Global Warming and Canada: Getting to Zero by 2060

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Global Warming and Canada: Getting to Zero by 2060

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Introduction

This guide addresses these questions. How could Canada achieve a substantial reduction in greenhouse gas emission by 2060? Would there be devastating consequences to our standard of living? Would Canadians be back living in the Stone Age? Where would our energy come from?

It takes as given that global warming is occurring, that humans are playing a major role through activities that release greenhouse gases into the atmosphere, that among humans Canadians are contributing more than their fair share of emissions to global warming, and that Canadians will collectively realize that it is in their interest to reduce Canadian emissions even though in the short run a warmer climate may appear beneficial.

As Canadians begin to contemplate drastic emission reductions, what would Canada be like? If Canadians were to end up back in the Stone Age from an aggressive emission reduction strategy, many of us might opt to take our chances with a planet ravaged by global warming, rather than take concrete steps to change our ways. On the other hand, if Canadians were to end up with a standard of living in line with current standards, perhaps many Canadians might make a different choice.

Some things to note about the 2060 target – a little more than forty years into the future. Forty years is sufficiently long for:

- Retirement of those currently in the work force,
- The development of new production processes and new products,
- The replacement of capital equipment which emits greenhouse gases,
- A fair return on existing investments in emitting industries,
- Retrofitting existing buildings,
- The application and fine-tuning of current emission-reduction technologies, and
- The development of infrastructure, including the massive expansion of the electricity sector.
- Canadians will have adjusted their expectations so that no one will have a legitimate complaint that they have "lost" something by addressing climate change.

The goal is a drastic reduction by 2060. The path is likely to involve initially low emission reductions that increase at an accelerating rate over time, as emission reduction policies take effect, as new infrastructure is developed, as high emission capital equipment lives out its economic life and is replaced by low emission capital equipment, as Canadians become trained and educated in emission reduction technology and practices, and as Canadians become aware of the seriousness of the problem.

Chapter 1 looks at Canada’s greenhouse gas emissions. What are the sources of the emissions? Where do the largest emissions come from?

Chapters 2 to 11 take a sector-by-sector look at ways to reduce Canada’s greenhouse gas emissions. They focus on the technologies that Canada will need to reduce its emissions.

Most of the technologies are already known, although some are not yet ready for widespread application.

Chapter 12 estimates Canada’s emissions in 2060 through the application of technologies and other measures identified in chapters 2 to 11.

Chapter 1: Canada's Emissions

Canada's Greenhouse Gas Inventory

Under the Kyoto Protocol, signatories agreed to track greenhouse gas emissions on a nationally consistent basis. Under this approach, the greenhouse gases to be tracked are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride. Emissions from international aviation and international marine are not included. Based on this methodology, the Government of Canada has tracked and reported on emissions of greenhouse gases recognized by the Kyoto Protocol since 1990. Key facts from this inventory include:

- By 2012, Canada's total greenhouse gases were estimated at 699 megatonnes of carbon dioxide equivalents, up 108 megatonnes (18.3 percent) from 1990, when estimated emissions were 591 megatonnes.
- Canada's 2012 emissions were 135 megatonnes above its Kyoto Protocol target of 563 megatonnes of emissions (6 percent below Canada's 1990 baseline level).
- Energy production and consumption rose by 99 megatonnes (20.7 percent) from 1990 to 2012, and accounted for almost all of Canada's emission growth of 108 megatonnes.
- Although Canadians make up about 0.5 percent of the world population, its greenhouse gas emissions account for 2.0 percent of the world total.

Canada's Emission Profile

The table on the following page summarizes Canada's emissions, expressed a kilotonnes of carbon dioxide equivalents, over the period 1990 to 2012.

The table is based on information provided by the Government of Canada to the United Nations. It has been reformatted to present the information in a more useful way. In the reformatting, all the subcomponents from the original data have been preserved, and then added to higher level totals. Subcomponents in the original data do not always add to higher level totals; this accounts for slight inconsistencies between the following tableand government data.

Canada's 1990–2012 Green House Gas Emissions by Sector					
Greenhouse Gas Categories	**1990**	**2012**	**2012**	**Change 1990-2012**	
	kt CO2 eq	**kt CO2 eq**	**% Total 2012**	**kt CO2 eq**	**% Total Change**
Total – All Sectors	590,253	708,713	100.0%	118,460	20.1%
Fossil Fuel Production, Fugitives, Transport	105,840	171,600	24.6%	65,760	62.1%
Electricity and Heat Generation	93,600	88,300	12.7%	-5,300	-5.7%
Stationary Combustion Sources excluding electricity & heat generation, fossil fuel production	129,310	116,770	16.7%	-12,540	-9.7%
Road and Off-Road Transportation	120,563	170,012	24.4%	49,449	41.0%
Aviation (Domestic)	7,100	6,100	0.9%	-1,000	-14.1%
Railways	7,000	7,600	1.1%	600	8.6%
Marine (Domestic)	5,000	5,800	0.8%	800	16.0%
Industrial Processes	55,990	56,621	8.1%	631	1.1%
Solvent and Other Product Use	180	310	0.0%	130	72.2%
Agriculture	47,100	54,130	7.8%	7,030	14.9%
Waste	18,570	20,670	3.0%	2,100	11.3%
Aviation (International)	6,100	9,100	1.3%	3,000	49.2%
Marine (International)	3,100	1,700	0.2%	-1,400	-45.2%

Within Canada's total emissions in 2012:

- The production of fossil fuels accounted for 24.6 percent. If Canada can significantly reduce its use of fossil fuels, then it will not need to produce fossil fuels, and these emissions will disappear.
- Industries producing electricity and heat accounted for 12.7 percent. For the most part, these are electric power generation facilities, powered by natural gas and coal. In a low emission Canada by 2060, the electric power generation facilities will have to be replaced by ones that use nuclear and renewable energy sources.
- Other stationary combustion sources accounted for 16.7 percent. These include residential, commercial and industrial heating facilities. Most of these facilities are already hooked into electric power grids, and could get their heat and electricity through an electric power grid powered by renewable and nuclear sources.
- Road and off-road transportation accounted for 24.4 percent. These forms of transportation rely on the fact that fossil fuels, particularly oil, can provide significant amounts of energy relative to their weight in a safe manner, and can be replenished conveniently. A low emission environment will require the improvements in batteries and other energy storage mechanisms to power our vehicles.
- Other forms of transportation accounted for 2.8 percent. These include marine, aviation and railways. A low emission environment by 2060 will see significant changes in these sectors.
- 8.1 percent of emissions were related to industrial processes. These emissions occurred an environment where emission reduction was not always a point of focus. This raises the question what would occur if emission reduction became a point of focus.
- 7.8 percent of emissions were related to agriculture, much of which comes from livestock production and the use of fertilizers. Changes are needed.
- 3.0 percent of emissions were related to waste. Current best practices carried out over 45 years and applied by everyone should make a significant dent.

The Challenge

Science is telling us that we have from 20 to 40 years, give or take a few, to reduce world greenhouse gas emissions to zero. If emissions are not brought near zero, average global temperatures are likely to increase by more than the amount (2ºC above pre-industrial levels) deemed to be manageable. This rise carries with it significant risks of a range of global disasters. The cumulative impact of these disasters is a threat to humanity, and more specifically, to our children and their children.

As a greenhouse gas emitter, Canada can certainly hold its own. Emissions per capita are among the highest of any country. Instead of reducing emissions, Canada is increasing its emissions. If the citizens of any country were to be held accountable by future generations for a climate disaster, those citizens would be Canadians.

How can Canada reduce its emissions to almost zero? Can it do so, without reverting back to a stone-age lifestyle? Can Canada cut emissions while retaining its current standard living? Can it do so with expected population growth? What about jobs?

The answer is yes, for the most part. The technologies that will propel Canada into the future are for the most part known, although not necessarily fully developed and certainly not fully applied. For the details, read on. The following chapters will outline the technologies that could get Canada close to zero emissions by 2060.

Chapter 2: Fossil Fuels

Past Emissions

Some current activities will disappear or be drastically reduced in a zero-emission world. In an emission-controlled world, the first victim will be the fossil fuel industries. The production, refining and upgrading of fossil fuels, the extraction of fossil fuels from the ground, pipeline transport, and inadvertent emissions through venting, flaring and coal mining account for 24.6 percent of Canada's emissions in 2012. They also accounted for 62.1 percent of Canada's increase in emissions since 1990.

Canada's 1990–2012 Green House Gas Emissions: Fossil Fuels					
Greenhouse Gas Categories	**1990**	**2012**	**2012**	**Change 1990-2012**	
	kt CO2 eq	**kt CO2 eq**	**% Total 2012**	**kt CO2 eq**	**% Total Change**
Total - All Sectors	590,253	708,713	100.0%	107,660	18.2%
Fossil Fuel Production, Fugitives, Transport	105,840	171,600	24.6%	65,760	62.1%
Fossil Fuel Production -Stationary Combustion Source	34,000	47,000	6.7%	13,000	38.2%
Fugitives - Venting	20,000	30,000	4.3%	10,000	50.0%
Fugitives - Natural Gas	11,000	19,000	2.7%	8,000	72.7%
Petroleum Refining - Stationary Combustion Source	16,800	16,800	2.4%	0	0.0%
Pipelines	6,850	5,700	0.8%	-1,150	-16.8%
Fugitives - Oil	4,200	6,500	0.9%	2,300	54.8%
Fugitives - Flaring	4,400	4,700	0.7%	300	6.8%
Fugitives - Coal Mining	2,000	1,000	0.1%	-1,000	-50.0%
Mining & Oil/Gas Extraction -Stationary Comb. Source	6,590	40,900	5.9%	34,310	520.6%

Note the significant increase of 520.6 percent in Mining and Oil and Gas Extraction from Stationary Combustion Sources between 1990 to 2012. As the mining sector has not grown anywhere near that amount, most of the growth would have come from oil and gas extraction, and within that component, we can assume tar sand development was a major contributor.

In the low emission world of 2060, the future for fossil fuels will be limited to national priorities determined by the government and production for non-energy uses. Where fossil fuels are produced, their production will come from emission-efficient sources such as natural gas and perhaps oil over coal and tar sands, and from situations where emissions can be captured, transported and stored and where fugitive emissions are minimized.

National Priorities

These will be determined by governments, based on criteria that include the "public good", the availability of alternatives, and the extent of emissions. Examples may include long-distance air travel by national leaders and the operation of long-distance ferry services such as to Newfoundland. Other potential national priorities will be noted as we proceed.

Non-energy Use of Fossil Fuels

A portion of the production of fossil fuels goes to the production of plastics, paints, pharmaceuticals, adhesives, lubricants, sealants, and other chemicals, as strands of carbon-based molecules are vaporized and rearranged with the help of various catalysts. In 2012, Canada used 1,152,617 terajoules of fossil fuel production went to non-energy uses, from a total production of 15,628,969 terajoules (7.37 percent).

Efficient Fossil Fuels

Fossil fuels are widely used because they store a lot of energy that can be released as and when needed. Fossil fuels can be assessed in terms of energy produced per unit of volume, per unit of weight, as well as emissions. The transportation sector in particular is looking for lots of energy with minimal volumes and weights. Getting to zero by 2060 requires attention to emissions. The table below provides energy information for various fossil fuels.

Energy Characteristics and Carbon Emissions for Key Fossil Fuels				
	Specific Energy	**Energy Density**	**Carbon Dioxide Emitted**	
Fossil Fuel	**Megajoules per Kilogram**	**Megajoules per Litre**	**Grams Per Joule**	**Pounds per 10^6 BTUs**
Methane (burned in air)	55.6	0.04	n.a.	n.a.
Natural Gas (burned in air)	53.6	10.00	50.35	117
LPG Propane (burned in air)	49.6	25.30	59.81	139
LPG Butane (burned in air)	49.1	27.70	n.a.	n.a.
Gasoline	46.4	34.20	67.13	156
Diesel Fuel/Residential Heating Oil (burned in air)	46.2	37.30	69.28	161
Jet A Aviation Fuel	42.8	33.00	65.84	153
Anthracite Coal	32.5	72.40	97.68	227
Bitumen Coal	24.0	20.00	88.22	205
Source: Wikipedia				

The problem with fossil fuels is that they are ultimately combusted to produce carbon dioxide and other greenhouse gases. In this regard, coals produce lots of emissions relative to the energy produced. Natural gas produces significantly less. In the low emission world of 2060, only those fossil fuels that produce lots of energy with relatively few emissions will continue to be used. This will effectively end the combustion of coal and tar sand products, to be replaced by natural gas and other more efficient alternatives.

Carbon Capture and Storage

The primary hope for the fossil fuel industries is carbon capture and storage. The concept is straight forward. Capture the carbon dioxide from the burning of fossil fuels, and store it in the ground forever. The reality is more complicated. The technology is attractive, because so much of the world relies on fossil fuels, particularly coal, to provide electricity. Despite the attractiveness, the technology is a long way from widespread application. The issue gets down to three components: capture, transport and storage.

Capture from Combustion

Approximately 44.21 percent of Canada's emissions come from combustion in stationary sources. This combustion lends itself to carbon capture because the concentrations of CO_2 in the post-combustion gases are high. Within the stationary sources, the large-scale facilities for electricity generation are the prime targets for carbon capture, because they are large facilities. Electricity and heat generation accounts for about 12.7 percent of Canada's greenhouse gas emissions. Almost all the emissions are in the form of carbon dioxide.

Canada's electricity generation comes primarily from natural gas, although a few provinces have coal generating stations. Older generating plants combust the fuel in air. Newer plants sometimes combust the fuel with water, producing CO_2 and hydrogen as byproducts. With the newer plants, the CO_2 is more concentrated, and therefore easier to separate from other gases.

The capture process needs to separate the CO_2 from these other gases, to reduce the volumes to be stored. Under current methods, flue gases are at high temperatures and low pressures. To separate the CO_2, the flue gases are compressed and chilled before passing them through a membrane or solvent that traps CO_2. The solvent contains organic chemicals called amines. At low temperatures, CO_2 and amines combine. At high temperatures, they separate. The amines react with the CO_2 but not the other gases. To extract the CO_2 from the amines, the amines are heated, and this releases the CO_2 into a controlled area. The capture rate under existing methods is about 85 percent – a rate that is not good enough for a minimal emission world.

New carbon capture technologies are on the horizon.

For example, UCLA researchers have created powders of porous crystal that soak up CO_2. The crystals have pores big enough to allow CO_2 inside, and small enough to retain them. When loaded with CO_2, the crystals release the CO_2 when the pressure is reduced. The most efficient crystals soak up 83 times their own volume. The plan is to test the technology in power stations by about 2010.[1]

Researchers at the University of Wyoming have designed a cheap filter that can capture 90 percent or more the CO_2. The filter consists of specially prepared carbon pieces about the size of a pinhead. With porous surface, the grains trap and bond with the CO_2 in the flue gases at temperatures up to 50ºC, while allowing nitrogen to escape. Heating the carbon pieces to 100°C releases the CO_2.[2]

One anticipates that over time, capture processes will become both more efficient in capturing CO_2, energy efficient, and less expensive. Even with better capture technologies, there are still problems.

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[1] New Scientist, Crystal sponges capture carbon emissions, February 23, 2008, p. 26
[2] New Scientist, Carbon grains slash the cost of storing CO2, May 24, 2008, p. 26

Transportation and Storage of Captured CO_2

Storage requires that the CO_2 be pressurized, liquefied, and moved to a storage site. Ideally, sites should be near places where the fossil fuels have been combusted. If no suitable sites exist, pipelines need to be built. The need for pipelines increases the cost of carbon capture and storage. It also increases the risk of leaks, which will contribute to global warming, but also pose a risk to people living near the leak. Canada's best storage sites are on the prairies, so Canada may need to develop pipelines from combustion or collection points to the prairie storage sites. This will not be cheap.

Carbon storage underground is not a new idea. Statoil, Norway's state oil company, buries a million tonnes of CO_2 annually. It strips CO_2 from natural gas from the Sleipner West gas field, and puts it into a sandstone aquifer beneath the seabed. Similar schemes operate at Weyburn Saskatchewan, and In Salah, Algeria. Compared with the volumes of carbon dioxide that need to be stored to preserve the fossil fuel industry, these are small scale operations. The purpose of these projects is to enhance the recovery of fossil fuels, not store carbon dioxide. However, they have demonstrated that well-chosen sites can store CO_2 effectively.

The best storage sites are at a depth of a kilometer or more, to provide enough pressure to keep CO_2 as a supercritical fluid so it is more likely to stay put. The rock has to have enough pores and cracks to hold CO_2. It also has to be covered by non-porous, non-cracked rock to provide a leak proof cap. Potential storage sites include:

- Voids left by worked out oil fields. Recent studies show natural CO_2 has remained in such sites for 120 million years. Oil and gas fields could hold up to a trillion tonnes of CO_2. Canada's sedimentary sites are in the prairies, and off the east coast of Newfoundland and Labrador, and Nova Scotia.
- Unminable coal seams, where CO_2 could be absorbed in a layer on the surface of the coal.
- Deep porous rocks such as sandstone, capped by a permeable lay of shale or other rock that trap the CO_2. Estimated capacity worldwide is 10 trillion tonnes

Security is an issue with all potential storage sites. CO_2 belched from a natural storage area under Lake Nyos in the Cameroon. It created a thick blanket on the surface, asphyxiating 1,700 people. These people died from the release of a relatively small amount of carbon dioxide. A release from a viable storage site of sequestered CO_2 through an accident, sabotage or an earthquake would have a much bigger impact. Because of security challenges, local residents are likely to challenge any suggested storage sites.

Slow leakage from a storage site is also concern, since the CO_2 needs to be buried forever. Storing CO_2 is like storing nuclear waste, except that nuclear radiation diminishes over time, but the problems with CO_2 do not.

Various research projects are under way to test the viability of CO_2 storage. Tests have been small scale, short-term and for the most part at the best available sites.

To illustrate the types of problems to be resolved, in one case, CO_2 was inserted into sandstone formation which once contained oil and now contains brine. The CO_2 acidifies the brine, which then dissolves metal oxide minerals in the rock. This could create tunnels, allowing the CO_2 to escape.

Responsibility for storage is also an issue. Responsibility has to be maintained forever. Adequate funds need to be set aside to manage the CO_2 storage when the CO_2 goes into the site. Sufficient money has to be put into a fund and left there so that the interest on the fund will pay for the operation of the storage site. This may not work well.

There is also a need to learn how to manage a site. The understanding of how much CO_2 a particular site can take, and how to spot problems, needs to be enhanced.

Carbon capture, transport and storage add to the cost of burning fossil fuels. Estimates put the cost of carbon capture and storage in the range of $30 to $47 per tonne of carbon dioxide. From an energy efficiency perspective, carbon capture and storage will use up 10 to 40 percent of the energy produced by the fossil fuel.

The future of carbon capture and storage does not look promising. It was once highly touted as a way to maintain the fossil fuel industry, particularly with regard to power stations. However, progress has been slow.

In September 2007, Thomas Kuhn of the Edison Electric Institute, which represents most American power generators, half of which use coal, told a House Select Committee that commercial deployment of carbon capture and storage from large coal stations will require 25 years of research and development, and cost $20 billion. Shell does not see widespread use of this technology until 2060. This is too late for our goal for emission reduction.

Without carbon capture and storage on a significant scale, the future of the fossil fuel industry is bleak.

Fugitive Emissions

Fugitive emissions from fossil fuels are the intentional or unintentional releases of greenhouse gases from the production, processing, transmission, storage and delivery of fossil fuels. They include released gases that are combusted before disposal (e.g. flaring of natural gases at oil and gas production and processing facilities). Sources include are coal mining and handling, and activities related to the oil and natural gas industry.

To the extent that the production of oil and gas continues, there will be a need to substantially reduce fugitive emissions. About 8.7 percent of Canada's emissions come from fugitive emissions from fossil fuel industries.

Over the period 1990 to 2012, factors affecting fugitive emissions included:

- The closing of coal mines in eastern Canada.

- Increased production of natural gas, heavy oil, crude bitumen and synthetic crude oil.
- The shift in production from easily removal fossil fuels to more energy and emission intensive forms of oil.
- The increased use of multi-stage fracturing during well-completion.
- The introduction in Alberta of regulations to reduce flaring and venting in the oil and gas industry in 1999.
- The introduction in 2006 of leak detection and repair best management practices in Alberta regulations.

By 2060, much stricter regulation of fugitive emissions will be required for whatever production of fossil fuels there is. Presumably, the technology for identifying and dealing with fugitive emissions will have improved.

Getting to Zero by 2060

Getting to zero by 2060 means:

- The combustion of fossil fuels will substantially but not completely end. Some combustion will continue for national priorities (government services, remote mine sites, ferry services, essential air travel), where no alternatives exist. These emissions are estimated at about 4.83 percent of current emissions. Some extraction, processing and distribution of fossil fuels for purposes other than burning (e.g. plastics) will continue. Currently, these activities account for around 7.37 percent of total production. Exports particularly to the United States will disappear, since the other countries will be abandoning the combustion of fossil fuels. Canada's fossil fuel reserves will be sufficient to meet Canada's needs for the foreseeable future, primarily because removal from reserves will diminish.
- To the extent that fossil fuels continue to be used, the focus will be on fossil fuels that produce the most energy per emission. This means natural gas and conventional oil will be used, and tar sand and coal extraction will not.
- There will be some carbon storage facilities available, and where feasible, those who combust fossil fuels for national priorities will be required to capture, ship to a storage location and store CO_2. At the same time, those projects allowed to operate in 2060 will be selected in part because of their capacity for carbon capture and storage.
- Carbon capture and storage will not be the vehicle that allows current levels of combustion to continue into the future for several reasons:
    - Current capture technologies do not capture all the CO_2. Some emissions remain even where there is the desire for carbon capture and storage, so carbon capture and storage are only a partial solution to the greenhouse gas problems.
    - There are storage issues. The amount of CO_2 to be stored is huge, yet there remain questions about where it will be stored, how will it be stored,

whether the storage is safe, and whether communities will accept storage in their neighbourhoods.
  - There are transportation issues related to getting the CO_2 from the place of combustion to the place of storage.
  - Carbon capture and storage increases the cost of using fossil fuels, and makes other technologies, particularly renewable technologies cost competitive. Put another way, the energy consumed in carbon capture and storage uses up a significant portion of the energy in the fossil fuel, thereby reducing the emission efficiency of the fossil fuel as a net source of energy.
  - Even if all the outstanding issues related to carbon capture and storage are answered eventually, it is unlikely that the questions will be answered and facilities built in time to address the greenhouse gas crisis. Other technologies are closer to implementation and will have occupied the field by the time carbon capture and storage is ready.
- Where extraction, processing and distribution do occur, there will be strict regulations to eliminate all emissions that are incidental. The current tolerance of unnecessary fugitive emissions will end.
- In addition, the selection of drill sites will focus on sites that are less likely to lead to fugitive emissions. Furthermore, there will be strict monitoring of sites to detect and stop fugitive emissions. The unpredictable nature of fracking may be problematic for the technology.
- Where oil and gas are extracted, refined and transported, the energy source will be electricity and not oil and gas combustion.

Projected Emissions

Projected Emissions for 2060: Fossil Fuels			
Greenhouse Gas Categories	**2012**	**2060 Projection**	**Comments**
	kt CO2 eq	**kt CO2 eq**	
Fossil Fuel Production, Fugitives, Transport	171,600	5,512	Sector Total
Fossil Fuel Production - Stationary Combustion Source	47,000	0	Current emissions times zero, as electricity replaces fossil fuels to power production facilities
Fugitives - Venting	30,000	366	Current emissions times12.20 percent representing the residual 2060 demand (7.37 percent for non-energy uses and calculated 4.83 percent for combustion for national energy priorities) times 10 percent representing the residual after improvements to reduce venting.
Fugitives - Natural Gas	19,000	1,159	Current emissions times 12.20 percent representing the residual 2060 demand (7.37 percent for non-energy uses and calculated 4.83 percent for combustion for national energy priorities) times 50 percent representing the residual after improvements to prevent fugitive emissions.
Petroleum Refining - Stationary Combustion Source	16,800	0	Current emissions times zero, as electricity replaces fossil fuels in petroleum refining
Pipelines	5,700	0	Current emissions times zero, as electricity replaces fossil fuels in running pipelines
Fugitives - Oil	6,500	397	Current emissions times 12.20 percent representing the residual 2060 demand (7.37 percent for non-energy uses and calculated 4.83 percent for combustion for national energy priorities) times 50 percent representing the residual after improvements to control fugitive emissions
Fugitives - Flaring	4,700	287	Current emissions times 12.20 percent representing the residual 2060 demand (7.37 percent for non-energy uses and calculated 4.83 percent for combustion for national energy priorities) times 50 percent for improvements to control flaring.
Fugitives - Coal Mining	1,000	0	Current emissions times zero, as coal mining ends
Mining & Oil/Gas Extraction -Stationary Comb. Source	40,900	3,304	Oil and Gas makes up 50.0 percent of the subsector, based on minimum employment by size of business. Mining excluding coal makes up 44.7 percent, and coal 5.3 percent. Projected emissions equal (a) current emissions times 50.0 percent (oil and gas share) times 12.20 percent representing the residual 2060 demand (4.83 percent for combustion for national energy priorities and 7.37 percent for non-energy use) times 50 percent representing the residual after improvements in emission efficiency in oil/gas production PLUS (b) current emissions times 44.7 percent for the mining excluding coal share times 15 percent representing the residual for non-grid accessible mines (grid accessible mines will use electricity) times 50 percent representing the residual for improvements in emission efficiency in production times 75 percent representing the residual for emissions that are not captured PLUS (c) current emissions time 5.3 percent representing the coal mining share times 0 representing the disappearance of coal mines.

Chapter 3: Generally Electric

Past Emissions

Canada's 1990–2012 Green House Gas Emissions: Electricity and Heat Generation					
Greenhouse Gas Categories	**1990**	**2012**	**2012**	**Change 1990-2012**	
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Total – All Sectors	590,253	708,713	100.0%	107,660	18.2%
Electricity and Heat Generation	93,600	88,300	12.7%	-5,300	-5.7%

Meeting Canada's Energy Needs through Electricity Without Fossil Fuels

In 2012, Canada required 8,108,710 terajoules of energy. Of this, 32.41 percent was for transportation, 19.15 percent for manufacturing, 11.11 percent for commercial and industrial purposes, and 15.81 percent for residential purposes. There is always the potential to reduce energy consumption by doing less or doing the same things in more energy efficient ways. For the moment, let us assume current consumption patterns will continue and energy efficiency remains the same.

Primary and secondary energy, terajoules — Canada 2012 Revised		
	Terajoules	% Total
Energy use, final demand	**8,108,710**	**100.00%**
Total mining and oil and gas extraction	917,281	11.31%
Total manufacturing	1,552,737	19.15%
Forestry and logging and support activities for forestry	21,060	0.26%
Construction	92,029	1.13%
Total transportation	2,627,846	32.41%
Agriculture	265,336	3.27%
Residential	1,281,940	15.81%
Public administration	120,022	1.48%
Commercial and other institutional	900,859	11.11%
Other	329,600	4.06%

Source: Statistics Canada, Report on Energy Supply and Demand in Canada, 57-003-X 2012 Revision

To meet this energy demand, refined petroleum products provided 39.03 percent, natural gas provided 31.5 percent, and primary sources, hydro and nuclear provided 20.99 percent, and coal, steam, coke and coke oven gas, and gas plant natural gas liquids accounted for the 8.62 percent. Overall, 20.99 percent of Canada's energy needs came from primary, hydro and nuclear sources, and 79.01 percent came from the combustion of fossil fuels. For electricity to replace fossil fuels, the electricity sector would have to deliver an additional 6,406,376 terajoules of electricity. This represents a 376 percent increase over the current production of energy from renewable and nuclear sources.

Primary and Secondary Energy, terajoules - Canada		
Source	Energy Source	
	Terajoules	%
Total primary and secondary energy	8,108,710	100.00%
Total coal	56,430	0.70%
Natural gas	2,541,994	31.35%
Gas plant natural gas liquids (NGL's)	496,157	6.12%
Primary electricity, hydro and nuclear	1,702,364	20.99%
Steam	26,611	0.33%
Coke	93,907	1.16%
Coke oven gas	26,125	0.32%
Total refined petroleum products	3,165,123	39.03%

Source: Statistics Canada, Report on Energy Supply and Demand in Canada, 57-003-X 2012 Revision

In addition to meeting the final demand for energy, the electricity system needs to produce energy to run itself. In 2012, Canada's electricity sector produced 477,608.1 gigawatts and producer consumption was 53,724.4 gigawatts, about 11.25 percent of production. Consequently, in addition to producing an additional 6,406,376 terajoules of electricity, it would need to produce an additional 11.25 percent for producer consumption (720,717 terajoules), for a total increase of 7,127,093 terajoules.

Total Primary and Secondary Energy - Domestic Demand by Source	
Source	Average 2003-2005
	Gigawatt Hours
Primary Electricity Production (gigawatt hours)	477,608.1
Producer Consumption (gigawatt hours)	53,724.4
Producer Consumption as Percent of Total Production (%)	11.24%

Source: Statistics Canada, Report on Energy Supply and Demand in Canada, 57-003-X 2012 Revision

An electricity demand of **!Undefined Bookmark, CANADAELE** terajoules per year that was equalized throughout the year would require an electricity system with a capacity of **!Undefined Bookmark, CANADAELE** megawatts.

However, demand is not equalized throughout the year, so installed capacity needs to exceed effective load factor. In Ontario, the effective load factor is 76.7 percent.[3] As a consequence, the capacity of an electrical system to address all Canada's energy needs would be at least 0 megawatts.

[3] Pembina Institute, Renewable is Doable, a Smarter Energy Plan for Ontario, Analysis and Scenario Modeling of the Ontario Power System, July 2007, p. 26.

Potential Energy Sources

Our major potential non-emitting sources are already known: solar, on and off-shore wind, water power (hydro, ocean, salinity), and nuclear.

Wind

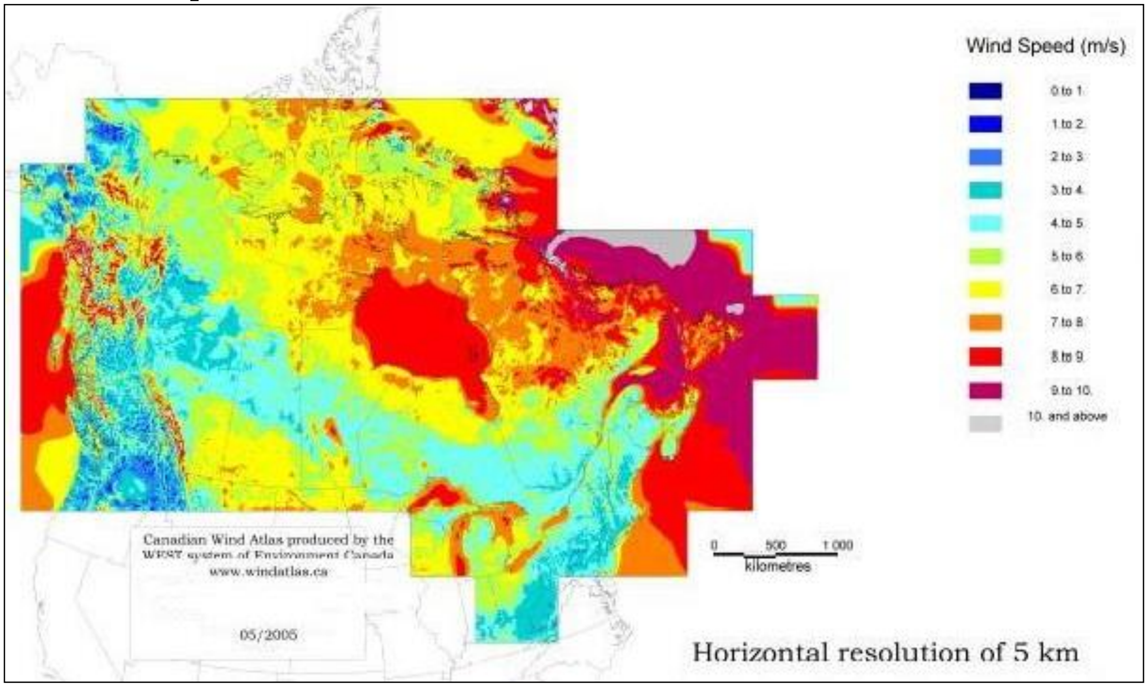
In the foreseeable future, the most likely technology for capturing the power of the wind is wind turbines. The power of the wind is estimated using the formula for kinetic energy. Kinetic energy of an object is one-half times the mass of the object times its velocity squared. In the case of air through a wind turbine, the kinetic energy of the air in watts is one-half times the mass of the air through the turbine in a second (measured in kilograms) times the velocity of the wind (measured in metres per second) squared. The mass of the air going past the turbine is the mass of a cubic metre of air (1.3 kilograms) times the area covered by the blades in the turbine (π times the length in metres of each blade squared) times the velocity of the wind (metres squared). The power of a totally efficient wind turbine measured in watts is therefore equal to the one-half times 1.3 times π times the length in metres of the turbine blade squared times the velocity of the wind in metres per second cubed. Because the power of the wind is tied to the cube of its velocity, the power goes up dramatically at higher wind speeds.

In a wind farm, if wind turbines are placed too close together, their performance degrades. The rule of thumb is that turbines should be separated by a distance 5 times the diameter of the turbine (or 10 times the length of each blade). The land area required for a wind farm is equal to the theoretical maximum power per turbine divided by the square of 10 times the length of each blade in the turbine. The power in watts per square metre of land area is one-half times 1.3 times π divided by 100 times the velocity of the wind (metres per second) cubed. Note that the size of the turbine is not relevant in determining the power output per square metre of land.

Wind turbines are not totally efficient. The theoretical efficiency maximum is 59.3 percent. Modern turbines capture about 50 percent of the available power. Turbines in areas subject to ice build-up need to direct about 3 percent of their wind power to produce heat to prevent damage from ice and to continue operations in icy conditions. The reliability of turbines is also improving. In 2002, turbines were out of commission 15 percent of time. Now they are out of commission only 3 percent of the time. The practical efficiency of Canadian turbines is likely about 44 percent.

Because of the importance of wind velocity in producing power, it is essential to know where Canada's winds are strongest. The best areas for wind are the East and West coasts, as well as Hudson Bay, with mean annual wind speeds between 8 and 9 metres per second. Very good wind areas are around the great lakes, with mean annual wind speeds of 7 to 8 metres per second. The prairies are good wind areas, with mean wind speeds of 6 to 7 metres per second.

Mean Wind Speed at 50 Metres Above Ground



Source: Government of Canada Wind Atlas

It is also important to note that wind speeds are higher are higher elevations. A doubling of the tower height increases expected wind speeds by 10 percent, and the expected power output by 34 percent. In night time, the wind speed increase is even higher, and accordingly, so is the power output.

Modern wind turbines have diameters of 40 to 90 metres, with tower heights of two to three times the blade length.

The land area required to meet Canada's energy demand of 0 megawatts depends on the wind speeds. At wind speeds typically found on the prairies (6.5 metres per second), 119,413 square kilometres would be required. At wind speeds typical of the Great Lakes and Lake Winnipeg (7.5 metres per second), an area of 77,734 square kilometres would be required. At wind speeds typical of Canada's coasts (8.5 metres per second), 53,399 square kilometres would be required. See the table below summarizes the foregoing.

Wind Turbine Power by Size and Land Area Requirements, and Capacity					
	Ave. Annual Wind Speed at 50 Metres Elevation				
	Metres / Second				
	6.5	**7.5**	**8.5**	**9.5**	**10.5**
	Kilometres / Hour				
	23.4	**27.0**	**30.6**	**34.2**	**37.8**
Minimum Windmill Power (KW) by diameter (metres)					
40	98.7	151.6	220.7	308.1	416.0
65	260.6	400.4	582.8	813.7	1,098.6
90	499.7	767.6	1,117.4	1,560.0	2,106.2
Minimum Windmill Power by land area (watts per square metre)	2.47	3.79	5.52	7.70	10.40
Area required to meet Canada's additional electrical energy needs (square kilometres)	119,413	77,734	53,399	38,249	28,329
Notes					
Canada's additional electrical energy needs = 294,652 megawatts					
Efficiency = 44%					
Mass of a square metre of air = 1.3 kilograms					
Distance between wind turbines = 5 times the diameter					
Wind power estimates are minimums because with a normal distribution of wind speeds around the average, the cube of actual the wind speeds is greater than the cube of the average wind speed.					

Canada is a big country, covering 9,984,055 square kilometres. There is a lot of wind energy available. Wind turbines on prairie crop land (292,992 square kilometres) would provide 2.45 times the requirement, and provide a nice supplement to farmers' income as well. In addition, there are 255,357 square kilometers of farmland not used for crops.

Prairie Farm and Crop Land, 2006		
	Farm Land	**Crop Land**
	Square Kilometres	**Square Kilometres**
Manitoba	77,295	46,944
Saskatchewan	260,213	149,734
Alberta	210,841	96,315
Total	548,349	292,992
Source: Statistics Canada, Snapshot of Canadian Agriculture		

The Canadian portion of the relatively shallow Lakes Ontario, Erie, St. Clair, Huron and Winnipeg is 83,677 square kilometres. The Canadian shoreline to one kilometre deep of these lakes, plus Lake Superior, provides another 9,878 square kilometres. Some combination of these resources should readily meet the requirement for 77,734 square kilometers at wind speeds typical of these lakes.

Major Canadian Lakes					
	Canadian Area	**Canadian Shoreline (including Islands)**	**Length**	**Width**	**Average Depth**
	Kilometres	**Kilometres**	**Kilometres**	**Kilometres**	**Metres**
Lake Ontario	10,000	617	311	85	86
Lake Erie	12,800	639	388	92	19
Lake St. Clair	490	56	42	39	3
Lake Huron	36,000	4,812	322	245	59
Lake Superior	28,700	2,384	560	260	147
Lake Winnipeg	24,387	1,370	416	100	12
Hudson Bay	1,230,000	n.a.	1,370	1,050	100
James Bay					
Sources: Wikipedia and Natural Resources Canada					

Canada's strongest winds occur along the coasts and in and around Hudson Bay. At wind speeds typical of these areas, 53,399 square kilometres of land are required to meet Canada's additional electricity requirements. Hudson Bay covers an area of 1,230,000 square kilometers with relatively shallow waters. Canada has over 243,798 kilometres of coast line. The eastern seaboard coastlines of Newfoundland, Labrador, Prince Edward Island, Nova Scotia, Cape Breton and New Brunswick provide 25,772 kilometres of shoreline. Utilizing the rural coastlines to a depth of 1 kilometre would make a sizable impact on Canada's additional electricity requirements.

Salt Water Coast Line	
	Kilometres
Labrador	7,858
Newfoundland Island	9,880
Prince Edward Island	984
Nova Scotia Mainland	3,498
Cape Breton	1,702
New Brunswick Mainland	1,850
British Columbia Mainland	8,458
British Columbia Major Islands	9,250
British Columbia Minor Islands	5,186
Nunavut Mainland	18,942
Nunavut Major Islands	68,315
Nunavut Minor Islands	26,644
Canada Mainland	58,509
Canada Islands	185,289
Canada Total	243,798
Source: Natural Resources Canada and Hammond World Atlas	

Some combination of Canada's best wind resources would more than meet Canada's additional electricity needs.

While wind technologies are relatively mature, there is still room for technological improvements. The technological challenges for wind turbines include:

- Building bigger blades that can also withstand stresses. Bigger blades make wind turbines more economic. Using materials, such as carbon fibre, would allow for bigger but lighter blades,
- Building smarter, variable geometry blades. For example, following ideas used in helicopter blades, one could use sensors controlling wing flaps along trailing edges of blades so that the flaps unfold in light winds to expand surface area and contract in strong winds to reduce stresses.
- Managing the torque on the drive trains, perhaps by using gearing systems.
- Developing ways to attach big turbines to the sea and lake beds. Mean wind speeds off-shore are about 90 percent greater than speeds on land, so off-shore turbines could produce substantially more electricity. For depths from 35 to 50 metres, tripods may be adequate but at deeper levels, floating platforms anchored to the seabed may be the answer.[4]

Because wind turbines are operating relatively close to their theoretical maximum efficiency, the benefits from waiting for technical advances may not be significant.

In addition to technological developments, wind farm owners are getting smarter in picking the best places for turbines. Also, grid managers are predicting weather and power sources better. From the point of view of an entrepreneur or investor, a wind farm can be built in stages as demand increases. In addition, the time between the initial investment and the time when the investment starts to yield a return can be short relative the time required to start fossil fuel power stations and nuclear facilities.

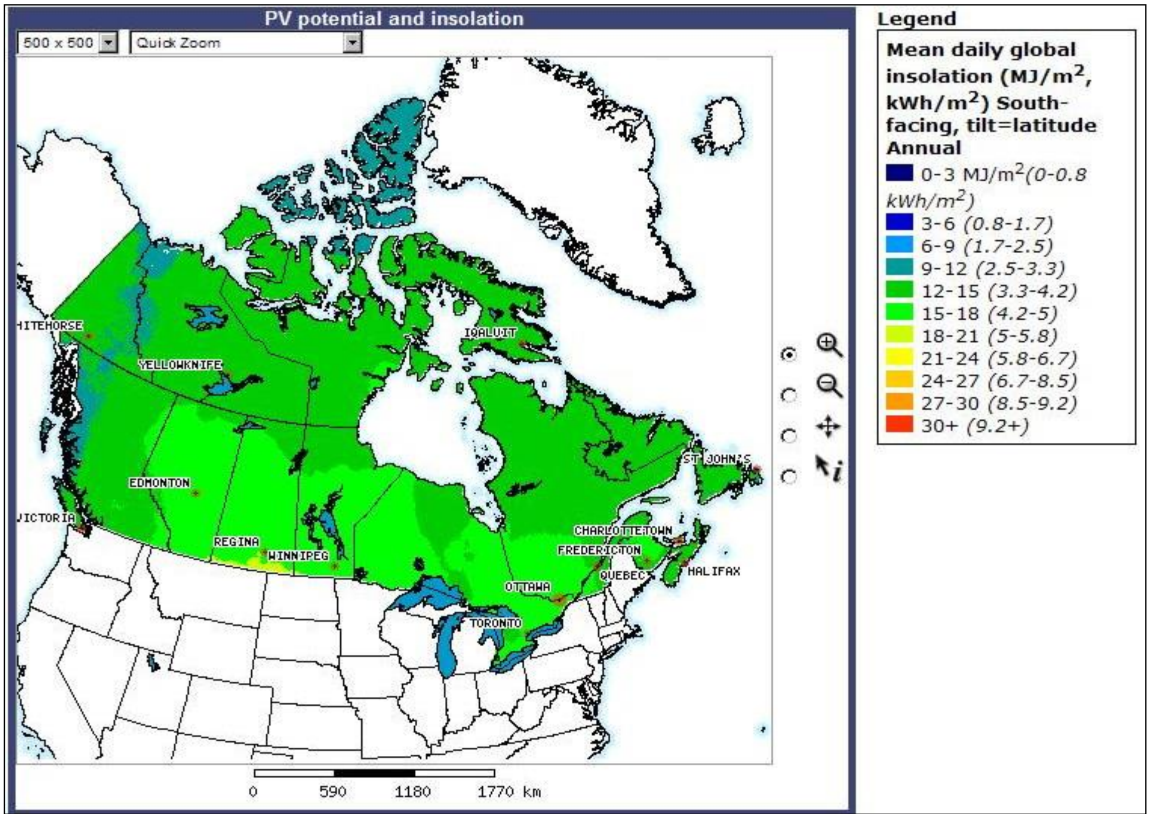
The current cost of generating electricity from wind turbines is competitive with nuclear energy, and slightly more expensive that coal and natural gas without carbon capture or a realistic carbon tax, and comparable with fossil fuels with carbon capture and a realistic carbon tax.

Solar

The sun is a powerful source of energy. It generates 1,360 watts per square metre in space. Of this, about 1,000 watts per square metre reaches a surface perpendicular to the sun at sea level on a clear day; the rest is absorbed in the atmosphere or reflected back into space. The energy from sunlight striking the earth for 40 minutes is equivalent to global energy consumption for a year.[5] A patch of land about half the size of Texas in a sun- drenched part of the earth, combined with technologies that capture 20 percent of the potential solar energy, could produce the world's human energy needs.[6]

In Canada, this solar potential is reduced because of Canada's latitude, variations in solar intensity during the day, and cloud cover. The map below shows the solar potential of Canada.

[4] New Scientist, Anywhere the wind blows, October 11, 2008, p. 33
[5] Scientific American, A Solar Grand Plan, December 16, 2007
[6] New Scientist, Our Solar Future, December 8, 2007



Source: Natural Resources Canada

Of Canadian cities, Regina gets the most solar energy. Cities on the prairies get more solar energy than cities elsewhere. Among cities in central and eastern Canada, Ottawa receives the most solar energy. Ottawa receives about 90 percent of the solar energy that Regina receives.

What are the land requirements to meet Canada's energy needs (**!Undefined Bookmark, CANADAELE** terajoules per year) through solar energy? The land requirements depend on the location and the technology used to collect the energy. By using the most efficient technology and assuming an efficiency of 20.0 percent in terms of collecting available solar energy, the land requirements to meet all of Canada's demand would be 3,776 square kilometres around Regina, or 4,446 square kilometres around Ottawa.

Solar Energy and Land Requirements				
	Latitude Tilt		Two Axis Sun Tracking	
	Mean Daily Insolation - Kilowatt-hours Per Square Metre (Annual Average)	Land Requirements to Meet Canada's Annual Energy Needs (square kilometres)	Mean Daily Insolation - Kilowatt-hours Per Square Metre (Annual Average)	Land Requirements to Meet Canada's Annual Energy Needs (square kilometres)
Regina	5.0	5,423.9	7.2	3,766.6
Calgary	4.7	5,770.2	6.7	4,047.7
Winnipeg	4.7	5,770.2	6.6	4,109.0
Edmonton	4.6	5,895.6	6.5	4,172.3
Ottawa	4.4	6,163.6	6.1	4,445.9
Montreal	4.3	6,306.9	6.0	4,520.0
Toronto	4.3	6,306.9	5.9	4,596.6
Fredericton	4.2	6,457.1	5.8	4,675.8
Quebec	4.2	6,457.1	5.7	4,757.8
Charlottetown	4.0	6,779.9	5.5	4,930.9
Yellowknife	4.0	6,779.9	6.2	4,374.1
Victoria	4.0	6,779.9	5.7	4,757.8
Halifax	3.9	6,953.8	5.3	5,116.9
Iqaluit	3.9	6,953.8	5.5	4,930.9
Vancouver	3.7	7,329.7	5.2	5,215.3
Whitehorse	3.5	7,748.5	5.0	5,423.9
St John's (Nfld)	3.4	7,976.4	4.5	6,026.6
Source: Natural Resources Canada				

To put these numbers in perspective, Canada is a country covering 9,984,055 square kilometres. Much of the land is not used intensively. In a desperate situation, there is certainly room to convert 3,800 to 4,600 square kilometres to the collection of solar energy.

Realistically, as energy production normally occurs in competitive environments, Canada's best solar areas would have to compete with solar power sources in Arizona, New Mexico and Texas, although they would be protected to some extent by transmission losses between American production points and Canadian end users.

It is not unrealistic to expect Canada's buildings to become solar energy collectors by 2060. Canada's residential buildings currently have a foot print of about 647 square kilometres. Its commercial and institutional buildings have a foot print between 116 and 131 square kilometres. Collectively, they could provide the basic infrastructure to meet about 17 percent of Canada's additional energy needs.

Solar Potential of Residential Buildings				
	Number of Homes (000)	**Floor Space (square kilometres)**	**Estimated Average Number of Floors**	**Foot Print (square kilometres)**
Single Detached	7,622	1,076	2	538
Single Attached	1,428	168	2	84
Apartment	4,021	338	n/a	n/a
Mobile Home	263	25	1	25
Total	13,334	1,607	n/a	647
Source: Natural Resources Canada, Office of Energy Efficiency				

Solar Potential of Commercial and Institutional Buildings (2000)				
Floors	**Buildings**	**Floor Space (square metres)**	**Building Foot Print (square kilometres)**	
			Minimum	**Maximum**
1	46,330	53,568,594	54	54
2	49,145	78,166,962	39	39
3	24,251	41,914,940	14	14
4 to 9	14,913	78,530,577	9	20
10 to 80	2,401	50,389,909	1	5
Total	137,040	302,570,982	116	131
Notes:				
1 It is assumed the tallest building has 80 floors				
2. The survey covers only buildings in cities with over 50,000 people in Atlantic Canada and over 175,000 people in the rest of Canada				
Source: Natural Resources Canada, Office of Energy Efficiency, Commercial and Institutional Building Energy Survey, 2000				

A range of technologies are currently available or under development to capture solar energy.

Photovoltaic Systems

The most common form of solar electricity generation is photovoltaic cells. The heart of a photovoltaic cell is a semiconductor which liberates an electron when struck by a photon. The liberated electron can be guided into a circuit, creating a hole to be filled by another electron from the circuit, creating an electric current.

Light from the sun comes at different energies. Each semiconductor has a characteristic band gap of solar energies that will dislodge electrons. When energy levels are too weak or too strong, the energy conversion does not occur or is low. Bell Labs discovered that silicon, which is cheap and easy to produce, has a relatively broad band gap.

The efficiency of solar cells in capturing energy is improving. Originally, solar cells captured only 6 per cent of the solar energy. In the past decade, inexpensive solar cells with an efficiency of 20 percent have become a commercial reality.

In 2006, Allen Barnett and colleagues at the University of Delaware achieved an energy conversion efficiency of 42.8 percent.

Silicon is the most common material in photovoltaic cells, but has a theoretical efficiency limit of 30 percent. However, the scientific potential for other materials may be around 74 percent. Some of the technologies that will make photovoltaic cells more feasible in future include:

- Thin film cells, which use as little as 1 percent of the material in more conventional cells and are thus cheaper to produce. Lab tests achieved an efficiency of 19 percent. Thin film cells can be laid on flexible surfaces such as sheets of steel the thickness of a human hair, which gives them wider application. Thin coats on steel could be used as a building material.
- Concentrators of solar light to reduce the need for photovoltaic cell materials to achieve efficiencies. Soliant Energy from California uses a system that consists of a box holding rows of half-pipes of photovoltaic material. Each pipe is lined with a strip of photovoltaic material. The open side of the pipe is covered with an acrylic lens that concentrates light up to 500 times, making the photovoltaic material more effective.
- Light splitting, which enables incoming wave lengths to be directed to the solar cells best able to handle those wave lengths. Expected efficiencies are 50 percent.
- Nanocrystals called quantum dots, which are seeking efficiencies of 42 percent. The goal is to design quantum dots to match specific light spectra.
- Heat capture in solar panels. Some solar energy is lost as heat within the voltaic cell, so technologies to capture and use the heat are also being developed. The challenge is in collecting the heat before it dissipates in the semiconductor material and loses its energy.
- Use of low cost, printed plastics, which while not efficient, have low production costs. Plastic photovoltaic cells could be manufactured through a process similar to printing, and as such, should be low cost.
- New production processes. Examples include:
    - One approach is to mimic sea sponges to create solar cells. Solar cells are typically made by vapour deposition, which lays down chemicals on an inert surface. The result is a crystalline semiconductor when struck by light. As the vapour deposition is done at high temperatures and low pressure, it is expensive and requires a lot of energy. Sea sponges produce similar silica layers at normal temperatures and pressures. They do this by using the enzyme silicatein to catalyze the conversion of silicic acid in seawater into silica spikes. A group of researches imitated this process by using aqueous zinc nitrate and ammonia. The ammonia catalyzes the breakdown of zinc nitrate into crystalline zinc oxide. They were able to control the structure of zinc oxide deposited on the glass substrate. While problems remain, the technique holds the potential to create devices at low temperatures and pressures, thereby reducing costs.[7]
    - Another group of researchers are working on a string ribbon technique, which halves silicon requirement. The technique draws the element out of a vat between two strings, redesigns surfaces of silicon crystals at the nanoscale level to keep reflected light bouncing around inside the cell until absorbed, reengineers the silver wires that collect current, and makes the wires thinner so they block less light.

[7] New Scientist, Sea sponge leads the way to cheaper solar cells, March 24, 2007, p. 32

By 2060, we can expect efficient, low-scale photovoltaic system that can be readily applied on buildings and elsewhere.

Solar Heat

Photovoltaic cells are not the only way to convert solar energy into electricity. Solar heat systems consist of two components.

- One component takes light from a wide area and concentrates it onto a useable area. Concentrating the light can involve mirrors, whether a bank of flat mirrors, or a bank of parabolic mirrors, or a dish-shaped configuration of mirrors. It can also involve arrays of Fresnel lenses, which concentrate the rays passing through it. Systems for concentrating solar energy can also be used in conjunction with photovoltaic cells.
- The other component uses the concentrated light to produce electricity. The concentrated light can be focused on pipes or tubes containing oil, water, or molten salts. The heated liquids are used to generate steam, which drives a turbine to produce electricity. Molten salts retain their heat well, so the electricity can be generated at night time, when the sun is no longer shining. Alternatively, the concentrated light can heat a gas, which expands and drives an engine.

There are a number of commercial projects in operation or being built that use solar heat systems, including the following:

- In sun drenched Nevada, nine commercial operations built in the 1980s use parabolic mirrors to track the sun and concentrate solar energy onto tubes filled with oil or water. The heated tubes produce steam that drives a turbine to produce electricity. Conversion efficiencies have been about 20 percent.
- In Seville, Spain, a system of mirrors on a tower tracks the sun and focuses it on pipes. The water boils, generating steam that drives a turbine. Efficiencies have been about 15 percent.
- In California, mirrors will focus solar energy onto an engine which contains a gas that expands under heating and drives a generator. The system is expected to achieve solar conversion efficiencies of 24 percent.[8]

Solar heat systems are conceptually practical but costs must decrease. Opportunities to decrease costs include achieving greater economies of scale and boosting the temperature of heat exchanger fluids.

Unlike photovoltaic systems, these systems can store heat for a period of time, and release the stored heat when the sun is not shining. The goal should be to store and subsequently produce electricity for 24 hours, despite night time. This gives them a cost advantage over photovoltaic systems, which need a storage system if they are to work effectively with electricity grids.

[8] New Scientist, Our solar future, December 8, 2007

Other Technologies

Other approaches are always under investigation, although their practical application before 2060 is questionable. These approaches include taking advantage of the fact that hot air rises in a confined area (e.g. a tower) or in the open (e.g. hot air balloon),

NASA conceptualized a space-based solar energy system. Panels far above the earth would collect solar electricity. Away from the earth's atmosphere and positioned in continuous sunlight, they would have distinct advantages over earth-based systems. The energy would be beamed to earth through microwaves. There are, of course, a few technical details to be ironed out. For example, if the microwave beam was inaccurate or malfunctioned, large urban centers could get doused in microwaves. There is also the issue of capital costs and maintenance.

Water Power

The primary mechanisms to produce electricity from water are:

- Hydro, including:
  - Hydro-electric generation from large scale dams;
  - Micro hydro systems producing up to 100 kilowatts of power; and
  - Damless hydro systems using the kinetic energy from rivers and oceans.
- Ocean energy, including:
  - Marine current power;
  - Tidal power, including motion in the vertical and horizontal directions;
  - Wave power; and
  - Salinity gradient power, which is based on differences in salinity between fresh and ocean water.

Other ideas from producing electricity from water include Ocean Thermal Energy Conversion, which uses temperature differences between warmer surface waters and colder lower waters, and vortex power, which places obstacles in rivers to create vortexes whose energy is accessed.

Hydro

The technologies for hydro-electric development are well known. Most Canadian provinces have significant hydro-electric developments currently underway.

Constraints to hydro-electric development have included:

- Economic factors. Often, the major projects are located at significant distances from the users of electricity, and require transmission lines.
- Environmental factors. Hydro-electric projects with dams disrupt fish habitat, vegetation, wildlife, and water quality. The larger projects with dams have significant environmental impacts by their size. They are damaging to populations that depend on fish and wildlife to make a living.
- Flooding and Land Rights. Hydro-electric projects involving dams cause flooding behind the dam. Flooding raises the issue of rights to the flooded land that must be addressed prior to proceeding with projects.

Because of the problems associated with large scale hydro developments, recent focus has been on small micro-hydro developments. The federal government estimates that there are more than 5,500 identified sites (11,000 megawatts). Most are in British Columbia, Newfoundland, Québec, Ontario, Northwest Territories and Yukon. It also has identified significant untapped low-head hydro potential (i.e. with heads less than 15 metres) at about 20,000 megawatts. Beyond this, there are opportunities to refurbish old existing or decommissioned small hydro plants. According to Statistics Canada, the current small hydro capacity is approximately 3,300 megawatts.[9]

In October 2005, Hatch Acres completed a comprehensive report for the Ontario Waterpower Association and the Ontario Ministry of Natural Resources. The report concluded there was over 20,000 megawatts of hydroelectric potential remaining in the province – an amount that is in line with a 1990 Ontario Hydro estimate of 19,900 megawatts. These opportunities included a practical potential of 9,720 megawatts, based on the following:

- Probable and committed, or practical projects:
    - < 10 megawatts — 70 sites 300 megawatts
    - 10–100 megawatts — 26 sites 700 megawatts
    - > 100 megawatts — 14 sites 3,500 megawatts
- Redevelopment or expansion of existing sites: 440 megawatts
- Efficiency improvements at existing sites: 100 megawatts
- New powerhouses at existing dams: 180 megawatts
- The Lower Albany: 2,300 megawatts
- Other large sites on the Abitibi, Moose, Missinabi Rivers: 1,200 megawatts
- Total within parks and protected areas: 1,000 megawatts

In Quebec, the James Bay Project includes a number of hydro-electric power stations along the La Grande River, and the diversion of a number of neighbouring rivers into the La Grande River watershed. The Project has an installed capacity of 16,000 megawatts. Completion of all the original planned dams under the James Bay Project, plus additional James Bay II projects would produce an additional 11,000 megawatts.[10]

In Newfoundland and Labrador, the Lower Churchill River Hydroelectric Generation project has a planned capacity of 2,800 megawatts.[11]

In British Columbia, BC Hydro identified opportunities for run-of-the-river projects up to 50 megawatts in size. There were 756 sites, with the potential capacity of 2,450 megawatts and capacity factors ranging from 25 percent to 70 percent.[12]

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[9] Natural Resources Canada, Renewable Energy Technologies, Small Hydro Power
[10] Wikipedia, James Bay Project
[11] Newfoundland and Labrador, Environment and Conservation, Lower Churchill River Hydroelectric Generation Project, Registration 1305
[12] BC Hydro, Green and Alternative Energy Division, Green Energy Study for British Columbia – Phase 2: Mainland, October 2002

In Manitoba, there is more than 5,000 megawatts of additional hydroelectric potential, including 1,380 megawatts at Conawapa, 630 megawatts at Gull (Keeyask), and 1,000 megawatts at Gilliam Island on the Nelson River.[13]

While hydro power will not produce all of Canada's energy requirements, it will make a significant dint in the overall requirement of 0 megawatts.

Many hydroelectric opportunities are around James and Hudson Bay, and require long transmission lines to bring power to markets. There is considerable wind potential around James and Hudson Bay, so these same transmission lines could bring electricity from wind farms in the area to markets.

Ocean Wave and Tidal Energy

Canada has 225,000 megawatts of potential, an amount approaching the overall requirement of megawatts. Of this, 160,000 to 180,000 megawatts are in wave energy and 40,000 megawatts are in tidal energy.

Wave energy is produced by the wind. To capture the energy, devices are attached to the shore or sea bottom, and incorporate one or more semi-buoyant or floating devices that go up and down with the waves. Pulling a tether turns a generator to produce electricity.

Most of the tidal energy is in the Bay of Fundy.[14] In the Bay of Fundy, 100 billion tonnes of Atlantic seawater flow in and out every day, causing an average rise of 17 metres at the narrowest point. The Bay of Fundy could generate 17,000 gigawatt hours (61,200 terawatts) per year. Tidal energy is typically captured through barrages or dams that open when the tide comes in and close when the tide goes out. An example of tidal barrage is in Brittany, France, where a barrage across the Rance estuary has been in operation since 1966. Arguments against barrages are loss of biodiversity, damage fish and birds, etc., although over time, these are replaced. In Bay of Fundy, tides would be affected far away. The cost of barrages is high, as they are big infrastructure projects.

An alternative to barrages and dams is to use turbines to capture the energy of the currents in the water. Working examples of this alternative approach exist in the Norwegian town of Hammerfest since 2003 and East River, New York. [15]
Under test are tidal power turbines in the Bay of Fundy. These turbines, which are about half the length of a football field and have a diameter of 10 metres, are attached to the sea bed. If tests are satisfactory, 200 to 300 turbines could be placed in the Bay of Funding.

A study of tidal current energy potential in British Columbia identified 55 sites with a gross energy potential of 20,000 gigawatt hours. However, of these 55 sites, 12 were considered feasible with energy production of 2,700 gigawatt hours, a capacity of 1,500 megawatts, and a capacity factor of 20 percent. Key factors in determining energy

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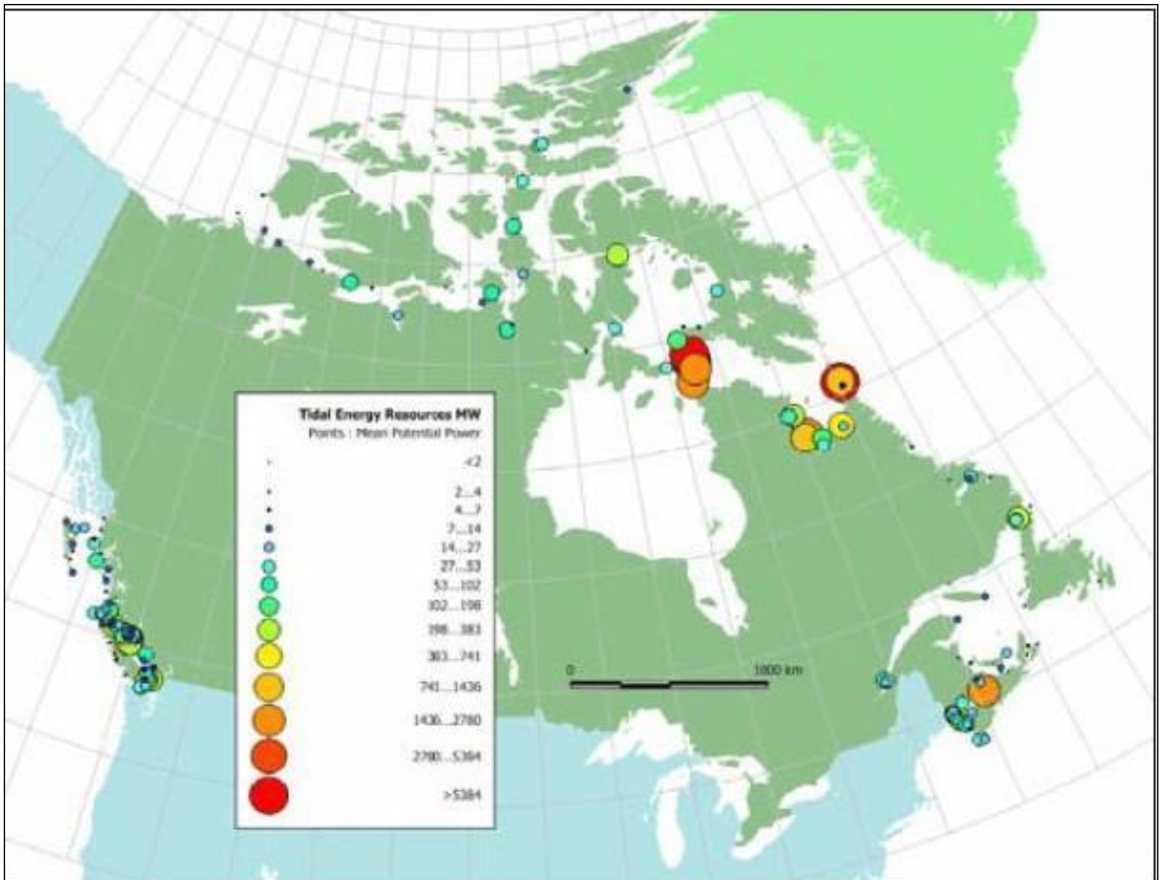
[13] Wikipedia, Manitoba Hydro

[14] Natural Resources Canada, Canmet Energy Technology Centre, Renewable Energy Technologies: Marine Energy

[15] New Scientist, The tide is turning, October 11, 2008, p. 35

potential are the phasing of the tides and the presence of narrow passages that concentrate the water flow. Tidal current energy is regular, predictable and renewable. In British Columbia, some of the highest velocity tidal flows occur in the passages between the Strait of Georgia and Johnstone Strait.[16] The costs of capturing the tidal energy is currently high, but the technologies are similar to wind farms.



Leading tidal current power sites in Canada

Salinity

Two technologies are currently under consideration to generate electric currents based on the differences in salinity between ocean water and fresh water from a river. These technologies place one or more membranes between salt water from the ocean and fresh water from a river. Generating systems would be located where there is salt water, with fresh water piped down to the station.

In one technology (pressure retarded osmosis), one membrane draws fresh water through it, increasing the water pressure on the salt water side. This increased pressure drives a

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[16] BC Hydro, Green and Alternative Energy Division, Green Energy Stu7dy for British Columbia – Phase 2: Mainland, October 2002, p. 23 - 26

generator. In February 2009, the Norwegian power company Statkraft was constructing the first power station using this technology.

In the other technology (reverse electrodialysis power-cell), one membrane allows positive sodium ions from the salt water to pass through it, while the other allows negative chlorine ions to pass through. The system is structured so that positive sodium ions move to the cathode, while negative chlorine ions pass to the anode. This creates a voltage across the cell.

The long-run power costs from the technology are estimated to be comparable to other renewable energy sources. As a power source, salinity power does not have the intermittency problems associated with solar and wind power. The estimated potential is about 2 megawatts per cubic metre of useable river flow.[17]

Nuclear

Nuclear power provides an opportunity to meet Canada's electricity need by 2060.

Canada is a leading supplier of uranium. Canada has developed relatively safe technologies for nuclear reactors. It has designed and built power plants around the world, and operated 7 power stations and a capacity of 15,358 megawatts.

Canada's Nuclear Power Generation Capacity, 2009

Nuclear Station	Province	Units	Output per Unit (MWe)	Output (Mwe)	In Service Date	Operator
Pickering A	Ontario	4	515	2,060	1971-1973	OPG
Pickering B	Ontario	4	516	2,064	1983-1986	OPG
Darlington	Ontario	4	881	3,524	1990-1993	OPG
Bruce A	Ontario	4	750	3,000	1977-1979	Bruce Power
Bruce B	Ontario	4	860	3,440	1984-1987	Bruce Power
Gentilly 2	Quebec	1	635	635	1983	Hydro Quebec
Point Lepreau	New Brunswick	1	635	635	1983	NB Power
Total				15,358		

Source: Natural Resources Canada

Meeting all Canada's energy needs by 2060 through nuclear energy would entail an increase of about 20 times the current capacity. An expansion of this magnitude is unlikely, given concerns about reactor safety, terrorism, handling radioactive waste, economic viability, and local opposition to new nuclear sites. For these reasons, no new reactors have come on line in Canada since 1993. Nevertheless, nuclear power does provide one mechanism to address Canada's energy needs by 2060. An informed debate on the nuclear option would need to balance the negative environmental consequences of the nuclear option, against the negative environmental consequences of uncontrolled global warming and fossil fuel emissions.

New Nuclear technologies that may improve nuclear energy include:

- Manufacturing approach, in which modules of components are made in factories and bolted together on site.

[17] New Scientist, Salt solution, February 28, 2009, p. 40

- Passive safety, where safety measures kick in automatically in an emergency e.g. control rods that control the speed of reactor drop by gravity rather than having to be inserted mechanically.
- Nuclear batteries, in which manufacturers deliver factory made sealed units with an output of 10 megawatts and a lifetime of 15 to 30 years. When finished, the batteries are sent back to the factory.
- Pebble-bed reactors, fueled by small spheres that are in essence tiny reactors made of uranium oxide and graphite. When the pebbles are piled together, a chain reaction starts. Inert gases such as helium are passed through pebbles to collect the heat. The systems have passive safety, because of Doppler Broadening, which changes the speeds of the neutrons and makes them less likely to cause fission, thereby shutting down the reactor if it overheats. However, graphite can burn, helium is hard to contain, and it is hard to keep air out of system and air can cause a fire.[18]

There is always the potential for a better understanding of the physical universe to lead to breakthrough technologies. One such technology is cold fusion. Discovered in 1989, cold fusion has been able to generate excess heat in ways not readily explained by current theories. While there is a reasonable potential for technological breakthroughs, it is unrealistic to factor this potential into Canada's energy supply by 2060.

Another technology is nuclear fusion. Fusion reactors have been operating since the mid-1950s in the Soviet Union, United Kingdom, the United States, Germany, India, Japan, China and South Korea. The latest nuclear fusion project is ITER, an international collaboration that began in 1988. The design of the reactor was approved in 2001, and construction is expected to be completed by 2020. The goal of ITER is to output power 10 times greater than the power input. The challenge is to achieve the remarkably high temperatures needed for atoms to fuse (150 million degrees Celsius), while confining the plasma within the reactor cell without touching the wall. If ITER is successful, the next stage would be to construct a fusion power plant in about 2030. Unlike fission reactions, fusion reactions do not produce long-lived radioactive waste.[19]

There are several problems with nuclear technologies. One is potential for nuclear accidents and terrorist attacks. Another is the storage and management of spent nuclear fuels. A third is the fact that nuclear reactions heat the atmosphere – an undesirable property if one is trying to limit global warming.

Thermal

A report from the Massachusetts Institute of Technology claims there is enough geothermal capacity in United States to meet its needs 2000 times over. Presumably, a similar situation exists in Canada.

The best sites are in places that are geologically active and have heat near the earth's surface that can be recovered as natural hot water or steam. These places include Iceland, Japan, New Zealand, and British Columbia.

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[18] Economist, Life after death, June 21,2008, p. 22
[19] New Scientist, ITER: the way to a benign and limitless new energy source, special supplement, 2009

BC Hydro has identified sixteen geothermal sites based on their geological setting (volcanism, faults), evidence of repeated volcanism, and the occurrence of hot springs and other geothermal manifestations. Of these, six offered the greatest potential for short-term commercial development based on factors such as resource characteristics, and proximity to the grid and markets.

BC Hydro estimated the resource potential of these sites at between 150 to 1,070 megawatts, with energy production potential of 1,200 to 9,000 gigawatt hours (4,320 to 32,400 terawatts) per year. Geothermal plants operate at 100 percent of capacity and plants were assumed to be in production 95 percent of the time.[20]

In locations that are not geologically active, the energy is there, but it is several kilometres below the ground.

The latest technology for extracting this energy is known as “advanced geothermal systems”. The concept involves finding hot, dry, impermeable rock such as granite. Canada is well endowed with granite rock. Impermeable rocks are the best reservoirs of heat. Rocks need to be at 150ºC to 250ºC. Dryness increases the heat capacity. Getting the heat out requires that the impermeable rocks become permeable to some extent through fracturing. This makes them porous, so that water can run through them. Then, water is injected into the rocks. The water heats up as it circulates through the hot rocks. The hot water is then pumped back to the surface through a heat exchange.

There are a variety of issues with this technology, including:

- Lack of survey data. Most geological surveys to date have looked for other types of geological information.
- Fissuring the rock. The starting point is to find rock that fractures reliably. Work is needed to find better ways to force open fissures in rock to make them permeable, but not too permeable. The heat exchange medium pumped out of the ground has to flow consistently at rates sufficient to run a power station. If the rock is too permeable, the medium will flow away.
- Drill design. Oil and gas companies carry out most of the geological drilling these days, but they avoid drilling through the hard rocks that are essential for advanced geothermal systems. Conventional drill bits wear out, lose effectiveness, and need to be replaced. Replacement lengthens the drilling time. Conventional drill bits are being replaced by high pressure jet streams at 800ºC. This reduces wear on equipment, and allows for longer drilling times and fewer delays.
- Heat exchange medium. Pressurized CO_2 could replace water as the heat exchange medium. Supercritical CO_2 can move through the system faster than water. This could increase extraction efficiency by 50 percent, and would sequester CO_2.
- Costs of well casings. With deep wells, a lot of casing is required.
- Earthquake risks. As oil and gas fracking has demonstrated, injecting fluid into hot dry rocks can trigger earthquakes. Scientists need to understand what causes these quakes and how to prevent them.

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[20] BC Hydro, Green and Alternative Energy Division, Green Energy Study for British Columbia, Phase 2: Mainland, p. 18-22.

An advantage of this technology is that most activity occurs well below the surface, so surface rights are not an issue.[21] [22] [23] [24]

Commercialization

A mix of renewable energy sources can easily supply Canada's energy requirements for electricity, but will they be able to do so at an affordable cost? Yes, according to the World Energy Assessment. The cost of most renewable energy sources will drop to become competitive or better than the current cost of coal – the cheapest fossil fuel. The future cost of energy from fossil fuels should rise as natural gas and oil supplies shrink and through the imposition of emission taxes or the regulatory requirement to capture and sequester CO_2 from the combustion of fossil fuels.

Electricity Costs		
	2001 Energy Cost	**Potential Future Energy Cost (2001)**
	US¢ per kilowatt hour	**US¢ per kilowatt hour**
Wind	4 - 8	3 - 10
Solar Photovoltaic	25 - 160	5 - 25
Solar Thermal	12 - 34	4 - 20
Large Hydropower	2 - 10	2 - 10
Small Hydropower	2 - 12	2 - 10
Geothermal	2 - 10	1 - 8
Coal	4	Not allowed
Source: Wikipedia, Renewable Energy from World Energy Assessment, 2004 Update		

Grid Management

The requirements of the electricity grid in 2060 will include:

- A collection system from an optimal mix of nuclear/renewable suppliers over a wide area to collect sufficient electricity to power Canada in 2060.
- A distribution system to meet existing demands as well as new demands to replace fossil fuels used in stationary combustion sources and for batteries to be used in road transport.
- A transmission system capable of moving electricity from collection to distribution points. The transmission system will be moving more electricity (because of the system expansion) greater distances (because of the geographic diversity of suppliers) and sometimes in both directions (because, for example, the West may supply the East on some occasions, and then receive power from the East on others).
- Storage/on-demand supply and demand management. The system needs to be able to deliver electricity when users want it. This will necessitate an array of strategies to store energy, to produce power on demand, and to manage demand so that requirements fall when electricity is in short supply.
- Reliability. With the country depending on the electrical system, special care needs to be taken to ensure that technical failures do not occur, that the system is not vulnerable to

[21] New Scientist, Who needs coal when you can have deep heat, July 19, 2008, p. 24
[22] New Scientist, Going underground, October 11, 2008, p. 37
[23] New Scientist, Who needs coal when you can have deep heat, July 19, 2008, p. 24
[24] Economist, Beneath your feet, June 21, 2008, p. 14

sabotage and that the system is protected against natural disasters such as earthquakes or solar storms.
- Optimization and lowest possible costs. Optimizing the design of the overall system is the best way to ensure costs of electricity are the lowest possible.

The Collection System

Electricity has to be available when people want it. Currently, Canadian systems generally entail the provision of a basic and relatively constant supply of electricity, combined with the additional capacity (usually driven by natural gas) that can kick in when required to meet peak demands.

In shifting to energy supplies that are not based on fossil fuels, Canadian grid managers will need to deal with intermittent supplies of electricity. One approach is to use a variety of types of supply: wind, solar, hydro, ocean, nuclear, thermal, space-based solar. Another is to collect electricity from a wide geographic area.

For example, the wind may not always be blowing. Furthermore, clouds and night-time and the differing duration of days over the seasons and the lower light intensity in winter reduce the reliability of solar energy. Winter freeze up may reduce river flows in winter while the spring thaw can dramatically increase river flows in early spring. With many forms of renewable energy, suppliers in a local area are often not able to provide a reliable supply of electricity because the wind is not always blowing, or the sun is not always shining. The solution is to incorporate suppliers from a wide area, because the wind will be blowing and the sun will be shining somewhere.

There are five electrical grids in Canada and the United States: the Eastern Interconnection (Manitoba, Ontario, the Atlantic provinces and the eastern American states); the Quebec Interconnection; the Texas Interconnection; the Alaskan Interconnection; and the Western Interconnection (Alberta, British Columbia and the western states). All electrical utilities within an interconnection are electrically tied together during normal times and operate at a synchronized frequency.

Currently, energy is collected from nuclear and renewable sources, and from fossil-fuel sources. The removal of fossil fuel sources of electricity, plus the need by 2060 to deliver electricity to replace energy previous provided by direct deliveries of fossil fuels through pipelines, gas stations, propane tanks, etc., the collection from renewable and nuclear suppliers will need to be up to 3.76 times the current level.

The Distribution System

Storage

However, even with diverse supply, storage capacity will be necessary. With non-fossil energy sources, storage will occur at all levels. Energy producers will be paid to some extent in accordance with the reliability of their electricity supply. Consequently, they will probably have electricity storage capacity on their sites. Electricity distributors will undoubtedly want control over energy storage, to ensure that power is available when needed. They will likely focus on large scale storage mechanisms. Consumers will need to store electricity in batteries at a minimum to operate their motor vehicles. To the extent that energy grids are not totally reliable, they will probably invest in storage mechanisms such as uninterrupted power supplies.

Storage options include:

- Natural gas and coal generation with carbon sequestration of the emissions. The viability of this option will depend on the viability of carbon capture and storage, and tolerance for emissions from the capture and storage process.
- Batteries. There are a number of battery options, including:
  - Lead acid batteries have been the standard for small scale use.
  - Sodium sulphur flow batteries have been used for grid storage in Japan and the United States.
  - Vanadium redox batteries. With vanadium redox batteries, electricity is stored in chemical solutions in large tanks, and passed into a battery when electricity is needed. The used solution is held in a tank, and when surplus electricity is available, it is used to reconvert the chemicals. This technology is scalable, and can store up to 100 megawatt hours of energy at a single site. Currently, vanadium redox batteries are often used with wind farms to smooth the flow of electricity into electricity grids. A 2 megawatt hour installation with a 12 megawatt hour capacity is to be installed at the Sorne Hill wind farm in Ireland at a cost of $6.3 million.[25] There is also the potential to use these batteries at the grid level.
  - Car batteries. The increasing use of plug-in vehicles equipped with batteries creates the potential to use these batteries to store energy. A 20 to 50 kilowatt hour battery pack has the potential to meet average daily household requirements (10 kilowatt hours) for 2 to 5 days, and to feed energy back into the grid.
- Hydroelectric dams. Currently, hydroelectric plants are run more or less continuously to meet base load energy needs. They can also be run intermittently, with water flowing at certain times and not flowing at other times. In this intermittent mode, they act as storage systems. Dams are, in effect, storage systems, collecting water over time so the water can be used at other times.
- Pumped hydro storage. In these systems, water is pumped up into the reservoir when there is excess energy, and drained out of the reservoir when power is needed. Two reservoirs at different elevations are needed. In Ontario, there is the potential for 1,235 megawatts of practical or probable pumped storage by 2027 from the Steep Rock Mine site (four phases, each 250 megawatts for a total of 1,000 megawatts peaking capacity), and the Fourbass Lake site (providing 235 megawatts peaking capacity).[26]
- Flywheel energy storage. Electric motors spin a fly wheel up to 80,000 revolutions per minute. These systems can store up to 150 kilowatt hours as kinetic energy. While heavier flywheels can store more energy, they also experience more friction. Putting flywheels in a vacuum and using magnetic bearings tend to make flywheels expensive. The faster the spin, the stronger the materials needed to keep the flywheel from flying apart. Technical and economic issues make flywheels more appropriate for short-term energy storage and load-leveling applications than for long-term energy storage.

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[25] New Scientist, Saving up for a windless day, October 11, 2008, p. 31

[26] Pembina Institute, Renewable is Doable, Analysis of Resource Potential and Scenario Assumptions, July 2007

- Super Conducting Magnetic Energy Storage. Energy is stored as a magnetic field generated by large currents circulating in a superconducting coil. These systems are highly efficient, with energy losses to, in and out of the coil of only 5 percent. However, superconductors need to be held at low temperatures, which lead to high energy consumption for refrigeration.
- Hydrogen. Electricity is used to split water into hydrogen and oxygen using surplus electricity. The hydrogen is liquefied or compressed, and then stored. When electricity is needed, the hydrogen is run through a fuel cell. As a storage medium, hydrogen is about 50 to 60 percent efficient. Battery and pumped storage are more efficient than hydrogen. In addition to the storage component, hydrogen storage systems also use up energy in creating the hydrogen through electrolysis, liquefying and compressing it, and the creation of storage systems. Tanks can be used, but large-scale storage for grid purposes can be expensive. As an alternative, underground storage may also be feasible. ICI has stored large quantities of hydrogen underground for years without problems.
- Heated Materials. In solar heat systems, the solar energy can be used to heat molten salts. They can retain their heat for some time before being used to drive an electricity generator.
- Compressed air energy storage. Energy is used to compress air, which is stored in the ground in underground caverns, abandoned mines, aquifers, and depleted natural gas wells. When energy is required, the compressed air is taken from the ground to either spin a turbine directly (replacing the need to compress air immediately before running the turbine), or as a replacement for the compressor in a conventional gas turbine, thereby increasing the efficiency of the turbine. Alternatively, when air is compressed, it releases heat, which can be stored in ceramic bricks. When electricity is required, the compressed air is passed over the bricks. It absorbs heat from the bricks, and then is used to drive a modified steam turbine. The Electric Power Research Institute in California estimates the cost of compressed air storage at about half that of lead acid batteries, and the facilities would add 3 to 4 cents per kilowatt hour to the cost of renewable energy. Issues related to this technology include:
    - Technical requirements of the storage site. The site has to be large and deep enough to be useful. The site needs to be able to contain the compressed air without leakage. Such sites are likely to have an aquifer covered by an impermeable dome. The compressed air is pumped into the dome, displacing the water. The dome and water contain the compressed air. The pressure from the water below keeps a constant pressure on the compressed air. The pressure needs to be sufficient to drive a turbine.
    - Finding technically suitable sites. The technical requirements for a compressed air storage site are similar to those needed to store natural gas, so gas utilities have identified potential sites.
    - Design of the compressed air injection and retrieval system. Operators need to determine the number of boreholes needed to get air in and out of the site quickly.
    - Reactions between the ground water and the compressed air. Operators need to make sure minerals in the ground do not react with oxygen in the stored air. Reactions could adversely affect the quality of the compressed air coming out of the storage site (e.g. in natural gas combustion chambers). Reactions could also affect the ground water.
    - Effects on other users of the aquifer. Aquifer storage may not be suitable near urban areas where there are competing demands for water in aquifers. Where

aquifer wells are nearby, compressed air storage could affect flow in wells.[27] [28] [29] [30] [31]

Super Grids and High Voltage Direct Current Transmission Lines

The more energy from renewable sources, the more unstable national electricity grids become, because most renewable sources generate electricity intermittently. Conventional wisdom among electricity grid designers is that 20 percent electricity supply from renewable energy is manageable and saves fuel costs. However, when renewable energy supplies 30 percent, problems start to emerge in the grid because of the intermittent supply inherent in many renewable energy sources.

Solutions include not only diversity in the types of renewable energy put into the electricity system, but also a wide-area grid. With a wide-area grid, the chances are that somewhere within the grid the wind will be blowing, or the sun will be shining, or both. Wide-area grids require the ability to move large amounts of electricity over large distances in any direction.

High voltage direct current transmission lines should be part of the answer. Traditionally, transmission lines bring electricity from sources of supply to markets. In some cases, transmission lines are long. For example, bringing electricity from hydroelectric dams around James Bay requires long transmission lines. In other cases, sources of electricity supply have been situated close to markets, reducing the length of transmission lines that are required. Nuclear, coal and natural gas power plants are normally located relatively close to markets.

When power grids rely on energy sources other than fossil fuels, the energy source locations are not necessarily aligned with population centres. This necessitates longer transmission lines.

In addition, there will be a need to move electricity over large areas to accommodate intermittent supply. If the wind is blowing in Western Canada and Atlantic Canada but not Ontario, electricity will need to move from Western and Atlantic Canada to Ontario. At a later time, electricity will need to move in the opposite direction when the Ontario has windy conditions and the other regions are calm. If electricity grids are to take advantage of the abundant solar energy in the south-western United States, northern areas like Canada will need long transmission lines.

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[27] New Scientist, Squeeze the breeze, September 29, 2007, p. 44

[28] Scientific American, A Solar Grand Plan, May 22, 2008

[29] New Scientist, Saving up for a windless day, October 11, 2008

[30] Examples of compressed air storage projects underway or planned include the Iowa Storage Energy Park, which will store wind energy to produce electricity 16 hours per day; the 290 MW system in Huntorf, Germany, which produces 2 hours of electricity at full power; a 100 MW system in Alabama, which produces 26 hours of electricity.

[31] Wikipedia, Grid Energy Storage

The ability to move large amounts of electricity over long distances becomes very important. There are basically two approaches to transmission lines. Both involve high voltages. High voltage is necessary to reduce energy lost in the resistance of the wires.

For practical purposes, manipulating direct current voltages only became possible with the development of high-power electronic devices, including mercury arc valves and semiconductor devices such as thyristors, insulated-gate bipolar transistors, and gate turn-off thyristors.

Traditionally, long distance transmission lines have been based on alternating current at high voltages. High voltage direct current lines are an alternative, offering several advantages:

- Construction costs: Direct current lines are cheaper to build and require less land than alternating current lines. Thinner conductors can be used to conduct the same amount of power. Fewer conductors can be used.
- Energy losses in transmission: With direct current, the current flows in one direction. With alternating current, the current reverses direction 100 to 120 times a second. This induces currents in the transmission line insulation, which is lost as heat. Oak Ridge National Laboratory has concluded that direct current lines lose far less energy than alternating current lines over equivalent distances. At 1,000 kilometres, alternating current transmission lines lose 10 percent of the energy pumped in, while direct current lines lose 3 percent. Against these efficiency gains is the cost of converting direct current to alternating current, estimated at 0.6 percent.
- Direct current cables can go on the seabed (e.g. between Newfoundland and the mainland, or Vancouver Island and the mainland) or underground, since power is not lost to the surrounding area. Alternating current transmission lines produce powerful electric fields that cause large power losses.

Manitoba Hydro installed two high voltage direct current transmission lines to bring power from hydroelectric projects on the Nelson River to load centres in southern Manitoba. At the time of construction, they were the longest (900 kilometres) high voltage direct current lines in the world. They carry about 68 percent of the generation capacity in the Province.

There are about 500 miles of high voltage direct current lines in the United States today. Europe has a direct current grid linking Scandinavia, northern Germany and Netherlands. A major grid is planned for Europe and Africa. There are over 100 high voltage direct current lines in current use. [32] [33] [34]

A number of studies have pointed out the potential of super grids covering a wide area and based on high voltage direct current transmission lines. These grids can manage the challenges of intermittent power sources and the need to average and smooth outputs to produce a stable supply of electricity.

[32] Scientific American, A Solar Grand Plan, May 22, 2008
[33] New Scientist, Edison's revenge, October 11, 2008
[34] Economist, Trade winds

Gregor Czisch, an energy system consultant, outlined the potential of a super grid in the European context. He made the first quantitative study demonstrating that a super grid can be economically viable, yet based on a totally renewable electricity supply. Czisch gathered relevant data for a renewable grid over years. The data covered weather, electricity consumption, power generation technologies, investment costs and the like. He considered only proven technologies. He entered the data into a linear optimization program designed to select the cheapest supply system from various options to satisfy European demand from renewable energy. The model picked the sites for power generation, as well as the routes and capacities of high voltage direct current transmission lines. The study concluded that the best option was based primarily on wind power mostly from the Baltic Sea, Morocco and Egypt, supplemented by hydropower from the Nordic countries to be used to meet peak load requirements.[35] [36]

There are, of course, several challenges in implementing a super grid in North America. In Canada, while one would think there is a role for the federal government, electric power systems are generally operated by provincial utilities, some of which not only distribute power but also generate it. Where provincial utilities are power producers or provincial governments depend heavily on the fossil fuel production for revenues, there may be resistance to move toward non-fossil-based energy sources. Corporate interests also need to be addressed; small area grids created area monopolies that would be challenged in a wide area grid. Jurisdictions where governments control electric power distribution are better equipped than those where distribution is in private hands.

There are also technical challenges. Most existing high voltage direct current transmission lines are "point to point", consisting of a single line with alternating current converter stations at each end. In a super grid, arrangements would need to be "multipoint", with converter stations able to feed in and draw out power at various points. The network would have to be able to deal with failures in one line by automatically diverting power along other lines. A sophisticated control system would be necessary. While a super grid may be technically feasible, the necessary equipment (e.g. better direct current circuit breakers) may not be commercially available at the moment, but keep in mind we are looking at a 2060 time frame.

Despite these challenges, the establishment and operation of a super grid could be completed well before 2060. The early completion of the North American equivalent of Czisch's study would provide guidance regarding the types of renewal energy sources necessary to create an efficient super grid.

Removing Demand Peaks

Electricity system managers require enough capacity in the system to meet peak demand. As a result, without efforts to distribute the demand over the time of day and day of the year, the capacity of the system has to be substantially above base or minimum operating

[35] New Scientist, Green grid, March 14, 2009, p. 42

[36] G. Czisch, Low Cost but Totally Renewable Electricity Supply for a Huge Supply Area – A European/Trans-European Example.

requirements. The creation of this capacity, which will be unused much of the time, increases the cost of electricity supply.

To address this problem, electricity managers will increasingly rely on a variety of techniques to remove the demand peaks that arise from time to time. These techniques will include:

- Smart meters and demand pricing. The concept is simple. Electricity users pay more when demand for electricity is high. As a result, a significant percentage of users may delay their electricity consumption to a time of lower demand and prices. To make this system work, electricity suppliers need to charge different amounts at different times and electricity meters need to record when electricity is used. As an example of how the system works, the United States Department of Energy equipped 112 homes in Washington State with meters that receive updates on energy prices every 5 minutes. Homeowners received devices that could regulate their heating systems by identifying an ideal temperature, and how many degrees they were prepared to see it vary in response to a price change. The system switched the heating on and off. It saved 10 percent on consumer electricity bills over a year, and reduced peak demand on the energy grid by 15 percent.[37]
- Smart appliances. These appliances switch themselves off when they detect a drop in electric current below an expected level. In Italy, 100 refrigerators were equipped with a controller that checks temperatures. The controller calculates how long a refrigerator can stay off before the temperature rises. There was a similar test for tumble dryers in Richland, Washington. Having consumers shed load saves the power companies from doing so. According to the United Kingdom's Department of Business, Enterprise, and Regulatory Reform Technology, the estimated cost of the controller is £4 against savings of £30 over the lifetime of a refrigerator. The savings comes from not having to build extra capacity to handle peak loads.[38]
- Smart Grid. In smart grid systems, utilities are in constant communication with controllers in consumer appliances such as dryers, refrigerators, and water heaters. Utilities predict when demand for power exceeds available supply, and tell non-essential appliances to shut off on some agreed basis. For example, the utility and the consumer may agree that the air conditioner might be shut off for 15 minutes – a time calculated to not allow a significant increase in house temperature. Alternatively, the thermostat on the air condition may be turned up a degree or two a limited number of times during the year. Consumers agree to the arrangement because they understand the benefits in terms of electricity costs, they get reduced rates as an incentive, or they get a new thermostat.
- Encouraging Users to Go Off the Grid. In the United States, there are 200,000 off-grid households. This figure has been increasing by about a third each decade. There are 30,000 grid-connected households that supplement supplies from the grid with renewable sources. In the United Kingdom, there are about 40,000 off-grid households. Renewable technologies for photovoltaics, windmills and turbines are improving rapidly. The costs are dropping through economies of scale. Many renewable technologies can be implemented on a small-scale basis, including within the residential home. It is likely that an increasing number of residential, commercial and industrial customers will either go off-grid completely, or produce energy for the grid and to take energy from the grid depending on need and availability. For consumers, the benefits of

[37] New Scientist, Smart heating fits the bill, January 19, 2008, p. 21
[38] New Scientist, Will the lights say on, October 11, 2008, p. 30

going off the grid, or supplementing grid supplies with renewable sources include guilt-free energy, savings related to distribution costs, and greater control (if something goes wrong, the consumer can fix it.). For electricity suppliers, it reduces demand on the grid. For this reason, Germany and other jurisdictions price incentives to encourage local production of electricity. Where local production exceeds local demand, utilities buy the surplus electricity.

A Final Note

Noted above was the fact that to meet final energy demand from renewable sources would require an expansion of renewable and nuclear energy production of **!Undefined Bookmark, RENEWABEE** percent. In 2012, 39.2 percent of current electricity production comes from fossil fuels. This production is currently delivered through the grid. The requirement to expand the grid will be less than the requirement to increase production, because grid capacity to distribute electricity produced from fossil fuels is already in place.

Getting to Zero by 2060

Getting to zero by 2060 means:

- An expansion of electricity production from renewable sources by about 3.76 times over the current level to replace the energy currently produced from fossil fuels.
- An electricity system based on:
  - A diverse array of renewable energy sources such as solar, wind, water, nuclear and geothermal energy sources.
  - The use of a diverse array of electricity storage systems (pumped hydro storage, hydro storage, batteries) at various levels (electricity producers, industry, households).
  - Super grids covering all of Canada and between Canada and the United States, and using high voltage direct current transmission lines to move power around the continent in response to supply and demand.
  - The operation of smart grids that increase efficiency.
- The decreasing reliance by households and industry on the grid as an energy source, driven by the desire for control over energy plus new technologies that facilitate the local production and utilization of renewable energy.
- The use of fossil fuels only for emergencies to manage peak loads and to address periods when the sun does not shine and the wind does not blow over a wide area.
- The capture of the fossil fuels that are used.

Projected Emissions

Projected Emissions for 2060: Electricity and Heat Generation			
Greenhouse Gas Categories	**2012**	**2060 Projection**	**Comments**
	kt CO2 eq	**kt CO2 eq**	
Electricity and Heat Generation	88,300	2,208	Current emissions times 5 percent contingency, as electricity comes almost totally from renewable sources, with natural gas used to address demand spikes times 50 percent for uncaptured emissions when natural gas is used.

Chapter 4: Stationary Combustion Sources

Past Emissions

Canada's 1990–2012 Green House Gas Emissions: Stationary Combustion Sources					
Greenhouse Gas Categories	**1990**	**2012**	**2012**	**Change 1990-2012**	
	kt CO2 eq	**kt CO2 eq**	**% Total 2012**	**kt CO2 eq**	**% Total Change**
Total – All Sectors	590,253	708,713	100.0%	107,660	18.2%
Stationary Combustion Sources excl. electricity & heat generation, fossil fuel production	129,310	116,770	16.7%	-12,540	-9.7%
Manufacturing Industries	55,850	43,080	6.2%	-12,770	-22.9%
Iron and Steel	*4,950*	*5,480*	*0.8%*	*530*	*10.7%*
Non-ferrous Metals	*3,260*	*3,250*	*0.5%*	*-10*	*-0.3%*
Chemical	*8,220*	*10,100*	*1.4%*	*1,880*	*22.9%*
Pulp and Paper	*14,500*	*5,890*	*0.8%*	*-8,610*	*-59.4%*
Cement	*3,920*	*3,960*	*0.6%*	*40*	*1.0%*
Other Manufacturing	*21,000*	*14,400*	*2.1%*	*-6,600*	*-31.4%*
Construction	1,870	1,450	0.2%	-420	-22.5%
Commercial & Institutional	25,700	27,800	4.0%	2,100	8.2%
Residential	43,500	40,900	5.9%	-2,600	-6.0%
Agriculture & Forestry	2,390	3,540	0.5%	1,150	48.1%

In 2012, 16.7 percent of Canada's greenhouse gas emissions came from the production of energy from stationary sources other than the production of fossil fuels and electricity and heat generation. Over the period 1990 to 2012, emissions from these sources fell by 9.7 percent (12,540 kilotonnes CO_2 equivalents).

Residential emissions accounted for 5.9 percent of Canada's total, but fell 6.0 percent from 1990 levels despite population growth. Commercial and institutional emissions were 4.0 percent of Canada's total, and increased by 8.2 percent of the 1990 level. Commercial and institutional emissions accounted for 4.0 percent of Canada`s total, and rose by 8.2 percent between 1990 and 2012.

Note the significant decline in residential emissions. While population and floor space use per capita went up 26 and 30 percent between 1990 and 2012, improvements in the energy efficiency of the housing units, the efficiency of the heating systems, and changes in the fuel mix (oil and coal to natural gas) pushed down emissions, leading to a net decline.

Most of these stationary emission sources are already on electrical networks. They choose emission-based sources of energy over other sources because emission-based sources are currently cheaper for them. To the extent that Canada can generate sufficient electricity without burning fossil fuels, get this electricity to the sectors, and persuade or force these sectors to use electricity for their stationary energy requirements, it could substantially reduce 16.7 percent of its emissions. The primary requirement by 2060 is the conversion of these industries to energy sources other than fossil fuels.

Stationary emission sources that do not have access to an electrical grid include remote mines, remote communities particularly in the north, rural residences and businesses. In many cases, they will be able to replace diesel fuels with energy from renewable sources, including wind and solar. Carbon capture may also be possible. In addition, the expansion of the electrical grid could enable these emission sources to get their energy from electricity from renewable sources. The use of direct current transmission technologies could enable island communities to access the grid.

While most entities that combust fossil fuels to produce energy can convert to electricity, the conversion process will be expensive, but there are forty-five years to 2060. Within this period, most furnaces, water heaters, boilers, and other machinery and equipment will be replaced several times.

Reducing Energy Demand

While the conversion from fossil fuels combustion in stationary sources to electricity will reduce emissions significantly, it is worth listing the potential for energy savings, particularly in the residential, commercial and institutional sectors as we head to 2060. These saving should more than offset any increased energy demands from population growth expected over the period.

- The outside temperatures will continue to rise as a result of global warming, reducing the heating requirements. Although cooling costs will rise, as a northern country, Canada uses much more energy for heating than cooling.
- As residential homes convert to electricity, there will be energy savings as electric (baseboard) heating systems are highly efficient; no heat goes up the chimney, and as heat pumps systems are installed. These systems produce more energy than they consume.
- Electrical heating opens up the potential for smart heating systems, where only the rooms in use are heated.
- The total housing supply will continue to become more energy efficient, through higher construction standards and more insulation on new homes, continued retrofitting of existing homes, and the replacement of older less energy efficient homes,
- Higher construction standards include:
    - Better insulation in the attic and basement.
    - Better insulation and sealing of heating and cooling ducts, so the hot or cool air is delivered more efficiently.
    - Preventing air leaks by sealing all joints.
    - Using high performance windows that reduce heat loss in winter and control heat in summer.[39]
    - Using heat exchanges to trap the collect and recycle the heat from hot water used in showers, dishwashers, wash basins and the kitchen sink.
    - Designing homes for point of service water heaters, so there is much less heat loss by storing hot water in a tank and by leaving hot water in pipes.

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[39] New Scientist, Building for a Cooler Plant, July 28, 2007

- Applying new and existing technologies to identify and correct air leaks in existing buildings.
- Designing energy efficient communities, including:
  - Increasing the proportion of multiple dwelling units, so more walls are shared and less are exposed to the outside.
  - Designing communities for collective solar heating systems. For example, in Anneburg, Sweden, 50 households pump water through solar heaters on rooftops to warm it. Water is stored in granite 65 metres deep, and pumped back in winter. The system reduced reliance on conventional heating by nearly 25 percent, but savings are expected to go to 70 percent as storage rocks get hotter.[40]
  - Designing communities for thermal pump storage systems. According to Natural Resources Canada, thermal pump storage systems produce 1.9 percent more energy than it costs to operate them.
- Better housing designs, including:
  - Better utilization of interior spaces, producing the same functionality with less floor space.
  - Utilizing the space previously occupied by furnaces and central air systems.
  - Positioning the house to take full advantage of sunlight.
- Changes in consumer purchasing patterns toward smaller housing units per capita, in response to increased environmental awareness and perhaps increased energy prices.
- Increased sharing of accommodation space, as part of the sharing movement now possible through computer technology and readily adopted by younger people.
- Using fans and improved mechanisms for removing hot air from houses in summer during the night time. In many houses, night time temperatures are higher in the house than outside, so improved removal of hot air will reduce the use of air conditioners.
- Using plants on walls and roofs to reduce air conditioning costs in summer. Green surfaces absorb less heat than typical building covers, and radiate more heat back into the immediate vicinity. Plants cool air through evaporation. In Montreal peak temperatures could drop by 4ºC.[41]
- Increasing efficiency of residential appliances by
  - Eliminating by government regulation electricity use by appliances when the appliance off. Surprisingly, some appliances use electricity when off.
  - Eliminating by government regulation electricity use in an appliance when in stand-by mode. In stand-by mode, the appliance continually checks for signals from a remote controller. Appliances consume electricity in varying amounts in standby mode, and government regulations could set maximum standards.[42]
  - Air drying clothes to the extent possible, rather than using the tumble drier.
  - Requiring by government regulation that home computers have the same energy saving technologies as laptops.
- Using energy efficient lighting. We have moved past the incandescent light bulb, to compact fluorescent lights (coiled up versions of fluorescent tubes), and are now moving to light emitting diodes, which are semiconductor devices that emit light when a voltage is applied. Each light emitting diode is typically a stack of five very thin layers of indium, separated by gallium nitride layers. In comparison with compact fluorescent lights and incandescent lights, light emitting diodes have several advantages:

[40] New Scientist, Solar heat in the depths of winter, July 21, 2007, p. 25
[41] New Scientist, It's Cooler to be Green, October 6, 2007, p. 6
[42] New Scientist, Feeding your gizmos, December 13, 2008, p. 23

  - They are more energy efficient, converting 70 percent of the electrical energy into light.[43]
  - They switch on immediately without a warm-up, unlike compact fluorescent lights.
  - They can burn on average 100,000 hours before needing replacement – ten times longer than compact fluorescent lights and 130 times longer than incandescent lights.
  - Unlike compact fluorescent lights, they do not contain small amounts of mercury, which creates a disposal problem.
  - Light emitting diode lighting does not cast ultraviolet or infrared radiation, so it is safe for illuminating art.[44]
- Improving efficiency in commercial and institutional buildings by:
  - Using existing technologies to reduce energy use in buildings. A collection of studies found that energy use in buildings could be cut by 30 percent using existing technologies, leading to savings that would pay for themselves in 3 to 7 years. For example, a slow flow of air at floor level in commercial buildings can cut energy used for ventilation by up to 60 percent.[45] Window sizes can be reduced.
  - Encouraging innovation. For example, Arian de Bondt, of Ooms, a Dutch building company, persuaded his company to create a circuit of interconnected water pipes under a street, just under the asphalt. Some pipes take heat down 100 metres into a natural aquifer, into which a series of heat exchangers have been built. The aquifer stores the heat, which is used to heat the building in winter and to keep the road snow and ice free. In winter, a reverse process transfers cold to the aquifer. Cool water is used to cool the building in summer. Taking heat from the asphalt lengthens its life by preventing softening.[46]
  - At the municipal scale, use colour to cool urban areas. In the Almeria region of Spain, there are 26,000 hectares of greenhouses. Satellite data indicate that in comparison with pasture land, the greenhouse region has cooled by 0.3ºC, while farmland in the rest of Spain has warmed by 0.5ºC.[47]
- Taking measures to apply new energy savings technologies rapidly, through rapid changes to building codes, etc. For example, engineers at Oak Ridge National Laboratory have designed a system to reduce the cooling bill of houses by 8 percent and reduce attic temperatures on sunny days by 5ºC. The system includes: reflective tile surface pigments; reflective material under the rafters; novel tile shapes that vent warm air from the roofing cavity; and special sheets above the attic floor. The special sheets start to melt at 23ºC and prevent temperature from rising till all is melted, delaying the transfer of heat to the living space. At night temperature, the sheets re-solidify. Different materials are being tested for the sheets. They include paraffin wax contained in microscopic beads and calcium chloride hydrate packed in aluminium foil.[48] The challenge is to get new technologies into practice rapidly.

Getting to Zero by 2060

Getting to zero by 2060 means:

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[43] New Scientist, It's lights out for the household classic, March 31, 2007
[44] Ottawa Citizen, Bark cabin has an enviro bite, October 6, 2007, p. I 4
[45] New Scientist, Building for a cooler planet, July 28, 2007, p. 8
[46] Economist, Heat from the street, December 8, 2007, p. 8
[47] New Scientist, Hot white roofs are height of cool, October 11, 2008, p. 15
[48] New Scientist, Cool your roof to save the planet, September 15, 2007, p. 32

- Where there is access to the grid, the conversion of industrial, residential, commercial and institutional facilities so that they stop using fossil fuels in stationary combustion equipment and start meeting their energy needs from the electricity grid, and non-grid renewable sources. Most current industrial, residential, commercial and institutional facilities have access to the grid.
- Recognizing that while this conversion may appear onerous, current emitters have over 40 years to carry out the conversion, a period sufficiently long that all combustion equipment will wear out and have to be replaced anyway, and buildings will need to be retrofitted.
- Where there is no access to the grid (e.g. remote industries, particularly mines and mineral refining operations; remote communities; rural homes), allowing the continuation of combustion of fossil fuels, subject to regulation and where feasible, carbon capture.
- Recognizing the considerable scope for the reduction in energy use, particularly in the residential and transportation sectors.

Projected Emissions

Projected Emissions for 2060: Stationary Combustion Sources			
Greenhouse Gas Categories	**2012**	**2060 Projection**	**Comments**
	kt CO2 eq	**kt CO2 eq**	
Stationary Combustion Sources excluding Electricity & Heat Generation and Fossil Fuel Production	116,770	2,919	Current emissions times 5 percent representing the residual after 95 percent of current stationary combustion sources get energy from the grid or create their own renewable sources, times 50 percent representing the residual after the remaining emissions are captured.

Chapter 5: Road and Off-Road Transportation

Past Emissions

Canada's 1990–2012 Green House Gas Emissions: Road and Off-Road Transportation					
Greenhouse Gas Categories	**1990**	**2012**	**2012**	**Change 1990-2012**	
	kt CO2 eq	**kt CO2 eq**	**% Total 2012**	**kt CO2 eq**	**% Total Change**
Total – All Sectors	590,253	708,713	100.0%	107,660	18.2%
Road and Off-road Transportation	120,563	170,012	24.0%	49,449	41.0%
Road Transportation	96,763	132,412	19.0%	35,649	36.8%
Light-Duty Gasoline Vehicles	*45,500*	*38,300*	*5.5%*	*-7,200*	*-15.8%*
Light-Duty Gasoline Trucks	*20,300*	*41,400*	*5.9%*	*21,100*	*103.9%*
Heavy-Duty Gasoline Vehicles	*7,440*	*6,910*	*1.0%*	*-530*	*-7.1%*
Motorcycles	*152*	*268*	*0.0%*	*116*	*76.3%*
Light-Duty Diesel Vehicles	*469*	*824*	*0.1%*	*355*	*75.7%*
Light-Duty Diesel Trucks	*702*	*2,130*	*0.3%*	*1,428*	*203.4%*
Heavy-Duty Diesel Vehicles	*20,000*	*41,700*	*6.0%*	*21,700*	*108.5%*
Propane & Natural Gas Vehicles	*2,200*	*880*	*0.1%*	*-1,320*	*-60.0%*
Off-Road Transportation	23,800	37,600	5.4%	13,800	58.0%
Off-Road Gasoline	*7,800*	*7,600*	*1.1%*	*-200*	*-2.6%*
Off-Road Diesel	*16,000*	*30,000*	*4.3%*	*14,000*	*87.5%*

Gasoline and diesel are a highly transportable form of energy. In internal combustion engines, they give Canadians the opportunity to drive powerful vehicles long distances without refueling. One problem with internal combustion engines is that most of the energy from the combustion of these fuels creates heat and does not contribute to the propulsion of the vehicle.

For every litre of gasoline burned, a car, truck or suburban utility vehicle puts out 2.5 kg of carbon dioxide. The average Canadian car burns 8.6 litres to go 100 km, while the average suburban utility vehicle burns 11.4 litres.[49]

In 2012, road transportation emissions accounted for 19.0 percent of Canada's total emissions. Over the period 1990 to 2012, road transportation accounted for 33.1percent of the growth in emissions.

Light-duty gasoline vehicles and light-duty gasoline trucks accounted for 5.5 and 5.9 percent of Canada's total emissions in 2012. Emissions from light-duty gasoline trucks,

[49] Sierra Club of Canada, On the road to Kyoto: Fuel-efficient cars for Canadians.

which include sport utility vehicles, pickups and minivans, increased 103.9 percent between 1990 and while emissions from cars decreased 15.8 percent.

In 2012, emissions from heavy-duty on road diesel vehicles accounted for 6.0 percent of Canada's emissions and increased by 108.5 percent from 1990. Data trends from major for-hire truck haulers in Canada show that freight hauling by truck has increased substantially since 1990.

Emissions from natural gas and propane vehicles, which were not large in 1990, declined by 60 percent since 1990.

Off-road fuel combustion emissions, which accounted for 5.4 percent of Canada's total, increased by 58.0 percent between 1990 and 2012. (Tar sands?)

Significant trends since 1990 include:

- Increases in the total vehicle fleet, a portion of which would be tied to population growth.
- Increases in the average kilometers driven per vehicle.
- A shift from the smaller light duty gasoline vehicles to SUVs, pickups and minivans.
- Increases in the fuel efficiency of the fleet.
- The replacement of older, less efficient vehicles with newer more fuel-efficient ones.
- The introduction of emissions control technologies, particularly for gases other than CO_2,. including CH_4 and N_2O.
- The adoption of "just-in-time" delivery by many businesses, which has resulted in reliance on heavy trucks in the freight transportation sector, which sometimes act as virtual warehouses.
- The rapid expansion of on-line purchasing and home delivery in the retail sector.
- The expansion of hybrid vehicle usage, with anomalous result that the average weight of hybrids increased by 30 percent, their power increased by 60 percent, and their fuel consumption rose by 15 percent, according to researchers at UBC.[50]
- The trend to more powerful cars, despite the persistent traffic jams in major Canadian cities that make powerful cars irrelevant.

The Electric Vehicle

The table below compares electric vehicles against internal combustion engine vehicles. There are a lot of advantages to an electric vehicle. The main problem is range. The range issue arises because the specific energy in fossil fuels (energy per unit weight) is about 44 times higher with gasoline than with lithium batteries. It should be noted that we only confront the range limitations when we make long trips.

[50] New Scientist, Bigger is dirtier, even for hybrids, April 7, 2007, p. 23

	Electric Vehicle	Internal Combustion Engine
Energy Efficiency	A high percentage of energy is utilized to propel the vehicle	Only a small portion of the energy in fossil fuels (18 to 21 percent) is used to propel the vehicle. Much of the energy is sent out the exhaust pipe as heat
Engine Complexity	A simple engine that rotates a shaft in direction proportion to the current provided.	A complex engine that attempts to convert multiple fuel explosions in a cyclinder into the rotation of a shaft, while managing engine temperature and dealing with exhaust gases
Engine Cost	Relatively low, because of the simplicity	Relatively high, because of the complexity
Maintenance and Repairs	Lower, because there is relatively little going on	Higher, because of the complexity
Reliability	Higher	Lower, because there are more moving parts likely to not work
Transmission	Not needed, as the engine can be direct drive	Needed, to convert the rotating shaft coming out of the engine into usable motion
Transmission Cost and Repairs	None	Capital Cost
Utilization of braking energy	Can be captured and stored in the vehicle's batteries	Not captured, as no place to store it.
Brake life	Longer, because of braking systems	Shorter
Performance	Meets normal requirements	Meets normal requirements
Overall Weight. Note this affects energy requirements to overcome road friction. These requirements are not large.	Less weight in engine and transmission, but more weight required to store energy in battery packs. Overall, heavier.	More weight in engine and transmission, but less weight to store energy in gas tank. In addition, the weight of energy stored in gas tanks falls as the car is driven. One expects gas tanks on average to operate slightly above half full.
Design Flexibility/Getting More Functional Space for a Given Car Volume	Less space is required for propulsion. There is more flexibility in location and size of engine.	More space is required for propulsion. There is less flexibility in location and size of engine, transmission.
Air Pollution	None	Some
Engine Noise (Note: tire noise is the same for both options.)	Less	More
Range per Refill/Recharge	100 – 300 kilometres	500 – 600 kilometres
Convenience of Refilling/Recharging	The lower range will necessitate more frequent charging, but the charging will involve plugging in the car every day.	Less gas fill-ups because of the greater range, but each fill-up requires a trip to the gas station.
Reliability in Extreme Weather	There are concerns about battery function in extremely cold temperatures.	There are concerns about starting in extremely cold temperatures.
Competitiveness of Auto Industry	More competitive, as limitations in engine and transmission technologies do not restrict new entrants into the industry	Less competitive, as engine and transmission technologies restrict new entrants into the industry.

Battery-Powered Vehicles

A critical issue in the development of electric vehicles is the development of better batteries. A technological breakthrough would be welcome, but note that incremental improvements of 1 percent a year over 45 years will lead to 56 percent improvement 45 years from now (in 2060). That takes the maximum range in current vehicles from 300 kilometres per recharge to 450 kilometres, enough for 4.5 hours of driving.

Problems with the current generation of car batteries include:

- Limited storage capacity. Cars operating on batteries have a limited range (100 to 300 kilometres) before recharge. They can handle the daily commute, but not handle longer trips. For these, an additional power source (e.g. a gas piston engine or a gas turbine to generate electricity) is needed for backup.
- High purchase cost.
- Limited life span and resulting replacement costs.
- Lengthy recharging times.
- Fire and explosion hazards.

Different strategies are being applied to improve car batteries. Major companies are supporting these efforts.

In current editions of electric cars, lead acid batteries have played a role. They are cheap and store lots of energy. However, when they are repeatedly and rapidly charged and discharged – as happens when storing braking energy from a hybrid electric vehicle and then releasing it – the battery's negative plate becomes coated with deposits. This limits the battery's working life.

Improvements are possible. Researchers are marrying the lead acid battery with supercapacitors. Previous attempts to use supercapacitors required switching between using the capacitor to store energy when accelerating or braking, and draining the battery when cruising. In a new approach, the capacitor is placed in parallel with the battery, so the capacitor acts as a buffer during charging and discharging. In tests, the battery produced 50 percent more power than the traditional lead acid batteries, and lasted four times as long.[51]

Despite improvements, new technologies, such as lithium ion batteries and solid-state batteries are likely to offer more potential.

Lithium ion batteries offer the best bet to replace gas engines, because they can pack more energy into a small, light package than alternatives such as lead acid batteries. The cathode in a traditional lithium ion battery is made from layers of lithium cobalt dioxide and wears out quickly. When the battery is charging, positively charged lithium ions migrate from the cathode across a separator screen into a porous graphite anode, which fills with lithium ions. The battery delivers power when the lithium ion atoms feed electrons via the graphite electrode into an external circuit. The lithium ions then leave the anode and go back to the cathode.

Lithium ion batteries work by trying to slot ions into structural gaps. With lithium ion batteries, the continual gain and loss of ions causes expansion and contraction of the cathode, leading to its degradation of its layers and a build-up of impurities. If stressed or overcharged, overheating can result and there can be short circuits and electrical fires. Engineers now understand why the problems occur, and are working on solutions. By 2060, one should expect the problem to be managed.

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[51] New Scientist, Smart battery gives a boost to hybrid cars, October 18, 2008, p. 26

A clear strategy is to make lithium ion batteries better, by being able to store more charge per unit way, by speeding up charging time, by reducing production costs, etc.

Some potentially game changing technologies are currently under study. Researchers at Stanford University are developing thin films—some only atoms thick—to enclose the positive electrode. This would allow it to safely contain more lithium, which coupled with a sulphur negative electrode (sulphur, like lithium, also has a very high energy capacity) would enable a battery to hold about five times as much energy by weight as today's lithium batteries do.

Researchers at Oak Ridge National Laboratory are developing a lithium sulphur battery that has a solid rather than liquid or gel-like electrolyte. This would also make the battery more stable.

One company makes the cathode more durable using lithium iron phosphate with a birdcage-like nanostructure which allows lithium ions to enter and exit without causing damaging expansion and contraction. As a result, it can survive about 10 times as many charges and discharges.

MIT researchers are addressing the lengthy period of time to recharge a battery. Recharging takes time because the lithium ions must detach themselves from the cathode. The researchers' battery has a cathode of tiny balls of lithium iron phosphate. The balls release the lithium ions 100 times faster than normal. Coating the balls with lithium phosphate accelerates the process. A vehicle's lithium battery using a high-powered charger could take only 5 minutes of a recharge.[52]

A researcher at Ohio State University developed an anode made of nanoscopic cobalt oxide wires. With a larger surface area, lithium ions can flow in and out more easily, boosting the battery's capacity and peak power.

A company is replacing the graphite anode with lithium titanate nanoparticles, which are supposedly safer (graphite can burn) and quicker to recharge (ten minutes).

Current efforts focus on identifying the best cathode and anode materials. There are about 30,000 inorganic chemical compounds. The materials genome project takes known properties of inorganic compounds and turns them into a sophisticated computer model to calculate the quantum mechanical properties of the chemicals they are mimicking. This should make the quest for better anodes and cathodes more systematic.[53]

By 2060, these ideas, plus others that will come along, will make lithium batteries a viable replacement for current use of fossil fuels.

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[52] New Scientist, Fully charged in a flash, thanks to 'nanoball' batteries, March 14, 2009, p 19
[53] Economist, The end of the petrolhead, June 21, 2008, p. 21

Beyond lithium, there is also the potential for solid state batteries. Tiny solid-state batteries are already found in small devices and sensors, often providing backup power to a microchip. They can be made by depositing materials onto a substrate in the same way that semiconductors are made. Despite an extremely high energy density, making large solid-state batteries has been too expensive for phones and cars. Nevertheless, some companies are investing in this technology. By 2060, a lot is possible.

That current innovations are yielding quantum improvements in battery performance suggests that battery technology is still developing, and has not matured to the point where future improvements are incremental. As a consequence, it is reasonable to expect within forty-five years that batteries will be light in weight, able to hold substantial energy, safe, able to withstand a large number of charges and discharges, (for Canadians) able to operate in cold weather, and relatively affordable.

Suppose, for a moment, that battery technologies to not fully evolve, and that electric cars will have limits in the range they can be driven without recharge. The world of 2060 is likely to have easily replaceable car batteries. If your vehicle's battery pack is running low, take it into a battery replacement station, swap our your current (leased) battery back, get a new one and continue on your journey with a fully charged (leased) battery pack. Government regulations and industry practices will ensure interchangeable battery systems.

By 2060, we will be driving better, cheaper cars than today, without emissions and without using as much energy. Battery powered vehicles are much more efficient than internal combustion engines. With the latter, much of the energy in fossil fuels is not utilized, and is lost as heat. The United Kingdom's Department of Energy calculates that to switch to battery electric cars would cause electricity demand to rise by only 16 percent.

Hydrogen-Powered Vehicles

Hydrogen has been considered a possible replacement for fossil fuels. Like fossil fuels, it can produce a considerable amount of energy for its volume. Unlike fossil fuels, it does not produce greenhouse gases. Hydrogen has a higher energy density and greater range than batteries. There are four elements to a hydrogen economy: production, distribution, and storage of hydrogen, and the use of hydrogen in the generation of electricity.

Production of Hydrogen

Most hydrogen today comes from refineries heating natural gas with steam in the presence of a catalyst. CO_2 is a byproduct. If the goal is to eliminate greenhouse gases, other methods of producing hydrogen need to be found.

Hydrogen can be made through the electrolysis of water. Industrial processes use huge cells containing a liquid electrolyte like potassium hydroxide in solution. This is alkaline, and requires a nickel catalyst. Hydrogen and oxygen must be kept separate, so the cells are bulky. Overall, the electrolysis is energy intensive and costly.

In 1960s, NASA developed cells that replaced liquid electrolytes with proton exchange membranes (PEMs). The membranes were acidic and needed platinum, which is expensive. Research efforts are trying to reduce platinum requirements down to 20 percent, because platinum is produced in only 5 mines around the world. Although platinum can be recycled, a large-scale requirement would use up world supplies in a short time.

Research at the University of California Berkeley is investigating the use of green algae, which produces hydrogen as a byproduct of photosynthesis. Only 1 percent of the solar radiation received produces hydrogen, but researchers hopes to improve efficiency to 7 percent through genetic engineering of the algae. This would make it competitive with natural gas reformation. Researchers are also looking at the bacteria which produce hydrogen through photosynthesis,

A company says it has found a way to produce hydrogen on a small-scale basis. Its cells have a membrane that can be made alkaline, so nickel can replace platinum. Using a dozen commonly available hydrocarbons, its membrane is a solid, flexible polymer gel which is three times as conductive as existing proton exchange membranes. The cost is 1 per cent of existing membranes. The product is the size of a refrigerator, and designed for home use, using solar or wind energy. The small-scale cell bypasses the need for a distribution system.

Distribution of Hydrogen

The widespread use of hydrogen as a replacement to fossil fuels would require an extensive distribution system comparable to the one for petroleum products and natural gas. The economics of such a distribution are poor without demand. Demand itself is dependent on distribution. While the prospects of a widespread distribution system are not great, more limited systems may be viable. For example, where vehicles travel scheduled routes on a consistent basis (e.g. railways, intercity trucking), a limited number of distribution points could address the need. These distribution points could also be points of production based on electrolysis using electricity generation from wind, thermal, hydro or solar sources, or photosynthesis using solar sources.

Storage of Hydrogen

As a fuel source in transportation, hydrogen requires an efficient storage system. Current approaches store it under high pressure. This necessitates heavy tanks. The United States Department of Energy says hydrogen storage should be 6 percent of the weight of the gas. Metal hydrides, which combine loosely with hydrogen, can store only 2 percent. A Dutch lab is creating a material in which billions of carbon Bucky balls are sandwiched between sheets of graphene – another form of carbon. To date, a 40-layer sandwich has been completed. A team at the University of Crete reported that a computer simulation of a layer of graphene sheets connected by hollow nanotubes could store 6.1 percent of its weight. The Dutch lab is now looking at replacing the Bucky balls with nanotubes, with a view to testing the results of the computer simulation. The development of efficient storage systems will be a key to the use of hydrogen, particularly in transportation.

Electricity Generation

Fuel cells consist of two electrodes separated by an electrolyte. Hydrogen enters at one electrode, oxygen at another. These undergo a redox reaction across the electrolyte. A redox reaction is the electrical equivalent of combustion. It causes a release of energy and pushes electrons around an external circuit.

Researchers from the Massachusetts Institute of Technology studied the chain reactions in photosynthesis. In their fuel cell, they use cobalt and phosphate on an electrode, instead of platinum. Cobalt costs $2.25 per ounce and phosphate $0.05 per ounce versus platinum at $1,700 to $2,000 per ounce.

Other researchers have developed new electrodes for fuel cells made from a special conducting polymer. The polymer costs $57 per ounce. The polymer is as effective as platinum at harvesting electricity.

Implementing the Hydrogen Economy

Despite considerable talk and investment, progress on building the hydrogen economy has been slow. Consider these modest examples of progress:

- Iceland, a country which touted itself as a path breaker in the hydrogen economy, has one hydrogen filling station, a handful of hydrogen cars and a whale watching boat. A trial of three hydrogen buses is over, with 2 scrapped and a third in a museum.
- California has 5 hydrogen filling stations.
- Several auto makers are testing small scale roll-outs of hydrogen vehicles.

The central problem is energy efficiency. In a vehicle, what percentage of useful energy is left over to do useful work, after the expenditure of energy on production, distribution, storage, and power generation? According to Gary Kendall in a report to the World Wildlife Fund, only 24 percent of the energy in hydrogen is available to power a vehicle. In an electric car or a hybrid, the corresponding figure is 69 percent. The United Kingdom's Department of Energy calculates that to switch to battery electric cars would cause electricity demand to rise by 16 percent. Switching to hydrogen would double the amount. New technologies may increase the energy efficiency in the production, distribution and storage of hydrogen, and power generation, but hydrogen has a long way to go. As a consequence, hydrogen is unlikely to replace fossil fuels for private and small commercial vehicles by 2060.

Where hydrogen-powered vehicles will likely find their niche is in various forms of trucking, where the heavy-duty power of hydrogen is fully utilized, and the space requirements for storage can be managed. The operation of trucks on scheduled routes where a limited number of filling stations can be established, perhaps with adjacent wind farms to supply the power, would likely work well. So too would the operation of hydrogen vehicles at mine sites. [54] [55]

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[54] New Scientist, Whatever happened to hydrogen? September 20, 2008, p. 28
[55] George Monbiot, Heat, pp. 142 - 163

Biofuels

Some have argued that we will be able to replace fossil fuels taken from the ground with biofuels, fuels from plant material. We leave the fossil fuels in the ground, grow and utilize plant material which has taken carbon dioxide from the atmosphere, and put the carbon dioxide back into the atmosphere when we combust it in an internal combustion engine.

Biofuels have the added advantage that they burn cleanly, and produce less local air pollution than fossil fuels.

There have been several approaches to biofuel development.

In one approach, crops (sugar cane in Brazil, corn in the United States) were used to make ethanol for road transportation. The technology involved extracting the starch from plants, extracting the sugars from the starch, and converting the sugars to alcohol using enzymes. One effect of this was rising food prices, as farmers sent their crops to vehicles and not people.

In another approach, the focus was on using non-food plant materials (e.g. timber waste, bagasse from sugar cane, husks from corn, other leftover components of plants after processing, naturally occurring grasses). Various approaches are under development to produce biofuels from these products (separating lignin from cellulose, using enzymes or genetically engineered bacteria to convert cellulose to sugar, using natural or genetically engineered plants whose cellulose can be readily converted).

A third approach has been to try to grow organic matter (e.g. algae) designed for easy conversion. For example, algae are an efficient converter of sunlight into biofuels. Algae can double their size in a day. The challenge with algae is to find the best type to grow, to figure out how to grow it on a commercial scale, and how to convert the algae into a biofuel. Algae, like other plants, take in carbon dioxide from the air. Some algae can feed on nutrients in sewage. Others can grow in salty or brackish water. While some algae are primarily lipids, others are starch and have the potential to be a high yielding source of biofuels. As algae require water to grow, algae production will be limited to areas where water is available.

Even with another 45 years of development, none of the three approaches is likely to provide the energy needed for Canada’s road transportation for several reasons:

- By 2060, food will likely to be scarce on a world-wide basis. Food land will need to be left for food.
- Biofuels need energy in their production. Other sources are likely to be significantly better net energy producers than biofuels.
- Biofuel production cannot be scaled up to meet the energy needs. For example, algae production needs a lot of tanks and water.

Trucking

Trucking heavy loads is a major emitter of greenhouse gases, and has caused a significant increase in emissions since 1990. The increase has been due among other things to just-in-time inventory management approaches and increasing population. By 2060, trucking will change in response to a variety of factors:

- Battery development will reduce the reliance on fossil fuels. Trucks are not restricted by the same weight and size restrictions that passenger cars, SUVs and light truck face.
- The current trend to just-in-time inventories will likely be reversed with 3-dimensional printing. The plans for world-wide products will sent to printers close to the final consumer, eliminating the need for a great deal of trucking.
- Railroads, which can be emission efficient, will absorb an increasing amount of truck traffic. Main line railways by 2060 will be electrified. In addition, they will continue to be energy efficient. Energy is needed in transportation to overcome rolling resistance (friction between the ground and the vehicle) and to move air out of the way. Railroads are more efficient than trucks because metal wheels and (smooth) tracks have a much lower rolling resistance than truck tires and (bumpy) roads and because a long train expends approximately the same amount of energy moving air out of the way as much shorter trucks. Global trade patterns will change by 2060. Controls of marine emissions will limit Canadian trade with Asia, Australia and Europe. Canadian international trade will be north-south in orientation, utilizing railroads to a significant degree. As global trade patterns change, so will trucking patterns by 2060.
- Trucks will become more efficient. Since a great deal of energy is required to move air out of the way, longer trucks provide a mechanism to reduce energy requirements.
- Hydrogen powered vehicles will be used main regular routes.

After all the foregoing, some use of fossil fuels for heavy trucking may be required to meet national priorities by 2060.

Vehicle Usage Strategies

These include strategies to reduce vehicle usage and speeds, and include measures such as:

- Government enforcement of speed limits. In some jurisdictions, police tolerate speeding that is above the speed limit. Enforcement methods such as radar cameras are not used.
- Reduction of speed limits to fuel efficient levels. A large part of the energy related to transportation involves getting the air out of the way. The amount of energy required goes up exponentially the fast one goes. A general reduction in the highest speed limits to limits that existed several decades ago would have an impact.
- Reducing distances travelled to and from work, including:
  - Reducing the tendency of urban areas to spread.
  - Locating places of work close closer to where people live and vice versa.
  - Providing public transportation, particularly in relation to daily commuting.
- Converting emitting forms of public transportation to non-emitting forms.
- Turning off the car's air conditioner
- Reversing the current trend to more powerful cars, particularly in view of the fact that there are few functional uses for the power.
- Reversing the trend to bigger cars.

Improving Car Design

The auto industry expects to introduce new technologies in the next 45 years. These include:

- Lighter materials such as aluminum, fiberglass, plastics, and carbon fibre. Lighter cars accelerate quicker with less power. One possibility is to use aluminum bodies. However, aluminum is expensive and factories need to be adjusted. Carbon composites are another option. They are light and strong, and lend themselves to aerodynamic styling because they can be shaped easily. While current costs are currently higher than steel. These costs should fall. These products are as strong as steel, but have only 40 percent of the weight. Toyota has a composite Prius car. Composites could destabilize the auto industry, because new producers can enter easier than existing ones[56]
- Tires that have low roll resistance.[57] Low rolling resistance tires allow a car to use less power to move. Overcoming rolling resistance accounts for one-fifth of CO_2 emissions. However, lower rolling resistance tires mean less friction. Current low rolling resistance tires use silicic acid in the surface. This changes the properties of the rubber. The braking efficiency may be 10 percent less.[58]

Getting to Zero by 2060

Getting to zero by 2060 means:

- Vehicles powered by the combustion of fossil fuels will be substantially off the roads. Vehicles propelled by the combustion of fossil fuels will be reserved for priority situations for which there are no available alternatives. High priority non-routine long-distance trucking in remote locations comes to mind.
- Almost all consumer vehicles and light commercial vehicles will be battery-powered.
- Apart from propulsion systems, these vehicles will have other attributes to make them energy efficient (e.g. light-weight materials).
- Various initiatives will be established to reduce the amount of driving. Whatever driving there is will occur at energy efficient speeds.
- Biofuels and hydrogen will no longer be under serious consideration for consumer and light commercial vehicles.
- The demand for heavy duty road transportation will fall considerably, as rail alternatives in particular become more attractive, global trade patterns change, and 3-dimensional printing reduces the need to ship manufactured goods.
- Hydrogen-based technologies are likely to find a role in heavy duty road transportation where a robust, mobile source of energy is needed and distribution is simple. This includes trucking along fixed routes. Refueling points can be established at key points along the routes, with local production facilities based on windmills, solar panels and the like situated near the distribution points.
- Some use of fossil fuels for energy efficient heavy-duty road transportation may continue for national priorities.

[56] New Scientist, Less is more, February 2, 2008, p. 33
[57] New Scientist, Ford Advertising Feature, November 10, 2007.
[58] New Scientist, Losing their grip, February 2, 2008, p. 36

Projected Emissions

Projected Emissions for 2060: Road and Off-Road Transportation			
Greenhouse Gas Categories	**2012**	**2060 Projection**	**Comments**
	kt CO2 eq	**kt CO2 eq**	
Road & Off-Road Transportation	170,012	8,621	Sector Total
Road Transportation	132,412	4,861	Subsector Total
Light-Duty Gasoline Vehicles	*38,300*	*0*	*Current emissions times zero, as vehicles become battery powered*
Light-Duty Gasoline Trucks	*41,400*	*0*	*Current emissions times zero, as vehicles become battery powered*
Heavy-Duty Gasoline Vehicles	*6,910*	*691*	*Current emissions times 10 percent, representing the residual after regulatory prohibitions on uses that do not meet the "national priority" test, the increased use of electrified railways, use of hydrogen power, emission efficiency improvements, and changes in shipping patterns*
Motorcycles	*268*	*0*	*Current emissions times zero, as vehicles become battery powered*
Light-Duty Diesel Vehicles	*824*	*0*	*Current emissions times zero, as vehicles become battery powered.*
Light-Duty Diesel Trucks	*2,130*	*0*	*Current emissions times zero, as vehicles become battery powered*
Heavy-Duty Diesel Vehicles	*41,700*	*4,170*	*Current emissions times 10 percent representing the residual after regulatory prohibitions on uses that do not meet the "national priority" test, the increased use of electrified railways, use of hydrogen power, emission efficiency improvements, and changes in shipping patterns*
Propane & Natural Gas Vehicles	*880*	*0*	*Current levels times zero as vehicles become battery powered*
Off-Road Transportation	37,600	3,760	Subsector Total
Off-Road Gasoline	*7,600*	*760*	*Current emissions times 10 percent representing the residual after regulatory prohibitions on the use of fossil fuels not meeting the "national priority" test, use of hydrogen power, emission efficiency improvements.*
Off-Road Diesel	*30,000*	*3,000*	*Current emissions times 10 percent representing the residual after regulatory prohibitions on uses that do not meet the "national priority" test, use of hydrogen power, emission efficiency improvements.*

Chapter 6: Aviation and Marine

We are living in a global economy. Goods and services are produced all over the world, and transported considerable distances by air and ships. This tendency to produce goods in the most efficient location and ship to them to markets depends on low cost transportation by air and sea.

In response to these trade patterns, multinational companies operate globally to compete and manage global trade. They often establish local manufacturing companies to take advantage of their managerial expertise and corporate knowledge.

Through the development of electronic communications technologies, information is moving around the globe instantaneously. People are moving too. Primarily those with skills and persons related to them are moving from developing countries to more developed countries. The movement of people brings to Canada not only a demand for foreign goods and services, but also contacts for the purposes of access foreign markets for trade. It also brings essential skills to the Canadian workforce.

Global institutions have been established to manage these global processes, including an international banking system, international trade laws, international air and shipping systems, and an international system for regulating patents and intellectual property. Reducing emissions is likely to have significant impacts on current trends to globalization.

Aviation

In 2012, Canada's emissions for domestic air travel were almost 6,100 kilotonnes of CO_2 equivalents, and accounted for 0.9 percent of Canada's total emissions. Emissions had decreased by 14.1 percent since 1990.

Past Emissions

Canada's 1990–2012 Green House Gas Emissions: Aviation					
Greenhouse Gas Categories	**1990**	**2012**	**2012**	**Change 1990-2012**	
	kt CO2 eq	**kt CO2 eq**	**% Total 2012**	**kt CO2 eq**	**% Total Change**
Total – All Sectors	590,253	708,713	100.0%	107,660	18.2%
Aviation (Domestic)	7,100	6,100	0.9%	-1,000	-14.1%
Aviation (International)	6,100	9,100	1.3%	3,000	49.2%

The international system for counting national emissions has not included international air travel to date, because of debates related to the attribution of emissions from international air travel. For example, attributing emissions based on where fuel is loaded onto a plane seems unfair when most of the passengers come from some other country. Eventually, international air travel emissions will be included in counts of national emissions, and the current period of grace for international aviation will end.

Emissions for international air travel, based on fuels loaded in Canada, were slightly higher in 2012 at 9,100 kilotonnes, representing 1.3 percent of Canada's total emissions. Growth since 1990 was 49.2 percent.

Currently, emissions from a fully loaded passenger aircraft per passenger mile are comparable to a motor vehicle carrying 3 to 4 people. One problem with air travel is that the mileages are substantial. Two people flying a return trip between Europe and the United States produce the equivalent of 4 tonnes of CO_2. This amount is equivalent to emissions from a typical American automobile in a year.

Counting the greenhouse gas emissions from jet aircraft understates the climate impact of air travel for several reasons:

- Greenhouse gases higher in the troposphere have a greater warming effect than greenhouse gases at lower levels. This occurs because they are colder, and more likely to absorb radiation from the surface and less likely to reflect it. Aircraft spew out their greenhouse gases at high altitudes. These high-altitude emissions increase the greenhouse effect of aircraft emissions.
- Aircraft produce contrails as they spew behind them exhaust consisting of water vapour and other particles. When contrails first form and before the water vapour has crystallized into ice, daytime contrails reflect sunlight back into space, and contribute to cooling. The reflective capability of contrails, and hence their capacity to cool the earth, is greater when the solar radiation strikes a contrail at an angle. This occurs at higher latitudes, and or at all latitudes at dawn and dusk.[59] Gradually, the contrails spread, thin out, and freeze. Some disappear within an hour or two. Others evolve into larger cirrus clouds. While most types of cloud screen out solar radiation and help cool the earth, cirrus clouds let sunlight pass through to the surface, and then trap radiation flowing back up from the surface. The net effect of these two processes is warming. Day travel produces less warming than night travel, because there is an initial cooling effect from the reflection of solar radiation by the water vapour.

Overall, the effects of air travel are greater than emissions alone. The Intergovernmental Panel on Climate Change concluded that in 1992, the aircraft induced global warming was 2.7 times greater than the release of fossil carbon alone.[60]

Aviation industry has demonstrated an ability to improve the fuel efficiency of aircraft over time. Today's jet engines are about 40 percent more fuel efficient than those designed in the 1960s, according to the International Air Transport Association. Furthermore, aerosols such as soot and sulphur have been largely eliminated from jet exhaust. Aircraft are now made of lighter materials. Designs have less drag. Planes are flying fuller, and airlines are selecting efficient aircraft for the routes to be flown.

Nevertheless, the airline industry is conservative. The basic turbine engine was invented in 1947. It is still the basis for aircraft engines. There is no indication that this situation will change in the foreseeable future. Today's aircraft have a long lifetime. The Boeing

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[59] Robert Henson, The Rough Guide to Climate Change, Rough Guides Inc.
[60] Intergovernmental Panel on Climate Change, Chapter 6, Potential Change from Aviation, Executive Summary

747 was introduced in the early 1970s, and these aircraft are still flying. The Airbus 380 is expected to operate until 2080. The projected improvement in jetliner fuel efficiency is only 2 percent annually.

One can see the potential for additional improvements. At highly congested airports, there may be some scope to reduce flying times through better air traffic control and more direct flights, although with the exception of Pearson, Canadian airports are not overly busy. The International Air Transport Association estimates that better air traffic control would reduce global CO_2 emissions by 12 percent. Pulling aircraft to and from runways with electric tractors could reduce fuel consumption from aircraft on the tarmac with engines running while waiting to take off. Virgin Airlines estimates this could save 2 tonnes of fuel per flight.[61]

Radical ideas for improving the efficiency of jet aircraft exist at various stages of development. These include:

- Reducing the friction between a plane and the air by:
    - Putting thousands of holes on the top of aircraft wings and using a fan inside to suck the disturbed air around the boundary of the wing back to the wing. This reduces turbulence around the wing. This theory was tested from the 1970s to 1990s, to the point where drag could be reduced by 20 percent in everything from jet fighters to airliners. However, the idea was abandoned for economic reasons. The technology needs to address complications such as clearing dust, insect remains and ice from the holes.
    - Modifying the fuselage by sucking air in through a slot near the back of the plane, and blowing the air out the back. Tests indicated this could reduce fuselage drag by half.
- Using struts to brace the aircraft's wings. To withstand the forces of high-speed flight, aircraft wings are built strong. These means they are heavy. Struts could provide comparable strength at less weight. Researchers at Virginia Tech calculate that wing weights could be reduced by two-thirds, improving fuel efficiency by 25 percent. Struts could be widened to provide extra lift. Struts could allow:
    - the lengthening of wings without adding appreciable weight, and reducing "lift-induced drag", and
    - the placement of engines at the ends of wings. They would suck in turbulent air and further reduce drag.
- Developing the flying wing aircraft. This idea is the product of a consortium of university engineers and aircraft manufacturers. The initiative is called the Silent Aircraft Initiative. The aircraft would have a pair of thick, swept-back wings. The engines would be inside the wings. There would be no tail, which would be replaced by gyroscopes and raised winglets to maintain stability. Passengers would sit inside the wings. Instead of flaps, the plane would have a moveable leading edge that maximizes lift. The design is about 25 percent more fuel efficient than conventional airlines. However, there would be fewer windows, and with passengers sitting in the wings, they would move considerably more in turbulent air than in conventional aircraft.[62]

[61] New Scientist, Green sky thinking: eight ways to a cleaner flying future, February 22, 2007
[62] New Scientist, Green sky thinking: eight ways to a cleaner flying future, February 22, 2007

These ideas could reduce the greenhouse impact of the aviation industry, and the advances would be welcome. However, in a world striving for zero emissions, they will not solve the problem. The problem is that aircraft burn kerosene.

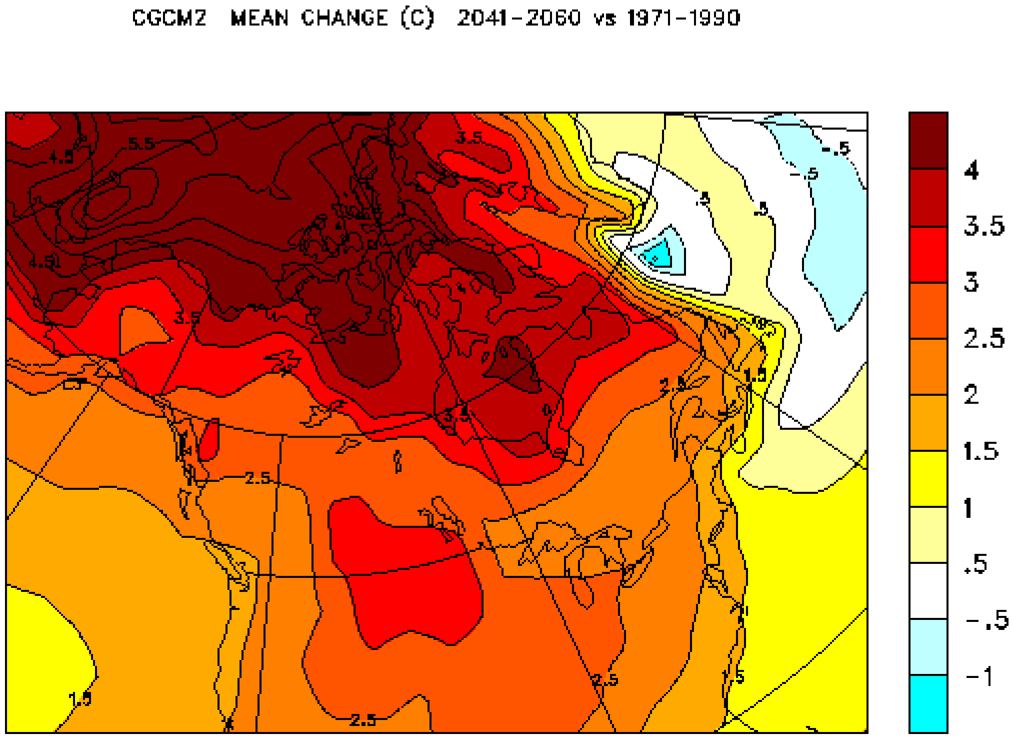
Viable alternatives to kerosene are not on the horizon. Consider[63]:

- Hydrogen. According to Boeing, a hydrogen powered 737 aircraft would require insulation and pressurization equipment just to keep the hydrogen flowing. The tanks would need to be in the fuselage, necessitating a wider cabin. The wider cabin would increase drag. Combusted hydrogen would produce about three times as much water vapour as kerosene. This additional vapour would contribute to contrails, which have a net warming effect.
- Biofuels. Because biofuels are grown within a relatively short time before they are burned, it is argued that their long-term effect on the greenhouse gas levels is neutral. In comparison with kerosene, they weigh 60 percent more, and 64 percent more volume is needed to get the same energy. An ethanol fueled 737 would need a 25 percent larger wing and engines with 50 percent more thrust to get airborne. As ethanol freezes at low temperatures, tanks would need to be heated. This adds to the cost. Furthermore, the contrail problem still exists. Finally, the amount of biological material to keep today's planes in the air is astronomical.[64]

The bottom line is that in a world striving for zero emissions by 2060, air travel as we now know it will almost cease. Limited travel for priority purposes such as government travel, international immigration and perhaps some priority business travel would continue where other options did not exist. Governments seeking zero emissions would not allow national allowances for greenhouse gas emissions to be used for holiday travel. Businesses would need to learn to operate using the internet, video conferencing, and the like. If these cannot be made to work, then the modern global business may lose ground to local enterprises.

Leisure travelers, particularly those wanting to go south for the winter, can take some solace in the fact that by 2060, Canada will be than it has been in the past.

[63] Ibid.
[64] New Scientist, a tank of the green stuff, August 16, 2008



Where flights occur, they will be long-haul, since there are alternatives to short haul flights that create fewer emissions. Long haul travel would occur through propeller driven aircraft. Recent designs use 59 percent of the fuel used by jet aircraft, and since they fly at lower altitudes, they do not create climate warming effects through their contrails. Of course, they travel slower than jets. Passengers will be expected to travel light, and where practical, stay longer rather than fly multiple times.

Another option may be airships. These are aircraft kept aloft by gases lighter than air. Their climate impact is 80 to 90 percent less than that of jet aircraft. They have a range of up to 10,000 kilometers, and can travel at up to 130 kilometers per hour. A transatlantic trip would take about 43 hours.[65]

With the demise of the civil aviation, public investments in runways and air terminals are unlikely to be profitable in the long run.

[65] George Monbiot, Heat, pp. 170-188.

Marine

Past Emissions

Canada's 1990–2012 Green House Gas Emissions: Marine					
Greenhouse Gas Categories	**1990**	**2012**	**2012**	**Change 1990-2012**	
	kt CO2 eq	**kt CO2 eq**	**% Total 2012**	**kt CO2 eq**	**% Total Change**
Total – All Sectors	590,253	708,713	100.0%	107,660	18.2%
Marine (Domestic)	5,000	5,800	0.8%	800	16.0%
Marine (International)	3,100	1,700	0.2%	-1,400	-45.2%

The production of emissions in the domestic marine sector in 2012 accounted for 0.8 percent of Canada's total emissions, and grew 16.0 percent since 1990. Presumably, this includes ferries, great lakes and coastal shipping, fishing, and recreational uses. International ships loading fuel in Canada generated another 1,700 kilotonnes and fell 45.2 percent since 1990. Like international aviation emissions, international marine emissions are not included in Canada's total emissions, as defined by UN conventions.

In a world getting to zero emissions, international shipping as we know it will disappear, because there are no clear alternatives to fossil fuels as the energy source for large marine vehicles. While nuclear powered ships are technically possible, a private, nuclear-powered shipping industry is unlikely to be acceptable to most countries. The most likely scenario is nuclear-powered, heavily armed ships operated by national governments or international organizations created by national governments. The scenario of a few, extremely large ships would be more manageable than many smaller vessels. There may be some scope for commercial shipping based on wind power and following the wind-based routes abandoned years ago. For national priorities, the continued use of fossil fuels may be allowed, but only with some form of mobile carbon capture.

The consequences for domestic marine from a zero-emission world will be less drastic, because there are alternatives.

The future of the fishing industry by 2060 is in doubt, because of the combination of warming and increasingly acidic oceans. To the extent that a wild salmon fishery continues, the harvesting will occur in the rivers when the salmon return to spawn, rather than the oceans. The current practice of fishers chasing salmon on the high seas is inherently wasteful. To the extent that fishing continues, the combination of battery powered vessels with sailing capabilities will operate in an emission reduced environment. Recreational marine activities will follow this path as well.

Great lake shipping, and other shipping within Canada, will be replaced by shipping through electrified railways.

Hydrogen fuel should be available for ferry services to accommodate people living on islands within Canada. Hydrogen production facilities will be established at ferry docks. Battery powered boats combined with sails will replace some ferries powered by fossil fuels. Where short distances are involved, bridges may be built. For the remaining ferry services, expect governments to review the need for service, and continue to allow the use of fossil fuels for priority services. Mobile carbon capture will be required where fossil fuels continue to be used.

Getting to Zero by 2060

Getting to zero by 2060 means:

- International and domestic aviation and marine will substantially, but not completely, come to an end, because aviation and marine rely on the combustion of fossil fuels and carbon capture is not usually feasible.
- What aviation remains will be limited to national priorities (defense, government priorities, services to rural communities, strategic industrial purposes).
- The more fuel-efficient propeller-driven aircraft will replace jets. Air travel will be only for long-haul routes, because there will be viable alternatives such as railways on short-haul routes.
- Alternatives such as airships are unlikely to replace a significant amount of aviation based on fossil fuels.
- Domestic marine shipping will generally be replaced by:
  - Railways and trucking for inland shipping.
  - Battery powered and sail boats for inshore and inland fishing.
  - Hydrogen powered ferries for most routes, and for priority routes, fossil fuel powered ferries combined with the capture of CO_2 emissions.
- International shipping based on fossil fuels will be substantially eliminated. The alternatives (nuclear, sail powered, hydrogen powered) will fill the gap only on a minor basis. Some fossil fuel consumption and related emissions may continue for national priorities (strategic exports and imports), but emissions of CO_2 will be regulated and subject to carbon capture wherever practical.
- Globalization will be redefined. There will be substantially fewer imports from, and exports to sources outside the Americas. Imports and exports will be restricted to places that can be reached without international shipping. In Canada's case, this means the United States, Mexico, Central and South America, and the Caribbean. Exports of raw materials to Asia and Europe will disappear, but so will imports. Some economic doors, particularly the export of natural resources, will close, but others, notably manufacturing, will re-open. Trade within the Americas will continue, and will be based on electrified railways and hydrogen powered trucks. The Americas will need to become self-sufficient. Competition will be limited to competitors from the Americas.
- For manufactured products, 3-dimensional printing close to buyers will replace manufacture in distant countries, shipping to Canadian ports, and transportation within Canada by trucks or rail.
- Multinational corporations that carry out significant trade between subsidiaries in different continents will find this raison d'être no longer relevant. They will shift their focus to the exchange of ideas on patents, technologies, and operating procedures.

- Intercontinental business will be conducted through electronic means – video conferencing, email, etc. Without international marine and aviation, globalization as we know it will come to an end, but undoubtedly will evolve into different forms.

Projected Emissions

Projected Emissions for 2060: Aviation and Marine			
Greenhouse Gas Categories	**2012**	**2060 Projection**	**Comments**
	kt CO2 eq	**kt CO2 eq**	
Aviation (Domestic)	6,100	305	Current emissions times 5 percent representing the residual as domestic aviation is limited to national priorities only
Marine (Domestic)	5,800	145	Current emissions times 5 percent representing the residual as domestic marine activities become tied to national priorities only times 50 percent for captured emissions
Aviation (International)	9,100	455	Current emissions times 5 percent representing the residual as international aviation is limited to national priorities only
Marine (International)	1,700	85	Current emissions time 5 percent representing the residual as international marine activities become limited to national priorities only times 50 percent for captured emissions

Chapter 7: Railways

Past Emissions

Canada's 1990–2012 Green House Gas Emissions: Railways					
Greenhouse Gas Categories	**1990**	**2012**	**2012**	**Change 1990-2012**	
	kt CO2 eq	**kt CO2 eq**	**% Total 2012**	**kt CO2 eq**	**% Total Change**
Total – All Sectors	590,253	708,713	100.0%	107,660	18.2%
Railways	7,000	7,600	1.1%	600	8.6%

From 1990 to 2012, greenhouse gas emissions from railways increased by 8.6 percent. In 2012, these emissions represented 1.1 percent of Canada's total emissions.

To serve in a low emission world, railways will have to adapt. Luckily for them, they have good solutions. They have two options.

One is electric trains. They have been in use around the world for a long-time. They are quiet and non-polluting, and more to the point, do not generate greenhouse gases when the electricity comes from non-emitting sources.

Another option is hydrogen powered fuel cells. Various systems are at various stages of testing around the world. There are several challenges with hydrogen systems, including:

- The need to produce powerful systems.
- The cost of building economic fuel cells.
- The need to develop cheap ways to produce hydrogen.

In comparison with electric trains, hydrogen powered trains do not require an expensive infrastructure of wires. In addition, electric trains require space above the rail line for the wires. This has implications for bridge design, and the use of the airspace above the train line for other purposes.

Some of the negatives of hydrogen fuel cells for motor transport are not so problematic for trains. For example, hydrogen trains have more space for a fuel cell and a bulky hydrogen tank. Also, establishing a network of refueling stations on train lines is simpler than establishing a network of filling stations for vehicles. These railway refueling stations could include wind and solar generating plants along the train lines. The collocation of refueling stations and production facilities reduces the need to transport hydrogen.[66]

By 2060, the railways will likely electrify the main traffic corridors. The electrification will occur in stages, with the higher traffic routes electrified first. Railways will likely rely on hydrogen powered engines for shunting and less travelled routes.

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[66] New Scientist, Fuel Cells set to switch trains onto a greener track, March 17, 2007, p. 30-31

In terms of demand for services, there is good news and bad news for railways. The good news is that as Canada moves toward zero emissions by 2060, the demand for railway services will grow substantially. Intercity traffic will increase substantially, as air travel is significantly curtailed and the competitive position of railways relative to buses and private vehicles improves. Freight traffic will also increase as marine freight disappears and as railways become more competitive relative to trucks.

One piece of bad news is that Canada's trade patterns will change from east-west to north-south. With the end to transoceanic trade, Canada's raw materials and grains will no longer travel to ports. In addition, imports will no longer arrive at these ports for shipment in land.

Getting to Zero by 2060

Getting to zero by 2060 means:

- Getting rid of engines based on fossil fuels.
- Electrifying the main lines and using electric engines.
- For other routes, using hydrogen engines, perhaps supplied by hydrogen produced at refueling points based on wind or solar power.

Projected Emissions

Projected Emission for 2060: Railways			
Greenhouse Gas Categories	**2012** **kt CO2 eq**	**2060 Projection** **kt CO2 eq**	**Comments**
Railways	7,600	0	Current emissions times zero as railroads electrify mainlines, use hydrogen power from renewables elsewhere on other lines and batteries for shunting, etc.

Chapter 8: Industrial Processes

Past Emissions

Canada's 1990–2012 Green House Gas Emissions: Industrial Processes					
Greenhouse Gas Categories	**1990**	**2012**	**2012**	**Change 1990-2012**	
	kt CO2 eq	**kt CO2 eq**	**% Total 2012**	**kt CO2 eq**	**% Total Change**
Total – All Sectors	590,253	708,713	100.0%	107,660	18.2%
Industrial Processes	55,990	56,621	8.1%	631	1.1%
Mineral Products	8,360	8,360	1.2%	0	0.0%
Cement Production	*5,400*	*6,300*	*0.9%*	*900*	*16.7%*
Lime Production	*1,760*	*1,440*	*0.2%*	*-320*	*-18.2%*
Mineral Product Use	*1,200*	*620*	*0.1%*	*-580*	*-48.3%*
Chemical Industry	16,620	6,934	1.0%	-9,686	-58.3%
Ammonia Production	*4,510*	*5,770*	*0.8%*	*1,260*	*27.9%*
Nitric Acid Production	*1,000*	*1,100*	*0.2%*	*100*	*10.0%*
Adipic Acid Production	*11,000*	*0*	*0.0%*	*-11,000*	*-100.0%*
Petrochemical Production	*110*	*64*	*0.0%*	*-46*	*-41.8%*
Metal Production	22,620	16,327	2.3%	-6,293	-27.8%
Iron and Steel Production	*10,200*	*9,840*	*1.4%*	*-360*	*-3.5%*
Aluminum Production	*9,310*	*6,230*	*0.9%*	*-3,080*	*-33.1%*
SF6 Used in Magnesium Smelters and Casters	*3,110*	*257*	*0.0%*	*-2,853*	*-91.7%*
Production and Consumption of Halocarbons/SF6	990	8,000	1.1%	7,010	708.1%
Other & Undifferentiated Production	7,400	17,000	2.4%	9,600	129.7%

Companies emit greenhouse gases when they combust fossil fuels to produce heat and electricity. Their production processes also emit greenhouse cases. Emissions related to the former were addressed in Chapter 4. Here, we discuss the latter.

In 2012, industrial processes accounted for 8.1 percent of Canada's emissions. Among industries, certain processes (cement, ammonia, halocarbon production and consumption) saw their emissions grow, while other significant industries (adipidic acid, aluminum, SF6 in magnesium smelters and casters) saw significant drops.

With 80.5 percent of emissions in the form of CO_2, there may be some potential for carbon capture to reduce these emissions.

The progress made by some industries and corporations when they tried to control emissions for whatever reason offers some promise that industries and corporations could reduce emissions even further if required to do so.

To date, many of the monitored greenhouse gases are not regulated. There is no requirement to eliminate greenhouse gas emissions, or to get permission to emit subject to conditions, or to meet process standards related to emissions, or penalties for non-compliance. There should be considerable potential to reduce emissions through regulation.

In addition, when given incentives to do so and appropriate time frames, industries should be able to carry out research and development activities that will lead to modifications of processes that will result in emission reductions, or to product replacements.

Getting to Zero by 2060

Getting to zero by 2060 means:

- Significant reductions on industrial processes because industries will:
    - Be regulated for greenhouse gas emissions.
    - Respond to regulations and other incentives by carrying out research, development and related investments to find ways to produce existing products with no or less emissions, to develop new products that can be produced without emissions, and to find ways to capture emissions in production processes so that they do not enter the atmosphere.
- A continuation of limited emissions where the foregoing does not work, the product is essential, and there are no alternatives.

Projected Emissions

Projected Emissions for 2060: Industrial Processes			
Greenhouse Gas Categories	**2012**	**2060 Projection**	**Comments**
	kt CO2 eq	**kt CO2 eq**	
Industrial Processes	56,621	14,155	Current emissions times 50 percent representing the residual as emission efficiency improves times 50 percent for carbon capture

Chapter 9: Solvent and Other Product Use

Past Emissions

Canada's 1990–2012 Green House Gas Emissions: Solvent and Other Product Use					
Greenhouse Gas Categories	**1990**	**2012**	**2012**	**Change 1990-2012**	
	kt CO2 eq	**kt CO2 eq**	**% Total 2012**	**kt CO2 eq**	**% Total Change**
Total – All Sectors	590,253	708,713	100.0%	107,660	18.2%
Solvent and Other Product Use	180	310	0.0%	130	72.2%

Getting to Zero by 2060

Getting to zero by 2060 means:

- Monitoring all solvents for their greenhouse gas effects.
- Prohibiting the production, import and use of solvents that have greenhouse gas effects unless authorized by the government in the case of national priorities that cannot otherwise be addressed.
- Supporting the development of solvents that meet Canadian needs and that do not have greenhouse gas effects.

Projected Emissions

Projected Emissions for 2060: Solvent and Other Product Use			
Greenhouse Gas Categories	**2012**	**2060 Projection**	**Comments**
	kt CO2 eq	**kt CO2 eq**	
Solvent and Other Product Use	310	78	Current emissions times 25 percent representing the residual as emission efficiency improves and solvents are regulated against national priorities

Chapter 10: Agriculture

Past Emissions

Canada's 1990–2012 Green House Gas Emissions: Agriculture					
Greenhouse Gas Categories	**1990**	**2012**	**2012**	**Change 1990-2012**	
	kt CO2 eq	**kt CO2 eq**	**% Total 2012**	**kt CO2 eq**	**% Total Change**
Total – All Sectors	590,253	708,713	100.0%	107,660	18.2%
Agriculture	47,100	54,130	7.8%	7,030	14.9%
Enteric Fermentation	16,000	18,000	2.6%	2,000	12.5%
Manure Management	5,700	6,400	0.9%	700	12.3%
Agriculture Soils	25,200	29,700	4.3%	4,500	17.9%
Direct Sources	*14,000*	*17,000*	*2.4%*	*3,000*	*21.4%*
Pasture, Range and Paddock Manure	*2,200*	*2,700*	*0.4%*	*500*	*22.7%*
Indirect Sources	*9,000*	*10,000*	*1.4%*	*1,000*	*11.1%*
Field Burning of Agricultural Residues	200	30	0.0%	-170	-85.0%

Agriculture accounted for 7.8 percent of Canada's emissions in 2012. Unlike other sectors, CO_2 is not the primary problem. With agriculture, the problem is methane, which accounts for about a third of the sector's emissions, and N_2O, which accounts for the remaining two-thirds. The methane emissions result from the raising of livestock, specifically their digestive processes and from the management of manure. The N_2O emissions come from fertilizers.

Enteric Fermentation

Cattle are a significant emitter of methane. Using Japanese practices, a kilogram of beef emits 36.4 kilograms of carbon dioxide (primarily in the form of methane from animal digestive systems), releases fertilizer compounds equivalent to 340 grams of sulphur dioxide and 59 grams of phosphate (primarily from animal waste), and consumes 169 megajoules of energy (primarily for producing and transporting animal feed). Measures to reduce the impact of beef consumption on emissions include organic beef production based on grass (which emits 40 percent less greenhouse gases and consumes 85 percent less energy.[67] Eight percent of the energy used to grow the livestock goes into making methane – a waste.

One solution is to consume less beef and dairy products. Neither are essential for good health. There is evidence that both may be detrimental to certain aspects of health.

Another solution is to change meat consumption patterns. Not all meat products come from livestock that emits methane. Kangaroo meat is one exception. So is chicken meat.

To the extent that we want to continue to consume beef and dairy products, research may provide some solutions to reduce the methane production.

For example, methanogen bacteria in cattle and sheep convert the carbon dioxide and hydrogen to methane. It may be possible to eliminate the bacteria or change the way they operate, to reduce methane production. One possibility is a vaccine against the bacteria

[67] New Scientist, Meat is murder on the environment, July 21, 2007

(although questions remain whether the public would accept food from vaccinated animals).

Unlike cattle and sheep, kangaroos do not have methanogens in their digestive system. By comparing digestive systems in methane-emitting species and kangaroos, it may be possible to learn why methanogens are prevalent in the methane-emitting species and not in kangaroos, and to develop mechanisms to reduce or eliminate methanogens from emitting species.

At the same, more traditional agricultural research is underway to reduce methane production in livestock by dealing with the food animals eat. Researchers at the University of Manitoba found that grass-fed cattle produce 20 percent more methane than those fed a mixture of grass and corn. The addition of unsaturated fats (coconut, sunflower) could also help curb methane by a further 20 percent by absorbing the hydrogen. The animals can absorb the hydrogenated fats to store for energy.

Researchers in the United Kingdom are suggesting that a diet rich in legumes can reduce methane. The tannins are thought to slow the growth of methanogens. They also suggest a garlic extract may lower methane output.

Manure Management

Manure is a byproduct of raising livestock. If manure is put in a pile and left to decompose through natural processes, the organic matter not close to the surface decomposes through anaerobic processes (i.e. in the absence of oxygen) to produce methane. If the manure is spread out over fields as a fertilizer and soil enhance, N_2O results.

According to the 2006 Census, there are **!Undefined Bookmark, CANADAPOP** people in Canada. We all produce manure. As we shall see in the following chapter, emissions related to our manure production are negligible. At least one solution to the manure management emissions in agriculture is to apply the same standards for animal manure as we apply to human manure. We go to great lengths to protect our health by treating our waste, but do not apply the same standards for animal waste.

Agriculture Soils

Soil organic nitrogen is lost through plant removal, leaching, denitrification, and ammonium volatilization. Nitrogen in the proper form is essential for plant growth. Consequently, nitrogen fertilizers are applied to crops. They are the largest input for most crops. Nitrogen fertilizer is the highest on-farm cost. Plants take up only half of nitrogen applied. The nitrogen not taken up by plants can have serious adverse effects. It can leach through the soil to contaminate ground water with nitrates. Nitrates can contribute to algae overgrowth on surface waters, leading to low oxygen levels and harm to aquatic flora and fauna. When soils become anaerobic, the nitrates from fertilizer are used by soil microbes to produce N_2O.

There are several potential solutions to the problems presented by nitrogen fertilizers.

Nitrogen fixation is a natural process through which some plants convert atmospheric nitrogen into form useable by plants. Such bacteria already provide nitrogen for legumes such as soybean, alfalfa, beans, clover and peas. Agriculture scientists have for a long time wanted to extend this nitrogen fixation characteristic to wheat, rice, corn, maize and tomatoes, as well as to biomass crops such as switchgrass and sugarcane.

Thanks to the work of a team of German and French scientists from the University of Munich and the Institut de Recherche pour le Développement, this dream is significantly closer to fruition.

Certain plants have a natural symbiosis between nitrogen fixing bacteria on the one hand, and the plant’s roots or between these roots and mycorrhizal fungi. The team has identified a common genetic mechanism at work that allows the symbiosis in both legumes and a tropical tree. Their finding may make it possible to transfer this capacity to a wide range of crops.

In legumes, rhizobia bacteria pull nitrogen from the air. They establish inside the root nodules of legumes. They transform nitrogen in the air to ammonium that can be taken up by the plant. In return, the plants provide the organisms with complex glucides. This symbiotic relationship works for both the plant, which gets nitrogen, and the bacteria, which get food.

In 2000, scientists discovered the gene responsible for the signaling molecules that are crucial for the rhizobia to establish in root nodules. As a separate issue, actinorhizal plants have acquired the capacity to work with another type of nitrogen fixing bacteria called frankia. These plants grow in soils starved of nitrogen (beaches, volcanoes, etc.) One such actinorhizal plant is the Casuarina tree, found on tropical beaches. The scientists found that the gene responsible for the molecules crucial to the establishment of rhizobia in root nodules in legumes is also found in the Casuarina tree. They developed transgenic plants in which the expression of the common gene was strongly suppressed. In the suppressed plants, the ability to fix nitrogen was strongly reduced.

More research is needed to understand whether other genes are involved, and the physical and chemical processes at work in nitrogen fixation. With the crucial gene or genes identified, additional work is needed to get the crucial genes and other characteristics into common plants, and to test the effects of the genetically modified plants in production circumstances. By 2060, the prospect that nitrogen fertilizers will not be necessary is decidedly real.[68]

In the short run, scientists are working on seed inoculation. The idea is to inoculate seeds, prior to planting, with nitrogen fixing bacteria. The cost of inoculation is about $1

[68] Bioenergy news, Scientists discover genetics of nitrogen fixation in plants – potential implications for future agriculture, March 8, 2008

per acre (versus nitrogen fertilizer costs of $20 per acre plus related labour and fuel for multiple applications throughout the growing season).[69]

In another initiative, Arcadia in California is interested in a gene for an enzyme alanine aminotransferase, which produces protein and was originally isolated from barley. It boosts the ability of plants to take up nitrogen from the soil. Tests with the oilseed rape showed it could produce the same yield using a third of the fertilizer, or boost yield by a third using current fertilizer levels.

There are other techniques for reducing N_2O emissions under consideration. These include more effective timing of fertilizer applications, or changes to the way fertilizers are applied.[70]

Getting to Zero by 2060

Getting to zero by 2060 means:

- Reduced meat and dairy consumption.
- Changes in the types of meats consumed (chicken versus beef and lamb).
- Vaccines, changes in feed, and other mechanisms to reduce the methanogens in the digestive tracks of livestock, particularly cattle and sheep.
- Manure management for livestock at the same methane-management standard as for human waste.
- The introduction of genetically modified crops that can fix nitrogen without the application of nitrogen fertilizers.
- Where nitrogen fixation is impractical, seed inoculation practices instead of broadcast fertilizer, as a more efficient way to deliver nitrogen to plants.
- The development of plants more efficient in taking up nitrogen from fertilizers.

Projected Emissions

Projected Emissions for 2060: Agriculture

Greenhouse Gas Categories	**2012**	**2060 Projection**	**Comments**
	kt CO2 eq	**kt CO2 eq**	
Agriculture	54,130	2,385	Sector Total
Enteric Fermentation	18,000	900	Current emissions times 5 percent, representing the residual as demand for beef and dairy consumption fall, costs rise because of manure control, switching to non-greenhouse gas meats (farmed fish, chicken), and more emission efficient animal husbandry
Manure Management	6,400	0	Current emissions times zero, as manures are methane-managed like municipal waste
Agriculture Soils	29,700	1,485	Current emissions times 5 percent contingency representing the residual as nitrogen fixation replaces nitrogen fertilizers
Field Burning of Agricultural Residues	30	0	Current emissions times 0, as the practice is disallowed

[69] Microbe, A Nitrogen Story, Volume 2, Number 8, 2007
[70] New Scientist, Genes for greens, January 5, 2008, p. 28

Chapter 11: Waste

Past Emissions

Canada's 1990–2012 Green House Gas Emissions: Waste					
Greenhouse Gas Categories	**1990**	**2012**	**2012**	**Change 1990-2012**	
	kt CO2 eq	**kt CO2 eq**	**% Total 2012**	**kt CO2 eq**	**% Total Change**
Total – All Sectors	590,253	697,913	100.0%	107,660	18.2%
Waste	18,570	20,670	3.0%	2,100	11.3%
Solid Waste Disposal on Land	17,000	19,000	2.7%	2,000	11.8%
Wastewater Handling	830	1,000	0.1%	170	20.5%
Waste Incineration	740	670	0.1%	-70	-9.5%

Waste accounted for 3.0 percent of Canada's emissions in 2012. Waste emissions grew by 11.3 percent since 1990. Almost all waste emissions (91.9 percent) come from the disposal of solid waste on land.

Waste emissions are primarily in the form of methane. These emissions come almost exclusively from solid waste disposal on land. The problem arises because the organic matter in landfills gets buried and is allowed to decompose in the absence of oxygen, with methane the result of the decomposition.

Since 1990, overall emissions from Waste grew by 6%, mostly from increases in emissions from landfill operations. Emission releases in this sector are significantly mitigated by the growing volumes of landfill gas (LFG) captured and combusted at the landfill sites. While the CH4 emissions generated by all MSW landfills increased by 35% to 1302 kilotonnes (kt), the amount of CH4 captured increased by 144% to 470 kt in 2013. Of the overall CH4 captured, 49% was combusted for energy recovery applications and the remainder was flared. The number of landfill sites with LFG capture systems is rapidly rising in Canada, with 81 such systems operating in 2013.

Wastewater treatment and waste incineration facilities in Canada are minor sources of CH4 and N2O emissions and have generally remained stable.

Solid Waste Disposal on Land

Publicly and privately owned municipal solid waste landfills are responsible for approximately 82 percent of emissions. The rest originate from industrial landfills of wood residues. As markets for wood residues grow, these landfills are declining.

There are simple and complicated solutions to emissions from solid waste disposal on land.

The simple solutions involve keeping organic matter out of landfills. Encouraging home composting of organic matter is one mechanism. Another is municipal collection of organic matter on both a seasonal basis for yard waste, or on a regular basis kitchen waste. Where municipalities collect organic matter, the matter should be composted on an industrial basis. The organic matter will break down over time, producing CO_2 and not methane – a much more potent greenhouse gas.

In the operation of landfills, it is essential to collect the methane, and to not release the captured methane into the atmosphere. Options for the methane include:

- Using it to make industrial chemicals,
- Combusting it to produce electricity. In Canada, 49 percent of methane captured in solid waste landfill sites is used for energy recovery.
- Burning the methane releases the CO_2 into the atmosphere instead of allowing methane emissions into the atmosphere. Burning reduces the greenhouse gas effect of methane by 95 percent. Currently, 51 percent of captured methane in Canadian solid waste landfills is burned.

More complicated solutions are also being developed.

Geoplasma of Atlanta Georgia has developed an efficient torch for blasting garbage with a stream of superheated gas (plasma). The torch heats trash in a chamber to 10,000ºF. The organic components (food, fluids, paper) vaporize into a hot, pressurized gas, which is used to turn a turbine to provide energy. Inorganics such as metals condense at the bottom and can be used for roadbeds and heavy construction. Geoplasma is building a plant in St. Lucie, Florida to process 1,500 tons garbage by 2011, producing 60 megawatts of electricity. Emissions are lower than in a standard incinerator, and there is no methane. The approach significantly reduces landfill volumes.[71]

The Australian company Global Renewables has developed a process for decontaminating and separating waste. In its process, the waste is put into spinning cylinders with different sized slots on the curved side. The slots sift the waste. Vacuums of different strengths plus magnetic fields magnetize and then remove the aluminium. To separate out plastics of different types, light sensors examine material on a conveyor belt. A computer calculates the nature of the material by analyzing the reflected light. Wind jets blow specific materials into the relevant bins. To address the remaining materials, workers remove most of the 3 percent of waste deemed toxic. What is left is put into a percolator, which washes and aerates it, and removes specks of glass, metal and plastics. The carbon rich liquid that is left is put into a digester, where anaerobic bacteria break it down to methane, which in turn is captured and combusted to generate electricity to run the plant. The solid residue is composted.

The International Biochar Initiative is promoting the use of organic materials such as kitchen waste, garden clippings and diapers to make a biofuel called pyrolytic oil, which is an alternative to diesel. The process involves heating the organic matter in a kiln without oxygen. The byproduct in the bottom of the kiln is a charcoal high in organic carbon known as biochar. Biochar is a carbon sink, since it takes hundreds, even thousands of years to decompose and enter the atmosphere. When applied to soils treated with nitrogen fertilizer, it inhibits the release of N_2O.[72]

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[71] Scientific American, Florida's Garbage Vaporized, December 2008
[72] New Scientist, Make landfill history, October 20, 2007, p. 30

Getting to Zero by 2060

Getting to zero by 2060 means:

- Keeping organic waste out of waste sites to the extent possible.
- Where it gets into, or has gotten into, waste sites, collect the methane produced within the site, and:
    - Where possible, use the methane to produce organic compounds. By locking the methane in these compounds, the greenhouse gases are kept out of the atmosphere.
    - Use the methane to produce energy.
    - Ensure that whatever methane remains does not get into the atmosphere by converting the methane to CO2 through burning, since the greenhouse gas effects of CO2 are significantly less.

Projected Emissions

Projected Emissions for 2060: Waste			
Greenhouse Gas Categories	**2012**	**2060 Projection**	**Comments**
	kt CO2 eq	**kt CO2 eq**	
Waste	20,670	5,395	Sector Total
Solid Waste Disposal on Land	19,000	4,560	Uncaptured emissions (current emissions times 20 percent) PLUS captured emissions (80 percent of current emissions) times 5 percent representing the residual as methane is converted to CO2, which has 5 percent global warming effect compared to methane
Wastewater Handling	1,000	500	Current emissions times 50 percent representing the residual as emission efficiency increases
Waste Incineration	670	335	Current emissions times 50 percent representing the residual as emission efficiency increases

Chapter 12: The Six Percent Solution

Canada's Emissions in 2060

Will Canada get to zero emissions by 2060? Canada should be able to reduce emissions by 2060 to about 5.96 percent of the current level.

Projected Emissions for 2060: Sector Summary			
Greenhouse Gas Categories	**2012** **kt CO2 eq**	**2060 Projection** **kt CO2 eq**	**Reference**
Total – All Sectors	708,713	42,263	National Total
Fossil Fuel Production, Fugitives, Transport	171,600	5,512	See Page 13
Electricity and Heat Generation	88,300	2,208	See Page 42
Stationary Combustion Sources excluding Electricity & Heat Generation and Fossil Fuel Production	116,770	2,919	See Page 47
Road and Off-Road Transportation	170,012	8,621	See Page 59
Aviation (Domestic)	6,100	305	See Page 67
Railways	7,600	0	See Page 69
Marine (Domestic)	5,800	145	See Page 67
Industrial Processes	56,621	14,155	See Page 71
Solvent and Other Product Use	310	78	See Page 72
Agriculture	54,130	2,385	See Page 76
Waste	20,670	5,395	See Page 79
Aviation (International)	9,100	455	See Page 67
Marine (International)	1,700	85	See Page 67

Getting greenhouse gas emissions to 6 percent of current levels by 2060 is a good start, but the goal is zero emissions, and the sooner we get there, the better our lives.

Canada in 2060

What will Canada be like in 2060?

It will continue to combust some fossil fuels for energy purposes, but at only about 4.38 percent of the current rate. The oil and gas industry will be function at about 12.20 percent of current levels, thanks to non-energy uses, which currently account for about 7.37 percent of final demand. About 26 percent of the combusted fossil fuels will be captured. Fossil fuels will be combusted primarily in response to national priorities that cannot be addressed in any other way.

Canadians will not be flying much. Flying will be reserved for national priorities, and will occur in propeller-driven aircraft at low altitudes.

Marine travel will be limited to national priorities such as coastal ferries.

Trade will be primarily within the Americas and not transoceanic, because the latter requires the combustion of fossil fuels for the operation of large ships.

The electricity sector will be several times larger than at present, and will rely on a mixture of renewable and nuclear energy sources, combined with high voltage direct current transmission lines and a smart grid. Pressure on electricity grids will be offset to some extent by energy production by households and businesses. Unfortunately, the shores of the great lakes will probably be dotted with wind turbines.

Industries and residences will convert from using fossil fuels to produce heat and electricity to securing the energy either from the electricity grid or from their own renewable sources. Industries should be more efficient at managing fossil fuels, forced in part by regulations over greenhouse gas emissions.

Railways will see rapid growth, but they will have to rely primarily on electricity for main routes, and hydrogen on others. The sector will see rapid expansion, as it replaces aviation and marine and other forms of transportation.

Cars and light trucks will be powered by batteries. Heavy trucks on regular schedules will use hydrogen. Some fossil fuel use is likely to continue where alternatives do not exist and there is a national priority. A by-product will be cleaner air.

Through regulatory pressures to reduce greenhouse gases, industries will not only capture emissions from existing industrial processes, but develop new processes with fewer emissions or new products that do not require emissions. Industrial processes will be the largest emitter of greenhouse gases by 2060.

Emissions from enteric fermentation in animals will approach zero as the demand for animal products falls, farmers are regulated to control emissions, feed regimes are adjusted, and methane producing bacteria in animal guts are reduced or eliminated. Farmers will be forced to manage manure so that methane is either not produced, or is controlled and burned if it is produced. Nitrogen fertilizer use and related emissions will substantially come to an end, with the advent of nitrogen fixation in major crops.

Waste management processes will be improved to substantially reduce organic matter in landfills and to deal with the remaining organic matter in ways that do not produce methane. Where organic matter enters landfills, the methane likely to emerge will be captured and burned.

With the few exceptions listed above, Canadians will be able to keep much of their current lifestyle. The primary casualty will be air travel. New forms of leisure activities will emerge to replace air travel.

The Way Forward

The starting point to a zero-emissions future is legislation prohibiting emissions by individuals, companies and other Canadian entities without a license issued by the Government of Canada, starting in 2060 and authorizing the Government of Canada to issue licenses allowing emissions only for national priorities where there are no alternatives.

The legislation would focus the attention of all on emission reduction, give all parties fair warning about their future, and allow them sufficient time to make whatever adjustments are needed.

In addition to the legislation, the Government of Canada should request all sectors to provide sector-specific plans on how they will comply with the legislation by 2060. Those that are currently emitting greenhouse gases – oil and gas producers, electricity and heat generators, stationary combusters (manufacturers; constructors; commerce, institutional and residential owners; farmers and foresters), road and off-road transporters, railways, aviators, mariners, industrial processors, users of solvents, agriculturalists, waste managers – need to explain how **they** plan to eliminate their emissions, and what help they need from governments, businesses, citizens and other sources.

The plans will provide the foundation for a partnership between government and all sectors to reduce Canada's emissions. Regarding the plans:

- The plans may not be followed when the time comes, but those that have plans to do better than those that do not.
- All sectors need to be involved, and to take action. It is neither fair nor sufficient to focus attention on producers and combusters of fossil fuels.
- The role of governments is to support emitters with their emission reduction plans.
- Sectors that do not produce plans can expect neither sympathy nor support from others.

The path forward is likely to involve slow reductions in the short term that will rapidly escalate toward 2060, where the reduction is expected to be around 94 percent from 2012 levels.

It is not sufficient to make a drastic reduction in emissions by 2060. All emissions will add to global warming. Emission reduction work will not end in 2060. In many respects, it will have just started. Beyond 2060, hope lies in revolutionary, new technologies; the continued evolution of existing emission-reducing technologies; marginal improvements of regulatory regimes; and lifestyle changes including doing without and living for the purpose of helping each other.

Those of us alive in 2060 will regret the distant 2060 target, and wish it had been 2050 or sooner. By then, we will realize a lot can be done in a short time where there is a will and focus.