometres of northern Alberta, with a small fraction in western Saskatchewan.

The oil sands contain bitumen, which is a very heavy type of crude oil. The bitumen is found mixed with sand and water, and the mixture has a tar-like appearance. The bitumen is located at varying depths, from hundreds of metres underground to right at the surface.

The bitumen, sand and water mixture is thick and will not flow through wells and pipes using conventional drilling techniques. Instead, the bitumen is extracted using surface mining or in situ (in place) methods.

Surface Mining

About 20% of the bitumen is located within 75 metres of the Earth's surface and can be surface-mined using big shovels and trucks. Even though these areas constitute the smaller portion of the oil sands, surface mining has been the major method of oil sands production in the three decades since production started. Once mined, the oil sands are trucked to a facility and mixed with hot water, which separates the bitumen from the sand.

DRIVERS & IMPACTS: LAND USE, WATER DIVERSION AND TAILINGS

The Government of Alberta has granted approval for surface mining of the oil sands on more than 1,000 square kilometres of northern Alberta, an area of dense boreal forest that provides habitat for woodland caribou and other wildlife, and small communities, many of which are home to Indigenous peoples. Mining operations have resulted in clear-cutting and habitat loss. As of 2011, Alberta's Department of the Environment reported that 662 square kilometres of land have been disturbed by oil sands activity. Approximately 65 square kilometres of those disturbed lands have been undergoing active reclamation, including reforestation.

Once the bitumen and sand mixture is surface mined, companies use large volumes of fresh water to separate the bitumen from the sand. Oil sands companies take this water from the Athabasca River and its smaller tributary rivers, representing 65% of total water withdrawals from the Athabasca. The bitumen is separated from the sand, and the leftover mixture of water, sand and chemical residues is called tailings. The tailings are highly toxic and cannot be returned to the river; instead, they are stored in large tailings ponds, where the sediment can settle and the water can be treated for reintroduction to the river. This water recycling process can take decades, and there are concerns about the long-term stability of the tailings ponds, particularly their potential for leaching contaminants into ground and surface water.

To date, most of the oil produced from the oil sands has been surface mined, but this portion is declining, and in situ production is increasing.

In Situ Production

The majority (80%) of the oil sands are located deeper than 75 metres underground. For these deeper deposits, in situ methods are used to extract the oil. These methods involve the direct injection of steam into the deep bitumen. Once heated sufficiently, the bitumen starts to flow and can be pumped up through a well to the surface. In situ production techniques are expected to surpass surface mining as a share of oil sands production sometime before 2020.

DRIVERS & IMPACTS: GREENHOUSE GAS EMISSIONS

In situ oil sands methods have smaller land use and water use impacts than surface mining but result in more greenhouse gas emissions. In situ methods involve burning natural gas to generate steam, which is used to heat and dilute the bitumen, allowing it to flow through production wells and pipelines for further processing. Generating the hot water to separate the bitumen from the sand using surface mining techniques also produces greenhouse gases, but in situ methods generate roughly double the greenhouse gases per barrel of bitumen relative to surface mining.

Estimates vary depending on the particular fields and extraction processes used, but producing a barrel of bitumen from the oil sands and processing it for use as crude oil generates more greenhouse gases than conventional crude oil production – anywhere from 10 to over 50% more. And as conventional oil fields in Canada decline, in situ oil sands production is expected to increase to meet global demand for crude oil. When the whole process by which crude oil is converted into gasoline and burned as a transportation fuel is taken into account, the total difference in emissions ranges from 8 to 37%.

Natural gas combustion for in situ production from the oil sands is the largest single industrial source of greenhouse gas emissions in Canada, representing about 6% of Canada's total emissions. Should in situ production of the oil sands continue to increase, greenhouse gas emissions from Alberta's oil sands will continue to rise. Some of the natural gas combusted to generate steam for oil sands production is also used to generate electricity in cogeneration plants. Most of this electricity is used in oil sands operations, and the remainder supplies Alberta's electricity system, which is primarily powered by coal-fired plants.

Several jurisdictions have introduced regulations, such as California's Low Carbon Fuel Standard, that present a barrier to the import and use of energy commodities that are derived from more greenhouse gas–intensive production processes, such as oil sands operations.

From Bitumen to Crude Oil

Some refineries, such as those on the Gulf Coast of the United States, can use diluted bitumen directly to produce petroleum products. But bitumen is too heavy and contains too much sulphur for most oil refineries. The relative concentration of sulphur determines whether crudes are considered sour (high sulphur) or sweet (low sulphur). The sulphur must be removed from crude oil before it is refined for petroleum products. Upgraders are used to reduce the sulphur content and to transform the bitumen into synthetic crude oil, which shares qualities with conventional crude that is lighter and "sweeter."

Nearly two-thirds of the bitumen from the oil sands is sent to upgraders in Alberta and transformed into synthetic crude oil. Upgraders use heat provided by burning natural gas, which contributes to the overall greenhouse gas emissions associated with oil sands production.

Offshore Oil Production

Newfoundland and Labrador is the only province that produces offshore oil in Canada. The Jeanne d'Arc Basin off the coast of Newfoundland produces nearly 300,000 barrels of crude oil per day. The royalty payments that oil producers pay to the province account for nearly one-third of its total revenues.

Offshore oil platforms, or oil rigs, are structures used to drill for oil (or natural gas) beneath the ocean floor. Platforms are commonly anchored to the ocean floor by long columns, while floating rigs are used in deeper waters. The crude oil extracted is delivered to port via pipeline or marine tanker.

The majority of offshore rigs are located quite close to shore, in relatively shallow waters (up to 200 metres deep); however, new technologies and less accessible reserves are pushing production into deeper waters. Brazil is acknowledged as a world leader in deepwater offshore drilling, but many countries have offshore oil production, including the U.S. and Mexico in the Gulf of Mexico and the U.K. and Norway in the North Sea.

DRIVERS & IMPACTS: OFFSHORE OIL SPILLS

While the first edition of this primer was being developed, crude oil started gushing into the Gulf of Mexico as a result of the 2010 British Petroleum (BP) Deepwater Horizon drilling rig explosion and collapse. After the well was finally plugged in August 2010 (87 days after the accident), the U.S. Geological Survey estimated that it was the worst oil spill in American history, with over 5 million barrels discharged into the Gulf of Mexico. White House Energy and Climate Change adviser, Carol Browner, described the spill as "probably the biggest environmental disaster we've ever faced in this country."

Wildlife populations in the Gulf were severely impacted by the spill, with many species (such as dolphins, sea turtles, brown pelicans, laughing gulls, and many types of fish and crustaceans) undergoing massive die-offs as a direct result of the spill, and other fish, bird, whale, and coral species having their habitats and reproductive patterns drastically altered as a result. Five years after the spill, oil and dispersant compounds continue to be found in the eggs of migratory birds, even thousands of kilometres from the Gulf. Such compounds are also still being found in ocean bed sediments within a 1,000 kilometre radius of the accident.

In 2015, civil suits filed against BP on behalf of affected individuals, businesses, and states were settled at a total cost of over $25 billion. As a result of the spill, deep water drilling operations and proposals for such developments around the world are facing increasing scrutiny and increased costs with a view to ensuring that such an incident never occurs again.

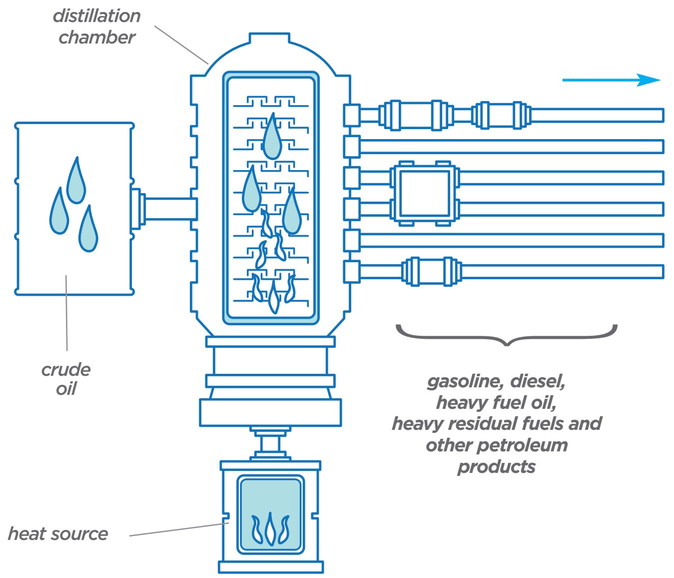
Petroleum Refining: Turning Crude Oil into Petroleum Products

Oil refineries convert crude oil into value-added petroleum products. There are 19 refineries across Canada, all of which take in crude oil as an energy source and produce petroleum products as energy commodities. These are distinct from terminals, where various petroleum products are stored in large tanks.

Figure 4-9: **Crude Oil Distillation**

Refineries can produce a variety of petroleum products by processing the complex mix of hydrocarbons present in crude oil.

Distillation, fractionation and cracking are methods of taking crude oil and separating it out into various petroleum products, such as gasoline and diesel. Oil is subjected to these processes, which use thermal and chemical refining techniques to provide petroleum products for heating, electricity generation and transportation.



DRIVERS & IMPACTS: OIL REFINERIES

Petroleum refineries are large industrial emitters of carbon dioxide, as well as oxides of nitrogen and sulphur and other air pollutants and toxics. Some of these pollutants are emitted from large stacks, but there are also fugitive emissions of light, gaseous hydrocarbons that leak from pipes, valves, flanges and storage tanks. These fugitive emissions contribute to smog and sometimes lead to complaints about odour in nearby communities.

Canadian refineries have reduced intentional discharges to water over the last few decades, but spills and accidents do happen from time to time. Safety is a major concern at oil refineries. Industrial accidents can endanger workers and nearby residents, particularly in the case of a fire or an explosion.

Petroleum Transportation and Storage

From the refinery, petroleum products are typically transported in bulk by pipeline to large storage terminals. From there, the petroleum products are usually delivered by truck to gas stations and other business and retail customers.

Pipelines

When the petroleum industry came into being at the end of the 19th century, virtually all crude oil and petroleum products were transported in wooden barrels by rail. It was not long, however, before pipelines started transporting crude oil across the United States. Using pipelines to transport liquids is an old idea, borrowed from the Roman aqueduct system that brought water from distant sources to cities.

In Canada, the bulk of crude oil, petroleum products and natural gas is transported by pipeline.

Figure 4-10: **Liquid and Natural Gas Pipelines**

The shaded areas represent sedimentary basins where crude oil and natural gas are found in various concentrations and quantities.

Transporting these energy sources and commodities by pipeline costs less than it would using rail or trucks. Pipelines also allow for the transportation of fuel over terrain not accessible by other modes of transportation, such as in the tundra.

North America was the first jurisdiction to build a large pipeline infrastructure. Today, North America has the largest and most sophisticated network of crude oil, petroleum products and natural gas pipelines in the world. Continuity of supply to meet the demand for energy commodities is central to the energy system facilitated by pipelines.

Trucks

Tanker trucks are used for higher-value products or where there are no rail links or pipelines. The local distribution of petroleum products to gas stations, other retailers and industries is almost always made by truck. The largest delivery loads are 65,000 litres, enough to fill up over 1,500 cars.

Trucks can travel on most roads and do not require pipeline and rail infrastructure, allowing for fuel delivery to multiple, smaller facilities. Transporting fuel by truck tends to be for distances up to about 300 kilometres.

Rail

Rail moves an estimated 280,000 barrels of oil products a day, which is almost 8% of western Canada's production. Canada's freight rail industry is changing from a manifest system, in which trains typically make multiple stops to deliver different oil products, to a unit system, in which trains travel directly from the point of origin to the point of destination. Unit trains are more efficient because they eliminate the need for the switching of rail cars, thereby shortening the overall duration of a trip.

Oil Tankers

Tankers are large ships used to transport liquids or gases in bulk across long, inter-regional water routes. There are many different types of tankers that play a role in the transport of crude oil and products associated with oil production, including oil tankers, parcel tankers, gas carriers, and combination carriers. All types of inter-regional tankers must adhere to international bulk chemical codes that are used to govern the safe transport of chemical and hydrocarbon cargoes and to ensure appropriate levels of protection against the release of substances that pose high environmental risks. A major concern with regard to bulk oil shipments via tankers is the tremendous amount of stress placed on tanker hulls by the massive size of the ships and the heavy loads they carry. Indeed, modern oil tankers are the biggest vehicles that have ever been built.

Using Petroleum Products

Heating: *Ten per cent of petroleum products used in Canada heat homes and buildings. Heating oil is similar to diesel and is usually delivered by truck and stored in tanks. Heating oil provides about 8% of the energy used for home heating.*

Electricity: *Three per cent of petroleum products consumed in Canada are used to generate electricity, mostly in New Brunswick, Nova Scotia and Alberta.*

Transportation: *Two-thirds of the petroleum products used in Canada are for transportation fuels, but 99% of Canada's transportation fuels are petroleum products. Gasoline supplied over half of Canada's transportation services in 2010, diesel accounted for one-third, and aviation fuel for 10%. These fuels are also used in industrial and agricultural vehicles.*

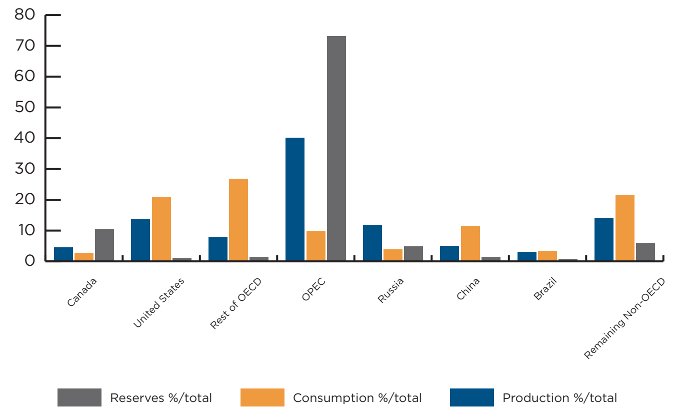
Industry: *Many industries combust petroleum products for applications where steam and/or hot gases are required. For example, oil refineries use over 5% of their production to run refining processes, mainly as fuel for the generation of steam.*

Not all petroleum products are combusted to generate heat. Nearly 10% are used to manufacture a wide variety of other products, for example, asphalt, which is used in construction, and lubricants, which are used in machines and engines to reduce friction. Petroleum products are also the raw material for the manufacture of thousands of commercial plastic products, ranging from garden hoses and plastic packaging to computer keyboards and automotive parts and accessories.

GLOBAL OIL SUPPLY, PRODUCTION AND RESERVES

The world's oil is not evenly distributed around the globe. Some countries, including Canada, have large reserves of oil, while others, like Japan, have none. The differences in consumption are just as striking

Figure 4-11: **Share of Global Oil Production, Consumption and Reserves, 2013** (%)



What is OPEC?

The Organization of Petroleum Exporting Countries (OPEC) is a cartel of mainly Persian Gulf countries (Iran, Iraq, Kuwait, Qatar, Saudi Arabia, United Arab Emirates), along with several countries from Africa (Algeria, Angola, Libya, Nigeria) and South America (Ecuador, Venezuela). All of these countries have significant oil reserves. OPEC was founded in 1960.

Venezuela, a founding OPEC member, has the largest share of oil reserves of any nation, with 20% of the global total. Saudi Arabia, another OPEC member, has the second largest share, with about 18% of global reserves.

What is the OECD?

The Organisation for Economic Co-operation and Development (OECD) is a group of 34 higher-income countries. Canada and other OECD members have high per capita rates of energy consumption.

Canada's oil sands are the largest national holdings of crude oil reserves of any non-OPEC country. As other non-OPEC countries accelerate their output, Canada's remaining crude oil will account for an increasing share of global oil reserves.

The Strategic Petroleum Reserve

While the idea of developing a petroleum reserve had been proposed before, it was not until 1975, several years after the OPEC nations staged a crude oil embargo on the United States and some European countries, that the U.S. established a strategic petroleum reserve (SPR) for similar times of crisis.

The United States' strategic petroleum reserves are the largest in the world and can hold up to 714 million barrels of crude oil, according to U.S. Department of Energy figures. These reserves are stored in giant salt caverns along the coastline of the Gulf of Mexico and equal a supply of 38 days of oil at current daily U.S. consumption levels (19 million barrels per day). The SPR has been used for emergency purposes only twice: during Operation Desert Storm in 1991 and after Hurricane Katrina in 2005. Its formidable size makes it a significant deterrent to oil import cut-offs and a critical tool in American foreign policy.

DRIVERS & IMPACTS: ENERGY RESOURCES, CONFLICT AND PRICE

Non-OPEC nations, including Canada, account for about two-thirds of the global consumption of oil but only control one-third of reserves. As a result, the world's remaining oil supplies are increasingly in the hands of OPEC nations. Together, they negotiate and agree to set limits on their collective production of oil in an attempt to control global prices. Crude oil sources in these countries are tightly controlled by state-owned companies, such as Saudi Arabia's Aramco, which are not audited or verified to any external reporting standards.

The 20th century witnessed numerous crises centred on the control of crude oil reserves and trade. After the Second World War, the majority of these events were centred in the Middle East, home of the largest conventional crude oil reserves in the world. These events included the Suez Crisis of 1956 (Egypt), the oil shock of 1973 (OPEC), the oil crisis in 1979 (Iran), the first Persian Gulf war in 1991 (Iraq and Kuwait) and the conflict in Iraq that started in 2003. Because these conflicts directly affect the supply of oil, they can have a major influence on its price.

Natural Gas

Because it is relatively easy to transport via pipeline and burns cleaner than other hydrocarbons, natural gas is prized as a fuel for heating homes and buildings and, increasingly, for thermal electricity generation. As an energy commodity, natural gas is almost all methane, with small amounts of ethane. It is a vapour at room temperature and pressure.

Raw Natural Gas

Natural gas is derived from raw natural gas found in deposits in the ground. Natural gas was formed from the same long-dead organic material, and through the same process, as crude oil. As a result, natural gas is often found with crude oil in associated deposits. It can also be found on its own in non-associated deposits or with coal.

Raw natural gas is a vapour, just like processed natural gas. In its raw state, natural gas always contains a significant portion of methane, but it can also contain high percentages of carbon dioxide and hydrogen sulphide as well as other hydrocarbons, such as propane, butane, ethane and pentane, called natural gas liquids. Natural gas fields that contain dissolved natural gas liquids are described as wet, while raw natural gas sources without hydrocarbon liquids are described as dry. The composition of any given natural gas deposit influences its economic viability and dictates the environmental impacts of developing it.

DRIVERS & IMPACTS: SOUR GAS

Like high-sulphur crude oil, natural gas deposits with a high percentage of hydrogen sulphide gas are described as sour. Environmental, health and safety concerns about the effects of sour gas production have sparked opposition in communities near sour gas wells in Alberta.

Canadian Natural Gas Production

Canada is the fourth-largest natural gas producer in the world, after the United States, Russia and Iran. Over half of Canada's natural gas production is exported, and all of these exports go to the United States. Natural gas imported from Canada supplied 10% of the natural gas used in the U.S. in 2014. American imports of natural gas from Canada have been declining since 2010, as U.S. production of domestic natural gas supplies has steadily increased.

Canada's natural gas deposits are found in three main areas.

*The **Western Canadian Sedimentary Basin** (WCSB) is the source of 98% of current Canadian gas production, three-quarters of which is produced in Alberta. The WCSB is also the source of most Canadian crude oil.*

*The **Sable gas reserve** is located near Sable Island off the coast of Nova Scotia, 5,000 metres below the ocean's surface. Natural gas production from Sable started in 2000.*

*Significant quantities of natural gas have been discovered in Canada's **Far North**. Early in 2011, approval was given for a plan to develop the Mackenzie natural gas field, one of North America's largest undeveloped sources.*

Figure 4-12: **Canadian Natural Gas Reserves**

Conventional Natural Gas Production

Conventional natural gas fields are drilled, just as crude oil fields are, but with different equipment. The fields are under higher pressures underground, so once a hole is drilled and a well is established, natural gas pushes up (like bubbles when you open a bottle of soda). Initially, the pressure in the reservoir is high, but it diminishes over time. The production rates decrease until, eventually, there is insufficient pressure for the gas to flow (just as the soda goes flat). At that point, secondary and tertiary production technologies can be used to produce more natural gas. These include pumping water into the well to push up more natural gas.

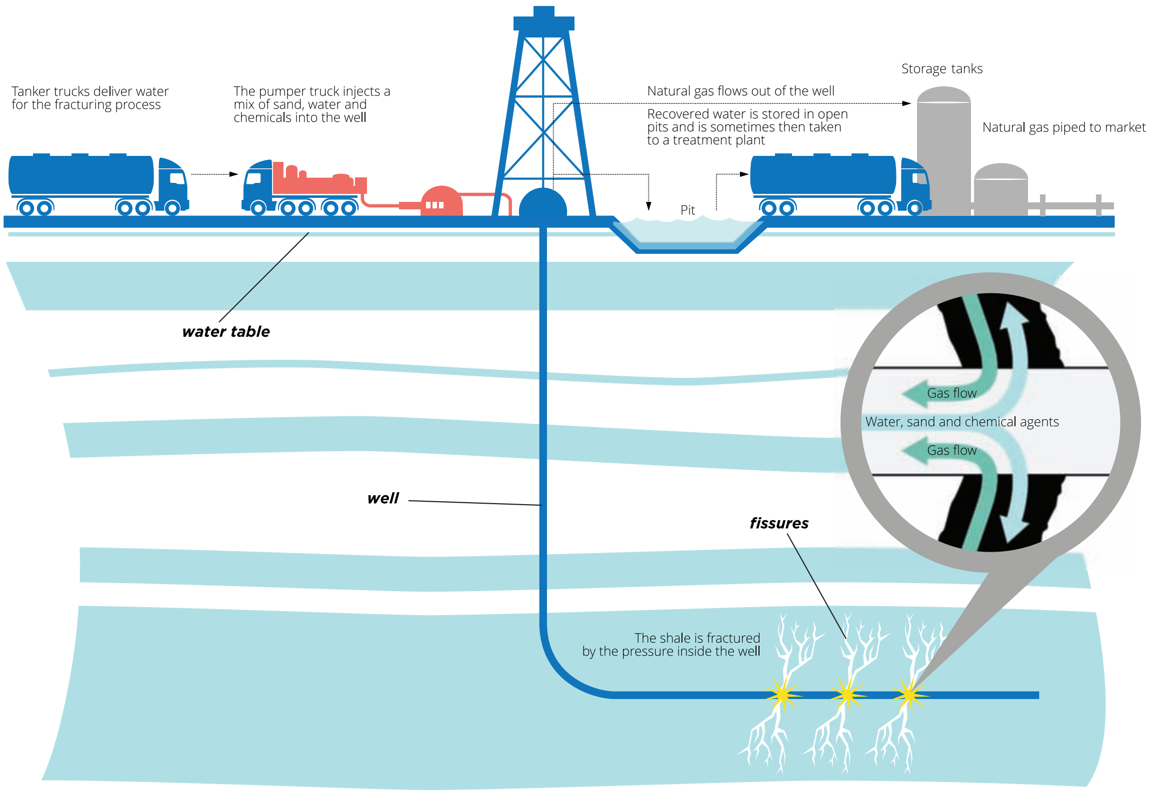
Shale Gas

Shale gas is natural gas that is embedded in layers of shale and other rock. Over the last decade, a new horizontal drilling and hydraulic fracturing technique ("fracking") has opened up huge volumes of shale gas that it was previously uneconomic to extract. There are extensive shale gas formations in several parts of North America, including northeastern British Columbia, Alberta, Texas, Louisiana, Pennsylvania and other northeastern states, as well as Quebec, the Gulf of St. Lawrence, New Brunswick, Newfoundland and Labrador, and Ontario.

How Fracking Works

Sedimentary rock formations below the Earth's surface can hold gases, water or oil in their pores. The fracking process involves the fracturing of shale rock deep below the Earth's surface, using explosives and high-pressure injections of water, sand and chemicals to get the rock to release its store of gases. A deep vertical hole is drilled, the drill pipe is removed and replaced with a steel pipe, and cement is pumped down the pipe. The cement flows back up between the borehole wall and the pipe, creating a barrier between the wellbore and any freshwater sources, and ensuring a tight well seal. Vertical drilling then continues down to an average depth of over 3 kilometres into the sedimentary rock. When the targeted layer has been reached, the wellbore curves and horizontal drilling commences. The drill pipe is eventually removed and steel casing is inserted through the full length of the wellbore. The entire pipe casing is cemented into place and a perforating gun equipped with explosive charges is lowered down and across the well to the rock layer with the gas reserves. The perforating gun is fired, creating holes through the casing, the cement and the surrounding rock layer, forming a connection between the wellbore and the reservoir rock. The holes *created by the perforating gun extend out only a few centimetres from the cement into the rock. The perforating gun is removed, and a hydraulic fracturing mixture of water, sand and chemical additives is sent down the wellbore under high pressure. Once the hydraulic pump pressure is relieved, the sand in the fracking fluid stays lodged in the rock fractures, keeping them open. Because of these tiny openings, the trapped gases and liquids in the rock formation will flow into the wellbore and, eventually, to the surface.*

Figure 4-13: **How Fracking Works**



DRIVERS & IMPACTS: BRIDGE FUEL, PUBLIC HEALTH HAZARD OR PIPE DREAM?

American oil and gas magnate T. Boone Pickens has called natural gas a bridge fuel that will help to "slash oil dependence while buying time to develop new technologies that will ultimately replace fossil transportation fuels." American President Barack Obama has come out strongly in support of natural gas development, citing it as a cleaner burning alternative to coal and petroleum products. The International Energy Agency expects global production of natural gas to grow almost everywhere in the next 30 years, with unconventional gas accounting for almost 60% of global supply growth. But critics of the shale gas revolution draw a much different picture.

Although processed natural gas does burn cleaner than other fossil fuels, data from the Intergovernmental Panel on Climate Change (IPCC) shows that the fugitive emissions (largely consisting of unintended releases of gas from pressurized equipment or improperly sealed wells) that arise from hydraulic fracturing activities are 133% higher than those from conventionally drilled natural gas deposits. Natural gas is predominantly composed of methane, a potent greenhouse gas that traps 84 times more heat than carbon dioxide in the first two decades after its release, resulting in an acceleration of climate change.

The processes of drilling and hydraulic fracturing are also water intensive. Several domestic and global jurisdictions have imposed moratoriums on fracking until compelling scientific evidence is presented that refutes claims about fugitive emissions, groundwater contamination, and fracking-induced earthquakes.

Natural Gas Processing

Just as crude oil is processed into petroleum products, raw natural gas is extracted from beneath the Earth's surface and processed to create the refined natural gas energy commodity that burns in our home furnaces. From the well, the raw natural gas is transported via pipelines to gas processing plants, which are usually located close to the wellhead. These can vary in size and complexity, but their purpose is to clean the raw gas to make it safe and usable for consumers. Any impurities, water, sulphur and carbon dioxide present in the raw gas are removed. Some gas processing plants are designed to separate out any propane, butane and other valuable natural gas liquids that may be present. Processing prepares the natural gas to meet the specifications required for long-distance transmission via pipelines (e.g., the TransCanada Mainline).

Processed natural gas burns cleaner than other fossil fuels, producing up to 60% fewer greenhouse gases per joule of heat energy than coal, and up to 30% less than most petroleum products (these figures are approximate, varying depending on the fuel and the efficiency of the equipment used). When combusted, natural gas emits significantly fewer nitrogen oxides than coal and petroleum products and emits virtually no sulphur dioxide, mercury or other air pollutants.

However, processed natural gas has a lower energy density than either solid or liquid fossil fuels such as coal or diesel, so greater volumes of it are needed to produce the same amount of heat. Because it is a gas (vapour), natural gas requires more sophisticated storage systems than those used to store liquid or solid fossil fuels and must sometimes be compressed or liquefied in special storage containers.

Natural Gas Transportation and Storage

Processed natural gas is transported via transmission pipelines from gas processing plants to city-gates on the borders of cities and towns, where mercaptan (which is responsible for the rotten egg smell) is added as a safety measure. The natural gas then flows through smaller distribution pipelines to homes and businesses. Most cities in Canada have an underground natural gas distribution grid. North America has the most extensive natural gas transmission and distribution infrastructure in the world, and natural gas pipeline grids are increasingly interconnected.

Natural gas is compressed to increase the rate of transfer through long-distance transmission pipelines and in urban distribution. Compressed natural gas (CNG) is still a gas, but it is denser than natural gas at room temperature and pressure, so it has a higher energy density than unpressurized natural gas.

Marine tankers are used to ship natural gas in liquid form. Liquefied natural gas (LNG) is contained at an extremely low temperature (−160 °C). Cooled to this temperature, the natural gas becomes a liquid that occupies 1/600 of the volume of uncompressed natural gas. As a result, LNG has a much higher energy density

Because LNG has such a high energy density, lower-volume containers are sufficient for transporting an equivalent quantity of energy to the final destination. This reduces transportation costs on a per unit energy basis. But liquefying natural gas is costly and energy intensive, and special precautions are required aboard LNG vessels and at liquefaction facilities to ensure safety. A state-of-the-art LNG terminal in New Brunswick, Canaport, was completed in 2009 for the purpose of receiving LNG, vaporizing it, and shipping it into the northeastern states of the U.S.

Natural gas can be stored in large terminals, underground geological formations or depleted fossil fuel reservoirs. Natural gas is typically stored in the summer, when the demand for heating services is low, and then used to meet increased demand in the winter. The Dawn Hub in southwestern Ontario is a large, regional natural gas site. The Henry Hub in Louisiana is another. There are over four hundred natural gas storage sites in North America, located near producing deposits and consuming regions.

Using Natural Gas

Heating: *Natural gas provides about half of the energy services used to heat homes and buildings in Canada. This represents approximately 20% of the country's total natural gas consumption.*

Electricity: *Natural gas accounted for more than 15% of energy sources used to generate electricity in Canada in 2012. This represents 18% of total Canadian natural gas consumption. These figures are rising as Ontario and Nova Scotia reduce the use of other fossil fuel sources in electricity generation.*

Transportation: *Natural gas provided less than 0.1% of transportation fuel in 2012. In gaseous or liquid form, natural gas requires special storage and pumping technology for use as a fuel in vehicles.*

Industry: *Natural gas is used as a heat source in all kinds of industrial, manufacturing and processing applications, where it is usually combusted to generate heat and steam. Oil sands producers in Alberta are the largest Canadian industrial users of natural gas; steam generated by burning natural gas is used to help with oil extraction. Industrial use accounted for 41% of national natural gas consumption in 2012.*

Biofuels

Biofuels, mainly wood, have been the dominant energy commodity for most of human history. And biofuels are still a major fuel in many of the world's lower-income countries, where wood remains the primary fuel for heating and cooking. It was only in the early 20th century that coal, petroleum products and electricity displaced wood and other biofuels as the dominant global energy commodities. These other energy commodities became cheaper to produce, demonstrated superior performance and were available in large quantities.

Like fossil fuels, biofuels can be solid, liquid or gaseous in form.

Biomass

Unlike fossil fuel sources, such as coal, crude oil and natural gas, which are products of organic matter (i.e., plants and animals) deposited millions of years ago, biofuels are processed from biomass, which is organic matter that is recently harvested. In Canada, the majority of biofuels are derived from four biomass sources: harvested forest and tree residues, agricultural crops (grown for the purpose of making biofuel), agricultural residues and other organic wastes, and landfill gas.

Forest Biomass

Forest biomass includes trees that are grown or harvested specifically for use as biofuels, branches and residues from harvested trees, and trees that are unusable because of fire, disease or insect damage. By-products from forest-sector processes, including sawdust, bark chips, wood pulp and black liquor from pulping, are often burned as biofuels to supplement the heating needed for those processes.

At least one estimate puts the size of Canada's annual forest biomass resources at more than 530 exajoules. This is comparable in scale to other major sources of fossil energy in Canada, such as the oils sands. When forests are properly managed, harvested wood and some forest residues are considered renewable energy sources.

Agricultural Biomass from Crops

***Corn** is primarily grown for the production of food (mainly corn syrup and livestock feed), but it is also the biomass source for most Canadian ethanol production. Ethanol is a biofuel that is commonly used as a gasoline additive or substitute fuel. The first cars ran on ethanol, before gasoline and diesel were available. Corn has relatively high sugar content, making it a useful biomass source for conversion into ethanol. Alternatively, the oil from corn can be converted into biodiesel. Canada imports corn from the United States to meet the demand for both food and ethanol production. About 40% of total U.S. corn is grown for the purpose of producing ethanol.*

***Wheat** has also been used to produce ethanol in Canada because it is a plentiful crop in Saskatchewan and Manitoba. However, wheat is priced higher than corn and has lower sugar content, making it a less economical feedstock than corn for ethanol production using current technology.*

***Soy** is an oily, protein-rich legume. Soybean oil can be turned into biodiesel through a process called transesterification. Soy is used for most of the biodiesel production in the U.S., which currently represents only a fraction of a per cent of total diesel production.*

***Sugar cane** contains the most sugar per acre of any crop. It grows in more tropical climates, such as those found in Brazil, the world's largest ethanol producer. Brazilian ethanol is economically competitive with gasoline mainly because of Brazil's high cane yields per acre.*

Advanced Biofuels

Biomass food crops such as corn, soy and sugar cane are known as first-generation biofuels. In recent years, extensive research has been done on second- and third-generation biofuels, also known as advanced biofuels. Classification as an advanced biofuel is based on feedstock type, conversion technology used and properties of the product. Advanced biofuels are produced from agricultural and forestry residues (e.g., wheat straw, corn stover), from non-food crops (e.g., grass, algae) or from bio-based waste streams. These biofuels are characterized by low life cycle carbon dioxide emissions and low impacts on land use relative to first-generation biofuels.

Some experts consider biofuels to be carbon neutral because the carbon they contain (which is released to the atmosphere when they are combusted) was taken out of the atmosphere by the feedstock plants as they grew – a process that mimics part of the Earth's natural carbon cycle. However, fossil fuel–powered machinery is commonly used to plant, harvest, process and transport biofuel feedstocks, so most experts prefer to describe biofuels as low carbon.

Algae are a particularly promising source for biofuels because they can produce yields per hectare that dwarf yields of traditional biomass crops and can be grown in closed loop systems, essentially large tanks containing water, a source of light, and a source of carbon dioxide. Some pilot projects have shown that algae growth tanks can be directly connected to smoke stacks from industrial facilities that burn various types of fuels; this means that the emissions from such facilities (mainly carbon dioxide) are effectively stored in the algae until the algae are converted into fuel and combusted. If the algae are combusted at the same, or a similar, facility, this process can theoretically recycle the carbon stored in the algae in perpetuity while eliminating emissions from participating industrial facilities.

DRIVERS & IMPACTS: FOOD OR FUEL?

Good arable land is limited, and changes in the way that land and water are used can have environmental consequences and create social conflict. There is considerable debate about whether sufficient land exists to grow crops to produce both fuel and food.

To ensure a steady supply of raw material to produce ethanol, a company might buy up large tracts of land to grow the required crops. This can jeopardize an area's biodiversity because the land is devoted to only one crop (i.e., monoculture). There are also concerns that soil quality may deteriorate because parts of plants or trees that used to be left behind to nourish the soil will now be used as raw materials in biofuels.

Whether the production of biofuels from crops poses a significant threat to food supply and soil health remains a point of dispute among many experts. Much depends on the technology that is used to convert biomass energy sources into energy commodities, and on the efficiency of the processes.

Solid Biofuels

Solid biofuels include any solid organic material that is used as a fuel. This includes trees and plants, agricultural crops and residues, and also food waste, manure and human waste. Just like coal, solid biofuels can be combusted to generate heat or to make steam for the production of electricity.

To remove moisture, solid biofuels are commonly dried and formed into pellets. This process enhances the combustibility of the biofuel and reduces the likelihood of it getting mouldy, thereby making storage easier. Removing the water in the biofuel also lowers its weight, making pellets easier and cheaper to transport. Many homes in Canada and the United States use wood pellets for home heating.

Agricultural and organic wastes are a potentially cheap source of biomass. However, they often consist of a variety of different materials, making them more challenging to process into transportation biofuels, which must meet strict standards for chemical composition. There are also significant costs associated with the collection and transportation of relatively small batches of biomass material for processing.

Despite these challenges, the use of organic waste material as a biomass source can complement waste diversion programs and generate new income for municipalities, farmers and businesses. To the extent that processing organic wastes into energy commodities can ease pressure on landfills and minimize the spreading of excess manure on fields, it can also mitigate the risks of contamination to groundwater, damage to local ecosystems and uncontrolled releases of methane, a potent greenhouse gas.

Gaseous Biofuels (Biogas)

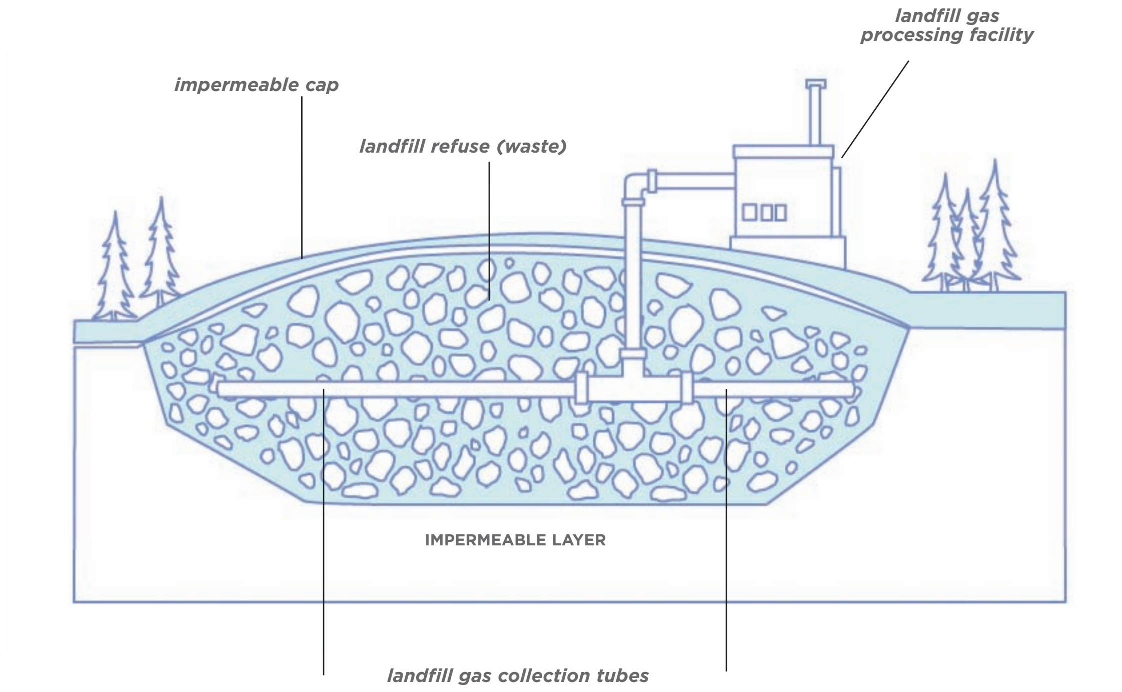
Biogases are gaseous fuels originating from biodegradable materials such as organic and municipal wastes, crop residues, food processing wastes and even manure. Biogas is a mixture of methane and carbon dioxide generated from these materials through anaerobic digestion. Gaseous biofuels can displace the use of natural gas to generate heat or electricity, using conventional natural gas technologies.

Biogas can be cleaned and injected into natural gas pipelines, reducing the demand for fossil fuel sources. The first biogas-to-methane direct injection into the natural gas grid in Canada took place in Abbotsford, British Columbia, in 2010.

Biogas Capture in Landfills

Biogas is collected in a number of landfill sites in Canada. Just like natural gas (a fossil fuel), biogas can be combusted to generate heat or electricity. Capturing and burning methane results in emissions of carbon dioxide, but this is considered preferable to venting the methane into the atmosphere because methane is a more potent greenhouse gas than carbon dioxide. Although methane does not remain in the atmosphere as long as carbon dioxide does, its global warming potential is over 30 times greater than carbon dioxide over a 100-year period.

Figure 4-14: **Biogas from Landfill**



Biogas produced from methane gas capture systems at landfills is referred to as landfill gas and contains about 60 per cent methane and 40 per cent carbon dioxide.

Biofuels Transportation and Storage

Agricultural and forest biomass sources are widely distributed over large areas of land. Gathering sufficient amounts of biomass to produce marketable volumes of an energy commodity contributes to the higher production costs of biofuels relative to fossil fuels.

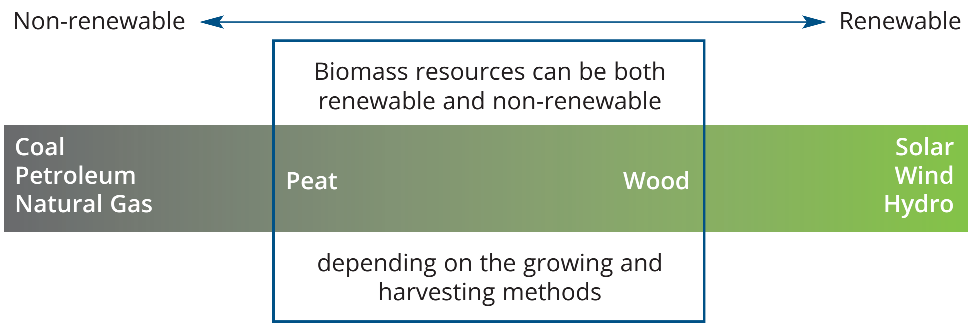
Organic material retains moisture, naturally decomposes and can develop diseases, mould and parasites. Because of this, solid biofuels are usually stored in temperature- and moisture-controlled warehouses or silos, just as grain has been stored throughout much of human history.

Are Biomass Sources Renewable?

Renewable energy sources renew and replenish within a reasonably short period of time – months or years. Non-renewable energy sources can take millions of years to form and, once removed, require as many years to form again.

Figure 4-15: **Renewable versus Non-Renewable Biomass Sources**

The degree to which biomass sources are considered renewable, in a practical sense, depends on management and harvesting practices, as well as the time that it takes for the biomass source to be replaced. For example, planted hardwood can take a few decades to grow to a sufficient size for harvesting, whereas bamboo takes just a few years. Peat, on the other hand, is considered non-renewable because it takes hundreds of years to form in peat bogs.



Processing Biomass into Biofuels for Heat and Electricity

Biomass sources are converted into biofuels through a number of fuel conversion processes, including fermentation, anaerobic digestion and pyrolysis.

Biomass-to-Biofuel Conversion Processes

Fermentation *is a process that uses micro-organisms to perform a chain of biochemical reactions that turn sugar into other products, such as alcohols and organic acids. Before starchy biomass sources (e.g., corn) can be fermented, the starches first need to be broken down into simple sugars. This is usually done by elevating the temperature of the biomass and adding an enzyme to catalyze the process. Once the starches have been broken down, a micro-organism, such as yeast, is added. The micro-organism digests the sugars and produces carbon dioxide and other compounds. The micro-organism species used during fermentation depends on the desired end product. For example, a yeast called* ***saccharomyces cerevisiae*** *is used to ferment corn and sugar cane into ethanol for use as a gasoline additive or substitute. This is the same species of yeast that has been used for centuries in brewing and baking.*

Anaerobic digestion *is a process in which bacteria, in the absence of oxygen, break down biological matter to produce methane and carbon dioxide. This process occurs naturally in marshes, for example, and in the digestive systems of cattle and sheep. It is the process at work in septic tanks and also occurs in landfills (both in uncontrolled conditions and by design).*

Pyrolysis *is a process that uses heat to decompose biomass in the absence of oxygen, which ensures that little combustion can occur. Ground-up biomass is exposed to temperatures just less than 500 °C, converting it to char and gases. The gases are then rapidly cooled, and some of them condense into pyrolysis oil. The pyrolysis oil is a mixture of water and many different organic compounds. It can be burned directly as a fuel or it can be refined to yield useful industrial chemicals and higher-grade fuels. A portion of the gases that are produced during pyrolysis can be burned to create heat needed for the process, thus improving process efficiency and helping to displace the need for fossil fuels.*

For more information, see Pollution Probe's ***Primer on Bioproducts.***

Using Biofuels

Heating: *Four per cent of Canadians rely on stoves that burn wood and other solid biofuels as their principal heating system. Many more use these stoves as a supplementary heating source in the winter. Biofuels used for heating are usually in the form of dry pellets, which burn cleaner and more completely than wood, which tends to retain moisture.*

Electricity: *Dozens of farm operations across Canada have small-scale combined heat and power plants that use biogas. These plants have a maximum power rating of 500 kilowatts.*

Co-firing: *Biofuel pellets can be introduced into the boilers of coal-fired electricity plants to partly displace the use of coal in generating electricity. As part of its coal phase-out efforts over the last decade, Ontario successfully converted its 230 megawatt Atikokan Generating Station and its Thunder Bay Generating Station (a peaker plant with an output of roughly 7 megawatts) from coal to locally sourced biofuel pellets. The Atikokan plant is now the largest biomass power plant in North America.*

Transportation: *Biofuels constitute approximately 5% of overall transportation fuel use in Canada. The federal government has mandated a minimum 5% ethanol blend in all gasoline sold in the country and a 2% biodiesel blend in all diesel fuel. Some provinces have mandated even higher blending rates for gasoline, up to 8.5% ethanol blends in Manitoba.*

Industry: *About three-quarters of biofuels are used by industry, predominantly in the pulp and paper manufacturing sector. The pulp and paper industry is a large user of forest residues as a fuel for heat and electricity generation in combined heat and power plants.*

A Closer Look at Biofuels for Transportation

Ethanol can be blended into gasoline at levels up to 10% by volume (E10) and burned in typical gasoline-powered cars or trucks. At ethanol-in-gasoline levels beyond 10%, special modifications to the engine and fuel system are required. Some vehicles sold in Canada are equipped to run on a special blend of 85% ethanol (E85), as well as E10.

All market-ready ethanol is the same, regardless of the original biomass source – ethanol made from sugar cane is chemically identical to ethanol made from corn. But there are significant differences in the processes required to convert various biomass sources into ethanol, and differences in the cost of production. Sugar cane contains simple sugars that naturally ferment as soon as the plant is harvested. Corn and wheat, on the other hand, contain more complex sugars that require an intermediate step to convert them to simple sugars. And ethanol from wood and other fibrous material requires further steps to break up even more complex sugars before fermentation can begin.

Cellulosic ethanol is produced by using enzymes to break up the carbohydrates in agricultural and forest waste and then rearranging those carbohydrates to make ethanol. Because cellulosic ethanol is produced from biomass residues, it does not require corn, wheat or other crops to be grown for that purpose. Instead, the stalks and leaves of the corn (stover) or the chaff of the wheat can be used as the energy source for producing ethanol. This addresses some concerns about switching farmland from producing food crops to fuel crops – the "food versus fuel" debate. There are currently a handful of Canadian plants producing small quantities of cellulosic ethanol, but commercialization of cellulosic ethanol on a large scale is not forecast for at least several more years.

Biodiesel is produced from oils and fats, not from carbohydrates. It is possible to make biodiesel from a range of oils and fats, including animal fats and oils from algae. Several facilities in Ontario and Quebec produce biodiesel from waste oils and waste grease from restaurants. While it is expected that production of biodiesel from canola will expand in western Canada, in the United States soybean oil is the primary source. Biodiesel is typically blended as an additive with petroleum-based diesel so that it makes up between 2% (B2) and 20% (B20) of the fuel, with the rest being regular diesel. In trials conducted to date, lower blends of biodiesel – up to B5, for example – do not appear to require special modifications to conventional diesel engines. Higher levels may not be compatible with some engines without compromising manufacturers' warranties. Cold-weather performance of biodiesel is also an issue in Canada. Testing is under way to address these uncertainties and to develop strategies for the effective use of biodiesel in Canadian fuel markets.

Renewable diesel is chemically equivalent (or nearly so) to conventional diesel but is made from renewable biomass sources, such as waste greases, animal fats and vegetable oils. Renewable diesel is synthesized by several companies, using proprietary processes.

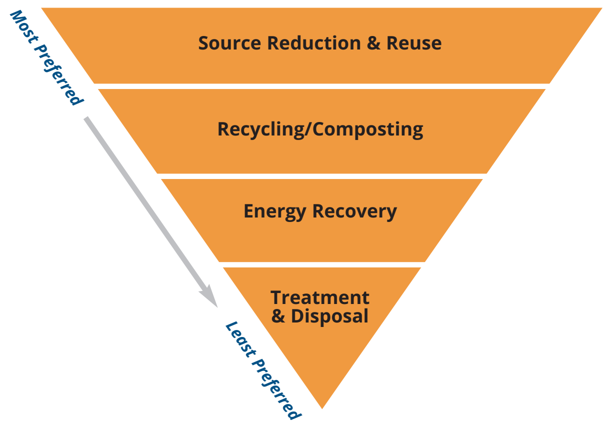
Energy from Waste

What is Energy from Waste?

Waste is usually defined as a material that no longer serves a useful or valued purpose. It has traditionally been viewed as a burden rather than a resource. But, in fact, virtually all materials currently designated as waste have some form of inherent value that can be recovered. Energy from waste refers to the recovery of energy – in the form of electricity, fuels, and/or heat – from the conversion of non-recyclable waste streams. Incineration, the combustion of waste materials with energy recovery, is currently the most commercially mature and widely practised method of converting waste to usable forms of energy. However, emerging forms of advanced energy-from-waste technologies, such as gasification, plasmolysis and pyrolysis, are beginning to emerge as viable waste management options and are being assessed in pilot projects around the world.

In the last decade, the amount of waste diverted from landfills in Canada, via reuse, recycling, composting, and energy recovery, has plateaued atroughly 25%. Waste from Canadian households constitutes roughly 35% of the country's total waste stream, while the institutional, commercial, and industrial sectors account for the remaining 65%. Residential diversion rates tend to be much higher than those from other segments of society, where much work remains to be done to address the creation of waste as well as its eventual processing. Creating and handling waste costs money, consumes resources, and generally reflects process inefficiencies that could and should be mitigated. Modern societies need to objectively assess exactly what constitutes waste and look for ways by which to eliminate it from production chains.

Figure 4-16:
The 4R Waste Management Hierarchy



Internationally, the jurisdictions with the highest waste diversion rates have included a fourth R – recovery – in their waste management hierarchies. This fourth R follows and complements, rather than trumps, the first three Rs, which are, in order of priority from a waste management perspective: reduce, reuse and recycle.

Two of Canada's provinces – Quebec and British Columbia – have established comprehensive waste management systems that integrate energy recovery into their policy frameworks. The Government of British Columbia has gone so far as to institute a 5R waste management hierarchy, consisting of the following steps:

1. **R**educe waste at source
2. **R**euse where possible
3. **R**ecycle products at the end of their useful life
4. **R**ecover energy or materials from the waste stream
5. Manage **R**esiduals in an environmentally sound manner

The fifth step is intended to address the fact that after waste has been incinerated and energy recovered from it, some residual material remains, in the form of ash. This ash typically constitutes between 10 and 15% of the original waste by volume. Some of this ash can be used as fill in new construction projects or as a component of asphalt or cement. Finer ash is captured by air pollution control equipment in the stacks of energy-from-waste facilities and is then tested for toxicity before being sent to a landfill site.

In its proper place in a waste management hierarchy and with the application of the best available technologies, the incineration of non-recyclable materials for energy recovery is now widely held to be a more environmentally sustainable option than landfilling. This is in part because modern pollution control systems in energy-from-waste facilities have delivered emissions reductions of over 90% in the last several decades; as a result of such advances, incineration with energy recovery can play an important role in reducing the roughly 20% of all methane emissions in Canada that stem from the degradation of waste in the nation's landfills.

Figure 4-17: **Energy-from-Waste Facilities in Canada**

Facility	Location	Year Opened	Annual Waste Processed (tonne)	Continuous Power Output (megawatts)	Number of Permanent Jobs
Emerald Energy from Waste Facility	Brampton, Ontario	1992	174,000	9	62
Durham York Energy Centre	Clarington, Ontario	2014	140,000	20	40
L'incinérateur de la Ville de Québec	Limoilou, Quebec	1974	312,000	70	75
Metro Vancouver's Waste-to-Energy Facility	Burnaby, British Columbia	1988	285,000	115	44
PEI Energy Systems Energy from Waste Facility	Charlottetown, Prince Edward Island	1983	60,000	22	31
Wainwright Regional Waste to Energy Authority Combustor	Wainwright, Alberta	1995	10,000	0.4	10

Towards a Zero Waste Future

Ultimately, societies around the world should be setting their sights on zero waste futures, and waste management policy must begin to emulate the zero waste systems in natural ecosystems, in which waste materials from one part of a system serve as the building blocks for other parts. If it is cheaper for society to designate materials that are undesirable or difficult to manage as waste and discard them without consideration for their potential utility, those materials will continue to be produced and used unsustainably. In a sustainable paradigm, there can be no waste; there can be only materials waiting to have their potential value realized so that they can serve an alternative function.

It would be exceedingly difficult to create a system of production and consumption that is a completely closed loop, requiring no additional inputs and creating no residual outputs. But as our society's technological expertise matures and our natural resources become increasingly scarce, we will have to shift our modes of production and consumption increasingly towards sustainability and comprehensive materials management. Industry should be encouraged to redesign products and processes to reduce waste at the source, as well as to design new products more suitable for reuse and recycling. We cannot afford to squander our vast endowment of natural resources any longer and must therefore explore ways by which to extract all possible value from the resources already in circulation.

ELECTRICITY

Electricity is unique among energy commodities because, unlike coal, natural gas or biofuels, it is not a physical object. Rather, electricity is produced when electrons – trillions and trillions of them – get excited and start vibrating. It is these vibrating electrons that produce both electric current and heat. Electricity defies simple categorization in other ways as well: it is itself considered an energy commodity but it can be derived from other energy commodities as well as directly from energy sources. The same versatility that makes electricity an anomaly in these respects is also the reason why it is such a critical component of Canada's energy systems.

Lightning is an example of naturally occurring electricity. But it comes and goes in a flash, and we have no means of harnessing it. Over the last few hundred years, scientists and engineers have developed electricity generation technologies that allow us to "make" electricity in a controlled manner, and we have built infrastructure that delivers the electricity to homes and businesses for a variety of uses.

The Benefits of Using Electricity

Electricity is the most versatile of the energy commodities. It is used to power almost all lighting technology and household appliances, and it has powered subways and streetcars for over a hundred years. Electricity has enabled whole industries to develop – without electricity, there would be no information technology systems, no communications systems, no traffic control on our roads or in the air. And the list goes on. Moreover, when we put electricity to use, it is "clean" – there is no combustion equipment or associated emissions at the point of use. This makes it ideal for servicing energy amenities indoors.

The Problems with Using Electricity

The problems with electricity use are largely invisible to the end-user. These problems arise mainly during electricity generation and in the delivery of electricity to our homes and businesses.

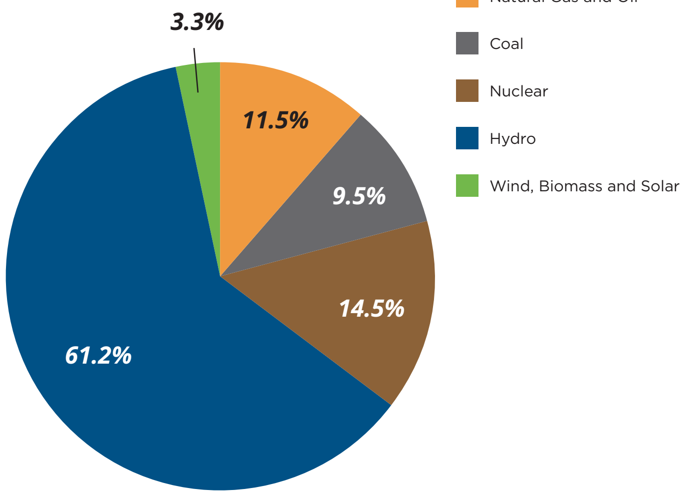
Burning fossil fuels for electricity is Canada's second biggest source of human-based greenhouse gas emissions, after transportation.

Electricity is also problematic in that it is difficult to store: in most cases, it must be transmitted in real time to the end-user. The hundreds of thousands of kilometres of transmission and distribution lines that we use to distribute electricity across North America can also be problematic. These power lines make electricity available, but they are expensive to build and maintain, and depending on where they are located, they can disrupt natural landscapes and ecosystems.

Electricity Generation

Figure 4-18: **Electricity Generation in Canada by Source, 2012**

Canada generates more than half its electricity from hydropower, power derived from water. Additional energy sources for electricity include fossil fuels, biofuels, uranium, and non-hydro renewables (wind, tidal and solar energy).



There are three methods of generating electricity: electromagnetic induction via turbines; the photo-electric effect via solar photovoltaics; and electrochemical reactions via fuel cells and batteries.

Electromagnetic Induction and Turbines

Electromagnetic induction describes the phenomenon whereby magnets rotating around a copper wire result in the generation of an electric current. The stronger the magnets, and the faster they rotate, the more electric current is generated. When a turbine is connected to a generator, the spinning blades of the turbine cause the magnets to rotate, which generates electric current in coils of copper wire. This electric current is the energy commodity produced. Over 99% of the electricity generated in Canada relies on turbines.

Power plants using thermal turbines burn fuel to generate high-pressure steam or exhaust gases to spin the turbines. Thermal power plants are responsible for the vast majority of worldwide electricity generation.

Non-thermal turbines spin using water (hydropower) or wind. Hydropower includes reservoir hydro and run-of-the-river. Wind power and tidal power are also used in Canada to run non-thermal turbines.

Steam Turbines

Steam turbines convert the thermal and kinetic energy in pressurized steam into rotary motion that is used to drive a turbine. The turbine is connected to a generator that produces the electricity.

Worldwide, steam turbines have historically been the workhorse of electricity generation, and steam turbines in various forms are responsible for about 80% of global electricity production. What differentiates the types of power plants that use steam turbines is how they produce the steam in the first place. Most countries around the world use fossil fuels or uranium to boil water to generate steam for electricity generation.

Steam Turbines at Fossil Fuel and Biofuel Power Plants

In a plant that uses a steam turbine, whether it runs on coal or coke, natural gas, oil or biofuels, the process is always the same. The fossil fuel or biofuel is combusted, generating heat and exhaust gases.

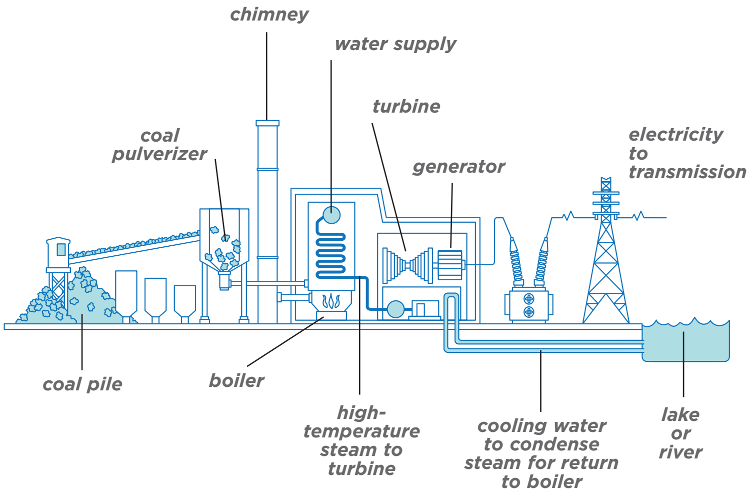
The heat generated by burning the fuel is used to turn water into high-pressure steam in a boiler. The steam is forced over the blades of the steam turbine, causing them to spin. When the turbine is connected to a generator, it generates electric current.

In most modern power plants, the water used to generate the steam is used over and over in a closed loop system. After the steam drives the turbine, it is condensed back to water, usually by exchanging the heat with cooling water, often sourced from a lake or large body of water. The newly condensed water is then fed back to the boiler in a closed loop. The cooling water from the lake travels in its own loop and, except for the exchange of heat, does not physically or chemically interact with the combustion process.

Figure 4-19:
Coal Plant Using a Steam Turbine

Steam turbines emit exhaust gases to the environment, just as home furnaces or boilers that burn fuel do. These exhaust gases include nitrogen oxides and sulphur dioxide, constituents of smog and acid rain.

Some power plants have technology installed to reduce levels of these gases in the emissions before they leave the chimney (or stack).



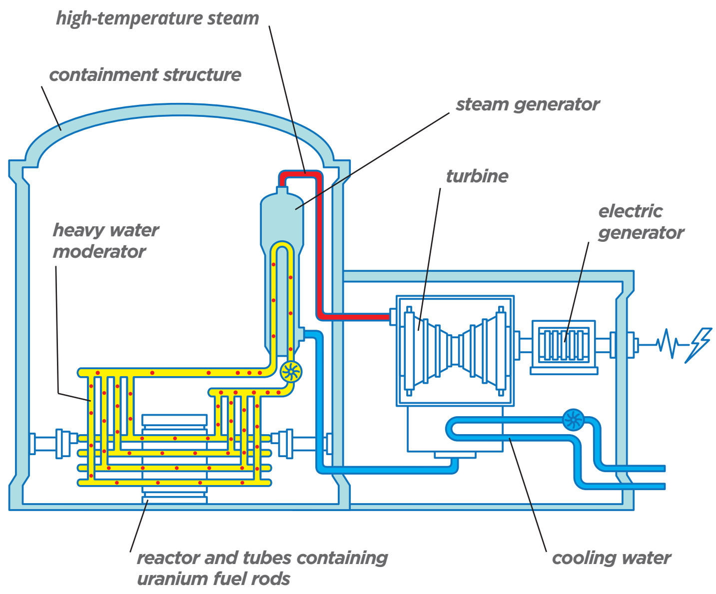
Nuclear Power Plants

Nuclear reactors generate heat through a process called fission, which is the splitting apart of uranium atoms into smaller, less heavy elements. When a uranium atom splits, it releases tremendous amounts of heat. Nuclear power plants use this heat to boil water to make steam, which then drives a steam turbine, generating electricity. There are different types of nuclear reactors in use throughout the world, but all of them work on this same basic principle.

Figure 4-20:
Nuclear Fission Process

The fission process is initiated when neutrons (non-charged particles common to almost all atoms) strike a uranium atom.

If the neutrons are travelling at the right speed and angle, they cause the uranium atom to break apart, releasing tremendous heat energy, smaller particles and more neutrons. These other neutrons can then strike other uranium atoms, which is how a self-sustaining nuclear reaction is achieved, under the right conditions and in the presence of enough uranium fuel.



Everything in Moderation

To ensure that the incoming neutrons strike the uranium atoms at the right speed, they must be moderated or slowed down. All of Canada's nuclear power plants use heavy water as the neutron moderator. Heavy water is called deuterium oxide – it is similar to normal water, but the water atoms have additional neutrons, making them slightly heavier. This is why the Canadian reactor is named CANDU, for CANada Deuterium Uranium. Because of the heavy water moderator, CANDU reactors can use natural uranium as the fuel source to create the nuclear reaction, while other nuclear power designs use regular water and enriched uranium, which does not require a moderator.

Uranium

Uranium is a naturally occurring metal that can be found in virtually all soils and rock in trace amounts. It is naturally radioactive and contributes to natural background radiation, to which we are all constantly exposed. Uranium is used as an energy source in nuclear power reactors for the production of electricity.

Figure 4-21: **Canada's Only Active Uranium Production Site**

Uranium from Saskatchewan supplied all of Canada's nuclear power plants and roughly 15% of the world's total uranium consumption in 2012. More than 85% of Canada's uranium production is exported to other countries for electricity generation. Sales of Canadian uranium amount to about $1.2 billion per year.

Because of their large size and high-grade uranium ore, the Saskatchewan deposits are more economical to mine than most other Canadian or international deposits.

Northern Saskatchewan has uranium deposits so rich that they were once open-pit mined. Today, the uranium ore is extracted using remote-controlled, underground mining techniques to protect workers from exposure to unsafe levels of radiation.

Saskatchewan's Athabasca basin – the world's richest source of uranium

Nuclear Production in Canada

Figure 4-22: **Canadian Nuclear Sites**

There are 19 nuclear units split among four nuclear installations in Canada. Ontario has three nuclear power stations and New Brunswick has one. In 2012, the 17 operational reactors (units) at these stations provided nearly 15% of Canada's electricity. The remaining two units have been shut down indefinitely or are being refurbished to extend their lifetimes for several more years.

DRIVERS & IMPACTS: NUCLEAR ENERGY AND RISK

The generation of electricity at Canada's nuclear power plants results in almost no emissions of greenhouse gases, air pollutants or toxics. There are, however, two main concerns related to using uranium fuel: nuclear waste and nuclear proliferation.

NUCLEAR WASTE

There are environmental risks associated with the storage of radioactive wastes and the decommissioning of nuclear facilities once they have reached the end of their operating lifetimes. Lower-level radioactive wastes in Ontario are transported to the Western Waste Management Facility near Lake Huron or are stored in dedicated waste management facilities at nuclear plants.

Used nuclear fuel is highly radioactive and must be managed carefully so that it does not pose a danger to people or the environment. Used nuclear fuel is high-level nuclear waste and has been stored at Canada's nuclear stations for several decades in large pools of water, sealed by several monitored barriers. But this is a temporary solution – spent nuclear fuel can stay highly radioactive for hundreds of thousands of years. The Nuclear Waste Management Organization (NWMO), the federal agency responsible for the long-term management of Canada's used nuclear fuel, has proposed designs for a deep, underground repository for both used nuclear fuel and for low- and intermediate-level wastes. The NWMO is currently working to identify a community with suitable geology that can host the long-term waste facility.

While radiation exposure is always a concern, levels near Ontario's nuclear facilities are lower than background radiation levels in many urban environments.

NUCLEAR PROLIFERATION

Uranium can be used to generate large amounts of electricity, but it can also be enriched to produce fissile material for nuclear weapons. Uranium that has been used for non-military purposes such as electricity generation (depleted uranium) can be used in conventional weapons. As residents of a country that has officially rejected the use of nuclear weapons, many Canadians are concerned about the potential dual uses of uranium in civilian and military operations.

Any state wishing to enter into a nuclear energy cooperation agreement with Canada must make a legally binding commitment to nuclear non-proliferation. This means becoming a party to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and accepting the application of full-scope safeguards by the International Atomic Energy Agency (IAEA) on all current and future nuclear activities. In addition, all countries wishing to enter into nuclear cooperation with Canada must conclude a legally binding, bilateral agreement with Canada − a Nuclear Cooperation Agreement (NCA) − that includes monitoring and reporting requirements.

Gas Combustion Turbines

Gas combustion turbines use the exhaust gases from the combustion process to drive the turbine. No steam is generated with a gas combustion turbine, so these power plants do not use a boiler. They are more like a big furnace, where the exhaust gases from natural gas or biogas combustion are forced under high pressure over turbine blades, causing them to spin.

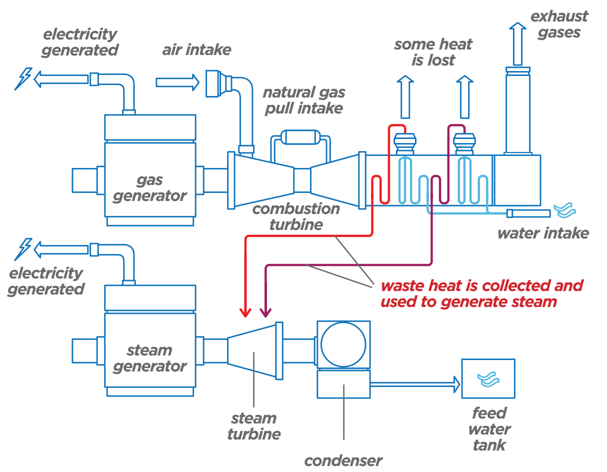
Combined-Cycle Systems

A combined-cycle plant consists of a gas turbine and a steam turbine, placed one after the other. First, a fuel, usually natural gas, is combusted, and the force of the exhaust gases drives the gas turbine. This is the same as a regular gas turbine. But a combined-cycle system has a second stage: the heat from the exhaust gases heats water, generating steam that drives a secondary, usually smaller, steam turbine to generate even more electricity.

Figure 4-23: **How a Combined-Cycle Turbine System Works**

Because the two turbines are in series, combined-cycle systems generate more electricity from a given amount of natural gas fuel than either a single-cycle gas or steam turbine would on its own.

When wasted heat from the gas turbine is recovered in this way, the overall efficiency of the process is dramatically increased. Combined-cycle systems can have efficiencies of up to 60%, compared with 30 to 35% for a single-cycle system.



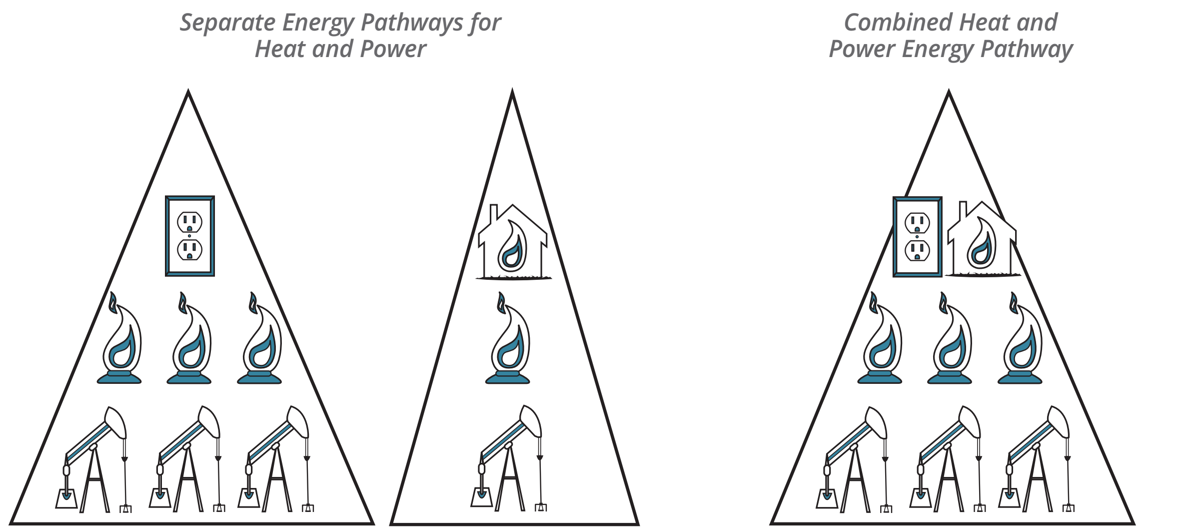
Because they include both a combustion turbine and a steam turbine, combined-cycle power plants are more expensive to build than single-cycle power plants. But because combined-cycle plants have higher conversion efficiency and can produce a unit of electricity using less fuel than a single-cycle plant, their operating costs are lower than single-cycle plants; as a result, combined-cycle plants become more economical the more they are used.

Combined Heat and Power (Cogeneration)

Combined heat and power (CHP) or cogeneration plants generate electricity and channel heat that is usually wasted, transferring it to nearby buildings, where it can be used for space heating or in industrial processes. While CHP systems most commonly use natural gas, it is possible to build them to use biofuels or coal.

A single CHP plant burns less fuel than two separate plants would use to generate the same amounts of electricity and heat. Because they are more efficient and use less fuel, CHP plants can save on fuel costs and reduce greenhouse gas emissions.

Figure 4-24: **Electricity and Heating Pathways**



To be economical, CHP plants must be located near where the heat is needed; otherwise, it dissipates before it can be used. The simultaneous production of both electricity and heat makes CHP systems ideal for buildings, such as hospitals and industrial facilities, that require a mix of both.

CHP systems are also well suited to provide electricity and heat to a community through district heating, where hot water can be distributed to homes using underground pipes. Locating CHP plants close to their heating and electricity loads also reduces transmission losses, compared with more distantly located power plants.

Hydropower

Canada's lakes and rivers are crucial sources of drinking water and irrigation and are also important for transportation, tourism and culture. They are also the energy source for over 60% of Canada's electricity generation. Lakes and rivers are found in abundance across the country, and some areas of the country have especially good hydrogeology for electricity generation.

There are two main types of hydropower plants: reservoir hydro and run-of-the-river hydro. Tidal power and energy from waves can also be harnessed to generate electricity.

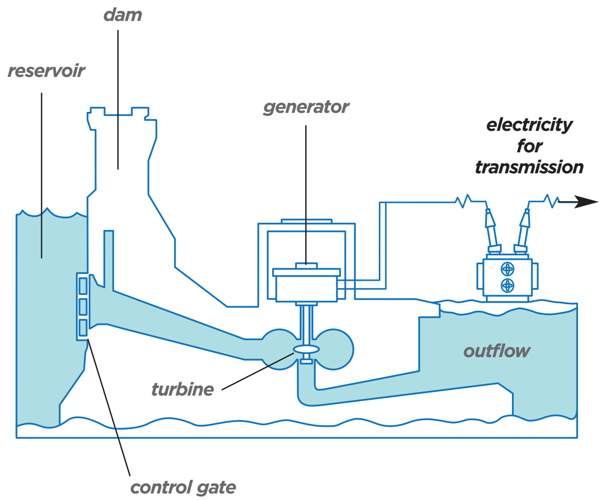
Reservoir (Dam) Hydro

Reservoir hydropower stations use the potential energy of water stored in a reservoir to drive a turbine. The amount of electricity generated is directly related to both the volume of water and the vertical distance between the water reservoir and the outflow, called the head (the pressure resulting from the weight of that water).

Figure 4-25: **How a Reservoir Hydropower Station Works**

Water at the higher level is diverted through a tunnel containing a turbine connected to a generator. The weight of the water forces the turbine and generator to spin, generating electricity. The water flows through the station and rejoins the main stream of the river.

Hydropower stations with a reservoir produce (i.e., dispatch) electricity as needed by controlling when and how much water flows through the turbine. Reservoir hydropower is unique in that the electricity is renewable, with no direct greenhouse gas emissions, but it is also dispatchable. This means that during peak periods, these stations can respond by producing power up to their maximum limit. During off-peak times, these stations can stay idle, saving the potential energy of the water for the next day's expected peak demand.



DRIVERS & IMPACTS: FLOODING AND ECOSYSTEMS

Reservoir hydropower facilities generate electricity without direct emissions of greenhouse gases or air pollutants. But they can have significant impacts on the local landscape and ecosystems. Because the construction of reservoir hydro involves construction of an upstream reservoir, significant amounts of land are flooded and converted to aqueous ecosystems. In addition, downstream ecosystems usually get far lower and more variable amounts of water than they did prior to the flooding. Suitable hydropower sites are often remote and, as a result, tend to be more ecologically pristine. And because communities tend to form around rivers, many sites that are otherwise suitable for hydropower development also have value to Indigenous and other peoples.

Reservoir Hydropower in Canada

There are hundreds of hydropower sites, and many more potential sites, of varying sizes across Canada. To date, the largest sites are clustered in six main regions, described below by province from west to east (only sites over 20 megawatts are shown on the map in Figure 4-27):

- Eastern British Columbia
- Northeast Manitoba
- The Great Lakes and St. Lawrence River
- Northern Quebec James Bay complex
- Southeast Quebec
- Newfoundland and Labrador's Churchill Falls

Figure 4-26:
Hydropower by Province/Territory, 2013

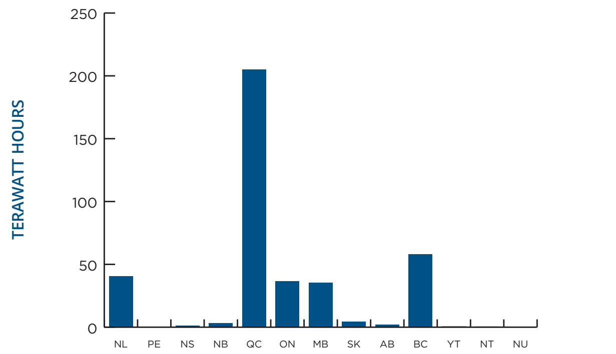


Figure 4-27:
Major Hydropower Sites in Canada

Reservoir Storage

Storing water behind huge dams continues to be the cheapest and most common system of large-scale energy storage in Canada and globally. Because reservoir hydropower plants are dispatchable, they can support the development of intermittent electricity sources, such as wind and solar (these energy sources are described as intermittent because they are available only when the wind blows or the sun shines). Thanks to its capacity for storage, reservoir hydropower has a unique operating flexibility. It can ramp up hydropower production within minutes, balancing out shortages caused by unexpected outages or providing power at times of peak demand.

Run-of-the-River

In contrast to hydropower stations that use the potential energy stored in a water reservoir, run-of-the-river stations generate electricity using the natural flow of a river.

Because the electricity generation from run-of-the-river power stations depends on the flow of the river, they are intermittent sources of electricity generation. However, because they do not involve the flooding of a watershed to form a reservoir, run-of-the-river stations generally have fewer land use and ecosystem impacts.

Run-of-the-river hydropower stations generate electricity in much the same way as reservoir hydro stations. All or a portion of a natural river current is diverted to flow through a tunnel, where it drives the station's turbines, which are connected to a generator, to produce electricity

Big or Small?

In the media, we often hear the term "big hydro." There is no consensus in Canada or, for that matter, in the world about what constitutes a big or small hydropower plant. In Quebec, "small" refers to plants with capacities of less than 25 megawatts, and in British Columbia, "small" refers to plants with capacities ranging from 2 megawatts to 50 megawatts.

There are often financial advantages (economies of scale) with larger plants because more electricity can be generated. Perhaps the important distinction for hydropower plants is not the size but the impacts of hydropower plants on the environment; potential impacts on the environment are site-specific and are assessed on a case-by-case basis.

Tidal Turbines

Canada has the largest coastline of any country (over 200,000 kilometres), with large coastal areas bordering on the Pacific, Atlantic and Arctic Oceans. When the tides come in and go out, the flow of water can be harnessed to power a turbine to generate electricity.

Although the tides rise and fall twice a day in all coastal areas, locations that can generate cost-competitive electricity are rare. The Annapolis Tidal Generating Station in Nova Scotia is one of only three tidal barrage power plants in the world and the only one in North America. It has a 20 megawatt capacity – enough to power about ten to twenty thousand homes when running at full capacity. In 2010, Nova Scotia legislated that 40% of the province's electricity should come from renewable sources by 2020, with a target of 300 megawatts of installed tidal generation capacity by that time.

A tidal barrage is a dam-like structure that captures the energy from a tide moving into and out of a bay or river mouth subject to tidal flow. A tidal barrage differs from a dam in that it controls both inflow and outflow. At high tide, the ocean's waters pass through the barrage sluice gates and through turbines that are installed in the barrage wall. Then, at low tide, as the water flows back out to the ocean through the sluice gates, it once again turns the turbines in the barrage wall.

Natural Resources Canada has identified 190 potential tidal power sites off the country's coasts with a total annual estimated capacity of 42,000 megawatts, which would account for more than 60% of Canada's annual electricity consumption.

Wind Turbines

Wind has been used for centuries to grind grain and pump water and, starting in the last few decades of the 20th century, to generate electricity. All wind turbines harness the power of the wind through the use of curved or angled blades. When the wind passes over these blades, aerodynamic forces make the turbine blades spin, generating electricity through electromagnetic induction, as with all turbines.

Horizontal axis turbines usually have three rotor blades affixed like a propeller at the top of the tower, facing into the prevailing winds. The actual turbine and electricity generation equipment is housed at the top of the tower in the nacelle, behind the rotor blades.

The majority of wind turbines are of the horizontal axis type. But there are other types of wind turbines, including vertical axis turbines and smaller, residential-style turbines with more than three blades. Wind turbines today come in a range of sizes, from a 3 kilowatt turbine designed to provide power to a cottage, to huge turbines standing over 200 metres tall and producing up to 8 megawatts of power. Even blimp turbines are being considered; they would float as high as 1,000 metres above the Earth, transmitting power through a conducting tether to the ground.

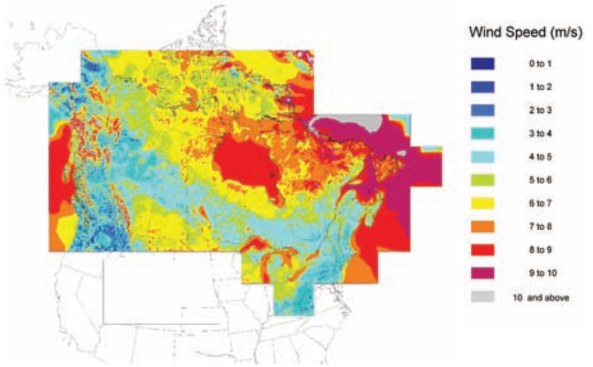
Wind

Wind speeds are stronger at higher elevations and on or near bodies of water where there are fewer obstructions to the wind. For these reasons, wind turbines are being designed to be taller, and there is much interest in developing wind farms offshore or near lakes and coastlines.

Figure 4-28: **Wind Speed Map of Canada**

This map shows average wind speeds in various parts of Canada. The highest wind speeds occur on the Pacific and Atlantic coasts, on the southern shores of Hudson Bay and James Bay, and on the Great Lakes.

On land, there is significant wind potential in the Atlantic provinces, much of northern Canada, the Rocky Mountains, and southern areas of Alberta, Saskatchewan and Manitoba.



Wind and Power

The stronger the wind, the more electricity a wind turbine can generate – the electricity produced generally increases with the cube of the wind speed – which is why consistently windy sites are in demand by those wishing to build wind farms. Wind turbines produce electricity when winds blow more than 13 kilometres per hour (roughly 4 metres per second) and can increase their output until they hit maximum power output at about 55 kilometres per hour (15 metres/second). When winds blow at 90 kilometres per hour or more, large wind turbines shut down for safety reasons.

Because generation depends on wind speed, and because wind speeds increase with height above the ground, new wind turbines are designed ever taller to maximize electricity generation.

Wind is an intermittent source of energy, and so power output is variable – when there is no wind, no electricity is generated. To maintain reliability in the electricity system, other generation facilities or storage options must be available.

Wind Farms

A large turbine might generate about 1 megawatt of power on a windy day, enough for 500 to 1,000 homes. Wind turbines are often grouped together in wind farms that can produce tens or hundreds of megawatts of power – enough to power thousands of homes when winds are blowing.

Wind farms are designed to take advantage of prevailing wind conditions. The wind turbines have to be spaced far enough apart to prevent the turbulence or wake of one turbine from affecting the flow of wind at another.

DRIVERS & IMPACTS: WIND TURBINES AND HEALTH AND ENVIRONMENTAL CONCERNS

Wind turbine siting has become a contentious issue in many communities. Some residents oppose wind turbines because they find them unsightly, they feel that they impose on the natural landscape or they are concerned about impacts on their property values.

Others are concerned about potential health impacts resulting from the noise that wind turbines make as the rotor blades cut through the air. A modern turbine operating properly generates noise levels, measured a few hundred metres away, that are usually lower than the average background level of noise in city residential areas. But some people appear to be more susceptible than others to wind turbine noise. Many studies have been conducted around the world, but to date, none have found any correlation between wind turbine noise and adverse health effects in humans.

Offshore Wind

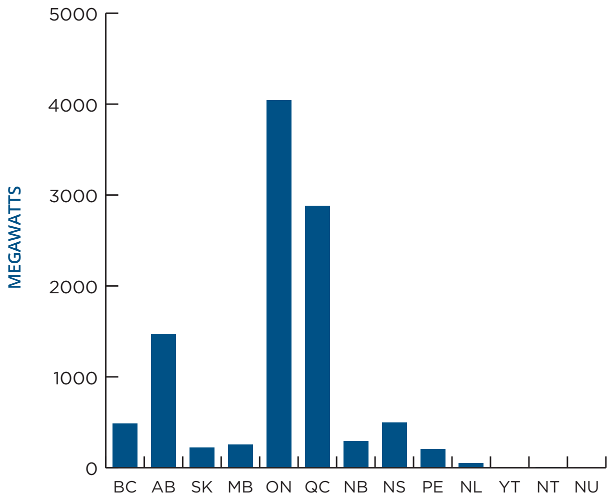
Wind speeds are usually higher next to large bodies of water, where there are no large structures or land formations reducing the power of the wind. As a result, it is often most economical and productive to build wind turbines offshore, where they can generate the most electricity. Offshore turbines disrupt the lake bottom or seabed where concrete foundations are set, affecting local ecosystems; however, building offshore is an alternative to the development of terrestrial wind farms, given community concerns about local land use impacts and noise.

In Europe, wind turbines are typically built several kilometres offshore. There are currently no offshore wind projects in North America, although there are several projects proposed for the Great Lakes and off the coast of the northeastern United States. The first of these projects, in the state of Rhode Island, is expected to come online in the summer of 2016 and will involve the installation of turbines with power outputs of up to 6 megawatts.

Figure 4-29: **Installed Wind Capacity in Canada, 2015**

Canada's wind capacity has grown rapidly over the last decade, with installed national wind capacity surpassing the 10,000 megawatt mark in 2015. Double-digit growth is forecasted to continue for at least the next two decades. Wind now represents approximately 4% of Canada's total electricity generation, supplying enough energy to power over 2.5 million homes each year.

Emerging options in large-scale electricity storage technologies, as well as developments in cross-jurisdictional electricity grid integration and grid management, are making wind energy more dispatchable and versatile for grid operators. Ontario, Quebec and Alberta are Canada's largest wind electricity generators.

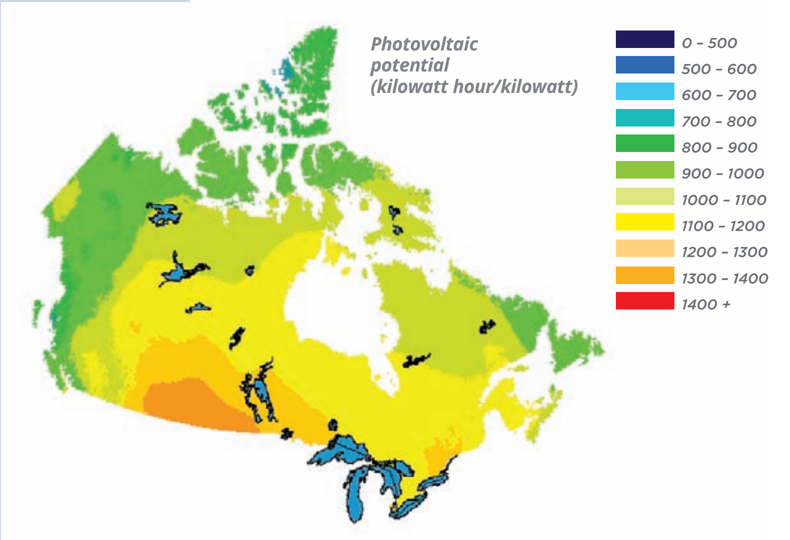


The Photoelectric Effect and Solar Photovoltaics

The sun is the ultimate source of almost all of the Earth's energy. It constantly radiates energy through space in all directions, and some of this energy hits the Earth, which is roughly 150 million kilometres away. The sun's energy influences the tides, ocean currents and the direction and strength of wind currents.

The sun generates tremendous amounts of heat, light and electromagnetic radiation (e.g., X-rays and ultraviolet [UV] rays) through a process called nuclear fusion, which combines two hydrogen atoms to form helium. The sun produces so much energy that the small fraction of radiation that actually hits the Earth in one hour is more than all of the energy consumed by the world during one year. It is no wonder that people have been trying to harness the power of fusion for over fifty years.

Figure 4-30:
Solar Radiation in Canada



Latitude and Clouds Matter

Because the Earth tilts on its axis, the amount of sunlight reaching it varies with latitude. Countries near the equator get lots of sunlight throughout the year, while northern countries at higher latitudes get considerably less which is one of the reasons why it is hot in Cancun, Mexico, when it is freezing in Edmonton, Alberta.

The Earth's tilt also explains why, in Canada and other northern countries, the south-facing sides of buildings receive the most sunlight.

Cloud cover prevents some of the light from the sun from hitting the Earth. Areas next to water tend to have more clouds because of evaporation. Southern Alberta and Saskatchewan see the most sunshine of any part of Canada.

Because Canada is located in the northern hemisphere, its ability to harness the sun's energy is limited, in contrast to tropical regions, which receive much more sunshine, on average, throughout the year. Despite its less-than-ideal position on the globe, Canada's installed solar capacity grew from 33 megawatts in 2009 to over 2,000 megawatts in 2015.

Solar Photovoltaic Systems

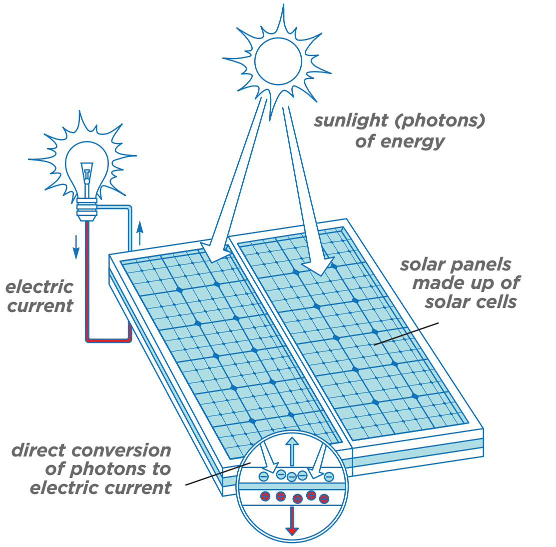
Solar photovoltaic (PV) systems consist of numerous solar photovoltaic cells combined into large, rectangular solar panels. The panels are covered with a durable, transparent material to ensure that the photovoltaic cells are protected from the elements. When several panels are mounted using rails or other support equipment, they form a solar PV array.

Solar PV panels generate direct current (DC) electricity, while Canadian homes and businesses are wired for alternating current (AC). To make the electricity usable, the DC electricity has to be changed to AC through equipment called an inverter, a process that results in energy losses.

Scientists and engineers are working on advanced design and manufacturing techniques to maximize the electricity that a cell can produce and to minimize the size of the cell and the cost of production. Current solar PV cells convert about 12 to 17% of the energy in sunlight into electricity. The first solar cells, which were built in the 1950s, had efficiencies of less than 4%. To date, the maximum efficiency achieved by solar PV cells in laboratories is about 45%.

Figure 4-31:
How a Solar Photovoltaic Cell Works

Solar PV cells typically consist of one or more thin layers of silicon treated to have a positive electric field on one side and a negative field on the other side, with electrical conductors attached to both sides. A potent semiconductor, silicon atoms release electrons when struck by photons of light. When sunlight strikes the PV cells, the liberated electrons are channelled through the conductors, creating an electric current. Unlike turbines, solar PV cells have no moving parts.



Considerations Related to Solar Photovoltaic

The materials and specialized techniques used to produce solar PV cells can make these systems quite expensive, although costs are rapidly decreasing. In addition, solar PV cells only work when the sun shines, so some solar PV systems include batteries that store power for use at night or on cloudy days.

Solar PV cells are a quickly evolving technology; efficiencies continue to improve, while cost, size and weight decrease. New advances in the design of solar panels, including the use of nanotechnology and thin film production techniques, are improving the competitiveness of PV technologies. Indeed, in 2014, solar PV electricity in several North American jurisdictions reached a major milestone – it became cheaper to produce than electricity from natural gas–fired power plants, while having a much smaller environmental impact.

In contrast to solar thermal panels, which work best when it is hot, PV cells generally perform best at lower temperatures – an advantage in Canadian climates. Another Canadian advantage for PV is snow reflection; under the right conditions, the light reflected off snow adds to the amount of light hitting the panel, increasing electricity generation.

Geothermal Power

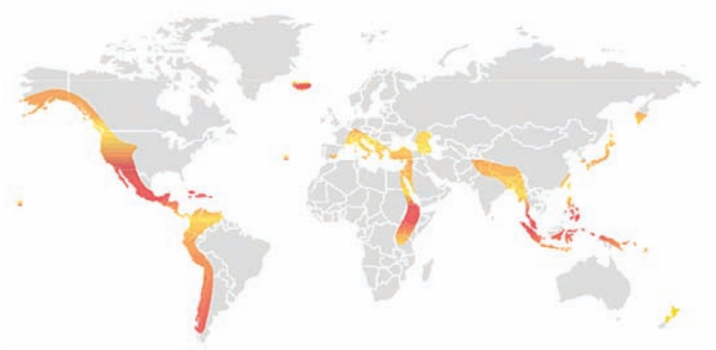
Geothermal power plants use the high temperatures present deep underground to heat water or to harvest groundwater that is already heated. The water is used to produce steam that powers electrical turbines. Like other forms of renewable energy, geothermal energy is without question abundant – the challenge lies in the difficulty of extracting it.

There are many regions where stores of superheated water in the Earth's crust are at depths that are within reach of conventional drilling technology. These regions tend to be seismically active, forming at the margins of the Earth's tectonic plates. The relative thinness of the Earth's crust near these margins can create ideal conditions for the siting of geothermal power plants.

Once installed, geothermal power plants can operate at or near full capacity all the time, unlike most other forms of renewable energy. This means that geothermal has the potential to provide reliable base-load electricity while producing a tiny fraction of the emissions that fossil fuels do, as well as avoiding the problem of radioactive waste disposal posed by nuclear power.

There are currently two commonly used processes to generate geothermal electricity: flash geothermal and binary geothermal.

Figure 4-32: **Global Map of Prominent Geothermal Hotspots**

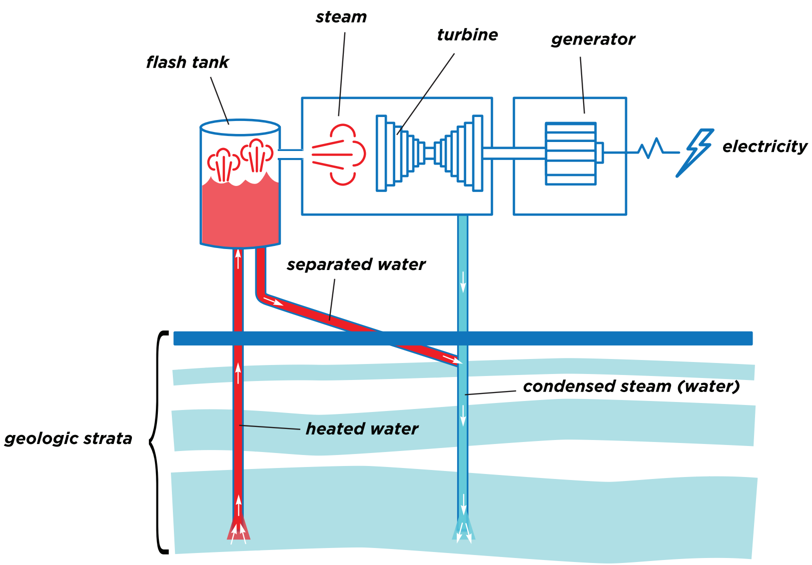


Red zones indicate the hottest known geothermal regions with high energy density. *Source: Glitnir Bank, Emerging Energy Research, May 2009*

Flash Geothermal

The tremendous pressure underground means that water can exist there as a liquid at much higher temperatures than it can on the Earth's surface. Flash geothermal taps this very hot, high-pressure water, which can reach temperatures in excess of 180 °C. To do this, a well is constructed, through which the groundwater rapidly rises to the surface and enters a low-pressure chamber. As the water enters the chamber, it quickly "flashes" into steam. The steam powers a turbine, which generates electricity. As the steam exits the turbine, it can either be released into the atmosphere as water vapour or be allowed to cool and condense, eventually being returned to the subsurface as liquid water.

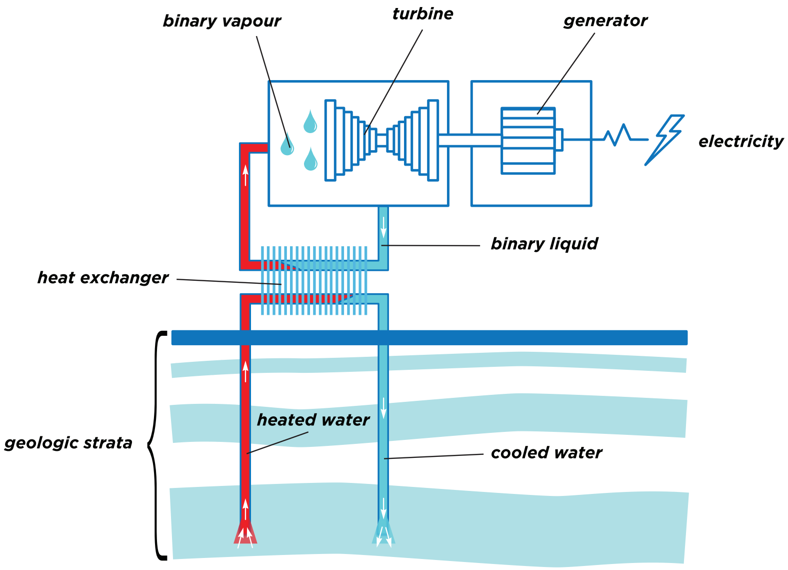
Figure 4-33: **Basic Schematic of a Flash Geothermal System**



Binary Geothermal

This process is used with lower-temperature geothermal resources. As in flash geothermal, hot, high-pressure subsurface water is tapped and brought up to the surface. But because the water temperature is too low to allow it to flash into steam, the heat energy from the water must be transferred to a secondary liquid with a lower boiling temperature. Therefore, the hot subsurface water is passed through a heat exchanger that transfers its heat energy to what is called the "working fluid." This working fluid is brought to a boil and its steam powers a turbine. The working fluid then cools, condenses and is recirculated through the closed system. The used water is also recirculated underground where it is heated once again. The working fluid and the groundwater are continually circulated in two separate closed loops – hence the name "binary" geothermal.

Figure 4-34: **Basic Schematic of a Binary Geothermal System**



Applications in Canada

Although Canada currently does not meet any of its electrical energy needs with geothermal power, the Canadian Geothermal Energy Association (CanGEA) estimates that British Columbia alone possesses over 5,700 megawatts in geothermal resources accessible with existing technologies. If this untapped source of baseload power were harnessed, it could offset more than 25 million tonnes of carbon dioxide emissions per year stemming from fossil fuel power plants. In addition, CanGEA estimates that Alberta, Manitoba and Saskatchewan all show significant potential for geothermal electricity production.

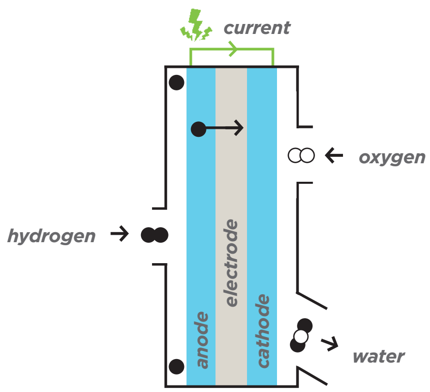
Electrochemical Reactions, Fuel Cells and Batteries

It is also possible to use a chemical reaction to generate electricity. This is the basic premise on which batteries produce an electric current, including old-fashioned lead-acid batteries and modern lithium-ion batteries. Fuel cells also generate electricity using an electrochemical reaction, but the process is somewhat different. Fuel cells require an external fuel, such as hydrogen, from which the electricity is generated. By contrast, batteries use chemicals inside them to produce electricity, without the need for an external fuel.

Figure 4-35: **Basic Fuel Cell Operation**

Fuel cells generate electricity through an electrochemical reaction. In a fuel cell, an externally supplied fuel (most commonly hydrogen gas) reacts with an oxidant (usually air or oxygen), separating the hydrogen gas into positively charged ions and negatively charged electrons. The electrons and ions "travel" through the anode and cathode in the fuel cell, generating an electric current.

There are no air-polluting emissions resulting from the generation of electricity from hydrogen fuel cells. Typically, the only by-products are heat and water.



Hydrogen Gas

Hydrocarbons are mixtures of carbon and hydrogen. Hydrogen gas is all hydrogen – no carbon. It is a very light gas that can be combusted to generate heat, just like hydrocarbons, but without the resulting emissions, except for water vapour. Hydrogen gas shows great potential for use in fuel cells.

Hydrogen gas is highly chemically reactive, meaning that it easily interacts with a wide range of substances (for example, with oxygen to form water – H_2O), and there are significant storage and transportation challenges. Hydrogen gas is so reactive that it does not occur naturally – it must be produced. While there are no emissions resulting from hydrogen fuel cell operation, energy is required to produce hydrogen gas – either from water through electrolysis (using electricity) or, more commonly, through thermal and chemical refining of hydrocarbons. Oil refineries are the biggest producers and users of hydrogen gas, which is separated out as a by-product during oil refining and then used as a fuel or inserted back into the process to produce other petroleum products.

Chemical Batteries

Chemical batteries, which store electrical energy in an electrochemical state until it is needed, offer versatility and can perform in a wide range of energy storage applications, both at the grid level and in small-scale residential or industrial applications. In general, chemical batteries offer a greater range of benefits in comparison to other energy storage options, but there are still several drawbacks.

On the benefit side, batteries are quiet and non-polluting in operation. Although chemical batteries can contain toxic chemicals and heavy metals, in most cases these materials can be recycled. Batteries are highly scalable, which gives power authorities and end-users the ability to tailor installations to their exact needs. Battery storage technologies are also very flexible, offering a wider range of applications than other types of storage. Like other large-scale energy storage technologies, batteries may be used to store surplus energy produced overnight for daytime use, but in addition, batteries can react to grid demands almost instantaneously. This rapid response capability means that battery systems can be deployed to smooth out moment-to-moment variations in the power supply from variable renewable energy sources such as solar and wind (this is known as capacity firming).

On the downside, because chemical batteries require electrochemical reactions to store energy, even under normal operation the energy storage capacity of chemical batteries degrades over time. Factors that negatively impact a battery, accelerating its degradation, include the heat generated by the charging process, the depth of discharges (deep discharges can degrade certain types of batteries), ambient temperature, and overcharging and undercharging. Currently, another major drawback to battery storage is its relatively high cost. Compared to energy-dense and widely available fossil fuels, batteries tend to be large, heavy and expensive, and are therefore often considered impractical for large-scale storage needs.

The following section covers several of the more than twenty chemical battery technologies that are currently being used around the world to provide energy storage solutions.

Lithium-Ion Batteries

Lithium-ion batteries were commercially developed by Sony in the early 1990s and are commonly used in cellphones and laptop computers. Most of today's electric vehicles (EVs) use lithium-ion battery technology because it outdoes competing chemical battery technologies in terms of energy density, while providing more power at lower weights and offering relatively long life cycles.

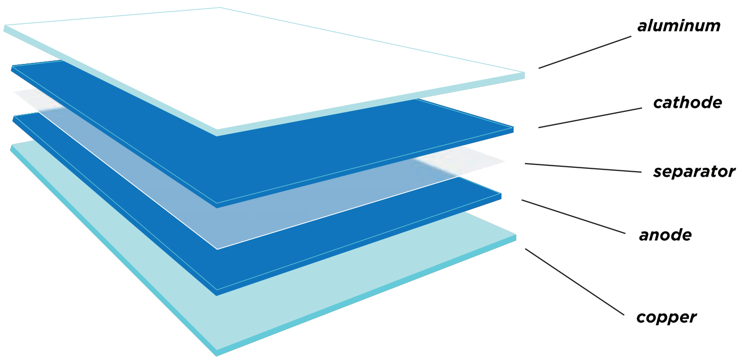
The same characteristics that make lithium-ion batteries useful for EVs also make them useful as grid-connected battery storage systems. An increasing number of energy storage demonstration projects are using series of linked lithium-ion battery packs to deliver a wide range of services, from time-shifting to renewable capacity firming, frequency regulation and voltage support.

Lithium-ion batteries are made up of many smaller storage units called electrochemical cells. Each cell consists of four layers. The top and bottom layers of a cell are made up of conductive materials – a layer of aluminum and a layer of copper – that allow the electrical current to reach the cells. In a lithium-ion battery, the positive electrode layer is made of pure lithium-metal oxide and the negative electrode, the anode layer, is made of graphite. A layer of nonconductive material is placed between the cathode and anode layers to prevent a short-circuit. The battery is filled with an electrolyte gel so that the lithium ions that contain the cell's charge can flow freely. The subatomic-sized lithium ions are so small that they can pass freely through the separator between the anode and cathode layers.

When the battery is charging, positively charged lithium ions pass from the cathode through the separator and are stored in the anode. When energy is needed, the cell discharges its positive ions, and they pass back through the separator to the cathode, creating an electric current.

Figure 4-36:
Lithium-Ion Battery Cell

In a lithium-ion battery cell, the conductive layers of aluminum and copper allow the electrical current to reach the cell's cathode and anode (the two dark-coloured layers in the middle).



Lead-Acid Batteries

Lead-acid batteries were invented in 1859 and are still found in most of the world's automobiles. The use of lead-acid batteries as storage devices in the power system dates back to the start of the 20th century. At that time, power stations were often shut down overnight, and the energy accumulated in lead-acid batteries would be called upon to meet overnight power demand.

Because they have been in production for so long and are the most affordable chemical battery, lead-acid batteries have long been a popular choice for a number of energy storage applications, including power quality maintenance and industrial uninterruptible power supply (UPS) systems. UPS systems provide short periods of emergency power in a blackout, affording backup power systems the time they need to come online. Lead-acid batteries are also frequently used in small-scale "off-grid" systems to store energy produced from intermittent renewable sources.

Like most batteries, lead-acid batteries consist of one or more electrochemical cells, containing positive and negative electrodes in an electrolyte storage medium (a solution of sulphuric acid and water). The cathode (positive) plate in a lead-acid battery is made up of lead oxide, a porous sponge-like form of lead, and the anode (negative) plate is made up of pure lead. When the battery is being discharged, a current flows from the cathode to the anode, causing both plates to be covered with solid lead sulphate. If too much lead sulphate builds up (sulphation), the battery cannot be recharged. When a lead-acid battery is totally discharged, the electrolyte liquid is mostly composed of water. When the battery is charged, the yellow sulphate recombines with the electrolyte to form a diluted sulphuric acid mixture.

Because of the steady buildup of lead sulphate on a battery's negative electrode, a traditional lead-acid battery has a relatively short life span of 500 to 1,000 charging cycles. Lead-acid batteries are heavy and offer low energy density compared to other battery technologies. Moreover, large discharges cause severe strain on the batteries. During each charging cycle, the lead-acid battery loses a small amount of its capacity. Lead-acid batteries are slow charging; a full charge can take up to 16 hours, and batteries must always be kept at or near a full charge to prevent sulphation.

Sodium-Sulphur Batteries

The sodium-sulphur (NaS) battery was developed by the Ford Motor Company in the 1960s. The technology combines high energy capacities with high rates of discharge, two characteristics that automakers look for in electric vehicle batteries. What prevented their adoption in vehicles and other mobile applications was their extremely high operating temperatures (typically between 300 and 350 °C) and the difficulty of handling the highly corrosive components.

In NaS batteries, the positive electrode is made of molten sulphur and the negative electrode of molten sodium. The electrolyte separating the positive and negative electrodes is made of a ceramic-like material. When NaS batteries are discharging power, sodium ions in the negative electrode pass through the electrolyte separator and react with the sulphur to form sodium polysulphide. When the batteries are charging, the process is reversed.

Since their development, NaS batteries have been deployed at over 190 sites worldwide, providing over 300 megawatts of storage capacity. Currently, twenty of those sites are grid-connected. The largest installation of NaS batteries is a 34 megawatt system integrated into a 51 megawatt wind farm in Japan, built in 2010; the NaS battery system ensures that a steady stream of power is delivered to the grid from this intermittent source.

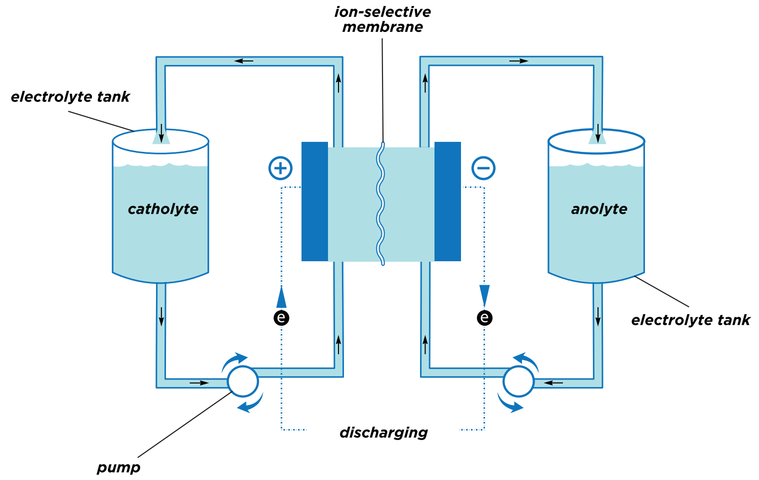
In 2013, BC Hydro installed a 1 megawatt NaS storage system in Trail, British Columbia. This system is capable of meeting the city's power needs for 7 hours. Before the system was installed, the remote city, connected to the grid by a single 55 kilometre distribution line, was beset by several power outages every year.

Flow Cell Batteries

Unlike a conventional battery, in which the energy is stored in the electrolyte mixture around the electrodes, the energy-containing electrolyte fluid in a flow battery is stored in external tanks and pumped into the cells to generate electricity.

The positive and negatively charged electrolyte liquids are stored in separate tanks and are separately pumped into the battery cells. The positive and negative electrodes in the battery cell are separated by a semi-permeable membrane. When a flow battery is charged or discharged, the electroactive materials cross the semi-permeable membrane, releasing or storing power.

Figure 4-37:
Model of a Flow Cell Battery



Because the energy-storing electrolyte is separated from the battery components, flow batteries offer operators flexible layout options and the ability to increase the battery's capacity easily, simply by increasing the size of the electrolyte storage containers. Storing the electrolyte separately from the electrodes also prolongs the lifespan of the electrodes because they do not undergo any radical chemical changes. Flow batteries can also be instantaneously recharged, simply by replacing the electrolyte liquid.

Because flow batteries are more complicated than conventional batteries, requiring a system of sensors, pumps, and control units to operate effectively, they can be used most effectively in large-scale (grid-level) storage applications.

Two types of flow batteries are common in energy storage systems around the globe: zinc bromine and vanadium redox. As of 2015, there were twenty-four vanadium redox grid-connected battery systems in operation worldwide and nineteen zinc bromine systems either in operation or under construction.

Emerging Grid-Level Energy Storage Options

As of 2014, global electricity storage capacity stood at just 3% of global generation capacity. But different types of energy storage technologies are emerging that are ideally suited for specific roles in managing supplies of energy. For example, flywheels and supercapacitors are relatively low in energy density, meaning that on a volume basis, they can store only a fraction of what other energy storage technologies can, but they are rapid responders – they can respond almost instantaneously to an array of grid demands and are capable of delivering large amounts of power quickly. These services are valuable in maintaining a stable energy grid, especially one in which more and more energy is being supplied by variable power sources.

Pumped Storage Hydroelectricity

Pumped storage hydro (PSH) facilities require two core components: a large source of water and a steep geographic gradient/change in elevation. In such facilities, large natural or artificial reservoirs at the top and bottom of the gradient are connected by a tunnel. At night, when demand is low, low-cost and/or excess electricity is used to pump water from the lower to the upper reservoir. The water is stored in the upper reservoir until electricity is needed. During peak periods, the stored water is released and flows downhill, powering hydroelectric turbines as it flows. The process as a whole tends to have efficiencies around 80%.

Figure 4-38: **The 174 megawatt Sir Adam Beck Power Plant at Niagara Falls, Ontario**

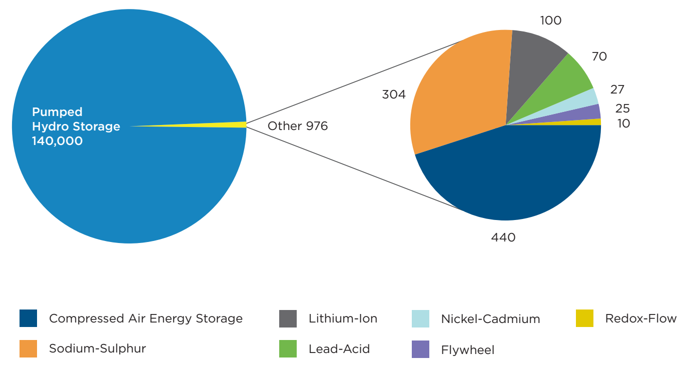
The upper storage reservoir can be seen in this aerial photo.

PSH has been used by utilities since the 1920s. In the United States, forty pumped storage plants with a total storage capacity of over 22 gigawatts are currently operational, and over sixty projects are being considered for development. The Bath County Pumped Storage Station in Virginia, with a storage capacity of 3 gigawatts, is known as the world's biggest battery. It helps provide power to

60 million people in thirteen states and in Washington, DC.

As of 2016, Canada's only PSH installation is the Sir Adam Beck Pump Generating Station near Niagara Falls, Ontario. The 174 megawatt facility was built in 1957 and allows Ontario Power Generation, its owner, to save surplus energy produced during off-peak hours and dispense it during times of high demand. Another PSH facility is currently under development in Marmora Township in central Ontario. When completed, this facility, at the site of an abandoned open-pit mine, will have a 400 megawatt capacity.

Figure 4-39: **Global Installed Grid-Connected Electricity Storage Capacity, 2014 (megawatts)**



To date, pumped storage hydro accounts for nearly all of the world's large-scale energy storage capacity.

Compressed Air Energy Storage

Aside from pumped storage hydro, compressed air energy storage (CAES) is the only storage technology that has been implemented at a large scale, with storage capacities of up to 1 gigawatt.

Similar to PSH systems, CAES takes surplus electricity generated during off-peak hours and stores it, in this case as compressed air, and then releases that energy back to the grid as electricity when needed.

In CAES systems, surplus electricity is used to power electrical compressors that compress air at atmospheric pressure (1 bar) to higher pressures (up to 414 bar). The compressed air is then stored either in underground caverns or aboveground pressure-sealed containers. The compression process generates a lot of heat energy. To capture this energy, the hot air passes through large heat accumulators, where much of the highly pressurized air's heat is saved in ceramic materials. The cooled compressed air is then injected into the storage medium. When demand for electricity is high, the cool compressed air is released from the storage medium and once again passes through the heat accumulator where heat is added to it to ensure that it does not freeze. The air then passes through a turbine, which generates electricity.

Compressed air energy storage systems, like PSH facilities, are highly dispatchable. They can be used in conjunction with intermittent renewable sources of energy to buffer their variable energy outputs as needed and can also be used for the time-shifting of baseload power.

Hydrostor, a Canadian Effort to Innovate and Transform CAES Technology

Based in Toronto, Ontario, Hydrostor is a pioneer in using the natural pressure created in deep lake or ocean water to store compressed air. Unlike other CAES technologies, which store compressed air in underground caverns or in pressure-sealed containers, Hydrostor's method uses large underwater balloons to store the compressed air. When energy is needed, a release valve is turned, and the weight of water surrounding the storage balloons sends the compressed air shooting back up to the surface where it powers turbines before being released back into the atmosphere.

Hydrostor built its first permanent demonstration plant on the Toronto Islands in 2015. The company has since been commissioned by the Caribbean island of Aruba to build an underwater CAES facility at Aruba's 10 megawatt Vader Piet Windpark. The installation will allow the Aruban utility to store 6 to 8 hours of surplus wind energy produced at night to meet daytime demand.

Flywheels

Flywheels have been used in industrial applications since the beginning of the industrial revolution to smooth out rapid bursts of power. Flywheels are used in sewing machines to keep the needle moving up and down at a constant speed as the foot pedal is pushed down. Internal combustion engine–based vehicles are also equipped with flywheels, which help to reduce jerkiness by smoothing out the engine's power delivery.

In energy storage applications, flywheels make use of excess grid electricity to power motors that accelerate "wheels" or cylinders sealed in a low-friction environment to high speeds. When energy is needed, the momentum from the large rotating cylinders is used to drive the motors in reverse so they act as generators. As this energy is captured by the motors, the flywheels gradually slow down until they can no longer power the motors and require recharging. Flywheels can respond almost instantaneously to address grid-scale power fluctuations, making them ideal for buffering the power output of intermittent renewable sources.

Made of steel, lightweight composite materials and magnetic bearings, modern flywheels are capable of achieving rotating speeds of up to 110,000 revolutions per minute. They are designed to operate for at least 20 years with minimal maintenance and to last for between 10,000 and 50,000 charge-discharge cycles – far surpassing the life cycles of chemical batteries.

In 2014, Canada's first grid-connected flywheel storage facility came online in Harrington, Ontario. The facility houses ten 250 kilowatt flywheels designed by Temporal Power, an energy storage company based in Mississauga, Ontario. Temporal Power's flywheels, which are encased in airless vacuum-sealed enclosures to minimize friction, are capable of storing much more energy than older models. Temporal Power's newest flywheel models can produce a continuous output of 500 kilowatts for up to 6 minutes and are up to 87% efficient. Multiple flywheels can be connected in an array to deliver up to 100 megawatts of energy storage at a single site.

Supercapacitors

In contrast to batteries, which store energy electrochemically, supercapacitors use static electricity to store electrical charges without chemical conversion. Because of the simplicity of their charge-discharge mechanism, supercapacitors can last millions of charge cycles without any reduction in their energy storage capacity. And they can be charged and discharged in seconds or minutes – much faster than even the fastest charging batteries.

Supercapacitors also differ from batteries in their power density to energy density ratio. Supercapacitors have a much higher power density than chemical batteries – they can unleash a tremendous amount of power quickly – but by weight they can store only about a fifth of the energy of a conventional lithium-ion battery. Supercapacitors are also costly – typically 20 to 40 times more expensive per kilowatt hour than their battery equivalents.

Again in contrast to batteries, ambient temperature is generally not a factor for supercapacitors. They can function without performance impacts in temperatures ranging from −40 to 65 °C and thus can be deployed in extreme weather environments where batteries might struggle.

Regular capacitors, used in a wide range of electronic devices from circuit boards to camera flash systems, contain two metal plates divided by an insulating material (usually air, a ceramic material or a plastic film). During charging, an equal number of positive and negative electrical charges build up on each plate. The insulating material helps store the charges by preventing the positive and negative electrons on either plate from coming into contact with each other. Once the plates are fully charged, the stored positive and negative charges will reject any other charges that are introduced. When a path is created in the circuit, the charges leave the plates and come together, creating a flow of electrical energy.

Supercapacitors work in a similar fashion, but their metal plates are made of various forms of carbon that have very large surface areas (e.g., activated carbon, graphene, carbon nanotubes), allowing the plates to hold hundreds of times as many charges as a normal capacitor.

Like flywheels, the supercapacitor’s strength lies in moderating frequency and voltage in a power grid. A supercapacitor’s “flash” charge-discharge capability can be used to regulate spikes and ripples in voltage and frequency, absorbing peaks and filling in valleys.

Electricity Transmission and Distribution

Let us think about lightning again for a moment. You see it, and then it is gone − in a fraction of a second. What happened to all that electricity? It dissipated, mostly as heat, to the environment.

Electricity "wants" to dissipate as heat, just like water "wants" to flow downhill. It is a fundamental part of how electricity behaves. And because it naturally wants to dissipate, storing large quantities of electricity is technically challenging and expensive. So, we use transmission wires to deliver the electricity, as soon as it is generated, right to our homes, where we can put it to use.

Taking a Closer Look at Electricity Transmission and Distribution

While there is no fundamental difference between transmission and distribution lines, the main characteristics of transmission lines are that they carry larger quantities of power, at higher voltages, over longer distances.

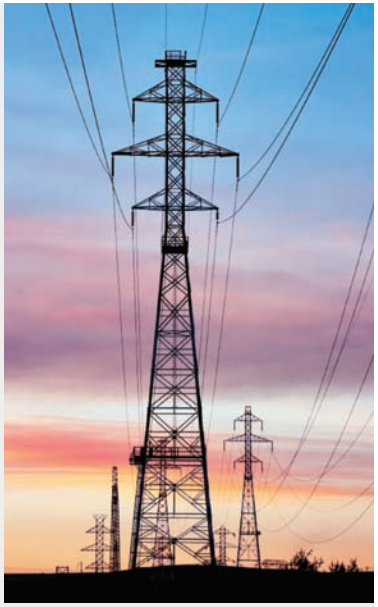
Voltage is a measurement of electromotive force. Higher voltages mean that more force or "electrical pressure" is pushing electricity through a circuit. When you plug your cellphone charger into an outlet, you close a circuit that allows electricity to flow through the battery, releasing the electrical pressure, until the battery is charged and accepts no more current.

Higher voltages are necessary to transmit electricity over long distances, to provide the required "pressure" or force to push the electrons.

Transmission Infrastructure

The need to transmit electricity from power stations to homes, farms and businesses has resulted in the development of an extensive transmission infrastructure that now criss-crosses the entire North American continent.

Transmission and distribution lines are essentially long, expensive, specialized extension cords that move electricity from one location to another. While the detailed physics of electrical transmission can be quite complicated, the basics can be understood if we think of the electricity grid as a series of water pipes that connect large pools of water. When the water level in one of these pools increases, it creates more water pressure at that end of the pipe, forcing the water to flow away from that end, into a pool with lower pressure, until the water levels in the two pools equalize, eliminating the pressure difference. When electricity is generated at a power plant, the "electrical pressure" at that point increases. This pressure forces the electricity to "flow" to points with lower pressure, just like water flowing through pipes.



High-voltage transmission lines in Quebec

DRIVERS & IMPACTS: ELECTRIC AND MAGNETIC FIELDS (EMFs)

Electric and magnetic fields (EMFS) are a natural phenomenon associated with electric currents – all of the wires in your home, the distribution lines connecting your home with substations and the larger transmission wires connecting cities with power plants result in electric and magnetic fields.

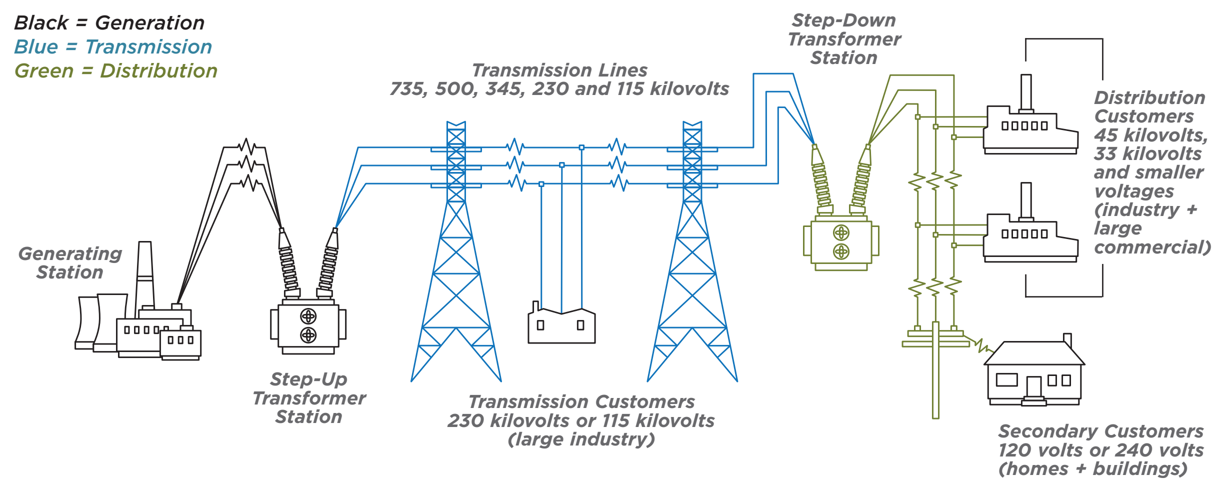
There are concerns about the human health effects of EMFS, particularly for people living near high-voltage transmission lines. Epidemiological and laboratory studies examining the effect of EMFS on human health have been largely inconclusive. However, concerns persist, and there are contradictory data regarding a connection between relatively weak magnetic fields and an increased risk of childhood leukemia.

From the Power Plant to Our Homes

A standard home in Canada or the United States has electrical outlets at 120 volts, and most appliances are designed to run on this standard voltage. Stoves, dryers and some air conditioners are more powerful and require special outlets at 240 volts.

Most of the electricity in Canada is generated in large hydropower, nuclear and fossil fuel plants. The electricity generated in these plants cannot be used directly in our homes because the voltage is too high for household appliances to operate safely. And these plants are usually located at a distance from residential areas.

Figure 4-40: **Transmission, Transformers and Distribution**



Electricity Generation	*Electricity is generated at high voltage, in the tens of thousands of volts. Voltage levels are related to how quickly and with how much force the generator spins.*
Step-Up Transformers	*Step-up transformers at the power station increase and regulate the voltage to 230 or 500 kilovolts. Quebec uses transmission lines as high as 735 kilovolts, the highest voltage in North America. In general, higher voltages reduce loss of energy in transmission.*
High-Voltage Transmission	*Long-distance transmission lines transmit electricity at these higher voltages over wires made of copper or aluminum, both of which are good conductors. Some industrial facilities have high loads and can be directly connected to the transmission system. These facilities are called transmission customers.*
Step-Down Transformers	*Local utilities, also called local distribution companies (LDCs), take electricity from the high-voltage transmission lines and use step-down transformers to lower the voltage to 35 kilovolts or lower for distribution to individual households and small businesses.*
Distribution	*Lower-voltage distribution wires carry electricity through cities and towns to homes and other buildings. These end-users of electricity are called distribution customers.*

The Electricity Grid

Long-distance transmission lines make electricity useful, but there are four major problems with them: first, they can be very expensive; second, few communities want them located nearby; third, they are vulnerable to extreme weather and terrorist actions; and finally, they result in line losses.

Line losses from transmission range from 5 to 15% in Canada, increasing with distance.

North America's transmission system is composed of loosely interconnected regional grids. Taken together, they are the largest machine on Earth, consisting of several hundred thousand kilometres of high-voltage transmission lines, and many more hundreds of thousands of kilometres of lower-voltage distribution wires. Overall, the North American transmission system has an estimated asset value in the trillions of dollars, representing decades of investment, labour and resources.

Most of Canada's population is connected to transmission and distribution wires supplying power, although there are many smaller communities in remote, rural and northern areas that are not. These communities have to generate their own electricity.

Figure 4-41: **North American Electricity Transmission Grid** (345 kilovolt lines and greater)

DRIVERS & IMPACTS: BLACKOUTS AND BROWNOUTS

The degree to which we are connected is evident from some large electricity transmission disruptions that have occurred in the last 20 years. A large blackout in 2003 affected most of Ontario and much of the northeastern United States, where some communities had no electricity for several weeks. It was caused by a delayed response to a power surge resulting from wires contacting overhanging trees in Ohio. The 1998 ice storm left close to 1.4 million people in Quebec and 230,000 in Ontario without electricity for days and, in some places, for weeks.

When electricity is completely unavailable, it is called a blackout, because there is no electricity to power lights. Brownouts describe a drop in voltage, but not a total blackout. Brownouts can result in dimmed lights and, if there is insufficient voltage, can lead to some equipment shutting down.

Blackouts and brownouts can be dangerous. For example, a loss of power in a hospital could pose a serious threat to people who depend on medical equipment to maintain their health or even their lives. For this reason, hospitals have backup generators to keep the power on in case of blackouts or other emergencies affecting their power supply. Similarly, the loss of street and traffic lighting also poses safety concerns during disruptions of power supply.

The ability to balance electricity supply and demand can help to avoid these situations.

BALANCING ELECTRICITY SUPPLY AND DEMAND

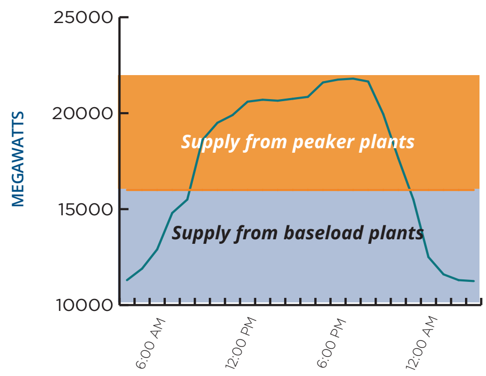
Balancing electricity supply and demand is a complex and delicate task. On the demand side, there are millions of residential, commercial and industrial electricity consumers whose demands vary throughout the day. On the supply side, there are dozens of large power plants and hundreds of smaller electricity generation facilities, in different locations, with varying potential to generate power in response to changing demand.

Demand Fluctuates

The demand for electricity changes during the day. As people get up and start turning on lights and appliances, and as manufacturers crank up production for the morning shift, electricity use increases.

Demand stays fairly constant, but there is a second spike in the early evening, as people arrive home and turn on lights and appliances again. Most of the time, the lights and computers in offices stay on for a while into the evening, so this spike includes some commercial and industrial power use as well as the electricity used by households.

Figure 4-42:
Daily Electricity Consumption



Demand also changes with each season. Figure 4-42 is representative of daily electricity use for Ontario in the middle of the winter. Other provinces vary in the quantity of electricity consumed, but in general all Canadian provinces have a similarly shaped daily consumption curve. In the summer, the evening peak is even more pronounced, as Canadians are increasingly turning on air conditioners and electronic devices, in addition to lights and appliances.

Operating the System

In Canada, provincial governments have jurisdiction over the design and operation of electricity systems. Depending on the province, Crown corporations or government agencies are responsible for the operation of the transmission system, to make sure that electricity is available when it is needed.

If, like most Canadians, you are plugged into the transmission and distribution system, you are dependent for your power supply on the skilled individuals sitting in control rooms at any time of the day or night, anticipating changing demand and providing direction to generation facilities to power up or down to balance supply and demand. These transmission operators balance the system in real time. They make estimates of shifting demand throughout the day and are in constant communication with power plants about how much electricity they need to generate to meet fluctuating demand.

System operators have to consider a number of factors when sending dispatch instructions. The location of plants relative to demand is important, as are their costs of generating electricity. Power plants can increase their power output only to a certain point without technical problems, and some plants may be shut down for maintenance.

Types of Power Plants

Baseload plants are designed to provide a steady, constant flow of power. Baseload plants are usually larger and more expensive to build but have lower generation costs and become more economical the more power they generate. Nuclear plants and reservoir hydro plants provide most of the baseload power in Canada, except in Alberta where most of the baseload is provided by natural gas and coal plants. Combined-cycle power plants are designed as intermediate sources of electricity, generating baseload and the lower end of peak demand.

Peaker plants are designed to ramp up or down with changing demand. Capital costs for these plants are usually lower than for larger baseload plants, but costs per unit of electricity generated are usually higher. Peaker plants usually run on a combustible fuel, such as natural gas or coal, but hydropower plants with a reservoir can hold water back to generate electricity when the demand is highest.

Intermittent plants are non-dispatchable, which means that they cannot be controlled to ramp generation up or down. Wind power, solar photovoltaic and some run-of-the-river hydropower plants are intermittent. They generate power when the wind blows, the sun shines and when water levels are sufficiently high. System operators usually "take" this electricity first, making use of it while they can.

SMART ENERGY GRIDS

Many governments and utilities across Canada are trying to transform the electricity transmission and distribution infrastructure into a new "smart" energy grid. This design for new infrastructure would integrate existing electricity generation capacity and transmission infrastructure with information technology and communication in real time.

A key concept of the smart energy grid is that it consists of both centralized, large power plants and small, decentralized, customer-owned and -operated power plants, all connected using two-way digital technology that communicates in real time on demand and supply requirements and options.

The smart energy grid concept includes "microgrids" that can separate from the larger distribution system, reducing impacts on neighbouring distribution systems in the case of a disturbance. Smart energy grids could allow specific generation facilities and loads to be isolated from the larger system – much as a firewall protects a computer network from external threats.

Smart Meters

Smart meters track electricity usage by time of day, usually on an hourly basis. Because the price of producing electricity varies depending on which sources are being used to generate it, smart meters make it possible to track the actual cost of electricity generation and base pricing on that cost. This pricing model is called time-of-use pricing.

Smart energy grids and smart meters also make it possible for utilities to control certain devices remotely. With the agreement of the homeowner, often in exchange for a reduced energy charge or other incentive, the utility can send a signal through a smart meter to a controller in an end-use device, such as an air conditioner, to turn it off or to change temperature settings, to control the demand for electricity.

Smart meters are an essential component of a smart energy grid, enabling two-way communication between end-users and utilities. End-users can use the information provided by their smart meters to modify their patterns of electricity consumption, reducing their overall energy use and the price they pay for it. Utilities can use the information to manage demand and supply requirements more efficiently. The reduction of peak demand resulting from the smart use of electricity can significantly reduce the cost and environmental impact of the electricity system.

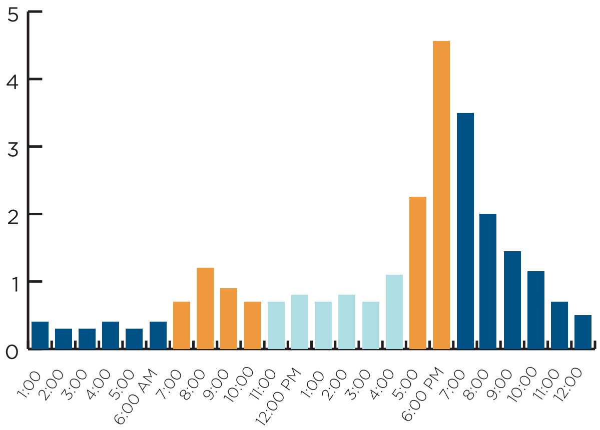
DRIVERS & IMPACTS: ELECTRICITY PRICES, TIME-OF-USE RATES AND SOCIAL EQUITY

Members of society who are already vulnerable to energy costs may be even more so under time-of-use pricing schemes. For example, the elderly, mobility challenged and parents of young children are more likely to spend their days at home and use electricity during periods of peak demand, when rates are highest. This does not mean that time-of-use rates are a bad thing. But it is important to consider who will be most affected by the implementation of time-of-use pricing and work to address these concerns. See Chapter 5 for more information on electricity pricing in Canada.

ENERGY STORY NO. 3 TIME-OF-USE PRICING

Some electricity utilities have started charging customers different prices for electricity, depending on the season and time of day. Time-of-use rates are intended to reflect the varying costs of electricity from different power stations generating power at different times of the day and year. Smart meters are installed at customers' homes to monitor both volume of electricity consumption and time of use. The Government of Ontario finished installing smart meters in every home and small business in the province in 2012. Roughly 4.7 million meters were installed, at a total cost of around $1 billion.

In the fall of 2012, Leanne received a letter from Toronto Hydro, indicating that a smart meter had been installed at her home and that, as a result, her household was now subject to time-of-use rates. She looked at her online account to see how much electricity she used during each hour of the day.

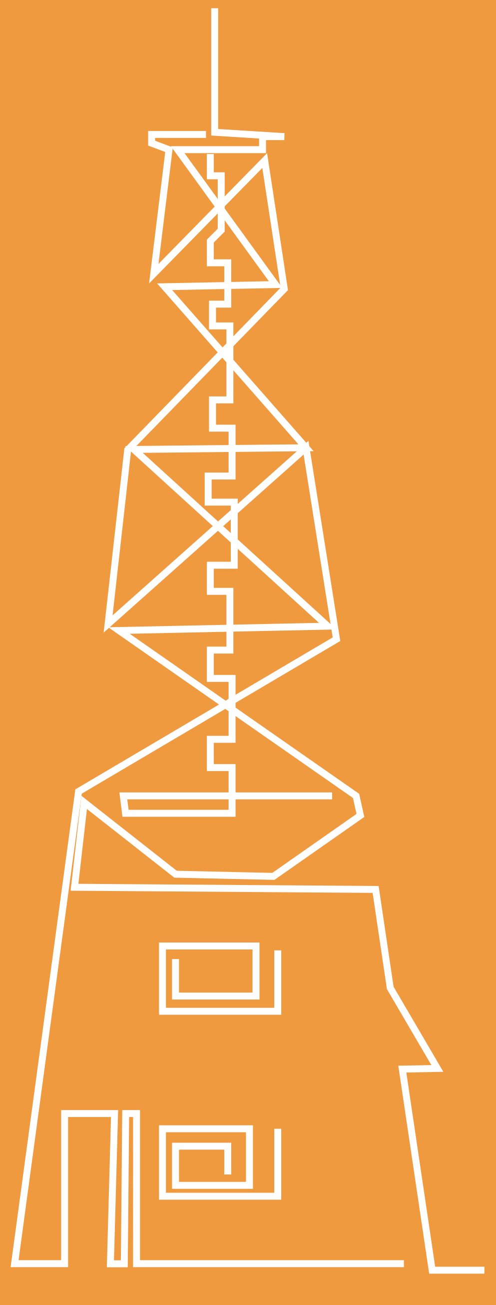


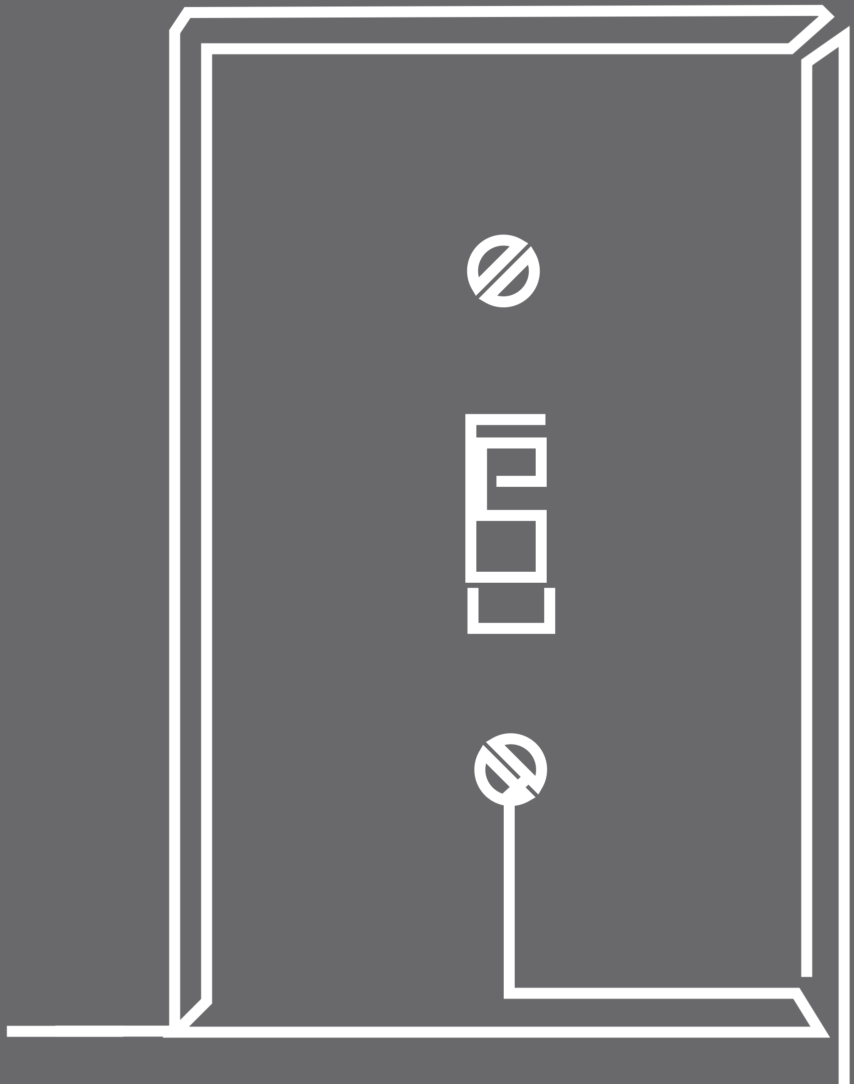
Time of Use

She took a close look at her electricity use on Friday, February 26, 2013. Leanne got home just before 6 p.m. that day. She put some clothes in the wash, started making dinner and turned on the television in the living room to keep her company. Leanne did not like seeing that big red spike on her electricity usage chart, indicating that she had used a fair amount of electricity while prices were highest.

Leanne had another look at how she could reduce her electricity use at peak times of the day. While she could not delay making herself dinner, Leanne realized that by waiting until after 7 p.m. to start her washing machine, or by leaving that chore for the weekend, she could cut the electricity costs of doing laundry nearly in half!

	Off-peak 8.3¢ per kWh	**Mid-peak** 12.8¢ per kWh	**On-peak** 17.5¢ per kWh
Clothes Dryer (1 load)	16¢	28¢	39¢
Clothes Washer (1 load/hot wash using electric water heating)	66¢	102¢	140¢
Clothes Washer (1 load/cold wash)	9¢	13¢	13¢
Electric Stove (1 family meal)	42¢	64¢	88¢
Dishwasher (1 load using electric water heating)	30¢	45¢	61¢



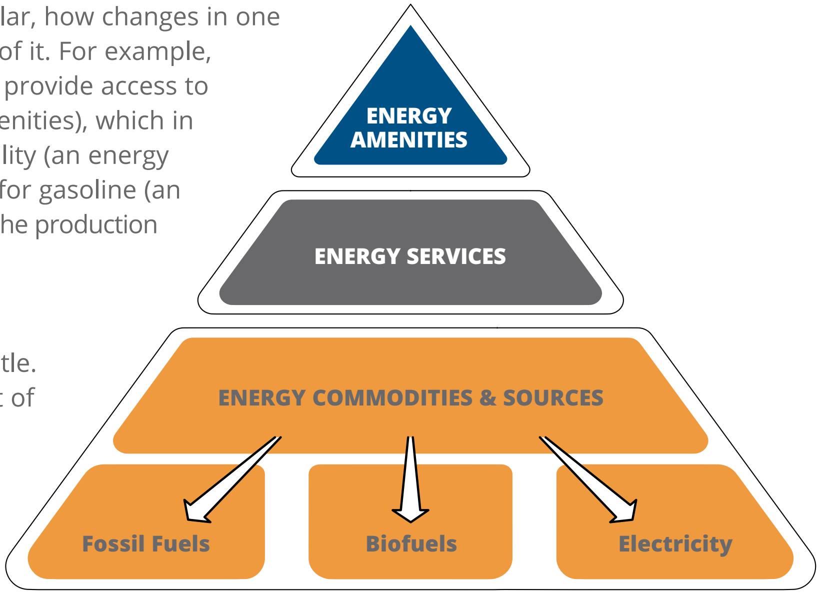


CHAPTER FIVE

Financial and Economic Dimensions of the Canadian Energy System

As illustrated in the energy pyramid below, Canada's energy system includes all the interconnected technologies and infrastructure that accommodate our demands for and access to amenities (e.g., comfort, safety, convenience), the energy services that contribute to the provision of those amenities (e.g., heating, lighting, transportation), the fuels and electricity (energy commodities) consumed in the provision of those energy services, and the primary energy sources from which those commodities are derived (e.g., fossil fuels, biofuels, sunlight, wind, water, uranium).

Such a broad definition of the system is necessary to understand its drivers, impacts and dynamics – in particular, how changes in one part of the system can affect another part of it. For example, telecommuting, e-shopping and e-learning provide access to employment, shopping and education (amenities), which in turn affects the demand for personal mobility (an energy service), which in turn affects the demand for gasoline (an energy commodity), which ultimately affects the production of oil (an energy source).



The financial dimensions of such a broadly defined system are complex and often subtle. Decisions that seem to affect only one part of the system can in fact have far-reaching consequences throughout the system. For example, telecommuting, e-shopping and e-learning platforms were not invented to save fuel and electricity, but their widespread adoption can have a profound impact on the financial outlook for the automotive and petroleum industries, among others. Or, to take another example, a household may choose to locate in a central, urban neighbourhood instead of a suburban neighbourhood for any number of reasons. Fuel and electricity expenditures may not have been a consideration in reaching that decision, but such a choice can nevertheless have a large impact on the level and pattern of energy use by that household.

There is a global energy transition now under way in response to a whole range of problems, including climate change, environmental degradation, resource scarcity and energy poverty. This transition involves changes in the relative roles of energy services, energy commodities and energy sources in meeting the demand for amenities. The economic and financial implications of these changes are profound, and the outcomes of them are difficult to predict. Historical data and recent trends will not necessarily continue smoothly into the future as the world navigates this global energy transition, seeking ways to provide for human needs and amenities sustainably and modifying its production and consumption of fuel and electricity in accordance with that goal.

With this in mind, we begin our exploration of the financial dimensions of the energy system by looking at the part of the energy system with which most Canadians are familiar – household spending on fuel and electricity.

Household Spending on Fuel and Electricity in Canada

In 2012, the average Canadian household spent roughly $4,600 on fuel and electricity: $2,048 for home heating, lighting and appliances and $2,560 for personal vehicles. For the average household, these expenses ranked fourth behind costs for shelter ($13,760), transportation ($8,656, not including fuel), and food ($7,739). As shown in Figures 5-1 and 5-2, energy costs represented 8.1% of current expenditures and 7.4% of disposable (i.e., after tax) income. These numbers are averages for all Canadian households. Most households occupying single-family detached housing would be at or above this average, and most households occupying attached housing, apartments or condominiums would be below the national average. In general, lower-income households pay a larger share of their household income toward fuel and electricity costs than do middle- and higher-income households.

Shelter costs (mortgage or rent) are the largest element of household expenses. When fuel and electricity costs are included in the shelter category (as they are in Statistics Canada reporting), they represent 13%

of total shelter costs, and about 10% if expenses for other household operations are included in the total. When fuel costs are included in the transportation category, they make up 23% of personal transportation costs, of which the largest element is the cost of vehicle ownership.

Figure 5-1: **Average Household Spending – Current Expenditures, 2012**

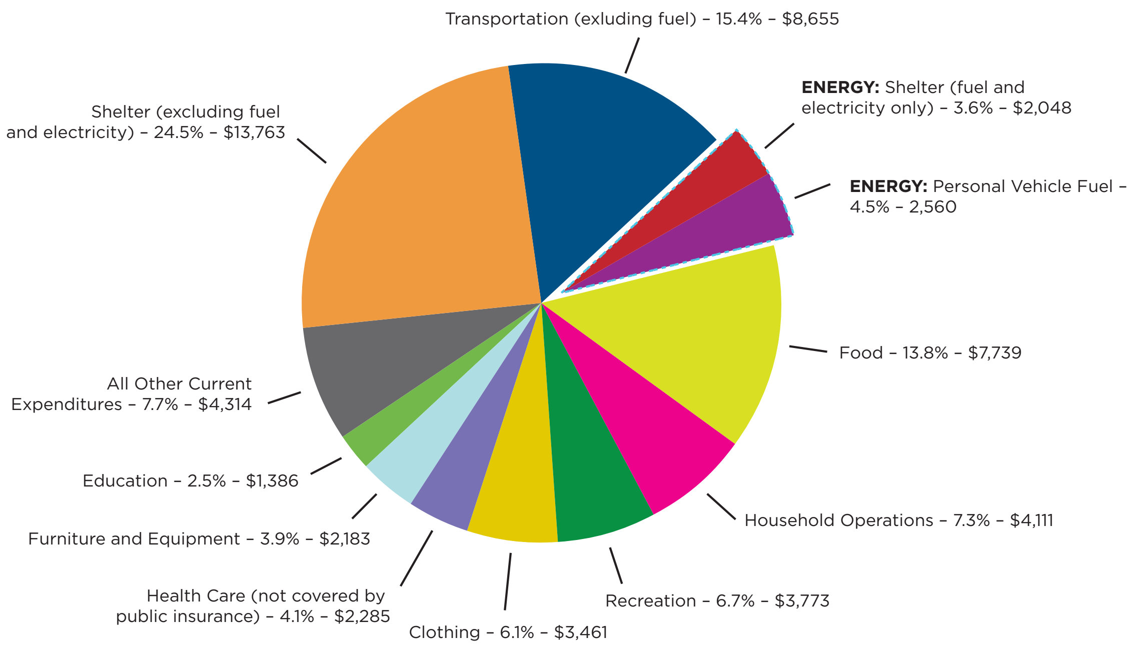
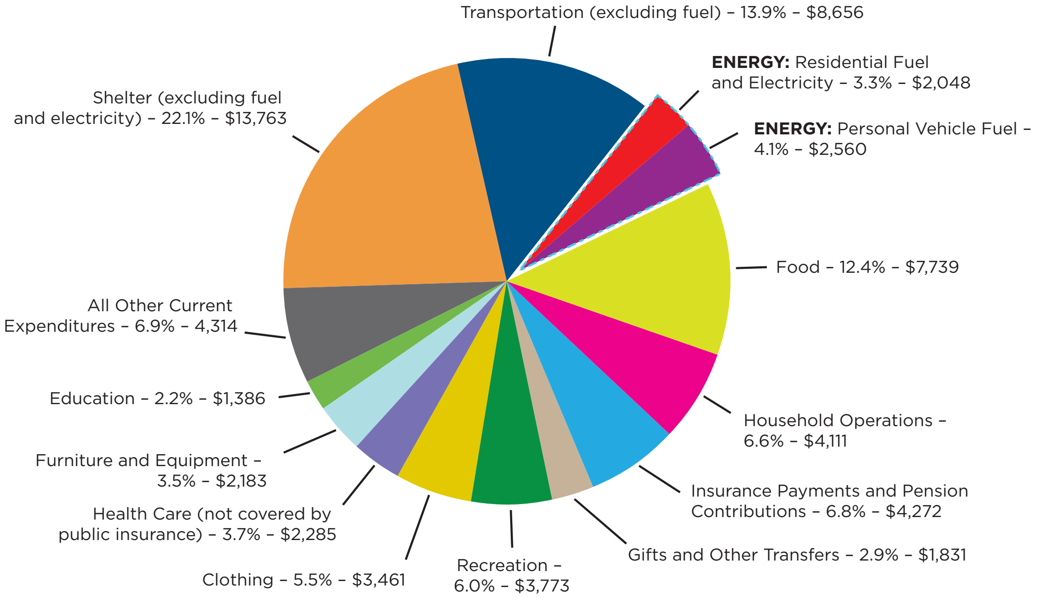


Figure 5-2: **Average Household Spending – Disposable Income (after income tax)**



Total household spending on energy varies depending on many factors. Some examples of these factors include:

- **Price differences.** Energy costs vary from province to province, especially for electricity, but also for gasoline.

- **Fuel choice.** Electricity costs much more per unit of energy than natural gas. While some of this difference can be offset by the greater efficiency of electric heating compared to forced air or hydronic heating systems, in most parts of Canada costs will be higher for households that use electricity for space and water heating.

- **Weather.** Because space heating is the single largest component of residential energy use, household energy costs are higher in colder regions. Air conditioning can also be a significant component of electricity costs, especially where time-of-use pricing makes electricity more expensive during the day when air conditioning is most likely to be operating.

- **The number and age of people in the household.** Hot water, appliance use, and transportation needs all tend to increase with the number of people in the household. People who are at home most of the day (e.g., retirees, people who work at home) tend to use more electricity during daytime hours; so in areas where time-of-use pricing is in effect, they incur higher-than-average costs.

- **The size and type of dwelling.** A large, detached, single-family house requires more energy for space heating and cooling than an attached house, condominium or apartment.

- **Lifestyle.** Transportation energy is especially sensitive to the lifestyles of household members. A single person living in an urban neighbourhood with amenities within walking distance and good transit service may seldom, if ever, need to use a car. At the other end of the scale, a household with two working adults and two teenagers in a suburban neighbourhood with poor transit service and few amenities within walking distance can have transportation fuel costs twice as high as the national average.

- **Conservation and efficiency.** Households can lower their fuel and electricity costs considerably by making efficiency and the conservation of fuel and electricity a priority. Personal vehicles, lighting, and home appliances all have energy efficiencies that vary over a wide range, and paying attention to efficiency at the time of purchase can pay off over the longer term. Most houses can also be retrofitted to achieve higher levels of thermal efficiency, leading to a reduction in space heating costs of 15 to 30% – or more.

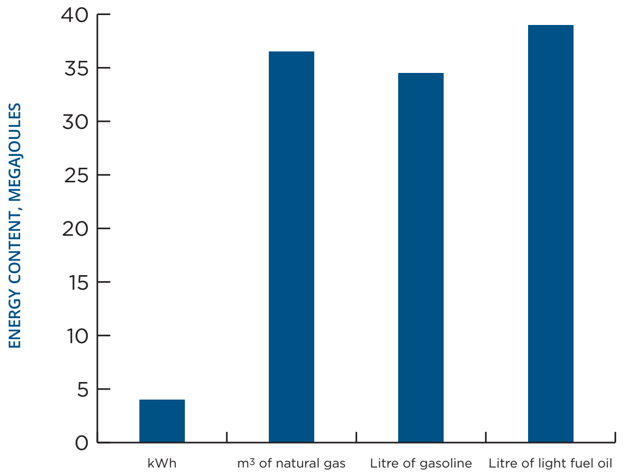
As this overview of some of the factors involved suggests, household spending on energy can vary widely. A household that does not own a car and rents a dwelling for which heat and utilities are included in the rent has no direct expenditures on fuel and electricity – its energy costs are indirect and are embedded in their rent and in any public transit or taxi services they use. At the other extreme, a household in a very large home (or maintaining more than one dwelling), with several energy-intensive vehicles or other equipment (e.g., heated pools, power boats, agricultural machinery) could have total energy costs several times the national average of $4,600.

COMPARING ENERGY UNITS

Fuels and electricity are commonly measured in different units – electricity in kilowatt hours, natural gas in cubic metres, gasoline, diesel and fuel oil in litres. As a general rule, the energy content of a litre of an oil product such as gasoline or fuel oil is in the same ballpark as the energy content of a cubic metre of natural gas, and the kilowatt hour represents about one-tenth of that energy content. In other words, electricity priced at ten cents per kilowatt hour would be roughly equivalent to gasoline at $1/litre or natural gas at $1/cubic metre. In reality, in many parts of Canada, gasoline and electricity do cost about the same amount per unit of energy, but natural gas is much less expensive. Where natural gas is available, it is generally in the range of 30 to 40 cents/cubic metre. Per unit of energy, that is less than half the cost of gasoline at $1/litre or electricity at ten cents per kilowatt hour.

The joule (megajoule [MJ] for a million joules, gigajoule [GJ] for a billion joules, petajoule [PJ] for a quadrillion joules) is an international standard unit for measuring energy. The chart below shows the energy content in megajoules of some of the units commonly used for different forms of energy.

Figure 5-3: **Energy Content of Units Commonly Used for Fuel and Electricity**



ENERGY COSTS FOR TYPICAL CANADIAN HOUSEHOLDS – SOME EXAMPLES

Let us look more closely at just how much household spending on energy can vary. In the following series of examples of typical Canadian households, fuel and electricity costs range from $1,300 for a young single person living a car-free lifestyle in downtown Toronto to over $10,000 for a family of five living in rural Nova Scotia.

A single young adult living in a high-rise condo in downtown Toronto with natural gas space and water heating. She is able to walk or take transit to work and to access most amenities but rents a car once a week from a car sharing service for grocery shopping and other errands.

Annual energy expenditures: $1,300

Two working adults sharing an apartment in West Vancouver with electric space and water heating. Both occupants walk or take transit to work and other daily activities. They have one compact car that they use only once or twice a week.

Annual energy expenditures: $2,200

A working couple with one school-aged child living in a walk-up flat in central Montreal with electric baseboard heating and electric water heating. They put 25,000 kilometres a year on their mid-sized sedan, but it is an electric car. They are above average in their efforts to use electricity efficiently.

Annual energy expenditure: $2,300

A retired couple living in an older (vintage 1940s) row house in Peterborough, Ontario, with relatively new natural gas hydronic heating and natural gas water heating. They have one compact car, which they drive 15,000 kilometres per year.

Annual energy expenditure: $2,600

A working couple with two school-aged children in a new single-family detached home in suburban Winnipeg. Space heating is provided by an electric ground source heat pump with an integrated water heating system. They live a conservation-oriented lifestyle as much as their suburban location will permit; they have one mid-sized sedan, which they drive 20,000 kilometres a year.

Annual energy expenditure: $4,200

Two working adults with two teenaged children in a suburban detached home in Richmond, British Columbia, with natural gas space and water heating. The family has one SUV and one mid-sized sedan; they put 20,000 kilometres on the SUV and 15,000 kilometres on the sedan each year.

Annual energy expenditure: $6,200

Two adults (one working) and two teenagers in an older (pre-1950) single-family detached house in central Saskatoon with natural gas space and water heating. The family has one mid-sized car, which they drive 30,000 kilometres a year. The house has had a limited energy retro-fit but is still much more energy intensive than newer homes in the area. The members of this household are above-average users of electricity and pay little attention to energy-saving practices.

Annual energy expenditure: $6,600

Two working adults (one works at home) with one school-aged child in a new single-family detached house in suburban St. John's with electric space and water heating. The family drives one SUV 10,000 kilometres a year and one mid-sized car 15,000 kilometres.

Annual energy expenditure: $7,800

Two adults, one working, three school-aged children (one a teenager who drives) living in an old farmhouse in rural Nova Scotia, with a combination (50/50) of wood and electric space heating and electric water heating. The family puts a total of 35,000 kilometres a year on their two SUVs.

Annual energy expenditure: $10,200

How Does Your Household Measure Up?

Do you know how much your household spends on fuel and electricity in a year? You may be surprised at the total! To find out, you simply need to add up what you have been charged over a twelve-month period on each of your utility bills, and then add what you have spent on gasoline over the same period. How does it compare to the national average of $4,600? Why do you think your household energy expenditure is higher or lower than that average?

Utility bills often include information about the different charges that contribute to the total price of electricity or natural gas. Typically, your local utility is buying energy wholesale and then selling it to you after adding its own costs for maintaining the local distribution system (wires and transformers to deliver electric power from the grid to your house, pipelines and service lines to deliver natural gas). These local distribution costs may be shown separately on your bill. In some cases, the wholesale cost of electricity is further divided into the cost of the electricity itself and the cost of the bulk transmission system used to deliver it to your local utility. And there can be other costs, taxes, and surcharges related to the special circumstances of your electricity or natural gas supplier. Most utilities in Canada provide guidance on their websites about how to read your bill, with explanations for the various items that appear on it.

Adding it Up – Total Household Spending on Fuel and Electricity in Canada

Direct spending on fuel and electricity by Canadian households totalled about $68 billion (including taxes) in 2012. This can be broken down into two major categories:

- **$28 billion for residential uses – fuel and electricity purchased for space heating and air conditioning, water heating, lighting, and powering appliances and electronic equipment such as refrigerators, clothes dryers, furnace fans, televisions, computers, cellphones and all the other devices that are part of day-to-day life in Canada.**

- **$40 billion for fuel – typically gasoline for personal vehicles.**

On a per gigajoule (GJ) basis, transportation fuel is more expensive than residential fuel and electricity. The total amount of fuel and electricity used for residential applications is about 1,500 petajoules, compared to an estimated 1,000 petajoules for personal vehicle fuel, but the transportation fuel costs more – $40 billion compared to $28 billion for residential fuel and electricity. Within the residential category, space heating is by far the largest energy end use (typically using more energy than all the energy used for water heating, lighting, and appliances and electronics combined), but in most cases, households are heated using natural gas, which is relatively inexpensive. In contrast, gasoline, which constitutes 99% of personal vehicle fuel consumption in Canada, costs three times as much per gigajoule as natural gas, which explains the higher level of expenditure on personal transportation fuel versus residential energy.

The total spending on fuel and electricity by Canada's 13.7 million households is a big number – $68 billion – but to put it in context, it represents only about 8% of Canadian household spending in 2012, which totalled $769 billion. It is an even smaller fraction – about 6% – of the $1 trillion of total household expenditures (including income taxes) in Canada in 2012. Many Canadians take issue with fuel and electricity costs, but perhaps we should really be asking ourselves if the wide variety of services and amenities that fuel and electricity provide are worth an average of 6% of household expenses. If those services and amenities were suddenly made unavailable, what lengths would we go to and how much would we pay to get them back?

HOW BIG IS A GIGAJOULE?

A gigajoule is equivalent to

- **278 kilowatt hours of electricity.** Most Canadian households use this much electricity in about two weeks, assuming that they are not using electricity for space heating or water heating.

- **29 litres of gasoline.** A little less than a tankful if you drive a small car, about half a tank if you drive a pickup truck or SUV. Or enough fuel to drive about 500 kilometres in a hybrid or subcompact, 350 kilometres in a mid-sized car, or 200 kilometres in a large SUV or pickup truck.

- **27 cubic metres of natural gas.** A detached single-family house needs this much gas for space heating on a cold winter's day, and a hundred times as much (100 GJ) for a full heating season.

Business Sector Spending on Fuel and Electricity in Canada

The $68 billion that Canadian households spent on fuel and electricity in 2012 made up only 38% of the total Canadian energy bill. Commercial establishments, institutions, shipping and manufacturing (in short, all the activities that generate the goods and services that make up Canada's economic output) all require fuel and electricity for their day-to-day operations, as do governments. Even the fossil fuel producers and electric power generators consume fuel and electricity in the process of extracting energy resources and delivering energy commodities to both Canadian and export markets.

Canada's annual gross domestic product (GDP) – the total value of all the goods and services the country produces each year – is generated by tens of thousands of businesses and organizations engaged in thousands of different types of activities. These activities all require fuel and electricity, but they vary over a huge range in the amount of fuel and electricity needed to generate a dollar of GDP, or "value added." An industrial chemical plant or pulp and paper mill requires much more energy to generate a dollar of GDP than an office building occupied by knowledge workers.

In energy-intensive industries such as cement, steel, pulp and paper, and chemical manufacturing, as well as petroleum refining and electricity generation, it takes 50 to 75 megajoules of energy to generate a dollar of GDP. These industries are engaged in the primary processing of raw materials – for example, converting ore to steel and refined metals, or trees to pulp and paper – and such processes often require high temperatures. Fuel and electricity are thus a big cost for these industries. With prices in the range of $10 to $35 per gigajoule, energy-intensive industries can spend up to one dollar or more on energy for every dollar of GDP they generate.

Figures 5-4 and 5-5 illustrate the variation in energy intensity of the various activities and industries that make up Canada's economic output. Primary processing industries, such as industrial chemicals, pulp and paper, and cement making, use up to fifty times more fuel and electricity per dollar of GDP generated than the service sector typically does. Figure 5-6 illustrates the significance of fuel and electricity costs for energy-intensive industries, reflecting the processes and technologies employed (e.g., blast furnaces in the steel industry, paper machines in the pulp and paper industry, and kilns in the cement industry). Fuel and electricity costs in a given jurisdiction can be a significant consideration in investment and plant location decisions in these industries.

Energy-intensive industries are, however, the exception to the norm in Canada. For most economic activity, including the nearly 75% of Canada's GDP generated in the service sector as well as for most manufacturing and assembly operations, fuel and electricity represent a relatively small cost, typically less than 2% of value added. More than 80% of Canada's GDP is generated by industries with fuel and electricity expenditures of less than $50 per $1,000 of value added. This includes all the industries shown to the right of the forestry industry in Figure 5-6: the auto industry, the food and beverage industries, general manufacturing, computers and electronic equipment, the construction industry and the entire service sector. Some of these industries may have large energy expenditures, but only because they are so large, not because they are particularly energy intensive. Continuity and reliability of fuel and electricity supply are critically important to these industries, but energy expenditures themselves are a secondary cost in comparison to capital and labour, their principal costs.

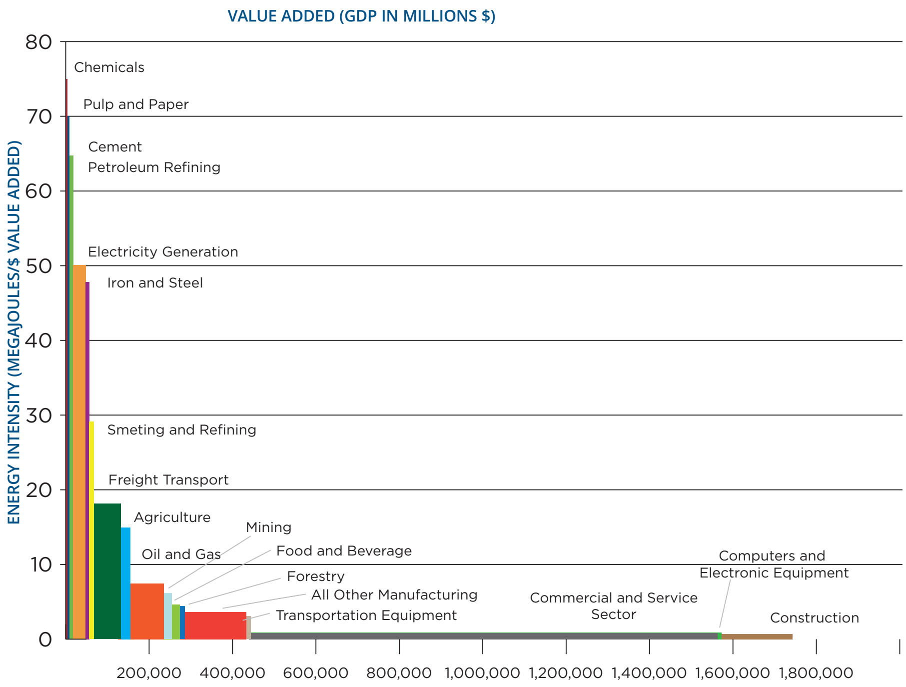
As an example, fuel and electricity costs typically represent well under 10% of the cost of owning and operating a modern high-rise hotel, and even less for an office tower. Even in the freight transportation industry, where energy costs are nearly ten times higher for transport by truck than by train, the total share of freight transport by road is increasing because the overall convenience and profitability of road transport trump its higher energy costs.

This is not to imply that fuel and electricity costs are not a concern for Canadian secondary manufacturing and service sector companies. Such costs are reducible, savings go directly to the bottom line, and reductions in fuel and electricity costs often lead to other benefits and efficiency improvements that add to the overall profitability and competitiveness of a company. Well-managed companies do manage their energy costs. Taking the freight transportation industry as an example again, companies opting to move a greater share of freight by road rather than by rail, notwithstanding the jump in fuel costs, often devote considerable resources to improving the energy efficiency of their operations (fuel costs can be 35 to 40% – or more – of the cost of moving freight by truck) through driver education, route optimization, fleet dispatch optimization, the adoption of energy-efficient trucks and other measures.

Figure 5-4: **Energy Intensity of Economic Activity in Canada, 2012**

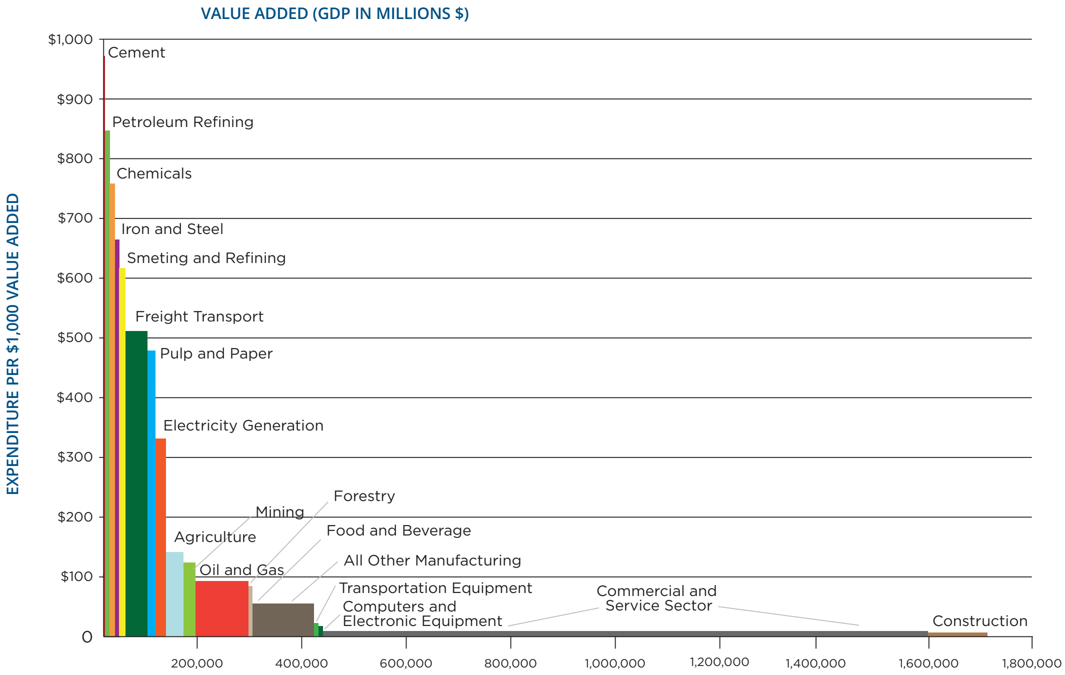
Sector / Industry	GDP, basic prices (million $)	Energy use (petajoules)	Estimated energy expenditure (million $)	Energy intensity (megajoules/$)	Energy expenditures per $1000 of GDP
Chemicals	3,503	257	2,629	73.3	$751
Pulp and paper	7,976	517	3,739	64.8	$469
Cement making	962	58	923	59.9	$960
Petroleum refining	6,227	347	5,226	55.7	$839
Electricity generation	33,167	1,656	4,980	49.9	$150
Iron and steel	4,872	231	3,239	47.4	$665
Smelting and refining	8,182	235	5,067	28.7	$619
Freight transport	68,842	1,182	35,255	17.2	$512
Agriculture	19,947	265	6,703	13.3	$336
Oil and gas extraction	112,545	968	9,969	8.6	$89
Mining	19,179	136	2,519	7.1	$131
Food and beverage	16,767	66	792	3.9	$47
Forestry	5,416	19	423	3.5	$78
All other manufacturing	129,609	413	5,966	3.2	$46
Transportation equipment	9,537	15	184	1.6	$19
Commercial and service sector	1,124,797	1,069	16,697	1.0	$15
Computers and electronic equipment	7,491	7	129	0.9	$17
Construction	122,070	81	1,497	0.7	$12
TOTAL / AVERAGE	**1,701,089**	**7,522**	**105,936**	**4.4 (average)**	**$62 (average)**

Figure 5-5: **Physical Energy Intensity versus Value Added by Industry for Canada's GDP, 2012**



This graph illustrates the extent to which Canada's GDP is dominated by the commercial and service sector, with its relatively low energy intensity, in contrast to much more energy-intensive processing industries such as pulp and paper, cement making and petroleum refining. The width of each block in the graph is proportional to that industry's contribution to Canada's GDP, and the height of each block indicates the energy intensity of that industry in megajoules per dollar of GDP. The area of each block represents an industry's total consumption of fuel and electricity, highlighting the relatively large contributions to total energy use made by the oil and gas, freight transportation, and electric power industries.

Figure 5-6: **Energy Costs per $1,000 of Value Added by Industry, 2012**



The width of each block in this graph is proportional to that industry's contribution to Canada's GDP, and the height of each block indicates dollars of expenditure on fuel and electricity for every $1,000 of value added. The area of each block represents the total expenditure on fuel and electricity for each industry

Total Spending on Fuel and Electricity in the Canadian Economy

All totalled, in 2012, a year in which the output of the Canadian economy was about $1.8 trillion, Canadian households, businesses and governments spent just under $180 billion on fuel and electricity, including fuel excise and sales taxes of about $20 billion. In other words, roughly 10% of the output of the Canadian economy was spent on fuel and electricity.

The tax collected in relation to total spending on energy might seem low by comparison to the average consumer's experience of energy taxes. This is because well over half of the $180 billion is spent by businesses, which do not pay taxes on the energy they use because it is categorized as an intermediate input in their operations.

Canadian energy spending is broken down by sector in Figure 5-7.

Figure 5-7: **Fuel and Electricity in Canada, 2012 – Consumption and Cost**

Sector	Fuel		Electricity		Total	
	Energy (petajoules)	Cost (millions $)	Energy (petajoules)	Cost (millions $)	Energy (petajoules)	Cost (millions $)
Residential	914	12,546	542	15,801	1,457	28,347
Commercial	728	7,944	448	13,210	1,176	21,154
Transportation (personal and freight)	2,586	75,245	4	96	2,590	75,341
Industrial	2,638	39,541	747	14,548	3,385	54,089
TOTAL	**6,867**	**135,277**	**1,741**	**43,655**	**8,608**	**178,932**

Residential energy use (e.g., for space heating, water heating, lights and appliances) cost Canadian households about $28 billion in 2012; add to that the estimated $40 billion households spent on personal vehicle fuel, and total household spending on fuel and electricity comes to $68 billion, including an estimated $14 billion in sales taxes and gasoline tax.

Electricity consumption and spending is concentrated in buildings – of the $44 billion Canadian households and businesses spent on electricity in 2012, two-thirds was to meet the demand for electricity for residential and commercial buildings. In both residential and commercial buildings, electricity accounts for about 37% of total energy use, but for well over 50% of total energy costs, reflecting its higher unit cost compared to natural gas.

Of the $136 billion Canadian households and businesses spent on natural gas and petroleum in 2012, 56% was for transportation, mostly gasoline for cars and diesel fuel for trucks. Transportation fuel represents a somewhat smaller share (38%) of the total amount of oil and gas consumed, but its higher unit cost (compared to natural gas and fuel oil) means that it makes up the lion's share of the total fuel cost.

Figure 5-8: **Fuel versus Electricity Expenditures in Canada by Sector, 2012**

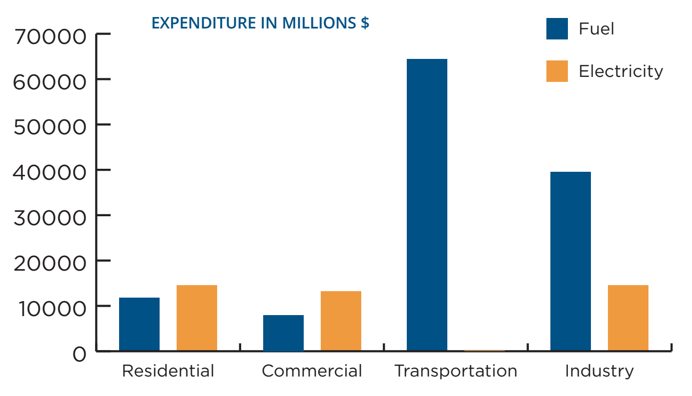
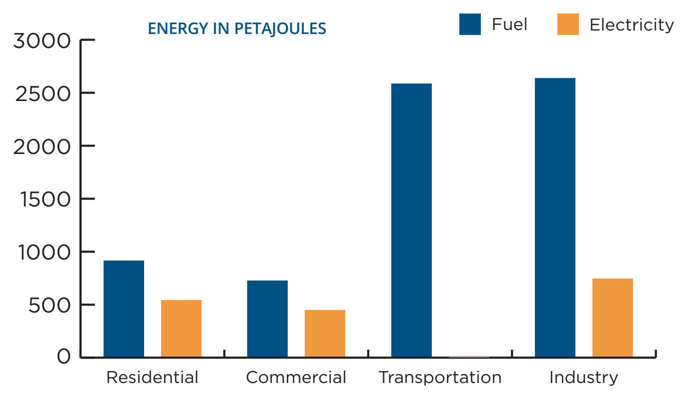


Figure 5-9: **Fuel versus Electricity Consumption in Canada by Sector, 2012**



The average cost of energy is highest for transportation and lowest for industry. Transportation relies almost exclusively on the highest-priced petroleum products – gasoline, diesel and aviation fuel. In contrast, business and industry, as noted above, do not pay sales tax on energy inputs to their operations. Moreover, they are sometimes able to use less expensive fuels (e.g., coal in the cement and steel industries) and are often able to negotiate volume discounts for energy purchases.

Fuel and Electricity Prices in Canada

Figure 5-10 lists average residential fuel and electricity prices for Canada in 2012. Prices for most fuels do not vary a great deal across the country, except for electricity, for which separate prices are given for each province. In the case of electricity, prices not only vary from one province to the next but can also vary by time of day and by customer class. Large commercial and industrial customers often pay different, usually lower, prices than the residential prices shown in this figure.

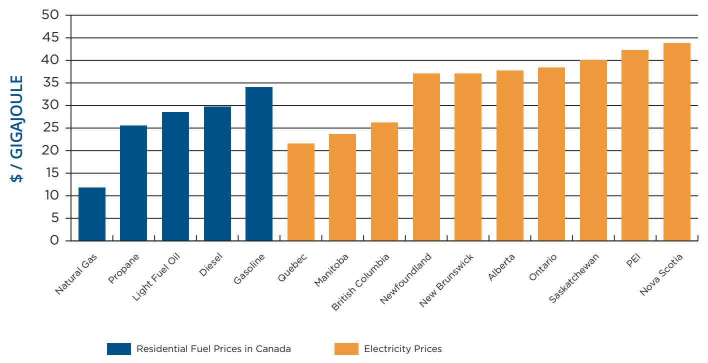
Cents per kilowatt hour for electricity, dollars per litre for gasoline, cents per cubic metre for natural gas – these are all familiar units for expressing the price of different forms of energy, but to compare prices, we need a common unit. The gigajoule is an internationally accepted unit of measure for energy. In Figures 5-10 and 5-11, fuel and electricity prices in Canada are converted to dollars per gigajoule so that they can be compared.

Figure 5-10: **Residential Fuel Prices in Canada (2012)**

FUEL	$/gigajoule	Customary Units	
Natural gas	11.8	40.6	cents/cubic metre
Propane	25.5	70.7	$/litre
Light fuel oil	28.5	1.2	$/litre
Diesel	29.7	1.2	$/litre
Gasoline	34.1	1.3	$/litre
ELECTRICITY	**$/gigajoule**	**Customary Units**	
Quebec	21.6	7.8	cents/ kilowatt hour
Manitoba	23.7	8.5	cents/ kilowatt hour
British Columbia	26.2	9.4	cents/ kilowatt hour
Newfoundland and Labrador	37.1	13.3	cents/ kilowatt hour
New Brunswick	37.1	13.4	cents/ kilowatt hour
Alberta	37.7	13.6	cents/ kilowatt hour
Ontario	38.4	13.8	cents/ kilowatt hour
Saskatchewan	40.1	14.4	cents/ kilowatt hour
PEI	42.3	15.2	cents/ kilowatt hour
Nova Scotia	43.8	15.8	cents/ kilowatt hour

These prices include any applicable taxes, including provincial and federal sales taxes (PST/GST/HST). Currently, the other consumption taxes on energy in Canada are British Columbia's carbon tax and the excise taxes imposed by both the federal and provincial governments on road transportation fuels – gasoline, diesel and propane. The impact of British Columbia's carbon tax is not included in the prices for gas and petroleum fuels given in Figure 5-10 but can be seen in Figure 5-12.

Figure 5-11: **Fuel and Electricity Prices (including taxes) in Canada, 2012**



Fuel and electricity prices in Canada also include the costs of the federal and provincial boards and commissions that regulate the energy industry. The costs of operating such bureaucracies (e.g., the National Energy Board and its provincial counterparts) are covered by the industry they regulate, not by tax revenue.

Figure 5-12 shows more detailed information on how taxes contribute to the prices of fuel and electricity in Canada. Average national prices are shown for natural gas, propane, light fuel oil and diesel. For gasoline and electricity, the figure gives average prices, illustrating how prices vary from province to province. These prices assume a base pre-tax price for regular gasoline of $0.90/litre in 2012 throughout the country, with taxes added to that base depending on the prevailing fuel and sales taxes in each province. Gasoline prices are lowest in the Prairie provinces, where gasoline is typically exempt from provincial sales tax and where provincial fuel taxes are relatively low compared to the rest of Canada.

There is much greater variation in electricity prices from province to province, not so much because of different tax rates, as is the case with gasoline, but because of differences in the cost of generating the electricity. Electricity is a manufactured product, and the cost of making it varies depending on the mode of production, with the cheapest power tending to be from hydroelectric dams (particularly from dams that were fully paid for years ago). Manitoba, British Columbia and Quebec have the lowest-cost electric power in Canada because they get most of their electricity from hydro dams that are relatively inexpensive to operate (no fuel costs) and for which capital costs are spread out over decades. Electricity costs more to produce from other sources (coal, nuclear, natural gas, oil), and the price of electricity is higher in provinces that depend on sources other than hydro-power for their electricity. Compared to the price of electricity in other countries, however, even the costliest electricity in Canada is relatively inexpensive.

Energy Prices in Canada versus International

Figures 5-13 and 5-14 compare the price of fuel and electricity for residential uses in Canada with the prices in a selection of other countries. As the data indicate, Canadians enjoy some of the lowest energy prices in the world. The prices shown include value added taxes (GST/HST in Canada) and any additional consumption taxes on fuel and electricity. To make the comparison, all prices have to be given in the same currency; the purchasing power parity (PPP) of the U.S. dollar has been used as the common denominator.

The main reason prices are so much higher in Europe than in North America is the level of tax applied; consumption taxes on fuel and electricity are both

Figure 5-12: **Fuel and Electricity Prices in Canada, by Province**

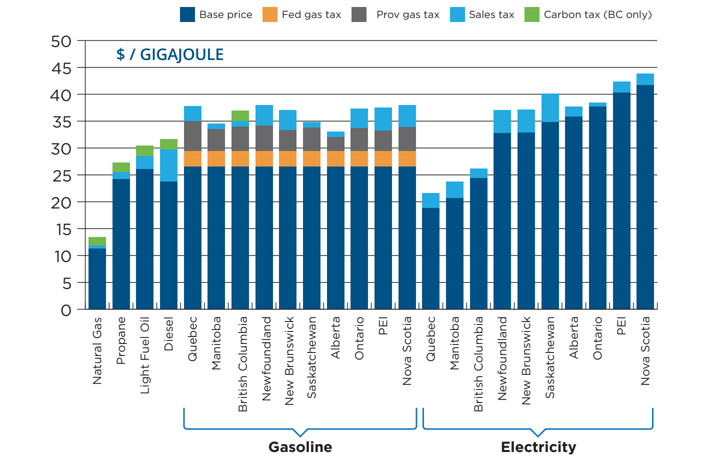
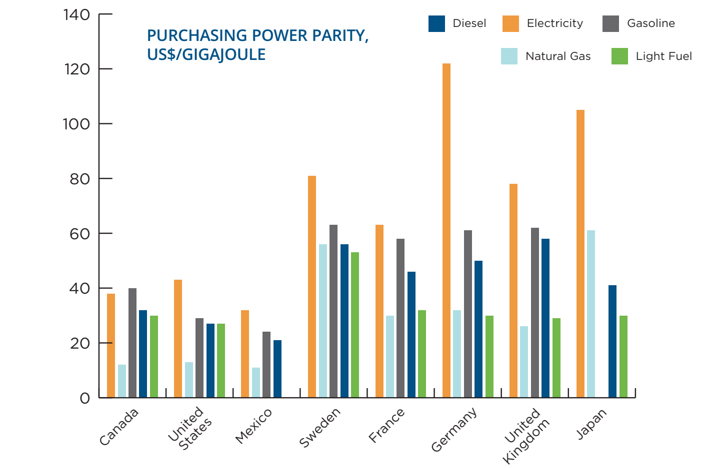
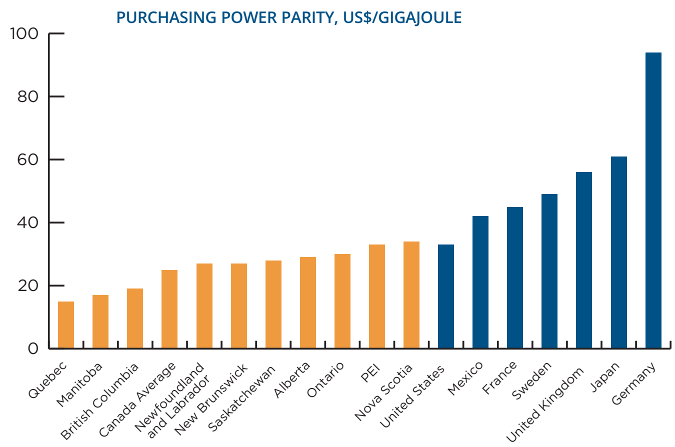


Figure 5-13: **Energy Price Comparison by Country and by Fuel, 2012**



larger and more widely implemented in Europe. Taxes on gasoline and diesel are in the 100 to 125% range, making the price at the pump more than 50% tax. By comparison, fuel taxes in Canada are in the range of 30 to 40%, with taxes constituting 25 to 30% of the price at the pump (see Figure 5-12).

Figure 5-14: **Canadian Electricity Prices Compared to Select Other Countries, 2012**



Taxes are also largely responsible for the difference in natural gas prices between North America and Europe. While they are lower than those for transportation fuels, European tax rates on natural gas for residential customers are typically in the 20 to 30% range, whereas in Canada there is no tax levied on natural gas beyond federal and provincial sales taxes (PST/GST/HST). Natural gas is particularly expensive in Sweden where the tax rate is nearly double that of other European countries, in part because it includes the world's highest carbon tax. In Japan, the tax rate is low (only 5%), but the gas must be imported in liquid form (LNG, or liquefied natural gas), which entails expensive shipping and processing infrastructure.

Electricity prices also vary over a wide range, with Canadian prices being, on average, among the lowest in the world. Average residential electricity rates are twice as high in France, three times as high in Japan, and four times as high in Germany. The most costly electricity in Canada tends to be in Nova Scotia and Prince Edward Island, but even in those provinces, electricity is inexpensive by European standards. Electricity is a manufactured product and the cost of making it varies depending on the type of power plant, with the cheapest power tending to be from legacy hydroelectric dams. While the cost of making electricity is the main reason for the variation in the international comparison, taxes are also a factor. In Canada, taxes on electricity consumption are generally restricted to federal and provincial sales taxes, whereas in Europe, residential electricity use is taxed at 40 to 60%, and by as much as 80% in Germany.

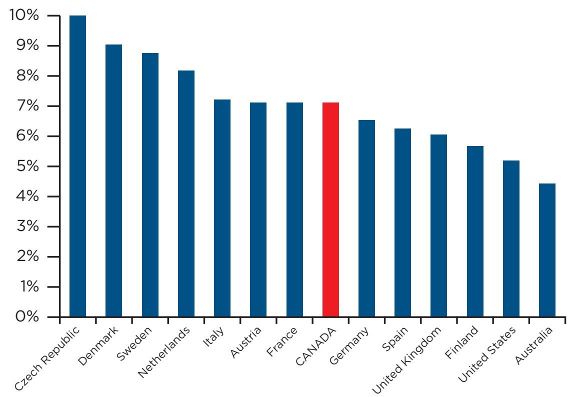
Energy Costs as a Per Cent of Household Income – an International Comparison

With fuel and electricity prices so much lower in Canada than in European countries, one might expect that Canadians would spend a much smaller portion of their household income on energy than their European counterparts. But such is not the case, as Figure 5-15 illustrates.

Canadian households spend about the same portion of their disposable income on fuel and electricity as do French and German households, even though fuel and electricity prices are two to four times higher in those countries than they are in Canada. Canadians spend a somewhat smaller percentage of their disposable income on energy than do Swedish and Danish households (7.4% in Canada versus 9.1% in Sweden and 9.4% in Denmark), but these are countries in which disposable (after tax) incomes are lower than in Canada and in which energy prices are much higher. Canadians spend a considerably higher portion of their disposable income on fuel and electricity than do British and Finnish households, notwithstanding the much lower fuel and electricity prices in Canada.

There are a number of reasons why energy costs represent a comparable or even lower contribution to household spending in countries with climates and living standards similar to Canada's, but where fuel and electricity costs are markedly higher. One of the key factors is higher efficiency in fuel and electricity use in European countries. Put another way, moving toward European levels of energy efficiency, in both residential and personal transportation end uses, could significantly reduce the portion of Canadian household income that goes to fuel and electricity.

Figure 5-15: **International Comparison of Energy Costs as a Per Cent of Household Income**



Fuel and Electricity Production and Canada's GDP

Canada is a relatively intensive consumer of fuel and electricity, but it is also a significant producer, both for domestic and export markets. In 2012, the Canadian economy produced $1.8 trillion in goods and services, and the production and distribution of fossil fuels and electricity made up just under 10% of this economic activity, as shown in Figures 5-16 and 5-17. The "oil patch" – the industry that extracts oil and gas – contributes about 6% of GDP, the electric power industry another 2%, and the remaining 2% derives from the various downstream components of the fossil fuel industry: refineries, pipelines, distribution utilities and gas stations. The shipment of oil and gas products by rail has grown significantly in recent years, with approximately 50 million barrels of oil shipped by rail in 2013. The GDP associated with the shipment of oil by rail, however, is still well below any of the shipping modes identified in Figures 5-16 and 5-17.

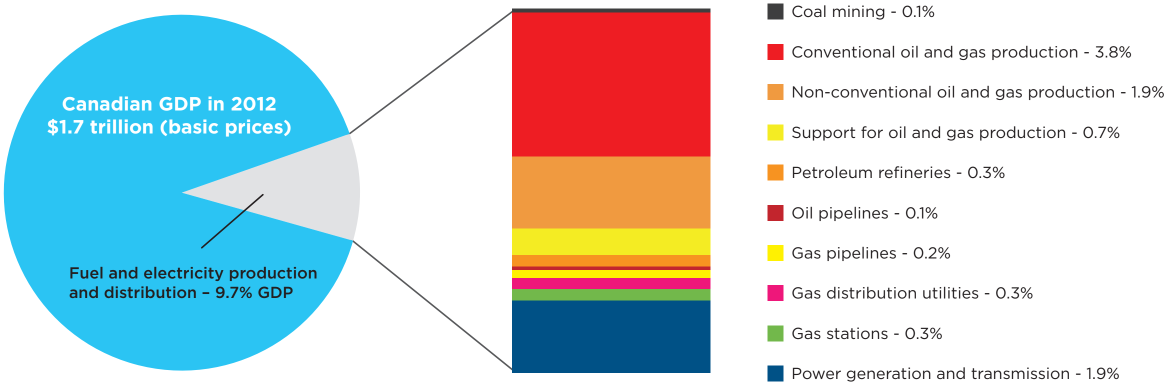
Fossil fuel extraction is concentrated in a few provinces – primarily Alberta, Saskatchewan, and Newfoundland and Labrador – where it plays a larger role in provincial economies than it does at the national level shown in Figures 5-16 and 5-17. Data on the economic output of industry segments in individual provinces are incomplete because of confidentiality restrictions, but the oil and gas extraction industry accounts for 25% and 16% of the GDP of Alberta and Saskatchewan, respectively.

Figure 5-16: **Canadian GDP, 2012 (in 2015 dollars)**

Fuel and Electricity Production and Distribution	Billions $	Per Cent of GDP
Coal mining	1.96	0.1%
Conventional oil and gas production	68.19	3.8%
Non-conventional oil and gas production	33.84	1.9%
Support for oil and gas production	13.30	0.7%
Petroleum refineries	6.17	0.3%
Oil pipelines	2.68	0.1%
Gas pipelines	2.79	0.2%
Gas distribution utilities	5.56	0.3%
Gas stations	5.54	0.3%
Power generation and transmissions	34.86	1.9%
Subtotal of fuel and electricity production and distribution	**175**	**9.7%**
Balance of GDP	**1,625**	**90.3%**

The 1.9% contribution the electric power industry makes to Canada's GDP is more evenly spread across the country, although there is still some provincial variation. The electric power sector generates 1% of Alberta's GDP. Electricity use in Alberta is restricted mainly to end uses where there is no practical alternative (lighting, appliances, small motors, telecommunications, and information technology). In contrast, in Quebec, where electricity is used extensively for space and water heating and, overall, provides about 40% of energy end uses in the province, the industry generates 3.4% of provincial GDP.

Figure 5-17: **Canada's GDP, with Fuel and Electricity Industry Detail, 2012**



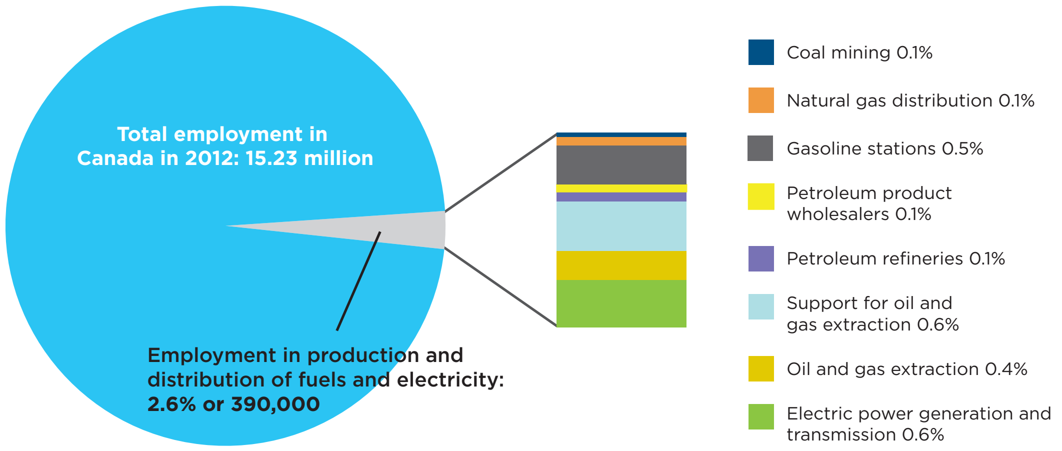
Fuel and Electricity Production and Distribution – Employment in Canada

The production and delivery of fuel and electricity to both Canadian consumers and export markets accounted for 9.7% of Canada's GDP in 2012. Employment in the industries that produce and distribute energy commodities in Canada totalled 391,000 in 2012, or 2.6% of total employment in the Canadian economy. A more detailed breakdown by fuel and electricity industry is provided in Figures 5-18 and 5-19. These figures do not include employment in the pipeline industry because the data are not available through Statistics Canada, due to confidentiality restrictions. However, according to the Canadian Energy Pipeline Association (CEPA), total employment in its member companies is about 13,600, a relatively small addition to the numbers given in Figure 5-18. Definitions of the energy sector and related data on employment often exclude gas stations and wholesale distributers of petroleum products, but they have been included here, adding 93,000 to the total employment figure. In fossil fuel–related industries, employment is heavily concentrated in the producing provinces (except for gas station employment, which is spread evenly throughout the country). Employment in the electric power industry is also spread evenly throughout the country, in proportion to population levels.

Figure 5-18: **Employment in the Fuel and Electricity Industries, 2012**

Industry	Number employed	Per cent of total employment
Coal mining	8,753	0.1%
Natural gas distribution	16,795	0.1%
Gasoline stations	78,885	0.5%
Petroleum product wholesalers	14,195	0.1%
Petroleum refineries	19,476	0.1%
Support for oil and gas extraction	98,906	0.6%
Oil and gas extraction	58,887	0.4%
Electric power generation and transmission	95,151	0.6%
Subtotal, fuel and electricity production and distribution	**391,048**	**2.6%**
Total employment in Canada, all sectors	**15,229,514**	

Figure 5-19: **Total Employment in Canada and in the Fuel and Electricity Industries**



By virtue of its size, the energy industry employs a large number of people, especially in the oil- and gas-producing provinces, but because it is a capital-intensive and technologically sophisticated industry, its share of employment is low compared to its share of GDP, especially for upstream extraction and refining activities. Figure 5-20 compares the contributions to GDP and total employment of the various components of the fuel and electricity industry.

Figure 5-20: **Fuel and Electricity Industry Contributions to GDP and Employment, Per Cent**

Industry	GDP share	Employment share
Coal mining	0.1%	0.1%
Oil and gas production	5.7%	0.4%
Support for oil and gas production	0.7%	0.6%
Petroleum refineries	0.3%	0.1%
Gas distribution utilities	0.3%	0.1%
Gas stations	0.3%	0.5%
Power generation and transmission	1.9%	0.6%
Total, fuel and electricity production and distribution	**9.7%**	**2.6%**

Fuel and Electricity and Canada's International Trade Balance

Some of the energy resources and commodities produced in Canada are exported, making a significant contribution to the nation's overall balance of trade (the difference between revenue generated from exports and expenditures for imports). Indeed, in 2012, more than half of Canada's oil and gas production was exported, mostly to the United States, generating $106 billion in revenue. This was offset by $46 billion paid out for imported energy products, but the resulting $60 billion surplus in the trade of energy products – mostly due to crude and bitumen exports – is the single largest item in Canada's merchandise balance of trade.

Canada's merchandise trade in 2012 is shown in Figure 5-21, broken down by major categories, with additional product details for the trade in energy products. In 2012, the energy product trade surplus was larger than the combined totals of the surpluses from all the other primary commodities that Canada exports – fishery and agricultural products, metal ores, metal and non-metallic products, minerals, and forest products.

Figures 5-22 to 5-24 illustrate Canada's merchandise imports and exports in 2012, the balance of trade for each category, and detail for trade in energy products

Figure 5-21: **Canadian Merchandise Trade by Category, 2012**

CATEGORY	Millions $		
	Import	**Export**	**Surplus or (Deficit)**
Energy products	45,755	105,585	59,831
Farming and fisheries products	12,316	27,287	14,971
Metal ores and minerals	10,040	18,557	8,517
Metal and non-metallic products	43,501	54,304	10,803
Chemical products	38,061	33,064	(4,997)
Forest products	20,465	30,625	10,160
Industrial machinery	45,221	26,850	(18,372)
Electronic and electrical equipment	55,515	22,917	(32,598)
Motor vehicles and parts	82,815	68,474	(14,340)
Aircraft and other transportation equipment	12,727	17,308	4,581
Consumer goods	92,747	48,561	(44,186)
All merchandise	**474,287**	**463,135**	**(11,152)**
Energy product trade detail			
Crude oil and bitumen	30,731	73,506	42,775
Natural gas	2,849	8,759	5,910
Natural gas liquids	1,049	1,868	820
Refined petroleum products	9,668	14,146	4,477
Electricity	233	1,927	1,694
Other energy products	1,225	5,379	4,154
Energy trade	**45,755**	**105,585**	**59,830**

Figure 5-22: **Import and Export Revenues for Canada, 2012**

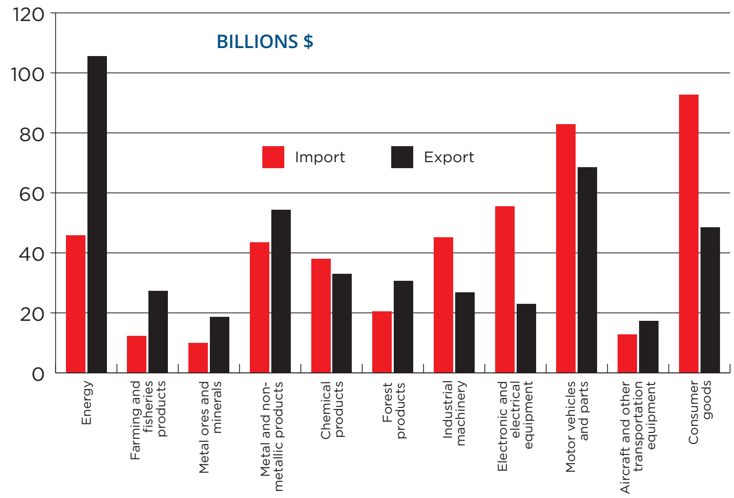


Figure 5-23: **Canadian Merchandise Trade Balance by Industry Group, 2012**

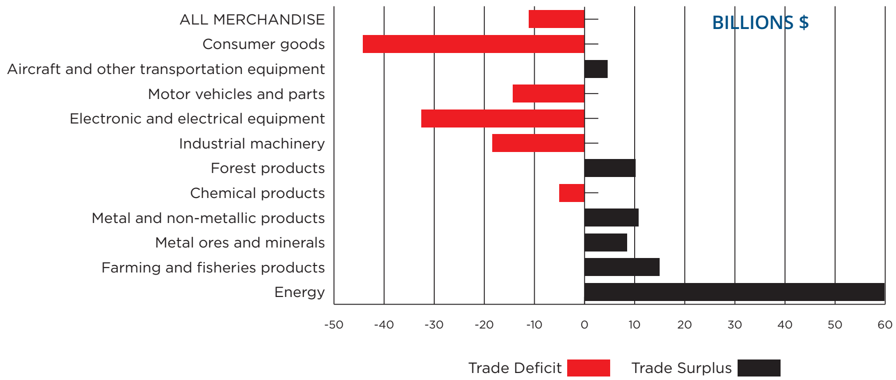
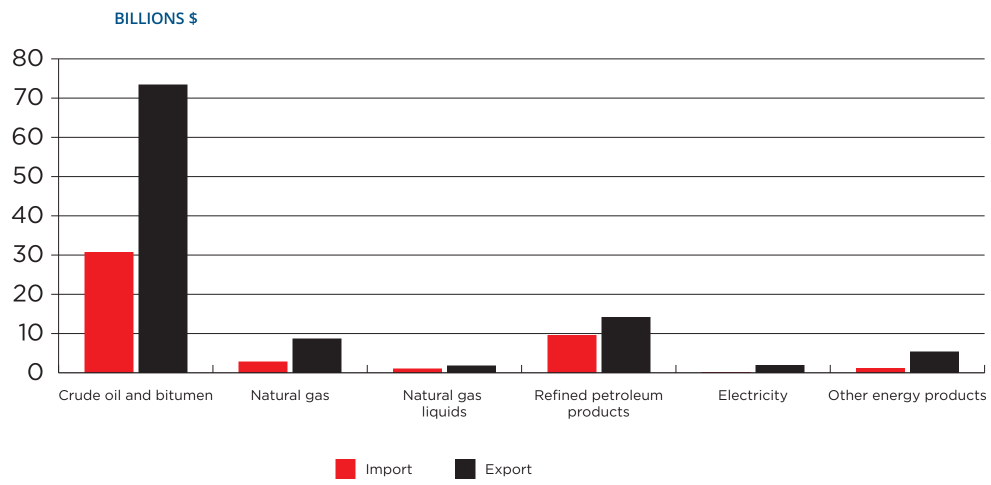


Figure 5-24: **Import and Export Revenues in the Fuel and Electricity Industries, 2012**



Over half of the natural gas and crude oil produced in Canada is exported, primarily to the United States, but the revenues from bitumen and crude exports are several times larger than the export sales of any of the other energy products. In 2012, revenues from crude and bitumen sales exceeded $73 billion, three times more than the combined revenues from the export of natural gas, natural gas liquids and refined petroleum products.

A certain amount of back-and-forth trade, or "wheeling," in electricity takes place between Canadian and U.S. utilities to maintain a reliable and balanced supply of electricity in both countries from day to day and season to season. But beyond this cross-border, bidirectional "wheeling" of electric power, exports of electricity from Canada to the U.S. have been growing in recent years and are poised for further growth in the years ahead. Historically, Quebec has accounted for most of the large medium- and long-term contracted exports of electricity to the United States, but exports from Ontario and Manitoba to the U.S. have been growing and now account for about half of Canada's net electricity exports to the U.S. On a national basis, the net surplus in electricity trade with the United States – $1.7 billion in 2012 – is small compared to the trade in oil and gas, but it is a significant source of revenue to the three provinces that account for most of the net electricity exports to the U.S., and it may play a larger role in the years ahead as the global energy transition proceeds and the value of low-carbon electricity (of which Canada has an abundance) increases.

Fuel and Electricity Production and Delivery – Investment

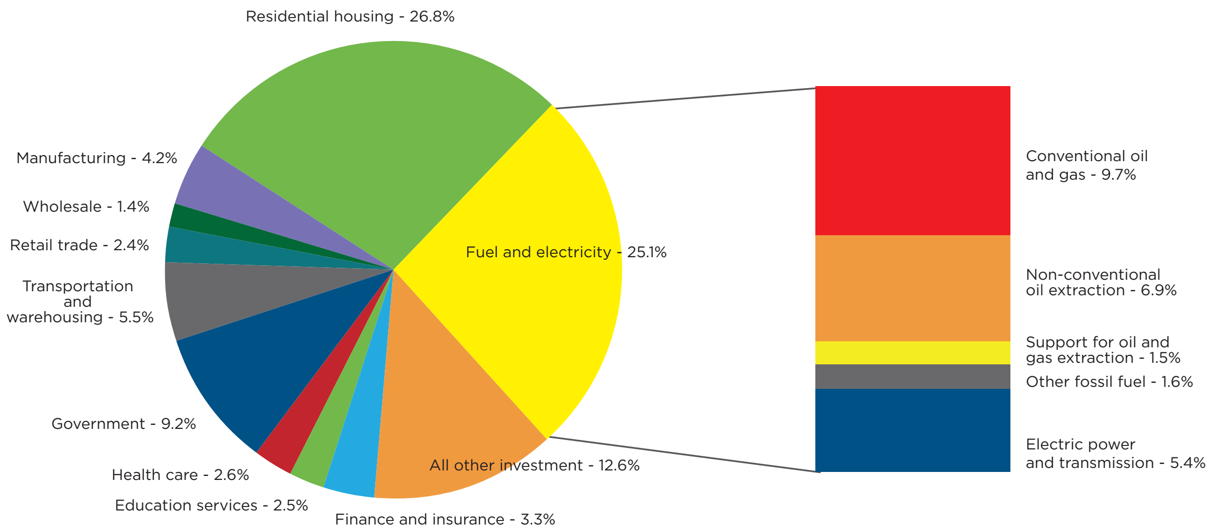
Canadian household, business and government investment totalled $392 billion in 2012, 79% from the private sector and 21% by governments. Investment is a special type of spending; it is money spent today to create wealth in the future. It includes spending on the construction of buildings, including residential housing, but also on future productive capacity and infrastructure, including machinery and equipment, roads and bridges, transit systems, factories of all sorts, office buildings, mines, power plants, transmission lines, pipelines and other capital facilities for maintaining and increasing the output of the Canadian economy – including the production of fuel and electricity.

Annual levels of investment fluctuate in response to economic and market conditions, including how investors anticipate future business opportunities and market conditions. In recent years, the fuel and electricity production and distribution industries have consistently received the largest share of non-residential investment in Canada. Figure 5-25 provides a summary of public and private sector investment in construction and in machinery and equipment in 2012.

Figure 5-25: **Investment in Construction and in Machinery and Equipment in the Fuel and Electricity Industries versus Total Investment in Canada, 2012**

Capital Expenditures	**Construction (billions $)**	**Machinery and Equipment (billions $)**	**Total (billions $)**
Residential housing	105.2		105.2
Non-residential investment	179.8	107.7	287.5
Total investment	285.0	107.7	392.7
Fuel and electricity industry			
Conventional oil and gas extraction	37.75	0.41	38.2
Non-conventional oil extraction	21.40	5.75	27.2
Support for oil and gas extraction	3.21	2.66	5.9
Coal mining	0.48	0.75	1.2
Petroleum refining	0.79	0.78	1.6
Natural gas distribution	1.53	0.72	2.2
Petroleum wholesalers/distributors	0.13	0.21	0.3
Gas stations	0.44	0.44	0.9
Subtotal – Fossil fuels	**66**	**12**	**77.5**
Subtotal – Electric power generation and transmission	**15.92**	**5.17**	**21.1**
Total – Fuel and electricity industries	**82**	**17**	**98.5**
Fuel and electricity as a share of investment (per cent)			
As a share of non-residential investment	45%	16%	34%
As a share of total investment	29%	16%	25%

Figure 5-26: **Investment in the Fuel and Electricity Industry versus Total Investment in Canada, 2012**



As Figure 5-26 illustrates, the fuel and electricity production and distribution industries together constituted 25% of total investment in Canada in 2012, second only to residential housing, which attracted 27% of total investment.

Housing is not usually considered part of the energy system, but in the context of this primer, with its emphasis not only on fuel and electricity but also on energy services, investment in buildings, including residential housing, can be seen as an important element in the broader energy system. Canadians invest more in new and existing homes than the combined investment in power plants and production and delivery systems for oil, gas, coal and electricity.

The energy industry accounts for 34% of non-residential investment and 45% of non-residential construction investments; there is no other industry that even comes close to these figures. Within total energy investments, investments in the fossil fuel industry make up nearly 80%, and within that total, over 90% consists of investment in oil and gas extraction and supporting activities. In 2012, investment in future oil and gas extraction capacity in producing provinces (mainly Alberta, but also Saskatchewan, British Columbia, and Newfoundland and Labrador) constituted 92% of investment in the fossil fuel industry as a whole, 72% of all investment in fuel and electricity production and distribution, 25% of all non-residential investment and 18% of total investment in Canada.

Government Revenue from the Fuel and Electricity Industries

The federal and provincial governments derive revenue from both the production and consumption of fuel and electricity in Canada.

At the consumption level, provincial and federal sales taxes are applied to household and other consumer purchases of fuel and electricity. The federal and provincial governments also levy a gas tax on transportation fuels (gasoline and diesel fuel).

On the production side of the industry, governments lease Crown land for oil and gas exploration and production, and the provincial governments in the producing provinces charge royalties and licence fees for oil and gas production rights. These charges vary by province and by the amount of energy produced, as well as by other criteria.

Electricity production is not generally taxed in Canada, but provinces do charge for the water rights for hydroelectric operations; for the hydro-rich provinces, this can be a significant source of provincial government revenue. Most of the large provincial electric utilities in Canada are wholly or partly publicly owned, and dividends from these Crown corporations can constitute another source of provincial government revenue. In addition, industries engaged in the extraction of energy resources and the production and delivery of energy commodities pay corporate income tax, while employees throughout the energy industry pay personal income taxes.

What does all this add up to? Some of the numbers are easier to find than others, but a rough estimate of federal and provincial government revenue from the energy industry in 2012 is shown in Figure 5-27.

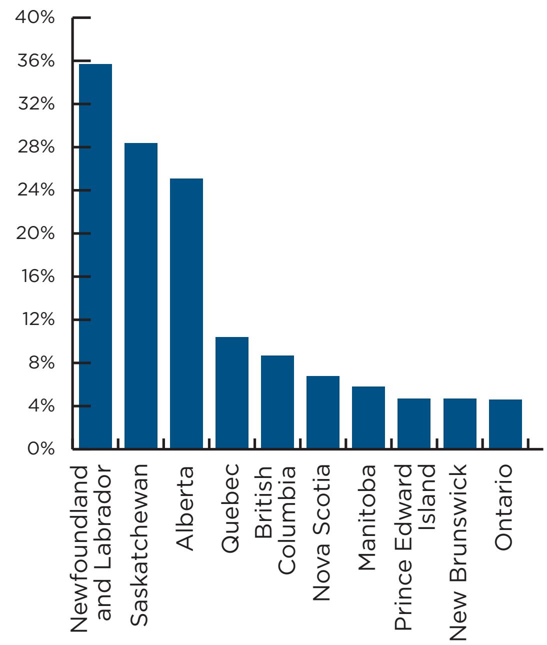
Figure 5-27: **Estimated Federal and Provincial Government Revenues from Fuel and Electricity Production and Consumption, 2012**

Revenue source	Federal (billions $)	Provincial (billions $)	Total (billions $)
Fuel and gasoline taxes	5.50	8.66	14.16
Carbon tax (British Columbia only)		1.17	1.17
Oil and gas royalties		10.11	10.11
Land leases, fees, other fossil fuel industry revenue	1.00	2.11	3.11
Water rental and Crown utility profits/dividends		5.05	5.05
Other direct income from energy industry		0.74	0.74
Subtotal – Direct revenues from fuel and electricity	6.50	27.85	34.35
Estimate of PST/HST on fuel and electricity, net of input tax credits	3.15	4.14	7.29
Estimate of income tax from fuel and electricity industry and employees	6.40	4.08	10.48
Total revenue, including income and sales taxes	**16.05**	**36.06**	**52.12**
Total federal and provincial government revenue from all sources, before intergovernmental transfers	254.20	256.14	510.34
Fuel- and electricity-related revenue as a share of total government revenue			
Not including income and sales tax	3%	11%	7%
Including income and sales tax	6%	14%	10%

Using these data from 2012, there are five main sources of government revenue from the energy industry, in order of decreasing size: fuel and gasoline taxes ($14 billion), royalties, leases and fees related to fossil fuel production ($13 billion), personal and corporate income tax from companies and employees in the energy system ($10 billion), sales tax (provincial and federal) on final consumption of fuels and electricity ($7 billion), and profits from Crown-owned electric utilities ($5 billion).

In total, federal and provincial government revenue from the production and consumption of fuel and electricity in Canada in 2012 was about $34 billion, not counting PST/GST/HST and income taxes, and about $52 billion with sales and income taxes included. This represents 7% and 10%, respectively, of combined federal and provincial government revenue from all sources.

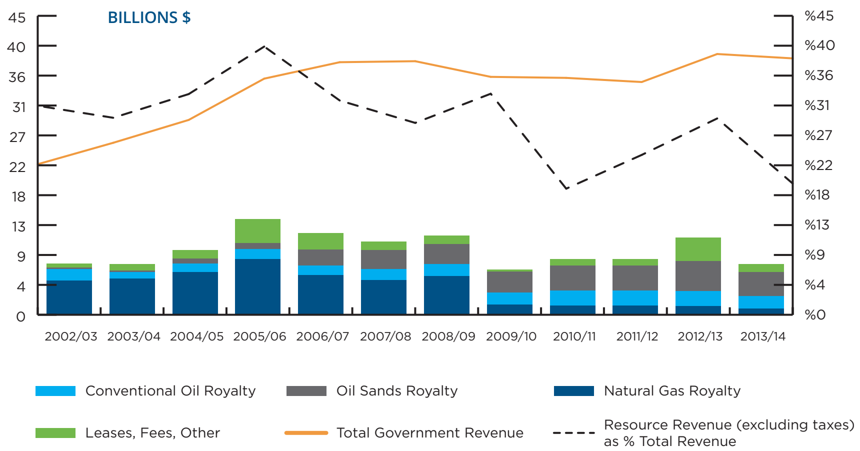
Figure 5-28: **Percentage of Provincial Government Revenue (Excluding Transfers from the Federal Government) Attributed to Fuel and Electricity Production and Consumption, Net of Income Taxes, Fiscal Year 2012/13**



On average, revenue from the production and consumption of fuel and electricity is a larger share of provincial (11%) than federal (3%) government revenue, but there are significant interprovincial differences in the provincial government revenue derived from the energy system, as shown in Figure 5-28. Newfoundland and Labrador, Saskatchewan and Alberta have the largest shares of provincial government revenue from the energy system because of the royalties they collect from oil and natural gas production. All the provinces levy a tax on gasoline and diesel fuel, and these add up to 4 or 5% of provincial government revenue, even in provinces without significant royalties and in which electric utilities are privately held or do not pay signifi-

Government revenue from the fossil fuel industry reflects the volatility and year-to-year variations in activity that characterize that industry, and the major producing provinces are especially vulnerable to revenue swings from industry business cycles. For example, as illustrated in Figure 5-29, over the ten-year period from 2002/03 to 2012/13, the revenue collected by Alberta for oil, gas and coal royalties and Crown land leases varied from a high of $14.3 billion in 2005/06 to a low of $6.8 billion in 2009/10, just four years later. This revenue can rise or drop by 35 to 50% in a single year. Figure 5-29 also illustrates the growth in the importance of bitumen royalties over the 2003 to 2013 period, as well as the collapse of natural gas royalties in 2009/10.

Figure 5-29: **Provincial Government Revenue from the Energy Industry in Alberta, 2002/03 to 2013/14 (excluding fuel tax and income tax)**



Even without the estimated $18 billion in sales and income tax related to the fuel and electricity industry, the $34 billion in energy-related government revenue in 2012 is many times higher than the direct government costs of managing, regulating and developing policy for the sector. Organizations such as the National Energy Board, provincial electricity system operators, and other provincial regulatory bodies operate on a cost-recovery basis and do not draw any significant funding from general government revenue. Government revenue from the energy system is more than ten times the combined budgets of all the federal and provincial energy ministries and environment ministries (which have a much broader mandate than energy). There are additional direct and indirect government expenditures that support the energy industry in Canada, but they are relatively small compared to government revenue from the industry.

Beyond these narrowly defined direct costs, however, there are unrecovered costs – known as externalities – and especially environmental externalities. The air and water pollution, land use disturbances, habitat destruction, and climate change brought about by the production and consumption of fossil fuels and electricity all constitute real costs that, sooner or later, translate at least in part to financial costs in the form of infrastructure destruction, community disruption, environmental degradation, and human injury and disease. These costs are both very large and very difficult to quantify; indeed, many would argue that they cannot be expressed in the unidimensional metric of dollars, although it may be possible to estimate the financial costs of avoiding some of these impacts. In any case, such costs are not currently factored into assessments of the financial dimensions of the energy system.

Federal and provincial government subsidies to the fossil fuel sector are another particularly contentious cost. Even trying to determine the amount of money involved is problematic, given that the sector receives government funds directly (estimated to be $3.6 billion each year), but also benefits indirectly through tax and duty exemptions, grants, loans, and other mechanisms. In a 2013 report, the International Monetary Fund (IMF) estimated that when uncollected taxes on externalized costs stemming from fossil fuel development, distribution and use in Canada were taken into account, federal and provincial governments provide over $34 billion in subsidies to the fossil fuel sector each year. Attempting to account for factors such as environmental externalities and government subsidies would greatly complicate the calculation of government revenues derived from the energy industry, as there are no agreed upon methods for generating such values conclusively.

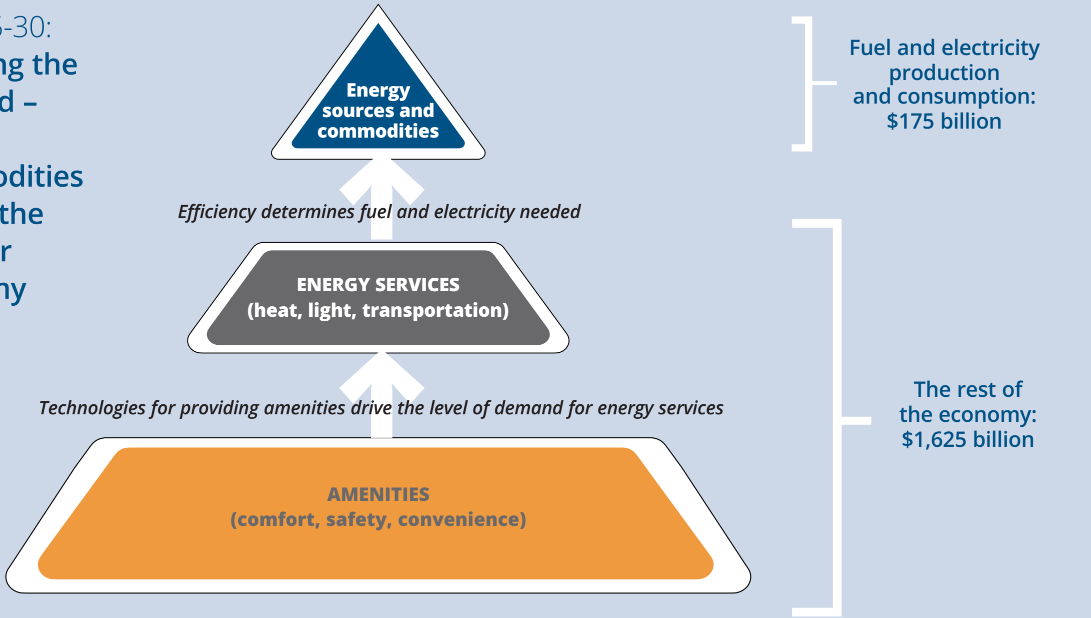
From Amenities to Services to Energy Commodities – Financial Dimensions of Energy Productivity and Efficiency

So far we have focused on energy commodities – fuel and electricity – in our exploration of the financial dimensions of Canada's energy system. But a central theme of this primer is that the energy system involves much more than the supply of and demand for fuel and electricity. A systems approach tells us that the demand for fuel and electricity is driven by demands for energy services (e.g., heating, lighting, transportation) , and that the demand for these energy services is in turn driven by demands for the amenities they provide (e.g., comfort, safety, convenience). Gasoline without a vehicle will not get you anywhere, and electricity without a light bulb will still leave you in the dark!

The amount of fuel and electricity required to meet the demand for a given energy service depends on the efficiency of the vehicles, furnaces, kilns, boilers, lighting systems, electronics or other energy end-use technologies employed to meet that demand. This is a key factor in the financial relationship between fuel and electricity and energy end-use technologies – a factor that is important both at the level of the individual consumer and at the level of the energy commodity supply system. Investing in greater energy efficiency at the individual technology level can result in financial savings over the lifetime of the end-use technology, whether it be a car, a home, an office building, or an industrial plant. When a new technology with an above-average level of energy efficiency comes along and is widely and quickly adopted (e.g., compact fluorescent or LED lighting compared to incandescent lighting), the implications reverberate throughout the energy commodity economy and can affect multi-billion dollar investment decisions and projects in the fuel and electricity supply industries.

In this context, energy commodity supply and demand is the tip of the iceberg, with the underlying decisions and behaviours in the rest of the economy determining the level and pattern of energy service demands, which in turn drive the demand for fuel and electricity. In Figure 5-30, we have inverted the energy pyramid to illustrate this point.

Figure 5-30: **Inverting the Pyramid – Energy Commodities versus the Broader Economy**



As the inversion of the energy pyramid suggests, decisions made by energy system stakeholders can have a significant impact on levels and patterns of energy demand, even though those decisions are not directly related to fuel and electricity consumption. The following examples demonstrate just how this can work:

- **Urban planners designing communities with little or no regard for the personal mobility choices that their designs impose on residents.**

- **A steel company opting to produce higher-value-added products as a competitive strategy, not because of the effect such a decision will have on its energy use.**

- **An office building interior designer opting for less space per employee for reasons that have nothing to do with the impact on the demand for heating, cooling and lighting services.**

- **Individuals making more or less frequent trips in their automobiles based on considerations of convenience and time constraints, with little or no regard for the energy cost implications.**

- **A logistics company shipping goods in half-empty trucks to meet client demands for just-in-time delivery, even though it means more truck runs and higher fuel consumption.**

- **Households opting for smaller or larger dwellings based on their perceived needs and aspirations for space, comfort, luxury, and amenities, with little or no consideration of the impact of their demands for heat and other energy services.**

Does this mean that a full discussion of the financial dimensions of the energy system becomes a discussion of the financial dimensions of everything? To an extent, the answer is yes. When we define the energy system as broadly as we have in the energy pyramid, bringing virtually the entire economy inside the system boundary (after all, almost everything requires energy), it follows that it is important to be aware of the energy implications of decisions, including financial decisions, that may not seem directly related to fuel and electricity consumption. And some decisions have larger and more direct implications than others when it comes to how they influence the level and pattern of energy demand. To pick up on one case from the list of examples given above, urban planners now tend to consider the mobility implications of their plans, recognizing that compact, mixed-use development can significantly shape the personal mobility choices residents will make to access the amenities they want. Looking at how energy decisions and behaviours such as these can drive levels and patterns of energy service demand underlines just how vital and important widespread energy literacy really is.

Energy Conservation and Efficiency – the Hidden Supergiant

The inverted energy pyramid illustrates how the amount of fuel and electricity consumed for any particular application, or in the economy in general, depends directly on the energy efficiency of the technologies employed to deliver the energy services. The thermal efficiency of residential and commercial buildings, the fuel efficiency of cars and trucks, the efficiency of lights and appliances in buildings and of furnaces, kilns and boilers in industry – all of these have a direct impact on the total quantity of fuel and electricity required.

The cost of conservation and energy efficiency varies widely. Most households and businesses could reduce their energy consumption simply through energy conservation behaviours such as turning off lights and equipment when they are not in use, consolidating their vehicle trips or carpooling, walking or cycling a little more, or turning down the heat or air conditioning a little. Some technological efficiency gains are so simple or have such a small impact on the cost of the vehicle or equipment to which they are applied that the cost per unit of energy saved is insignificant. For example, residential refrigerators have more than doubled in energy efficiency in recent years due to smaller, lighter motors, improved insulation and other technological and material efficiencies associated with better design, but their real cost has not changed much. In some cases, energy efficiency can actually have negative costs (i.e., more than pay for itself) because of other savings brought about as a result of the efficiency improvement. For example, new lighting technologies are not only much more energy efficient than older generations of lighting systems, they also last much longer, with bulbs and other components requiring replacement much less often. In commercial buildings with thousands of light fixtures, building managers are finding that the labour saved by not having to replace lights nearly as often, combined with the electricity savings, more than offsets the cost of upgrading.

Nonetheless, there is often a cost associated with improving the efficiency of fuel and electricity use, and it usually comes in the form of increased upfront, or capital, costs. The cost-effectiveness of the efficiency measure depends on whether the value of the fuel and electricity savings over the life of the efficiency measure will be enough to justify the cost of implementing it. Methods for making this comparison range from the simple payback method (cost of the efficiency measure divided by its lifetime in years, compared to the annual cost of the energy saved) to sophisticated analyses that take various factors into consideration, including the annualized cost of the efficiency investment, the present value of future savings, any expected changes in the price of the fuel or electricity saved over the life of the efficiency measure, the value of hedging against possible future fuel and electricity price increases, the financial value of any collateral benefits that come with the efficiency measure, income and other tax considerations, impacts of the efficiency measure on annual operation and maintenance costs, etc. Regardless of the sophistication

Between 1995 and 2010, the Canadian population grew by 16% and the economy grew by 46%, but total fuel and electricity use by households, government, businesses and industry grew by only 12%.

of the calculation method, it is almost always the case that there are efficiency investments available that are cheaper than the energy they save.

Spikes in the prices of fuel and electricity stimulate energy-efficiency advances that often become the "new normal", even after the price spikes subside. Countries where fuel and electricity prices are highest are the most active in research, development and innovation in energy efficiency, but the resulting energy-efficiency technologies and innovations usually enter the global marketplace when they are available at prices that are competitive with status quo technologies, once again leading to a "new normal" level of efficiency. Uncertainty about future energy prices and concern over the unsustainability of the current energy system also stimulate architects, planners, design engineers, policy-makers and others to think about energy efficiency, and this heightened energy literacy leads to long-term improvements in the efficiency of their plans and designs.

Direct savings from energy efficiency and other trends that allow amenities to be provided with less fuel and electricity accrue both at the level of the individual consumer and at the level of the energy commodity economy, and they are significant. Between 1995 and 2010, the Canadian population grew by 16% and the economy grew by 46%, but total fuel and electricity use by households, government, businesses and industry grew by only 12%. During this period, dwellings got larger, people drove larger vehicles and drove them further, the intensity of freight activity went up, and the oil industry made a significant shift from production of conventional crude to the much more energy-intensive bitumen. But, at the same time, economic sectors that do not use much energy, such as information technology (see Figure 5-6), grew faster than the rest of the economy, vehicles became more fuel efficient, and commercial buildings and housing became much more energy efficient, as did lighting, appliances and all sorts of industrial processes and equipment. The net result: per capita energy consumption actually declined by 4%, and the overall energy intensity of the Canadian economy, as measured by total energy consumed per dollar of GDP (E/GDP) declined by 23%. If not for this decline in E/GDP, by 2010, Canadian households and businesses would have been spending *over $50 billion per year more* on fuel and electricity than they actually did.

Improved energy productivity, including energy efficiency improvements, was not just the single largest "source" of new energy over this period, it was larger than all the new coal, oil, gas, hydro, nuclear, solar, wind and biomass energy *combined*. And yet, by 2010, the energy intensity of the Canadian economy was still nearly twice that typical of the wealthiest western European economies, underscoring that there is still much room for productivity and efficiency gains in the Canadian energy system.

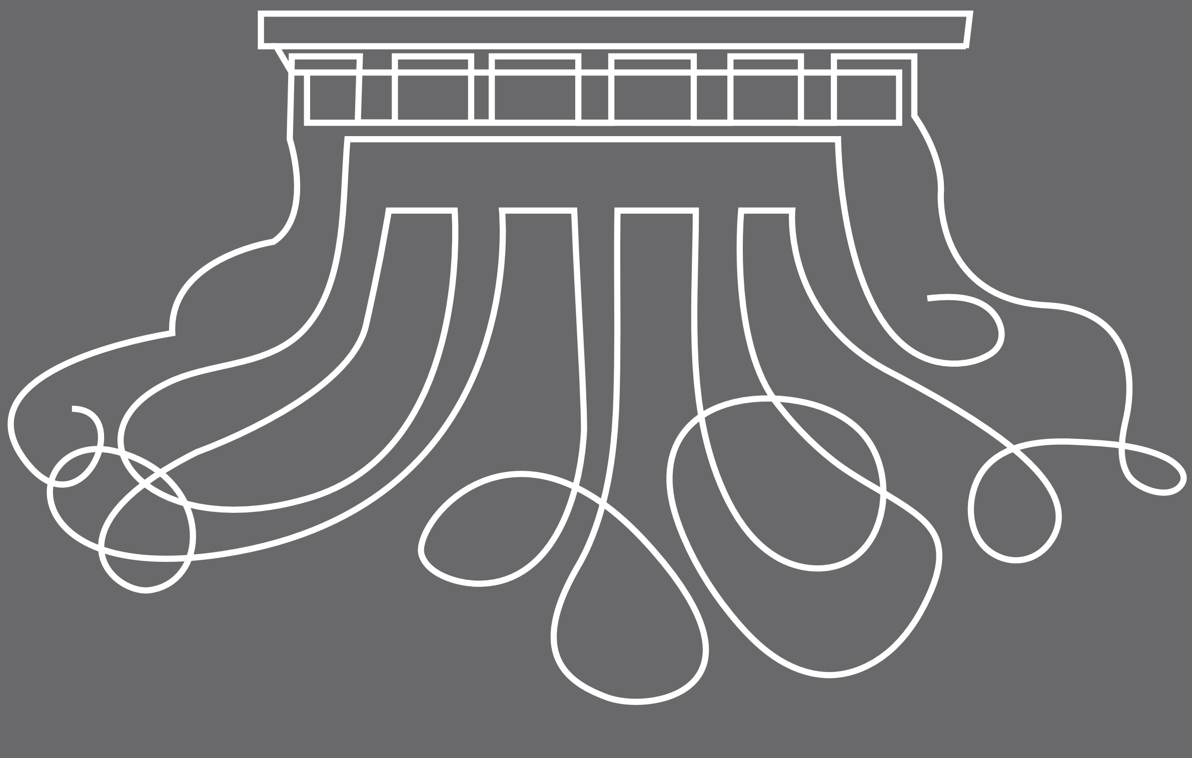
Carbon Pricing and the Cost of Fuel and Electricity

One of the policy measures available to address climate change is to put a price on the carbon dioxide emissions associated with the use of fossil fuels and electricity, either as a direct tax or by the application of a cap on emissions in combination with a market for trading emission allocations within the cap. The price premium on fuel and electricity that results from carbon pricing depends both on the carbon price itself and on the level of carbon dioxide emissions associated with a particular energy source. Figure 5-31 illustrates these premiums for a variety of fuels, as well as for electricity from coal, natural gas, and from the average mix of generators in each province in 2012. In the case of electricity, there are no carbon dioxide emissions at the point of end use, so the impact of a carbon price depends on the emissions that occur where the electricity is generated. In provinces where electricity is generated mostly from low-carbon hydroelectricity (British Columbia, Manitoba, and Quebec), the potential impact of carbon pricing on electricity prices is very small compared to the impact in provinces that generate most of their electricity from coal or other fossil fuels (Alberta, Saskatchewan, and Nova Scotia). Figure 5-31 shows the price premiums both in terms of customary units (cents per kilowatt hour, dollars per litre, etc.) and in dollars per gigajoule, to facilitate comparison between the different energy sources.

Figure 5-31: **Fuel and Electricity Price Premiums Resulting from Carbon Prices at Different Levels ($/tonne of carbon dioxide emitted)**

		Carbon Price, $/tonne of Carbon Dioxide							
		15	30	50	100	200	300	400	500
Price impact on	**Units**	**Price Premiums**							
Gasoline	cents/litre	3.43	6.87	11.45	22.89	45.78	68.67	91.56	114.45
Diesel	cents/litre	3.99	7.99	13.32	26.63	53.26	79.89	106.52	133.15
Fuel oil	cents/litre	4.09	8.18	13.63	27.25	54.50	81.75	109.00	136.25
Propane	cents/litre	2.27	4.54	7.57	15.13	30.26	45.39	60.52	75.65
Natural gas	dollars/cubic metre	0.03	0.06	0.09	0.19	0.38	0.57	0.76	0.95
Coal-fired electricity	cents/kilowatt hour	1.43	2.85	4.75	9.50	19.00	28.50	38.00	47.50
Electricity from gas turbines	cents/kilowatt hour	0.56	1.13	1.88	3.75	7.50	11.25	15.00	18.75
Average 2012 electricity price									
Canada	cents/kilowatt hour	0.24	0.48	0.80	1.60	3.20	4.80	6.40	8.00
Newfoundland and Labrador	cents/kilowatt hour	0.03	0.06	0.10	0.20	0.40	0.60	0.80	1.00
Nova Scotia	cents/kilowatt hour	1.05	2.10	3.50	7.00	14.00	21.00	28.00	35.00
New Brunswick and PEI	cents/kilowatt hour	0.63	1.26	2.10	4.20	8.40	12.60	16.80	21.00
Quebec	cents/kilowatt hour	0.00	0.01	0.01	0.03	0.06	0.09	0.12	0.15
Ontario	cents/kilowatt hour	0.14	0.29	0.48	0.96	1.92	2.88	3.84	4.80
Manitoba	cents/kilowatt hour	0.01	0.01	0.02	0.03	0.07	0.10	0.14	0.17
Saskatchewan	cents/kilowatt hour	1.13	2.25	3.75	7.50	15.00	22.50	30.00	37.50
Alberta	cents/kilowatt hour	1.23	2.46	4.10	8.20	16.40	24.60	32.80	41.00
British Columbia	cents/kilowatt hour	0.01	0.02	0.04	0.08	0.16	0.25	0.33	0.41
Premiums in $/gigajoules on									
Gasoline	dollars/gigajoule	0.99	1.98	3.30	6.60	13.21	19.81	26.42	33.02
Diesel	dollars/gigajoule	1.03	2.07	3.44	6.88	13.77	20.65	27.54	34.42
Fuel oil	dollars/gigajoule	1.06	2.11	3.52	7.04	14.09	21.13	28.18	35.22
Propane	dollars/gigajoule	0.89	1.78	2.96	5.93	11.85	17.78	23.71	29.63
Natural gas	dollars/gigajoule	0.76	1.52	2.54	5.08	10.16	15.24	20.32	25.40
Coal-fired electricity	dollars/gigajoule	3.96	7.92	13.21	26.4	52.8	79.2	105.6	132.1
Electricity from gas turbines	dollars/gigajoule	1.56	3.13	5.21	10.43	20.85	31.28	41.70	52.13
Average 2012 electricity price									
Canada	dollars/gigajoule	0.67	1.33	2.22	4.45	8.90	13.34	17.79	22.24
Newfoundland and Labrador	dollars/gigajoule	0.08	0.17	0.28	0.56	1.11	1.67	2.22	2.78
Nova Scotia	dollars/gigajoule	2.92	5.84	9.73	19.46	38.92	58.38	77.84	97.30
New Brunswick and PEI	dollars/gigajoule	1.75	3.50	5.84	11.68	23.35	35.03	46.70	58.38
Quebec	dollars/gigajoule	0.01	0.02	0.04	0.08	0.16	0.24	0.32	0.40
Ontario	dollars/gigajoule	0.40	0.80	1.33	2.67	5.34	8.01	10.68	13.34
Manitoba	dollars/gigajoule	0.01	0.03	0.05	0.09	0.19	0.28	0.38	0.47
Saskatchewan	dollars/gigajoule	3.13	6.26	10.43	20.85	41.70	62.55	83.40	104.25
Alberta	dollars/gigajoule	3.42	6.84	11.40	22.80	45.59	68.39	91.18	113.98
British Columbia	dollars/gigajoule	0.03	0.07	0.11	0.23	0.46	0.68	0.91	1.14

For a comparison to actual Canadian fuel and electricity prices, see Figure 5-12. The carbon tax that was passed in British Columbia in 2012, for example, is equivalent to $30/tonne of carbon dioxide, which amounts to less than half the gas tax already levied in British Columbia and other provinces; it is also lower than the sales tax on fuel charged in most provinces. Even with the carbon tax, gasoline in British Columbia in 2012 was cheaper than in other provinces that have higher gas taxes, and the overall impact of the carbon tax on retail prices for petroleum fuels was in the range of 5 to 7%. Ironically, the percentage impact of the carbon tax on the price of natural gas (11%) was higher than for the more carbon-intensive petroleum fuels, where higher base prices and tax rates resulted in the tax having a lower percentage impact on the bottom-line price.



CHAPTER SIX

The Geography of Canada's Energy Systems

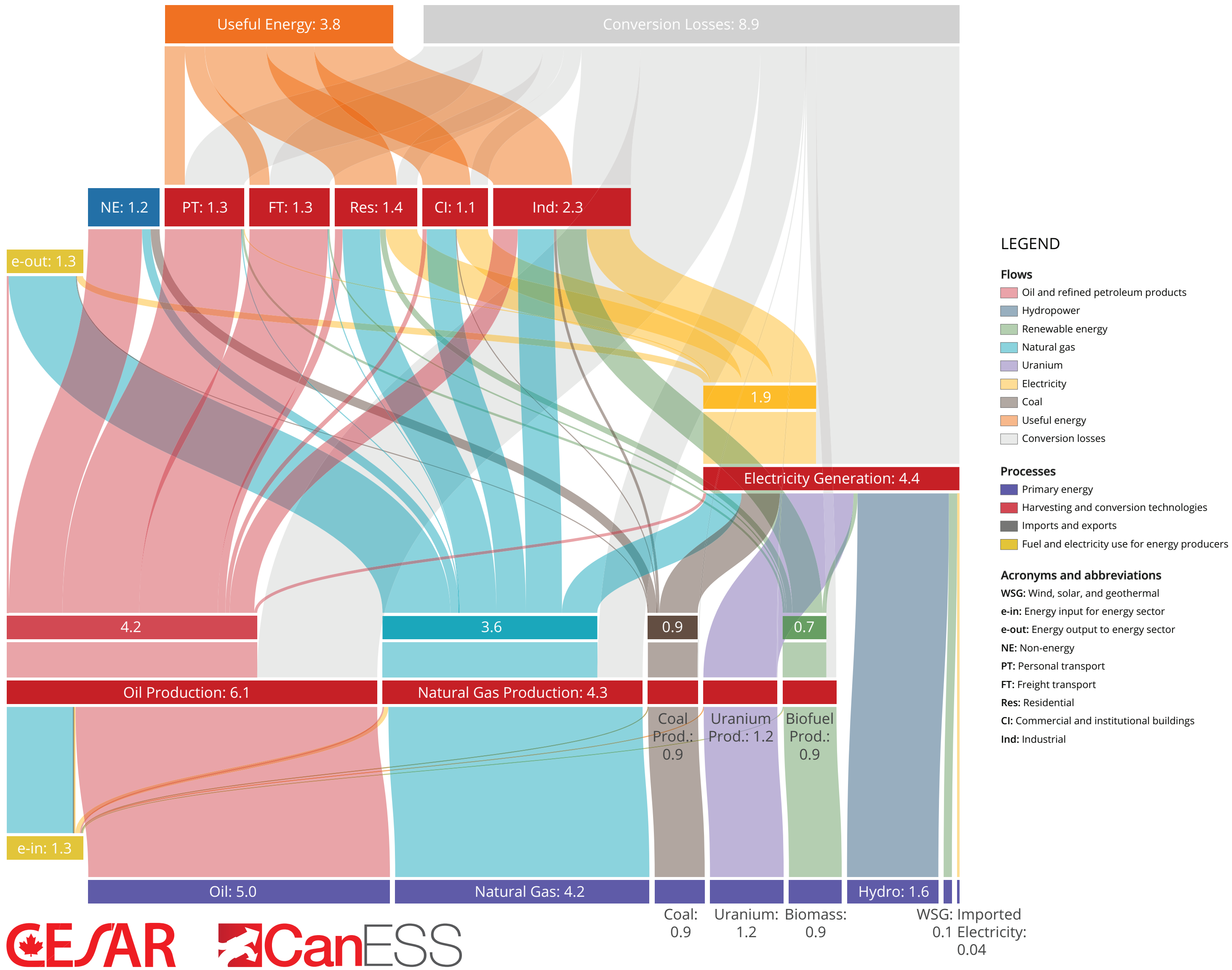
We have now explored Canada's energy systems based on categories of energy sources and commodities as well as some of its financial and economic dimensions. It is also useful to look at Canada's energy systems from a geographical perspective to see how the availability of a particular energy source in any given region has shaped the development of energy commodities and services in that part of the country. That history is key to understanding the different "energy cultures" we live in across Canada, and how those cultures have shaped our energy choices, both individually and nationally.

A National Picture of Energy Use

Before we look at regional differences in energy use, let us start by looking at a national picture of energy use (see Figure 6-1). Only one-third of the energy produced in Canada actually serves a useful purpose. This raises the question: why is so much energy in our system lost? The remaining two-thirds is wasted, primarily as heat energy expended during the combustion of fossil fuels – either in vehicle engines, industrial boilers, or thermal power plants. Upon close examination, you might notice that conversion losses associated with hydroelectricity – the country's number one form of electricity generation – are minimal. This is because hydro has a conversion efficiency of roughly 90%, whereas coal, single-cycle natural gas, and nuclear power plants all have conversion efficiencies between 30 and 35%. In regard to transportation, gasoline and diesel engines are roughly 25% efficient, while electric vehicle motors are 80 to 90% efficient. The natural gas furnaces that provide heat to the majority of Canada's buildings range broadly in terms of efficiency, with some older units being as low as 65% efficient, but newer units reaching upwards of 90% efficiency.

Figure 6-1: **Energy Flow Diagram of Domestic Energy Use in Canada, 2012**

(exajoules; values are approximate)



All of the values expressed in the energy flow diagram were obtained from the Canadian Energy Systems Simulator (CanESS) model, which was built and calibrated with 32 years of historical data drawn from government sources such as Statistics Canada, Natural Resources Canada, Environment Canada, and the National Energy Board. In order to extract full value from the diagram, note the following points of guidance:

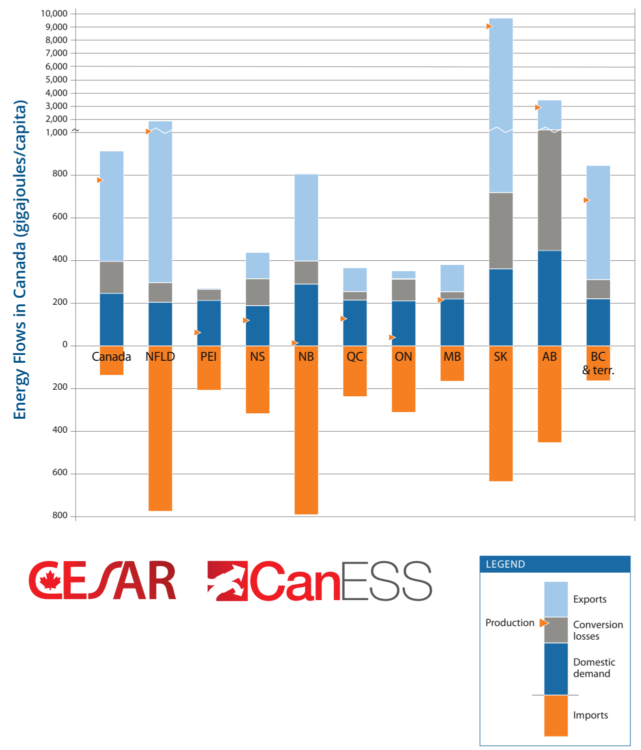
- The figure is reported in exajoules (**EJ**); 1 exajoule = 10^{18} joules
- The Non-Energy (**NE**) fraction of fossil fuel use accounts for the production of commodities such as plastics, paints and varnishes that depend on specific fossil fuels as material, rather than energy, inputs.
- Personal Transport (**PT**) includes not just energy consumed by personal vehicles, but by public transit as well as air, rail and marine travel. Personal transport is still heavily dominated by the use of gasoline as a fuel.
- Freight Transport (**FT**) includes energy for moving commercial goods via rail, truck, pipelines, marine cargo ships, and aviation. It also includes the use of fuels for off-road applications such as construction, forestry and mining. Freight transport is heavily dominated by the use of diesel fuel.
- Residential (**Res**) and Commercial/Institution (**CI**) energy use is dominated by natural gas and electricity, with a small portion of oil and biomass used for heating.
- The Industrial (**Ind**) category encompasses energy used for the manufacture and/or extraction of commodities. In the diagram, the industry sectors that produce energy (mainly electricity or fossil fuels) are considered service industries and are situated in the lower-middle of the diagram.
- The **e-in** and **e-out** categories capture the energy that energy recovery and conversion facilities typically require to produce energy commodities. Even oil wells and refineries, for example, require electricity, and many in Canada produce their own electricity from on-site natural gas power plants. Including these two categories reflects the fact that it takes energy to produce energy.

Provincial Energy Use Comparison

Figure 6-2 looks at the data from Figure 1-1 in Chapter 1 on a provincial basis. Note, however, that the unit of measurement used in Figure 6-2 is gigajoule/capita, which facilitates a direct comparison of energy use in different provinces without skewing results due to variances in provincial populations.

Per capita energy production in Saskatchewan dwarfs that of other provinces because Saskatchewan is the sole producer of uranium in Canada. Uranium is by far the most energy-dense commodity used in global energy systems. By way of example, 1 kilogram of coal yields 8 kilowatt hours of energy and 1 kilogram of petroleum yields about 12 kilowatt hours. One kilogram of uranium-235, however, yields roughly 24,000,000 kilowatt hours of energy. As a result, Saskatchewan's energy exports surpass those of any other energy commodity in the country in terms of energy value (as opposed to monetary value).

Figure 6-2: An Interprovincial Comparison of Energy Production and Use

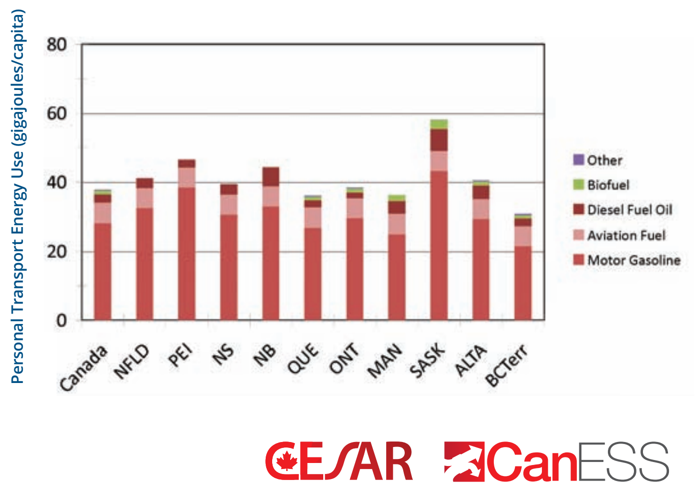


In addition to uranium, Saskatchewan also produces oil, and is one of the three oil-producing provinces, along with Alberta and Newfoundland and Labrador. Alberta's significant conversion losses speak to the fact that the extraction of non-conventional oil and gas from its oil sands is highly energy intensive. In contrast, conventional oil and gas extraction from three offshore oil fields in Newfoundland and Labrador has lower conversion losses.

Energy import figures from New Brunswick were skewed in 2012 because the province's only nuclear reactor, which typically supplies one-third of its electricity, was undergoing refurbishment at that time. An important point to note is that domestic energy demand is more or less consistent across the provinces. This demonstrates that all Canadians use a similar amount of energy in their daily lives. Alberta and Saskatchewan have higher demands mainly because of their particularly cold climates, resulting in greater heating demands throughout the winter. Those provinces are also characterized by a high percentage of light trucks (SUVs and pickups) owned as personal vehicles, which leads to higher energy demands for transportation. Generally speaking, provinces with higher proportions of rural populations tend to have more vehicle kilometres driven per person, per year.

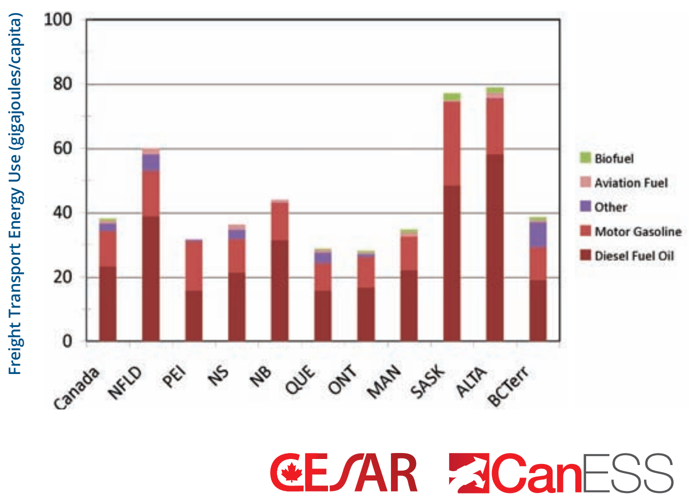
In Figures 6-3 to 6-7, we will look at energy use by province for specific categories of end uses to see what energy sources, commodities, and services are used in the different provinces. These energy end uses have been shaped by the energy sources available to that province. At the same time, the specific industries that have come to dominate a province's economy have in turn shaped the development of its energy systems.

Figure 6-3: **Energy Use for Personal Transportation, by Province, 2012**



The thin purple bars at the top of the columns for several provinces in Figure 6-3 are indicative of electrified mass transit in urban centres. The green bars indicating the use of biofuels would likely be much more consistent across all provinces in 2016. The numbers presented here are from 2012 – before all the provinces had adopted biofuel mandates of 5% ethanol in all gasoline and 2% biodiesel in all diesel fuel.

Figure 6-4: **Energy Use for Freight Transportation, by Province, 2012**

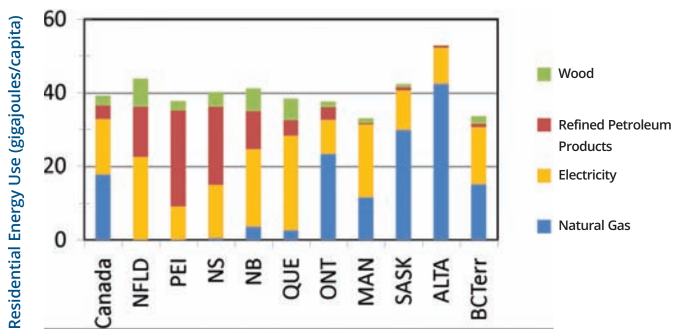


The numbers in Figure 6-4 include fuel used by agricultural, construction, and mining machinery, as well as other off-road vehicles that transport materials over short distances. The three highest energy users for freight transport are the high energy-producing provinces: Alberta, Saskatchewan, and Newfoundland and Labrador.

Alberta has the highest per capita fuel use for heavy trucking, mainly due to oil extraction and transport. It is interesting to note that Ontario and Alberta are roughly equal in terms of total freight energy usage. However, because Alberta's population is less than a third of Ontario's population, the per capita freight energy usage for Alberta ends up being significantly higher.

Saskatchewan's high per capita freight energy use stems from having the highest per capita rail freight demand in the country, while per capita medium and heavy trucking are also among the highest in Canada. The high per capita numbers are also a result of freight-intensive industries such as crop and animal production, mining, and oil and gas extraction, combined with a relatively small population. In Newfoundland and Labrador, the high per capita freight transport energy use is due in part to high off-road vehicle usage (also the case in New Brunswick) and in part to the movement of freight in support of the energy sector.

Figure 6-5: **Residential Energy Use, by Province, 2012**



The differences between provinces shown in Figure 6-5 are largely the result of different energy systems (i.e., the availability of different energy sources and commodities), the different technologies used for space heating and water heating, and the efficiencies of those technologies. For example, space and water heating with natural gas is on average much less efficient than electric heating. Ambient temperature differences also explain much of the variation between British Columbia and Alberta.

Among the Prairie provinces, which share a similar climate, Alberta has more, and larger, single-family detached houses than either Manitoba or Saskatchewan.

Figure 6-6: **Commercial and Institutional Energy Use, by Province, 2012**

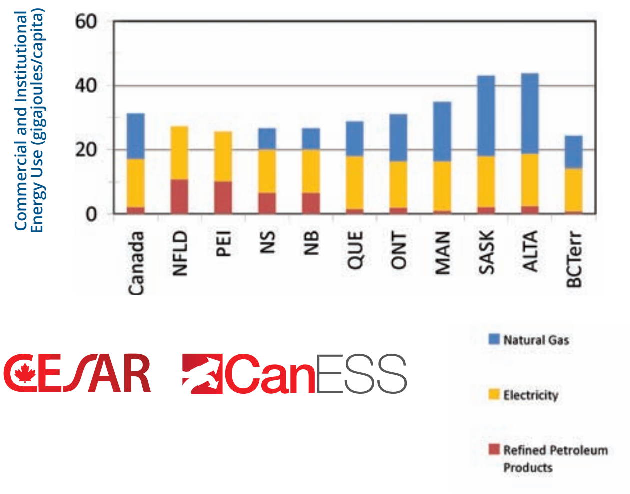


Figure 6-6 shows fuel and electricity use for all commercial and institutional buildings and for street lighting. This sector encompasses buildings used for retail, warehousing, office space, education, health, recreation, temporary accommodation, and other purposes. The major types of energy use in these buildings are space heating and cooling, water heating, auxiliary equipment operation, and lighting.

Consistent with residential energy use, the higher the share of electricity used, as opposed to fossil fuels, the lower the per capita energy use because electric technology tends to have higher efficiencies. Of course, this does not take into consideration the conversion efficiency associated with making the electricity, which can be relatively low.

Figure 6-7: **Industrial Energy Use, by Province, 2012**

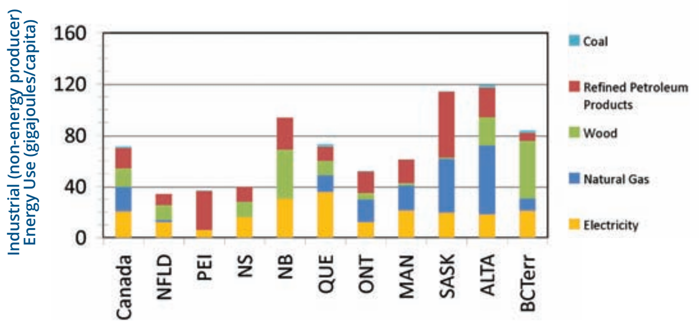


Figure 6-7 shows energy use in non-energy-producing industries. These industries include construction, pulp and paper, metal smelting and refining, cement, chemicals, iron and steel, forestry, mining, fertilizers, and agriculture. High rates of fertilizer and agricultural production in Saskatchewan and Alberta are responsible for the high per capita numbers for those provinces. The pulp and paper industry uses a lot of wood biomass and electricity for energy in New Brunswick, British Columbia, and Quebec. Quebec also uses a lot of its abundant hydroelectricity in its aluminum smelting industry.

Having looked at a province-by-province comparison of energy end uses, let us look at the similarities and differences between the provincial energy systems that have shaped our choices individually and regionally.

Hydropower Provinces – Quebec and Manitoba

Quebec and Manitoba both have significant hydropower sources, often located in remote areas. These provinces have a formidable history of building large hydropower plants and long-distance transmission lines to carry power from remote northern plants to towns, cities and industrial facilities.

Manitoba also operates coal-fired power plants, using imported coal, for a small fraction of its generation (less than 1% of its electricity in 2014). For several decades, Quebec produced power from a nuclear facility – the Gentilly Nuclear Generation Station – but this was closed in 2012. The development of hydropower has been the driving force in the energy strategy of both provinces.

In these provinces, “hydro” is synonymous with energy. Quebec and Manitoba rely far more on electricity to heat and power their homes, commercial buildings and industry than any of the other provinces. This is especially true for Quebec, which alone is responsible for half of Canada’s hydropower generation.

Electricity prices in these hydro provinces are among the cheapest in any higher-income jurisdiction in the world. These low electricity rates contribute to the profitability of industrial sectors such as mining, pulp and paper, aluminum smelters and oil refining.

Both provinces also export electricity from hydropower to neighbouring jurisdictions – particularly to American states that are eager to purchase electricity from sources that emit few greenhouse gases (and that are, in some cases, lower in cost than typical sources).

Figure 6-8: **Electricity Generation in Quebec, by Source, 2014**

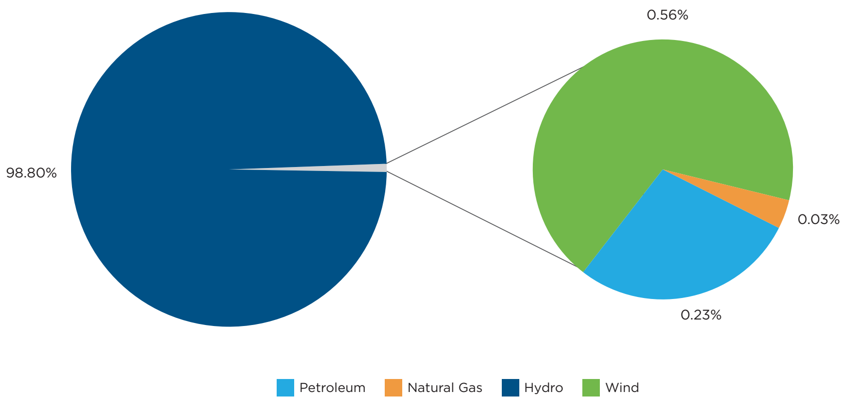
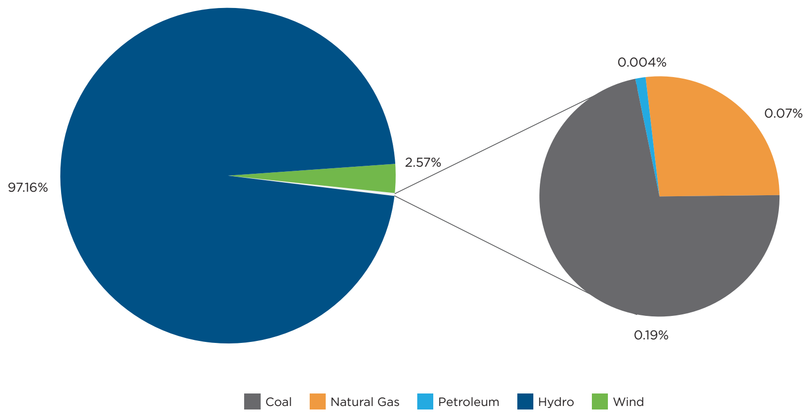


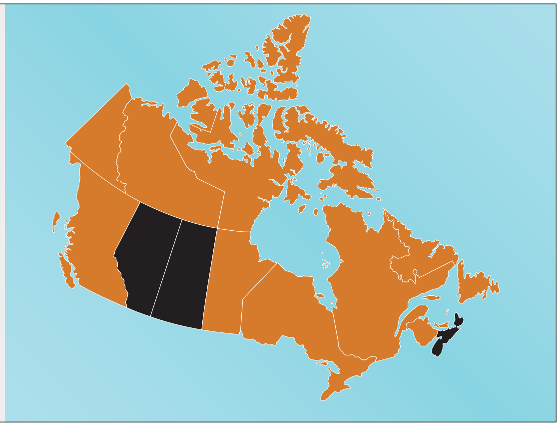
Figure 6-9: **Electricity Generation in Manitoba, by Source, 2014**



Hydrocarbon Provinces

Alberta, Saskatchewan and Nova Scotia all have a history of economic development based on coal, crude oil and natural gas. Like hydropower in Quebec and Manitoba, these industries are a source of pride and cultural identity for many residents in these provinces.

All three of these provinces are heavily reliant on fossil fuels, mainly coal, for electricity generation, with a smaller share from hydropower, wind, biofuels and other sources.



Energy policies in the hydrocarbon provinces, and the economic development they support, differ from those in the hydropower provinces. In these provinces, the development and use of fossil fuel sources is a key factor in economic development and energy services.

Alberta

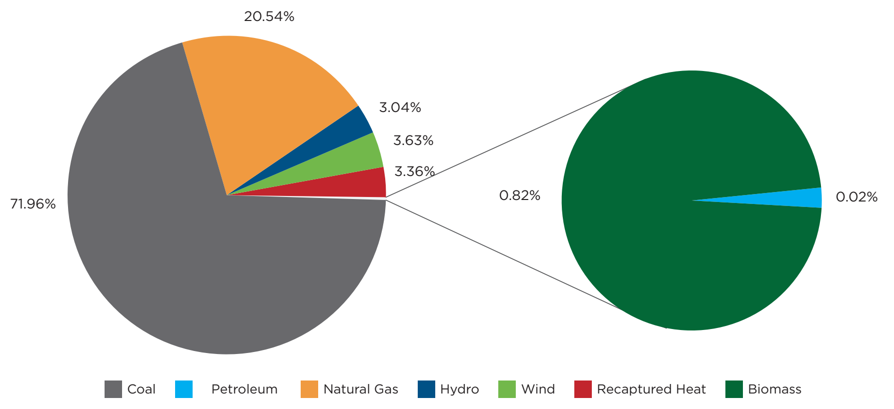
Alberta is Canada's largest producer of crude oil, natural gas and coal. While Alberta's conventional sources of oil are declining, production from the oil sands has a significant potential to increase.

Alberta's electricity sector is also very fossil fuel heavy, with nearly 90% of electricity generation from coal and natural gas. Alberta is Canada's largest user of coal for electricity generation: over 70% of the province's publicly available electricity is generated by coal-fired power plants. Alberta produces all of the coal that is used in these plants.

Much of Alberta's crude oil, natural gas and coal is produced for export to the United States, other provinces and international markets. Alberta's energy sector makes up the single largest share of economic activity, employment, income and government revenues of all sectors in the province, and it provides two-thirds of the value of Alberta's exports.

The Government of Alberta that was elected in 2015 has put plans in place to establish a lower carbon grid. In addition to imposing a carbon tax ($20 per tonne of carbon dioxide in 2017, rising to $30 per tonne in 2018), the province has pledged to completely phase coal out of its electricity generation portfolio by 2030.

Figure 6-10: **Electricity Generation in Alberta, by Source, 2014**

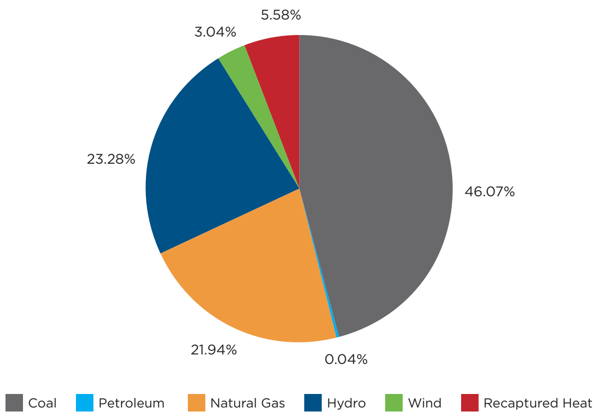


Saskatchewan

Almost half of Saskatchewan's electricity supply comes from its three coal-fired power plants. Saskatchewan produces all of the coal it uses. Natural gas plants generate a little over 20% of the electricity supplied to the grid, with hydro making a similar contribution. In 2015, Saskatchewan's energy policy shifted from a focus on coal, natural gas, and crude oil towards renewable energy, with a commitment to having 50% of its electricity coming from renewable sources by 2030. Most of this new generation is expected to come from wind, solar, and even commercial-scale geothermal energy.

Saskatchewan remains a major producer of fossil fuel energy sources, second only to Alberta in oil production and third in the country after

Figure 6-11: **Electricity Generation in Saskatchewan, by Source, 2014**



Alberta and British Columbia in both coal and natural gas production. Saskatchewan is also Canada's only supplier of uranium and, up until recently when it was overtaken by Kazakhstan, was the world's single largest supplier.

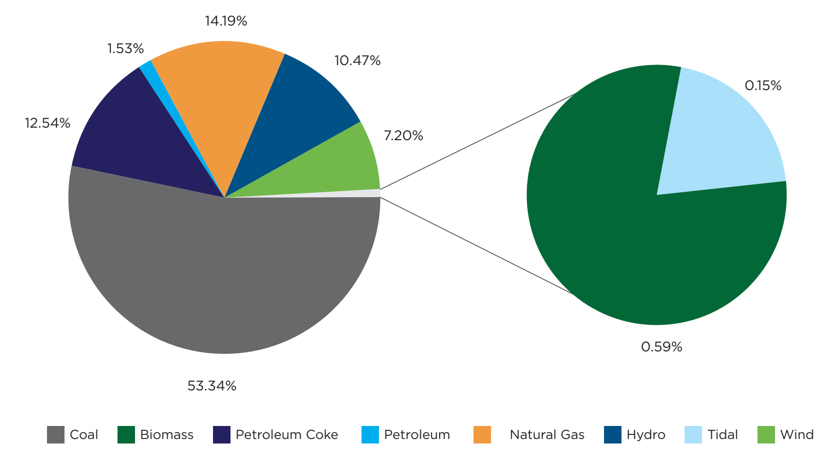
Nova Scotia

Coal was mined in Nova Scotia for hundreds of years, first to provide heat and, more recently, to power the electricity system. Coal is no longer mined in Nova Scotia, but two-thirds of the province's electricity is generated by burning imported coal and petroleum coke (a solid, high-carbon fuel from the petroleum refining process). Nova Scotia meets the balance of its electricity demand using other fossil fuels, complemented by hydropower and wind.

Offshore production from Nova Scotia's Sable natural gas field started in 1999. The royalties paid to the provincial government from companies producing natural gas amounted to the sixth-largest source of provincial government revenue. The development of these offshore fields has led to the construction of pipelines to bring the natural gas to the mainland and through New Brunswick, where they connect with the main North American natural gas transmission and distribution pipeline system. New offshore projects are under development, and the provincial government is granting new exploration rights to companies looking to develop additional offshore natural gas and crude oil fields.

Nova Scotia has pledged to completely phase out coal-fired generation by 2040, with the majority of new capacity slated to come from local renewable resources and clean electricity imports.

Figure 6-12: **Electricity Generation in Nova Scotia, by Source, 2014**



Mixed Producer Provinces

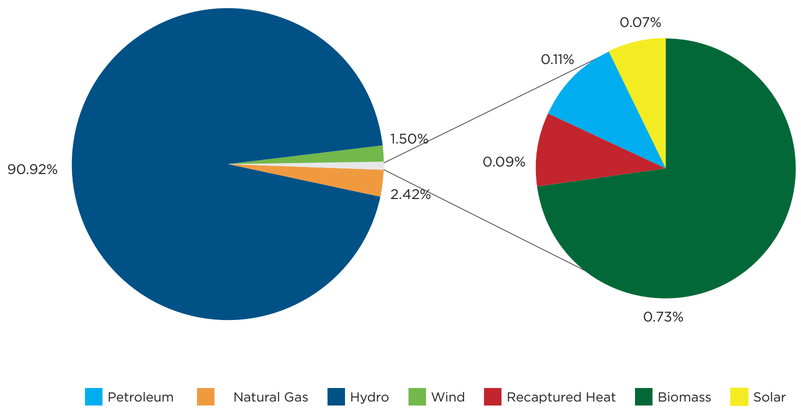
British Columbia and Newfoundland and Labrador both generate the bulk of their electricity from hydropower, and their energy systems are very similar to those in the hydropower provinces of Quebec and Manitoba. Both British Columbia and Newfoundland and Labrador are also major exporters of electricity generated from hydropower to neighbouring jurisdictions. Unlike Quebec and Manitoba, these two provinces are also large producers of fossil fuel energy sources.

British Columbia

British Columbia’s electricity generation is dominated by hydropower. In addition to being Canada's second-largest hydropower producer after Quebec, British Columbia is also the second-largest producer of natural gas in Canada, after Alberta. Because of its location on Canada's west coast, it is home to Canada's export terminals for Canadian crude oil, natural gas and coal destined for Asian and other international markets. In 2008, British Columbia was also one of the first provinces in Canada to introduce a price on carbon in the form of a revenue-neutral carbon tax and has also committed to having the cleanest liquefied natural gas (LNG) operations in the world.

Over the last decade, British Columbia has witnessed a series of prolonged controversies over proposed oil and gas pipelines that would transport crude oil and natural gas from northern Alberta to west coast export terminals. The proposed pipeline routes are controversial because they pass through ecologically rich areas of the province and would also bring hundreds of additional oil tankers each year to shipping ports that are likewise ecologically rich. The proposed pipeline routes also pass through areas that are of legal and cultural importance to local Indigenous communities. Many governments across Canada are looking to enhance models for engagement with communities in general, and in particular with Indigenous communities, as well as to improve the environmental assessment process, in part to address the concerns of citizens with regard to pipelines.

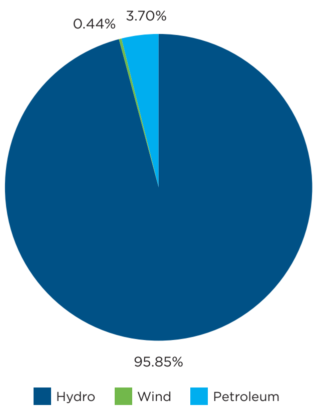
Figure 6-13: **Electricity Generation in British Columbia, by Source, 2014**



Newfoundland and Labrador

Newfoundland and Labrador's electricity grid is primarily supplied by hydropower. Churchill Falls in Labrador is the site of one of Canada's largest hydropower plants. All of the power generated flows to Quebec via high-voltage power lines, with a long-standing purchase agreement for the electricity set to expire in 2041. In late 2010, Newfoundland and Labrador announced plans to develop the Lower Churchill Project at Muskrat Falls, a site with large hydropower potential. Under the plan, the electricity generated from the new hydropower plants in Labrador would be transmitted to Newfoundland and then to Nova Scotia and on to other markets via underwater transmission lines. Construction on the project is slated to wrap up in 2018.

Figure 6-14: **Electricity Generation in Newfoundland and Labrador, by Source, 2014**



Newfoundland and Labrador is the country's third-largest producer of crude oil, all of it from Canada's only active offshore oil fields. These fields are now in decline, and the province's energy plan calls for the development of new crude oil fields in deeper water further offshore, as well as the exploration of potential natural gas fields and the development of wind power.

Mixed Importer Provinces

Ontario, New Brunswick and Prince Edward Island all rely on a mix of energy sources to meet their power needs. Ontario does export electricity to Michigan, Quebec and other neighbours, and New Brunswick supplies Prince Edward Island with most of its electricity, but these three provinces are all net importers of energy sources and commodities.

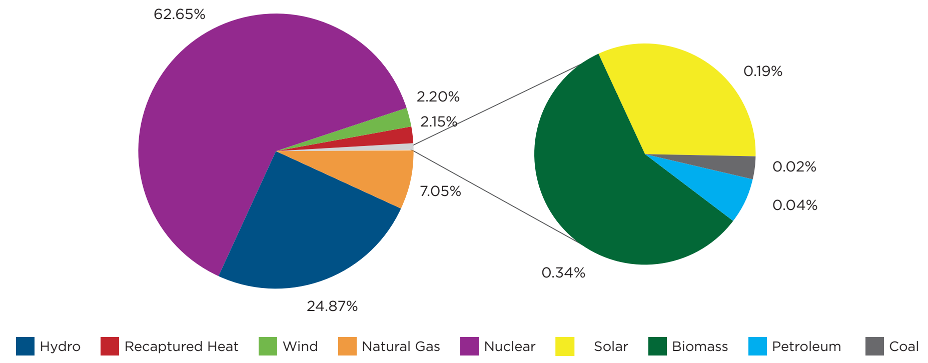
Ontario

By population and economic activity, Ontario is Canada's largest province and the largest consumer of all energy sources and commodities in the country. Historically, the province has had strong manufacturing and industrial sectors, but the economy is in transition, with robust growth in the services sector. The services sector uses less energy to generate economic value than do manufacturing and heavy industry. At the same time, energy used for transportation is increasing, especially for on-road freight transport that transports goods to southern neighbours in the United States.

Ontario's electricity sector is mixed: in 2014, over 60% of Ontario's electricity was generated from nuclear power, about a quarter from hydropower, 7% from natural gas, and over 2% from wind. Ontario’s electricity grid has undergone a transformation in the last decade, with coal being completely phased out as of April 2014, and wind generation contributing over an order of magnitude more in 2015 than it did in 2005.

Decentralized solar photovoltaic generation is also playing an increasing role at the sub-grid scale (not accounted for in Figure 6-15). In 2014, the Government of Ontario completed the installation of 4.8 million smart meters across the province. These meters, provided to every home, business and institution, allow electricity users and regulators to closely monitor energy use and apply time-of-use pricing to discourage non-essential electricity use during peak hours.

Figure 6-15: **Electricity Generation in Ontario, by Source, 2014**



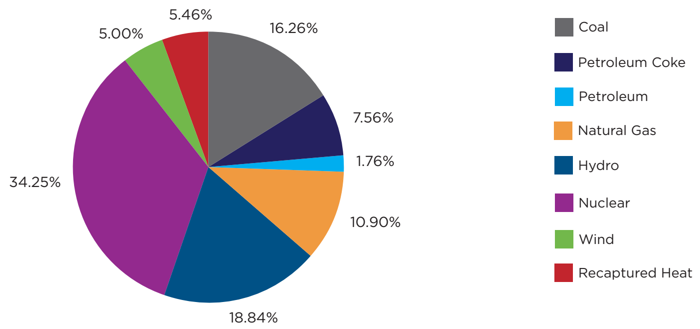
New Brunswick

New Brunswick has a mixed economy, ranging from forestry and mining to fishing, agriculture and food processing. Like Ontario, New Brunswick is experiencing a shift away from energy-intensive industries to the services sector, which is growing rapidly.

New Brunswick gets roughly one-third of its electricity from its nuclear plant, 16% from coal-fired plants, 19% from hydropower, and another 10% from natural gas–fired plants. New Brunswick Power finished the refurbishment of its Point Lepreau nuclear generating station in 2012. This station is home to the only nuclear reactor in the country outside Ontario. New Brunswick imports the bulk of the energy sources used for its power generation.

New Brunswick's natural gas distribution infrastructure for homes and buildings is relatively new. The distribution system was constructed after the main natural gas transmission pipeline was built in 1999, allowing for the bulk transport of natural gas from offshore Nova Scotia. New Brunswick’s major oil and gas shipping terminal, Canaport, was expanded in 2008 to facilitate the transport of liquefied natural gas (LNG).

Figure 6-16: **Electricity Generation in New Brunswick, by Source, 2014**

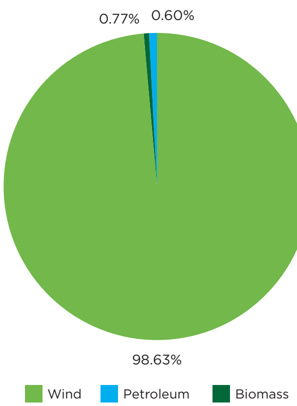


Prince Edward Island

Prince Edward Island (PEI) does not have domestic supplies of major energy sources such as crude oil, natural gas or hydropower, so the province is heavily dependent on imports. About $500 million flows out of PEI's economy every year to import transportation and heating fuels.

As a relatively small and flat island, PEI has strong, consistent wind speeds. The province now produces almost all of its locally generated electricity from wind turbines. Although roughly 85% of the electricity used in the province is imported from neighbouring jurisdictions, primarily New Brunswick, in recent years, wind generation in PEI has begun to surpass local demand at times, and so the province now exports almost 25% of the wind power it produces. PEI also has several fossil fuel–powered peaker plants, which are used as sources of backup power when demand is particularly high.

Figure 6-17: **Electricity Generation in Prince Edward Island, by Source, 2014**



THE TERRITORIES

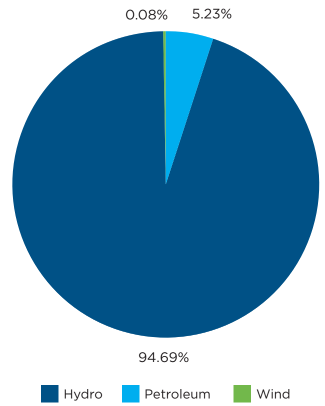
Canada's three territories are distinct from the provinces in several respects. They are geographically large and located in the far north, bordering on the Arctic Ocean. Their populations are relatively small, numbering in the tens of thousands, smaller than any province.

The population of the territories is largely made up of Indigenous peoples. While there are some urban areas, much of the population lives in small, remote communities located throughout the territories. These communities are often not accessible by permanent roads, and access to energy commodities is limited and expensive.

Yukon

Yukon's electricity needs are met mostly by hydropower and natural gas, with small diesel generators servicing more remote communities. There is active production of crude oil and natural gas in Yukon, and the territory borders Alaska, one of the largest crude oil and natural gas producing regions in the United States.

Figure 6-18: **Electricity Generation in Yukon, by Source, 2014**

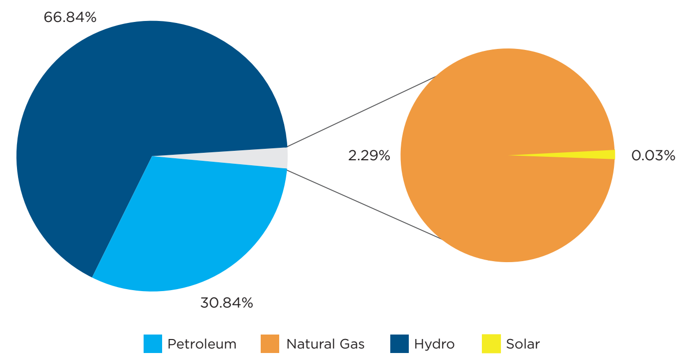


Northwest Territories

Like Yukon, electricity in the Northwest Territories is generated from hydropower, with small diesel generators servicing more remote communities. Active crude oil and natural gas production in the territory is a significant source of economic activity and employment. Studies and consultation on proposals to build a pipeline in the Mackenzie River Valley to deliver natural gas to markets in southern Canada and the United States have been ongoing for several decades. In early 2011, approval was given to a plan proposed by a consortium of corporations and Indigenous communities, but many questions remain surrounding the economic viability and environmental integrity of the project.

In 2014 and 2015, the Northwest Territories began to diversify its electricity mix, with a focus on renewables, including solar and wind. These options, in tandem with electricity storage technologies, are seen as having great potential to provide power to remote communities that are not grid connected – all of which are currently powered by diesel generators.

Figure 6-19: **Electricity Generation in the Northwest Territories, by Source, 2014**

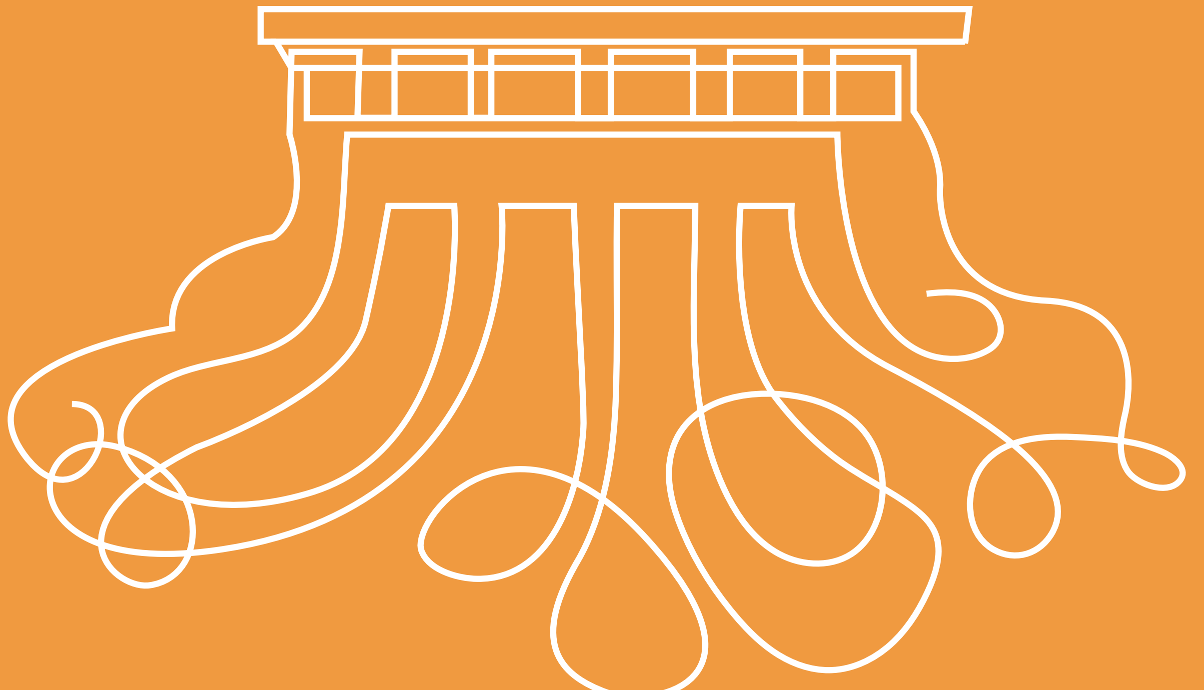


Nunavut

All of Nunavut’s electricity, heating and transportation needs are met by imported fossil fuel. There is no electricity transmission grid in Nunavut, and all the electricity is provided by small diesel generators. Several crude oil and natural gas fields have been discovered in Nunavut, but they are hard to access, and no fields are currently in production.

Summary

Congratulations! We have completed our journey through Canada’s energy systems. We can now see the whole picture of how our desire for energy amenities activates a demand for energy services, and how those services can be supplied by a multitude of energy commodities derived from energy sources, using a variety of technologies. Some of these energy pathways are more efficient and effective than others, some are less harmful to the environment and human health, and some are very much tied to the sources and economic history of particular regions of the country. With this systems approach to energy in mind, we are in a position to make much more informed choices at the individual level and to understand more clearly the implications and opportunities of the changes that lie ahead for Canada’s energy systems.



CHAPTER SEVEN

Taking a Systems Approach to Energy in Canada

Chapter 4 described the energy commodities and sources that we use every day to supply energy services, which in turn deliver the energy amenities that we demand. Chapter 4 also looked at the distribution of energy sources across Canada and how this has shaped energy use in different regions of the country.

The length of Chapter 4 and the breadth of subjects it covers reflect the broad range of energy options available in Canada and the multitude of choices in energy pathways we can follow to fulfill our demand for energy services and amenities.

Canada is in a fortunate position – it can build infrastructure and deploy technologies that will enable it to link services with sources in a way that helps to achieve social, economic and environmental objectives. By contrast, many countries have far fewer options from which to choose, either because they are constrained by a narrower range of energy sources or because they are largely dependent on imported energy.

But what energy future do we want to build in Canada, and what values do we want it to reflect? Consider the range of attributes that might describe the energy systems of the future. We would probably want them to be safe, clean and affordable. But we might also seek to build energy systems primarily to support economic productivity in the manufacturing and services sector. Or we might design them to support the development of our wealth of energy sources. Our goals might well differ from region to region across Canada, reflecting different priorities.

Such discussions lead well beyond the scope of this primer. The primer is, however, intended to provide an introduction to the key elements of Canada's energy systems, with a view to equipping us to participate in a national dialogue about our energy future. A systems approach will help us to evaluate the options for finding the right fit between energy source and commodity, and between energy service and amenity. It will help us to identify the implications of, and opportunities for, change.

And Change is Coming

People and organizations at the forefront of the energy sector are increasingly pointing to the need for change. The growing demand for energy, the convergence of climate change and energy policy, and the renewal of aging energy infrastructure are chief among the factors driving the dialogue

"As we all know, Canada is a major producer of energy in a world where energy demand is steadily growing and conventional energy supply is diminishing. Also, governments around the world are confronted with the challenge of how to achieve energy security in a sustainable way while reducing carbon emissions."

– *The Standing Senate Committee on Energy, the Environment and Natural Resources, Ottawa, Thursday, April 29, 2010*

Regarding climate change, the Intergovernmental Panel on Climate Change (IPCC) has estimated that global greenhouse gas emissions must be reduced between 60 and 90% from 1990 levels if we are to have a reasonable chance of keeping the concentration of carbon dioxide in the atmosphere to a level that will limit temperature increases to about two degrees Celsius above pre-industrial levels. At present, the pathways to achieving that goal are not clear. However, to address climate change, we will likely require improved technology, a change in behaviour and a rethinking of how our energy systems are designed and operate.

“Climate change caused by human activity poses great risks to our environment, economy and energy systems. Global energy consumption accounts for nearly 84% of the world's carbon emissions. Developing our energy systems in a way that reduces our carbon emissions is the core component of meeting the climate change challenge.”

– ATTENTION CANADA! Preparing for our Energy Future, Seventh report of the Standing Senate Committee on Energy, the Environment and Natural Resources (June 2010)

Transforming our energy systems will require serious thinking about our energy infrastructure. The pipelines and electrical infrastructure that we rely on today to transport and distribute energy commodities were built over decades, and most of this infrastructure will need to be replaced over the coming decades. Today's decisions on how to design new infrastructure and replace the old will “lock in” our energy systems for decades to come.

“In the current development model, the layout of buildings and houses is determined first and separately from planning for energy demand and efficiency, after which communities are wired for electricity, connected to natural gas lines for heat, and roads are paved to provide transportation by vehicles. The result is a design that locks in high levels of energy demand and usage patterns that are difficult to change and can persist for decades (lasting longer than many components of the energy system).”

– Pillar 1, "A Commitment to Sustainable Energy End-Use," Canada's Energy Framework Initiative, 2009

If we are to effect rapid change on the scale needed to address energy supply, climate change and infrastructure renewal, all stakeholders must agree on coordinated action. However, the governance of energy production, distribution and use in Canada is fragmented and complex. Authority for energy development and management is distributed across multiple levels in the public and private sectors. Because there is no shared vision for energy in Canada, decisions that affect its energy systems are often made in isolation and driven by divergent objectives. This can present a barrier to systems-based energy solutions, so it is important to understand why and how energy governance is structured.

Fragmented and Overlapping Authorities

To understand how policy decisions about energy systems are made in Canada, it is necessary to recognize that Canada's constitution divides the power and responsibility over natural resources and energy between the federal and provincial/territorial governments.

*The **federal government** has jurisdiction over international and interprovincial trade and resources located offshore, on federal lands and in all navigable waters. The federal government also sets economic policy for the country and makes investments in research and development and regional economic development affecting the energy sector.*

*The **provinces and territories** own the natural resources within their geographical boundaries and are, for the most part, free to regulate industry and the energy sector within their jurisdiction, provided that such regulations do not conflict with those set out by the federal government. Because these decisions are up to individual provinces or territories, there can be stark differences in energy sector policies and development activities across the country.*

Local governments, including municipalities, regional governments and Indigenous communities, make decisions about local zoning, planning and investment. Typically, local governments have the authority to approve and influence the location and design of individual projects related to energy production, distribution and use.

The location, size and nature of an energy project largely determine who is involved in its review and approval process. For example, a large, new hydropower plant would likely require approvals from governments at the local, provincial and federal levels, involving many departments and agencies.

For smaller projects, such as a small wind farm, approvals may be required only by local and provincial governments. But even for smaller projects, there may be aspects that impinge on areas of federal jurisdiction, such as protection of migratory birds or endangered species.

Every energy project is different, and every project has a range of impacts. As a result, who conducts the review and who ultimately approves the project varies depending on the nature of the project and its particular circumstances.

How Decisions Are Made

To understand how we as individuals can influence the future of Canada's energy systems, we need to understand how decisions affecting them are made. Because the processes differ from province to province, a detailed introduction to local engagement in energy policy-making is beyond the scope of this primer. The following is a brief overview of some of the key participants.

Provincial ministries of energy are responsible for setting overall energy policy. They draft the laws and set the processes that guide the development of energy projects. This is the level of government that is ultimately responsible for ensuring energy supply – for example, identifying the need for a new plant or new transmission wires to make sure that the electricity system is able to meet demand. The names of the ministries carrying the energy file vary from one jurisdiction to another – for example, in Alberta, it is Alberta Energy; in Quebec, it is the Ministry of Energy and Natural Resources.

Other provincial ministries and federal departments are responsible for approving various aspects of a project. For instance, ministries of the environment are responsible for determining what environmental impacts should be considered before construction of a new energy facility can proceed, while ministries of culture factor in cultural concerns, such as the protection of heritage buildings.

Federal government departments become involved when a project is being developed on federal lands. This also applies to projects in areas where the federal government has jurisdiction, for example, when a project straddles provincial or international boundaries.

Within the federal government, there are overlapping responsibilities among a number of departments for setting policies for energy systems, recording data from industry and the provinces, and making information about energy systems available to the public.

Natural Resources Canada is the federal department responsible for most energy-related matters, including setting energy efficiency standards, producing reports and other publications on energy issues, and establishing programs for residential, commercial and industrial energy users. Statistics Canada gathers information related to energy production and use and makes this information available in reports.

The National Energy Board oversees interprovincial and international trade in energy commodities and sources and holds final approval for transmission and pipeline projects that cross provincial boundaries. Environment Canada and the Department of Fisheries and Oceans have authority to review impacts and set project development parameters in areas of federal jurisdiction, while Industry Canada and other federal departments are involved in the promotion of energy development projects.

Developers and other private businesses are often the ones who initiate a project and end up building it. For example, a large energy company may want to build a new natural gas–fired plant, a group of farmers may want to build an anaerobic digestion facility to generate electricity and heat, or a group of oil companies may want to collaborate in building a new pipeline.

Energy regulators often act as independent arbiters at arm's length from government. Their role is to set detailed rules regarding pricing, consumer protection and safety, and reliability of energy supply. Depending on the province, a regulator might be in charge of looking after only electricity, or it might have multiple mandates to govern electricity, natural gas and other energy sectors.

Moving Towards an Energy Systems Approach

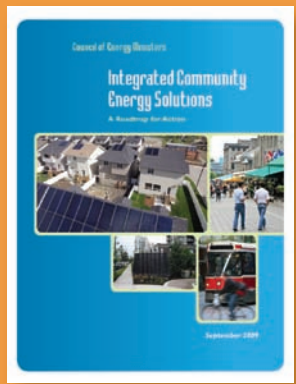
The future will challenge the existing structures and authorities that govern decision-making in Canada's energy sector, as scarcity of energy sources, climate change and aging infrastructure force us to consider operating in a more integrated fashion, so that our demand for energy amenities can be met in a sustainable and efficient manner. Taking a systems approach to exploring our energy opportunities can lead to innovative governance systems.

There are promising examples of a shift towards energy systems thinking under way.

THE COUNCIL OF ENERGY MINISTERS COMMUNITY ENERGY ROADMAP

"Communities play a central role in the quality of life that Canadians enjoy. They also account for close to 60 per cent of the nation's energy consumption. In recent years, communities have begun to identify significant opportunities for improving their energy performance through cross-cutting sector integration while enhancing quality of life and realizing financial benefits." *– Council of Energy Ministers, Integrated Community Energy Solutions: A Roadmap for Action, 2009*

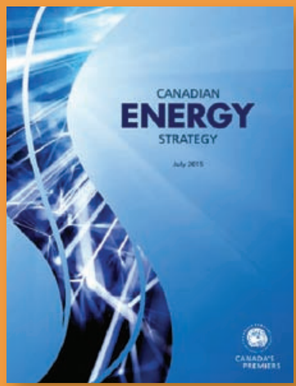
In September 2009, at the Council of Energy Ministers meeting, the energy ministers from all the provinces and territories and from the federal government endorsed the Roadmap for Action, which is focused on advancing integrated community energy solutions (ICES) in all communities in Canada. The vision of the roadmap is that, by 2050, all Canadian communities will be designed and operated as integrated community energy systems.



THE COUNCIL OF THE FEDERATION'S NATIONAL ENERGY STRATEGY

"The Canadian Energy Strategy is based on collaboration among provinces and territories to shape an energy future that provides energy security, contributes to economic growth and prosperity, and embodies a high standard of environmental and social responsibility."
– The Council of the Federation, Canadian Energy Strategy, 2015

In July 2015, at a Council of the Federation meeting attended by provincial premiers and territorial leaders, senior Canadian policy-makers adopted a national energy strategy that is focused on enhancing energy efficiency and conservation, lowering the country's carbon footprint across all sectors, and supporting technological innovation related to sustainable development. This strategy marks the beginning of an unprecedented collaboration between Canadian jurisdictions that will strive to use the energy assets of all provinces and territories in the most efficient, sustainable and mutually beneficial manner possible.



Conclusion

This primer has focused on the interconnections between the energy sources, distribution networks and people that constitute the country's energy systems. We have described the elements of these systems in some detail and shown how they have evolved to respond to the demand for energy arising from the choices that we make every day.

The energy systems we have today are a testament to the vision and technological advances of yesterday. The design, planning and development of those energy systems, in many ways, represent the very best that previous generations could do. They worked hard to overcome seemingly insurmountable technical challenges and forged ahead in the face of uncertainty and risk. And they found the money to make their visions a reality, through both public expenditure and business development. The energy systems they worked so hard to build propelled Canada into the modern world, and they still form the backbone of the economic and societal advantages – the high living standards – that we enjoy today.

As this final chapter of the primer demonstrates, there is an urgent need to grapple with Canada's energy challenges. Much of Canada's energy infrastructure is aging and in need of upgrades and replacement. Moreover, global patterns of energy use and demand are changing. The energy systems that we choose to build in the coming decade will determine, in part, the future of this country, its people, its prosperity, its international relevance and its culture.

That is why we have presented this primer: in order to identify the opportunities for improving the way that we produce, distribute and use energy, we need to understand how all of the elements of Canada's energy systems currently tie together. Equipped with a whole-systems perspective, we can better consider the implications of change and the role we can play in it.

We are a nation of individuals, a collection of provinces, territories and cultures, with varying priorities and wants and needs. But we are a nation. Each region and all Canadians have a similar stake in ensuring that our energy systems continue to provide for our needs. Beyond our own national concerns, Canada needs to put forward a national position and identify a common vision for our energy systems that will empower the country to play a significant and positive role at the international level in addressing the global energy and climate challenges that lie ahead.

Today, as many of the energy systems put in place over the last century come to the end of their lives, individuals and the governments that represent all Canadians are faced with some tough decisions. Will we honour the efforts of past generations by improving on their designs and vision through the use of better planning and design and improved technologies and infrastructure? Or will we rely on old designs and concepts to rebuild 20th century energy systems for a 21st century world? We can all help to address these vital questions.

"Current global trends in energy supply and consumption are patently unsustainable – environmentally, economically and socially. But that can – and must – be altered: ***there's still time to change the road we're on.****"*

– International Energy Agency, World Energy Outlook 2008

GLOSSARY

Where applicable, sources from which definitions have been derived are identified in square brackets following the definition.

Anaerobic digestion: a process in which bacteria digest organic material in the absence of oxygen. Anaerobic digestion occurs naturally in marshes and the digestive systems of cattle and sheep and is also the process at work in septic tanks and landfills.

Associated natural gas deposit: natural gas found in the same deposit as crude oil. The term can also be used to refer to natural gas found in coal deposits, such as coal-bed methane.

Baseload plant: a power plant designed to provide a steady, constant flow of power.

Blackout: a total failure of the electrical supply, during which there is no electricity to power lights or any other devices.

Brownout: a drop in voltage in the electrical supply that can cause lights to dim and other equipment to shut down. Unlike a blackout, a brownout does not result in a total failure of the electricity supply.

Carbon capture and sequestration (or carbon capture and storage): the capture, treatment, transport, use and/or storage of carbon dioxide from large sources (in particular, from centralized, thermoelectric power generation systems) for the purpose of reducing greenhouse gas emissions to the atmosphere. [Natural Resources Canada]

Central chiller: any centrally located air conditioning system that produces chilled water in order to cool air. The chilled water or cold air is then distributed throughout the building, using pipes or air ducts or both. Chillers are generally located in or just outside the building they serve. Buildings receiving district chilled water are served by chillers located at central physical plants. [U.S. Energy Information Administration]

Combined heat and power (CHP) plant (or cogeneration plant): an electricity generation plant that channels heat that would otherwise be wasted, transferring it to nearby buildings, where it can be used for space heating or in industrial processes. While CHP systems most commonly use natural gas, they can be designed to use biofuels or even coal.

Combustion (or burning): a process in which a fuel chemically reacts with an oxidant (usually air) to generate heat, light and exhaust gases. Common fuels include coal, petroleum products, natural gas and biofuels. Combustion is the process by which most energy commodities are converted into useful work to deliver energy services, e.g., the process by which internal combustion engines deliver motive power to the wheels of vehicles or natural gas furnaces generate heat.

Crude oil (or petroleum): a naturally occurring, flammable liquid found in rock formations in the Earth. It is a complex mixture of several hydrocarbons, which can be separated through distillation to produce different types of refined petroleum products. These products can be used as fuels by being combusted in the presence of oxygen. Crude oil is considered a fossil fuel because it is derived from the transformation of plant and animal remains over millions of years. [Natural Resources Canada]

Diesel fuel: a fuel composed of distillates obtained in petroleum refining operations, or blends of such distillates with residual fuel oil, for use in motor vehicles. The boiling point and specific gravity are higher for diesel fuels than for gasoline. [U.S. Energy Information Administration]

Dispatchable: a term used to designate power plants that can turn on and off and increase or decrease power in response to fluctuations in demand. These plants are called dispatchable because they receive dispatch instructions from the operator of an electrical system. Dispatchable power plants are key to ensuring that there is always power available to meet demand.

Distillate fuel oil: a general classification for one of the petroleum fractions produced in conventional distillation operations. It includes diesel fuels and fuel oils.

Products known as No. 1, No. 2 and No. 4 diesel fuel are used in on-highway diesel engines, such as those in trucks and automobiles, as well as off-highway engines, such as those in railroad locomotives and agricultural machinery.

Products known as No. 1, No. 2 and No. 4 fuel oils are used primarily for space heating and electric power generation. [U.S. Energy Information Administration]

District heating: a large, centralized heating system that distributes hot water, steam and/or chilled water to an entire community. Each household has access to the same heating and cooling services, but the use of a centralized source means that each house does not require its own furnace, water heater or air conditioner.

Electromagnetic induction: a process in which a magnet is spun around a conductor, such as copper wiring, to produce an electric current.

Energy amenity: a personal, social or economic good made possible by the provision of energy services. This primer focuses on the most common energy amenities: comfort, convenience, access and enjoyment.

Energy commodity: an energy product that powers the technologies used in homes and businesses. In this primer, energy commodities are defined as finished products – for example, the gasoline used in cars, the natural gas burned in home furnaces.

Energy density: the amount of energy released per unit amount of fuel consumed, usually as energy per unit volume or per unit mass.

Energy pathway: a method or means of obtaining a desired energy amenity. Each energy pathway is made up of a particular combination of energy sources, technologies and infrastructure, and there are often multiple pathways to obtain a desired energy amenity. For example, home heating can be provided through electric baseboard heating, a furnace using natural gas or a wood-burning stove. The desired amenity is comfort (provided through heating), but the combination of energy sources and technology differs. Some energy pathways are more efficient and less environmentally disruptive than others.

Energy service: the means through which energy amenities are obtained. Energy services are generally provided through the use of technology that draws on energy commodities and sources. Heating and cooling, lighting and appliances, and transportation technologies all deliver energy services.

Energy source: a raw form of energy, such as solar, wind, water, coal, crude oil, natural gas deposits or uranium, that can be converted by technology into energy commodities to provide services.

Exhaust gas: gas emitted as a result of the combustion of a fuel. Exhaust gas usually contains a mix of carbon dioxide and water vapour and can often contain air pollutants, such as oxides of nitrogen and sulphur. Exhaust gases are usually emitted to the atmosphere via smokestacks. In combustion gas turbines, hot exhaust gases from the combustion of natural gas are used to drive a turbine to generate electricity.

Furnace: a device used to heat homes by converting natural gas, electricity, heating oil or other fuels into heat. [Natural Resources Canada]

Gasoline: a complex mixture of relatively volatile hydrocarbons, with or without small quantities of additives, blended to form a fuel suitable for use in gasoline engines. [U.S. Energy Information Administration]

Generator: a device equipped with a magnet and copper coils that, when attached to a spinning turbine, produces electricity through electromagnetic induction.

In situ method: a method used to extract bitumen located deeper than 75 metres underground. This method involves the direct injection of steam into the bitumen. Once heated sufficiently, the bitumen starts to flow and can be pumped up through a well to the surface.

Intermittent plant: a power plant that cannot be controlled to ramp power production up or down. Wind, solar, and some run-of-the-river hydro plants are intermittent because they depend on the sun shining, the wind blowing, or the river flowing to produce electricity.

Joule (J): a unit of energy in the International System of Units (SI). One joule represents the amount of work it takes to produce one watt of power for one second, which is roughly the amount of work it takes to lift an apple one metre on Earth. Larger quantities of energy are described using gigajoules (GJ, billion joules, 10^9) or petajoules (PJ, quadrillion joules, 10^{15}).

Life cycle analysis (or life cycle assessment): a method of assessing every impact associated with each stage of a process from cradle to grave (i.e., from raw materials through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling).

Natural gas liquid: a heavier hydrocarbon (e.g., ethane, propane, butane, pentane) removed from natural gas at processing plants. [Natural Resources Canada, the Atlas of Canada]

Non-associated natural gas deposit: natural gas found in a deposit by itself, without the presence of any crude oil.

Non-conventional crude oil: crude oil that is difficult to access and cannot be extracted using conventional means. Non-conventional crude oil is thick and viscous and does not flow easily; it requires heating or dilution with solvents to flow through pipes. Canada's oil sands are a large source of non-conventional crude oil.

Nuclear reaction: the splitting apart of a uranium atom when a neutron (a subatomic particle without an electric charge) strikes the uranium atom at the right speed and angle. The uranium atom splits apart, releasing heat and other neutrons, which can continue the reaction, assuming the correct conditions and the presence of more uranium atoms.

Peaker plant: a power plant designed to ramp up or down in response to varying demand for electricity.

Peat: a firm, brown deposit resembling soil, formed by the partial decomposition of vegetable matter in the wet acidic conditions of bogs and fens, and often cut out and dried for use as fuel and in gardening. [Natural Resources Canada, the Atlas of Canada]

Radiate: deliver heat directly from a hot surface to people and objects in a space. The radiation of heat is also called infrared radiation. [U.S Department of Energy]

Refrigerant: a fluid that changes back and forth from a liquid to a gas as it absorbs and releases heat. Refrigerants are used in both air conditioning systems and refrigerators.

Residual fuel oil: a general classification for the heavier oils, known as No. 5 and No. 6 fuel oils, that remain after the distillate fuel oils and lighter hydrocarbons are distilled away in refinery operations. No. 6 fuel oil includes Bunker C fuel oil and is used for the production of electric power, space heating, and various industrial purposes. [U.S. Energy Information Administration]

Resistance: the measure of an object's opposition to the passage of an electric current. [Wikipedia]

Resistive heating: a technology that provides heat by passing a high electric current through coiled wires, which heat up and give off heat. [Natural Resources Canada]

Smart meter: a microprocessor-based electricity meter capable of showing how much energy is used and when it is used. [National Energy Board]

Smog: literally, a contraction of "smoke" and "fog;" the colloquial term used for photochemical fog, which includes ozone and numerous other contaminants. Smog tends to produce a brownish haze in the atmosphere. [Environment Canada; Pollution Probe's *Primer on Climate Change and Human Health*; Natural Resources Canada, the Atlas of Canada]

Solar thermal: solar radiation converted into heat, including the use of pumps or fans to actively transfer the heat to storage or for distribution directly to its intended use. [Natural Resources Canada, CanmetENERGY]

Space heating: providing heat to an enclosed space. [Natural Resources Canada]

Steam turbine: a turbine that converts the thermal and kinetic energy in pressurized steam into rotary motion to produce electricity.

Sweet or Sour: terms used to describe the relative concentration of sulphur in crude oil. Crude oil with low concentrations of sulphur is sweet, and crude oil with higher sulphur concentrations is sour.

Tailings: the mixture of river water, sand and chemical residues that is left over from the process used to separate bitumen from sand in oil sands operations. The tailings are put into a tailings pond, where sediments are left to settle until the water is clean enough to be recycled back into the river.

Thermal turbine: a turbine that is spun by the combustion of fuel such as coal or natural gas.

Time-of-use pricing: rates based on the time of day when the electricity is used. These rates allow consumers to pay less for the electricity they use during off-peak periods, i.e., when demand for electricity is low. Electricity used during peak hours, when demand is high, is more costly. [National Energy Board]

Turbine: a device that can be rotated by a fluid passing through it.

Upgrader: a facility where bitumen is transformed into synthetic crude oil (SCO). [Natural Resources Canada, CanmetENERGY]

Watt (W): a unit of power in the International System of Units (SI), defined as one joule per second (J/s). The quantity of power light bulbs can draw to convert into light is commonly measured in watts (usually 40 W or 60 W). Larger quantities of power, such as megawatts (MW, million watts, 10^6) or gigawatts (GW, billion watts, 10^9) are used to describe how much power can be generated from smaller and larger power plants.

Watt hour: a unit of energy, along with the joule (J). A watt hour is the amount of energy used when a one watt light bulb is on for one hour, which is equivalent to 3,600 joules (one joule is defined as one watt second). Megawatt hours (MWh) and gigawatt hours (GWh) are commonly used to describe how much electricity is generated in power plants over a day, month or year, or alternatively, how much electricity is used by industry or in homes and buildings.

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