CLIMATE CRISIS: Physical Science, Natural Variability, Anthropogenic Impacts & Mitigating Emissions

Arctic & Antarctic: Loss of Arctic Sea Ice, Ice Sheets & Global Glaciers

More Solar Energy

More Wind Turbines

More Electric Vehicles

C- Sinks by Preserving Nature & Biodiversity

Harold S. Gopaul
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Foreword

This seventh edition resource focuses on the physical science of climate change, climate projections, Earth’s natural climate variability, anthropogenic impact from greenhouse gas emissions, extreme weather and ways to mitigate global warming. **Climate change is a given while a climate crisis is in the making.** Research was conducted spanning ten years with supporting scientific evidence and updated annually including the year 2019. Human health and all ecosystems are being threatened by rising atmospheric greenhouse gases from the consumption of highly polluting fossil fuels such as coal and from our slow transition to decarbonize. **I would encourage teachers to share this resource with your students; it is primarily meant to empower them with the tools necessary to make wise decisions about their future.** “Canadian climate change education is not consistent with scientific understanding... We found that most Canadian secondary school curricula did not provide full coverage of six core topics associated with increased concern for the issue of climate change” as cited by the authors in the July 18, 2019 *Plos One* journal. Leadership in climate change initiatives or protests has begun with our youths in over 120 countries and 1,700 cities initiated by a 15-year old Swede, Greta Thunberg – refer to “Young People’s Movement” section in Chapter Three. **Our youths are on a wise march today and tomorrow who will live longest with the climate crisis.**

This resource identifies regional and global evidence of the physical science of climate change from both anthropogenic and natural influences; it investigates adaptive measures for protecting ecosystems and advances how to reduce our carbon footprint, and what progress is being made in Canada and globally. There is no doom or gloom scenario projected from both natural and anthropogenic climate forcing but supported by the science from reliable and credible sources including peer review journals. **End of Chapter Questions** for students’ discussion and **Websites** are included for additional research. About 400 **References** are cited with a **Glossary**, a list of **Acronyms** and **Abbreviations** to help clarify the text material.
NASAs former top climate scientist, James Hansen, in his *Storms of My Grandchildren*, warned: “Planet Earth, creation, the world in which civilization developed, the world with climate patterns that we know and stable shorelines, is in imminent peril.” The Fifth Assessment Report of the *Intergovernmental Panel on Climate Change* (IPCC) reminds the world that “human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.” Indeed, climate change has been exacerbated by human influences in the past 100 years with a net global warming of 1.1°C since preindustrial time mainly from consumption of fossil fuels. Temperature in northern Canada is now 2.3°C above the 1948 average while the Arctic is becoming the banana belt with more than twice the global average. The IPCC presented its latest report in 2018 covering several chapters with a “Global Warming of 1.5 °C” section as a Summary for Policymakers; it projects that global warming is *likely* to reach 1.5°C between 2030 and 2052 if emissions of greenhouse gases continue to increase at the current rate.

Climate change and projections in this century are reminders of the complex and changing nature of the *climate system* from both natural and recent anthropogenic influences that may best be described as *climate destabilization*. No one could predict with any high degree of certainty the economic and environmental conditions in the next few decades but based on past and present conditions with impacts on Earth’s atmosphere, biosphere, land, hydrosphere and cryosphere, the projections from climate models should be taken seriously. Those climate projection models that scientists use have the planet looking a bit cloudy with continued human greenhouse gas emissions or with business as usual.

The IPCC consists of an assembly of over 2,500 international scientists and writers and has documented the research from thousands of respected scientists worldwide. The IPCC establishes with *high confidence* that “warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and oceans have warmed, the annual level of snow and ice has diminished, and sea level has risen.” Visionary leadership in advancing climate change mitigation and the role nature in
protecting biodiversity need to be a major focus among world leaders. On ‘visionary leadership’ the Royal Society of Canada in one of its report some years stated that the Canadian government needed to be more proactive on environmental issues. In 2016, a Pan-Canadian Framework on Clean Growth and Climate Change was proposed by federal, provincial and territorial governments in Vancouver; this plan takes concrete steps on emissions reductions and in low carbon technologies. A poll taken in 2015 by Nanos Research reveals that 78 per cent of Canadians wants Ottawa to play a leadership role in reducing greenhouse gases while 64 per cent would accept higher taxes on gasoline, natural gas and heating oil to cut emissions, if the revenue created is used to support a greener environment and economy. An Abacus Data survey in 2019 posted on CBC “In Our Backyard Climate Change” asked “How concerned are you about climate change” and 57% replied “Very to Extremely” concerned while 26% said “Quite” concerned.

Misconceptions held by deniers of climate science are included in Chapter Three and reveal how they manipulate scientific evidence, falsify data and reject the science to suit their argument. The last appointed head of the US Environmental Protection Agency (EPA), Scott Pruitt, and the present US President and Vice-President are climate change deniers. Science is one way of learning about the natural world in which we live and we agree it should be taught and experienced at an early age at home and at school. Scientific literacy should not be silenced by politicians or industries or by lobbyists to satisfy immediate financial gains or for political purpose; the public needs and demands transparency and the truth from our elected leaders. Former Prime Minister Stephen Harper had muzzled government scientists; a similar trend is taking place with the US Administration against government scientists. Science and technology help us to understand ourselves in building a better future for all mankind; the technology is in place now to vigourously promote and advance renewable sources of energy.

References in this book support the evidence of climate change science and include peer review journals, well-established organizations such as NASA, NOAA, IPBES, IPCC, EPA, Environment Canada and Climate Change, selected media and much more. In NASAs website at www.climate.nasa.gov, for example,
you could access “Global Climate Change – Vital Signs of the Planet” - under “Resources” you could go to “Educators” and look for “NASA’s Climate Kids”, “Climate Change Lessons”, “NOAA: Teaching Climate” and other useful teaching and learning resources for students.

The published report on Canadian climate, natural resources, food production, human health, water and transportation in Canada entitled “Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation” can be accessed at www.adaptation.nrcan.gc.ca. The updated 2019 Canada’s Changing Climate Report is accessed at www.ChangingClimate.ca/CCCR2019. Reports from the Canada’s Commissioner of the Environment and Sustainable Development, the Oil Sands Advisory Panel, the Royal Society of Canada Expert Panel, and Natural Resources Canada are also a few of the Canadian sources cited throughout this resource.

New guidelines and projections for reducing greenhouse gas emissions were introduced by the government of Canada at the UN Conference of Parties (COP21) in 2015 for a Paris Agreement. The Intended National Determined Contribution (INDC) or pledges approved by the government of Canada to reduce greenhouse gas emissions (GGE) by 30% below the 2005 level by 2030; it seems unlikely that Canada will meet this stated target. Canada promises to phase out coal-fired plants and proposed a modest carbon tax starting in 2018 and to be increased in subsequent years. It also stated that by 2025 passenger vehicles and light trucks would emit about 50% less emissions. The Commissioner of the Environment and Sustainable Development in her 2014 Fall Report, cautioned that “there is strong evidence that Canada will not meet its international greenhouse gas emission reduction by its stated 2020 or 2030 targets. The federal government does not have an overall plan that maps out how Canada will achieve this target.”

Details of the Canadian COP 21 Paris Agreement to reduce greenhouse gas emissions are discussed in Chapter Three. Canadian Parliament enacted the Greenhouse Gas Pollution Pricing Act in 2018 in over 200 pages. The Act assesses fees on carbon-based fuels and on industrial facilities that exceed prescribed CO₂ emission limits. The fees apply in provinces that do not already
have sufficient carbon pricing or a carbon tax. Pricing Act’s conditional imposition of fees and charges amounts to a regulatory program and not a scheme of taxation aimed at raising revenue for general governmental programs. Canadians are aware that the oil and gas industry, renewables and technology play an important role in determining the future and state of our economy. In Chapter One, the 2019 Report on *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)* on “Nature’s Dangerous Decline, Accelerating Unprecedented Species Extinction Rates” are documented. The latter report advocates expanding and protecting nature and biodiversity, leading to enhanced carbon sinks and linking with the Paris Agreement to keep our planet from exceeding 1.5°C in this century.

During my own lifetime the human population climbed by 4 billion in the past 60 years. Today’s 7.7 billion humans are competing for Earth’s resources: food supply, water for human consumption and agriculture, and with major threats to nature and biodiversity. Population growth, affluence and industrialization contribute to rising concentrations of greenhouse gases and worldwide loss of natural resources and species. In *Tomorrow’s Earth* cited in *Science* journal, Jeremy Berg warns that “our planet is in a perilous state. The combined effects of climate change, pollution, and loss of biodiversity are putting our health and well-being at risk. Given that human actions are largely responsible for these global problems, humanity must now nudge Earth onto a trajectory toward a more stable, harmonious state.” The goal is to rapidly decarbonize and what we must demand for the future of our children and grandchildren; it cannot be business as usual.

Earth from space and Carl Sagan’s “pale blue dot” some 6.4 billion kilometres away taken by *Voyager 1* spacecraft. Credit NASA, NOAA & Jet Propulsion Laboratory.
**Introduction**

Climate change presents one of the greatest challenges and threats in the twenty first century. Some encouraging news emerged following the **UN Paris Conference of Parties** (COP 21) on climate change initiatives in 2015 with an agreement to limit global temperature to less than 2°C in this century from pre-industrialized time. The task seems daunting but not impossible for a likely target of 1.5°C from pre-industrial time over the next 80 years but the projection models appear cloudy. By 2020 countries including Canada as parties to the Paris Agreement would need to resubmit revised and achievable plans. In September 2018, the Global Climate Action Summit in San Francisco convened to *Take Ambition to the Next Level* and move another step forward following the Paris Agreement. We need to put the planet on track to prevent dangerous climate change impacts. It appears that we are conducting an unprecedented experiment with the only planet we have and not adapting fast enough, and as the climate changes faster, the more difficult and expensive it would become.

The **2018 IPCC Global Warming of 1.5°C** publication and the **2018 UN Emissions Gap Report** provide scenarios of a range of 1.5°C - 2.0°C warming between 2040 and 2100. In Chapter One, “Biodiversity, Ecosystem Services & Nature’s Dangerous Decline,” the UN & IPCC 2018 Reports, and in Chapter Four “The Way Forward: Reducing Emissions” provide ample evidence and ways that we could reduce greenhouse gas emissions and to keep our planet’s temperature from rising above 1.5°C before 2100.

The **Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report** confirmed that “the atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least 800,000 years.” Carbon dioxide concentrations rose by more than 40% since the industrial revolution primarily from fossil fuels emissions, and from a baseline since 1990 all greenhouse gases increased by 40 percent. Every passing decade clearly demonstrates increasing temperatures and each subsequent decade has become warmer than the previous. The planet’s average surface temperature has risen about 1.10°C in over a century, a change largely driven by anthropogenic greenhouse gases in the atmosphere. Carbon dioxide rising levels in the atmosphere always lead to an increase in surface temperature as both are well
linked. NASA’s *Goddard Institute for Space Studies* noted the combined years of 2015, 2016, 2017, 2018 and 2019 were the warmest of modern record-keeping, with present warming rate of about 0.17°C to 0.20 °C/decade.

An Arctic warming today is also accompanied by positive feedback mechanisms such as the thawing of the permafrost to release even more carbon dioxide and methane gases. Loss of albedo in the cryosphere also triggers additional melting of sea-ice, ice shelves and glaciers in the Arctic including Greenland, Canada’s North, Alaska, as well as the Western Antarctic and Peninsula. Simply put, Canada’s Arctic is now the banana belt with more than twice the mean temperature than the rest of the world. Northern Canada’s recent temperature is 2.3°C above the 1948 mean while the global average is at 1.10°C since preindustrial time. Not a day goes by without a piece being written about *climate change* or *global warming* in the media. *Climate change* often implies temperature rise over several decades and linked to increasing greenhouse gas concentrations but also implies impacts such as sea level rise, decline of ice in the cryosphere, warming oceans, extreme weather patterns, and loss of biodiversity. *Weather* and *climate* have similar elements but are defined in different ways as explained later. Earth’s climate has changed many times in the historic past and will in the distant future from natural climate variability of Earth’s changing axial tilt, precession and eccentricity about the Sun; the danger today is from rising anthropogenic greenhouse gases.

There is a *likely* projection of greater than 2°C warming by the end of this century if the major polluters cannot commit to their pledges made in the Paris Agreement. Greenhouse gas emissions (GGE) increased by about 3% in the last year with China and India having the highest GGE of a combined 35 percent globally. Both countries hold about one-third of the world’s human population and have rapidly growing economies and with heavy use of coal for electricity. The not so good news from the IPCC Fifth Assessment Report predicts that “surface temperature is projected to rise over the 21st century under all assessed IPCC emission scenarios. It is *very likely* that heat waves will occur more frequently and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise.”
Science and technology alone cannot solve the growing anthropogenic assaults from the Arctic to the Antarctic. Reducing our daily energy diet translates into lowering your carbon footprint as well as saving money. From the year 1900 to the present or in a microsecond of human existence the human population escalated from 1.6 billion to 7.7 billion and with over 5 billion people living in developing countries and mostly in megacities. The growth in human population, industrialization, affluence and consumption of fossil fuel all negatively impact on Earth’s resources. North Americans, Europeans, Japanese and Australians make up only 20% of the world’s population but use 75% of the world’s resources. The Chinese and Indians are now catching up with western nations. The world’s primary energy demand is expected to rise by 36% from 2008 to 2035. By 2018 the global output of carbon dioxide per year into the atmosphere was around 42 billion tonnes (GtCO₂) or 52 GtCO₂ equivalent (mixed GHG) per year. No new coal plants should be built and existing ones should sequester carbon, the latter seems unlikely for China and India that use 40% of the world’s coal for electricity. 

Canada seems to be doing its part in not building any new coal plants and will phase out those in Alberta, Saskatchewan, New Brunswick and Ontario. The following reports provide achievable plans for the protection and well-being of Earth’s biodiversity and to link with the IPCC goal of 1.5°C in this century: *Global Deal For Nature* ([https://www.globaldealfornature.org](https://www.globaldealfornature.org)), the *One Earth* ([https://www.leonardodicaprio.org](https://www.leonardodicaprio.org)), *RESOLVE* ([https://www.resolve.ngo](https://www.resolve.ngo)) call for 100% renewable by 2050 and much more as identified in Chapter one. Preserving nature to sequester carbon is a major focus from the latter reports. The 2019 *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (IPBES) goal at [www.ipbes.net](http://www.ipbes.net) advocates linking with the Paris Agreement and IPCC to stay under 1.5°C before 2100.

The chemistry of the atmosphere and stratosphere has been altered in the last 100 years mainly from increasing anthropogenic carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and the halocarbons. Biodiversity in aquatic and land ecosystems are under constant threat of extinction; we are creating the sixth mass extinction as claimed by climate scientists, in the IPBES Report and the World Wildlife Fund *Living Planet Report 2018: Aiming Higher*. The cryosphere at both poles is being subjected to increasing atmospheric and oceanic temperatures, loss
of albedo, sea ice loss, collapsing ice sheets and glaciers; mountain glaciers worldwide are also losing billions of tonnes of ice every year; the evidence is overwhelming.

Paul Ehrlich, Professor of Population Studies in the US, said that we cannot view consumption and population growth as separate issues but “it is consumption that damages our life support system as opposed to the expanding number of people. But they both multiply together.” On the economics of climate change, Professor Nicholas Stern, a former chief economist with the World Bank, claims that “climate change is a result of the greatest market failure that the world has ever seen and that every metric ton (tonne) of carbon dioxide emitted into the atmosphere imposes a damage of $25 to $85 on society.” The unborn, and our children and grandchildren, would be at greater risk if renewable energy sources are not fast-advanced on a global scale and greenhouse gas emissions reduced to at least the 1990 level before the year 2025. Can we push back carbon dioxide levels to 350 parts per million (ppm) from the present 415 ppm observed at the Mauna Loa observatory today? Is it possible to keep global temperatures under 2 °C from pre-industrial levels before this century ends? These questions and challenges that cannot be answered unless developed nations and developing economies work together to reduce fossil fuel consumption, putting a price on carbon, restoring and preserving nature, protecting biodiversity and advancing renewables. Population growth still poses major problems especially in African and Asian countries where food security, water supply and human health are growing concerns.

During our lifespan, we experience many technological advances that allow us to live longer, improve in our health care, provide adequate food supply, improve on water quality and safety in developed economies, communication with the internet, and yes, from the benefits of fossil fuels. The not so good news is increasing poverty and malnutrition in poorer countries, depleting natural resources on land and water, loss of ice mass from the polar regions and mountain glaciers, frequent droughts and other extreme weather, lack of clean water for human consumption and shortage for agriculture, air pollution in major cities and contaminated water on land and in our ocean, expanding desertification with crop losses, depletion of stratospheric ozone, population rise in poorer countries, and social unrest in some
societies; the list keeps growing as we have created a different planet in the past 100 years. We have now come to define this epoch for humankind as the **Anthropocene** following the last 11,000 years in the fairly stable **Holocene** or without the human impact.

We still have enough time to reduce dependency on fossil fuels such as coal, advance the work of the IPBES ([www.ipbes.net](http://www.ipbes.net)) to protect biodiversity and nature that also serves as carbon sinks, fast-track renewable of solar and wind power to return to under 400 ppm carbon dioxide. Planet Earth’s CO₂ concentration throughout the Holocene epoch remained well under 300 ppm. The fact remains that GHG are long-lasting in the atmosphere and even with reducing GHG under 400 ppm the atmospheric reservoir will still hold CO₂ in high concentrations for hundreds of years. The atmospheric reservoir today holds over 870 billion tonnes (Gt) of carbon or 3,200 Gt of carbon dioxide (1 Gt C = 3.67 Gt CO₂).

The climate in the past has been well researched and documented from ice core studies as explained in Chapter One. **Climate** refers to a region’s long-term weather patterns such as temperature, precipitation, sunshine hours, frequency of extreme weather and so on. Climate in past millennia was influenced by Earth’s orbital changes, ocean and atmospheric circulation, natural GHG (CO₂ and CH₄) and solar irradiance as natural variabilities with no human influence of GHG emissions. Planet Earth has experienced ice ages, warming periods and five mass extinctions; the last glacial maximum ended about 20,000 years ago followed by the Holocene epoch of a slow warming phase and then cooling period including the Little Ice Age that ended around 1850. All greenhouse gases (GHG) and the halocarbons are heat-absorbing and warm the atmosphere together with water vapour as the most abundant greenhouse gas.

**Climate change** arises from natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere. It used to be that “climate change” mostly referred to increasing temperatures near the Earth’s surface, but increasingly, climate change has come to mean much more; impacts include a warming ocean, loss of ice, changing and frequency of extreme weather such as
storms, droughts, precipitation, heat waves on land. *Weather* on the other hand is the state of the atmosphere at a given time and location. Weather conditions are short-term phenomena that include changes in temperature, air pressure, humidity, wind, clouds and precipitation, sunshine, snow and ice, and reported in the media daily. *Extreme weather* patterns now occur more frequently - droughts, heat waves, abnormal snowfall, cold spells, floods, forest fires, storms and hurricanes. The short-term natural variability of *El Nino* and *La Nina*, shifting jetstream coupled with climate destabilization contribute to extreme weather systems over vast regions of the planet. The IPCC found that some regions of the world such as southern Europe, Australia and West Africa have experienced more intense and longer periods of droughts. Recent research now reveals with high confidence that global warming from increasing GHG and natural variability promote many extreme weather events as discussed in Chapters One and Two. The *climate system* is combination of interacting systems and cycles in complex ways with the atmosphere, cryosphere, ocean and land; it is influenced by solar irradiance, clouds, greenhouse gases including water vapour, atmospheric and oceanic circulation, ice and snow, volcanic activities and the biosphere.

Scientists have developed mathematical models to predict future climate changes with a high degree of confidence based on specific scenarios and using supercomputers. The *Met Office Hadley Centre* research centre in England is one of the top scientific modelling and forecasting climate research laboratories; it predicts that “half the years in the next decade will be warmer than the previous record for global temperatures …if the world fails to make the required reductions, it will be faced with adapting not just to a 2°C rise in temperature but a likely 4°C by the end of this century.” The *National Oceanic and Atmospheric Administration* (NOAA) is another world class projection modelling research centre for climate and weather; temperature data obtained from Met Office and NOAA are close to agreement by a fraction of a degree and highly reliable. The *Pacific Institute for Climate Solutions* in Victoria, BC, is well-known for climate studies and projections in Canada. Projection models are not carved in stone and are always subject to changes from natural and human influences. Models, however, give us a good overview of future climate events based on current and past scientific data. The IPCC warned “nobody on this planet is going to be untouched by the impacts
of climate change - the very social stability of human systems could be at stake.” Climate change has posed a real threat to human survival on food supplies, available water for agriculture and consumption, sea level rise especially impacting on small island states, coastal villages, towns and cities.

Carbon dioxide (CO$_2$), methane (CH$_4$), nitrous oxide (N$_2$O), the halocarbons and carbon soot pollution are the major anthropogenic climate driving forces that contributed to an observed rise of 1.10°C globally since 1850. Looking at the combined years 2015 – 2019 were the five warmest years on record according to the World Meteorological Organization, Met Office Centre and NOAA. The IPCC projects “that following the doubling of CO$_2$ concentrations the global temperature is likely (defined as greater than 66% probability) to be in the range of 2°C to 4.5°C with a best estimate of about 3°C, and it is very unlikely (less than 10% probability) to be less than 1.5°C” by 2100. Scientists at the United Kingdom’s Tyndall Centre for Climate Change Research suggest that “even with global cuts of 3% per year starting at 2020, it could leave us with 4°C warming by the end of this century.” Some climate scientists speculate that the years in which a 2°C increase could have been prevented for the 21st century have already passed. Because of the complex nature of the climate system guarded terms such as likely, very likely, high or low confidence are used in projecting climate trends. To quote Professor Michael Mann at the Earth System Science Center, asking if climate change “causes” specific events such as extreme weather is the wrong question. “The relevant question is: ‘Is climate change impacting these events and making them more extreme?’ and we can say with great confidence that it is.”

Our craft in space is indeed a fragile one. The late Carl Sagan called it a pale blue dot less than one millimetre across some 6.4 billion kilometres away and said that “everything that has happened in all of human history has been and is being recorded on that insignificant distant blue dot” as a visible image in the previous image. Following the last glacial period, the Holocene epoch has seen the growth and impacts of the human species worldwide, including all its written history, development of major civilizations, and overall significant transition toward urban living. Millions of our non-human passengers have lived in balance and relatively trouble-free except for mass extinctions and glacial maximum periods. We travel
together as passengers on our tiny craft, dependent upon its vulnerable reserves of fossil fuel, water, arable soil, biodiversity on land and water, and preserved from annihilation only by the care we give to our fragile planet. The environmental roadmap is clear, we have but one choice, to have the vision and moral authority to see all these (environmental concerns) not as political problems, but as moral imperatives, an opportunity to find our better selves and create a brighter future. The United Nations Foundation (UNF) has outlined a roadmap for preventing unmanageable climate change and adapting to that degree of change that can no longer be avoided. The UNF stated that “humanity must act collectively and urgently to change the course through leadership at all levels of society. The time for collective action is now; there is no more time for delay.” We need to rethink our survival strategy to attend to this planetary emergency.

The UN Secretary General Antonio Guterres delivered a major address in 2018: “Climate change is the defining issue of our time, and we are at a defining moment. Scientists have been telling us for decades. Over and over again. Far too many leaders have refused to listen. If we do not change course by 2020, we risk missing the point where we can avoid runaway climate change.” The IPBES Chair, Sir Robert Watson warns: “The health of ecosystems on which we and all other species depend is deteriorating more rapidly than ever. We are eroding the very foundations of our economies, livelihoods, food security, health and quality of life worldwide.” NASA’s former leading climate expert, James Hansen, said that the “special interest groups seek to maintain short-term profits with little regard to either the long-term impact on the planet that will be inherited by our children and grandchildren.” In The Race of Our Lives Revisited (www.gmo.com), Jeremy Grantham puts it bluntly: “We will need all the leadership, all the science and engineering, all the effort, and all the luck we can muster to win this race. It really is the race of our lives.” Edward O. Wilson, the world’s leading entomologist and naturalist: “Humanity is a biological species, living in a biological environment, because like all species, we are exquisitely adapted in everything: from our behavior, to our genetics, to our physiology, to that particular environment in which we live. The earth is our home. Unless we preserve the rest of life, as a sacred duty, we will be endangering ourselves by destroying the home in which we evolved, and on which we completely depend.”
Chapter 1

Scientific Evidence of Climate Change: Globally & In Canada

Measuring Carbon Dioxide Concentrations

“The role of climate change in biodiversity loss is also severely underestimated because of the lag between rising levels of CO₂ concentration and the equivalent accumulation of the radiant heat that leads to warming and biological impact. Ironically, climate change is also, in part, the consequence of biodiversity destruction: The amount of carbon in the atmosphere from degraded and destroyed ecosystems is now equal to what remains in extant ecosystems. The additional CO₂ emanating from the combustion of fossil fuels is in fact ancient solar energy that was trapped and converted by ancient ecosystems and is now being released in a geological instant.” Thomas E Lovejoy (Science Advances, May 2019).

Charles Keeling and Roger Revelle set out to measure and monitor global carbon dioxide levels at the summit of Mauna Loa in Hawaii. It was a unique scientific undertaking designed to accumulate consistent and reliable data on carbon dioxide (CO₂) concentrations in the atmosphere. Keeling discovered a growing increase in CO₂ concentrations over the years. The zig-zag line on the graphs (Figures 1.1 A & B) shows the annual rise (source) and fall (sink) of CO₂ levels in the atmosphere; there is a noticeable decline (sink) of CO₂ concentration during the spring and summer months when plants are absorbing CO₂ from the atmosphere during the growing season or from photosynthesis in food manufacture. When plants are not making food CO₂ levels in the atmosphere would increase, notably during late autumn and winter months.

Planting more trees (afforestation) and reforestation is one way to reduce atmospheric carbon dioxide and improve on carbon sinks. When trees die or from deforestation more CO₂ is emitted into the atmosphere; in fact, deforestation and land misuse worldwide release more CO₂ than in all of transportation. Cars and trucks account for 14% of global carbon emissions, while most analysts attribute 15% carbon loss to deforestation and land degradation. British Columbia (BC) saw an estimated 74 million tonnes (Mt) of CO₂ emitted in 2009 from the devastation
of trees killed by the mountain pine beetle - a loss of the carbon sink; this loss of a carbon sink continued in affected regions of BC and Alberta. Canada’s forests cover 310 million hectares total and over 10 million hectares in BC were devastated by the mountain pine beetle. Forest fires and the mountain pine beetle

Figure 1.1 A. The curved line (zig-zag) shows the monthly and annual fluctuations of CO$_2$ concentrations; the steady mean increases from 2015–2019 of CO$_2$ in ppm. Credit to NOAA and the National Climate Data Center.

account for a significant increase in CO$_2$ in the atmosphere according to Natural Resources Canada data; in 2015 forest fires in Canada emitted 237 Mt CO$_2$. Over the last six decades atmospheric temperature has been rising in Canada, with average increase temperature over land by 1.7°C between 1948 and 2018, and northern Canada with a higher temperature rise of 2.3°C, more than twice as high the global average, according to the 2019 Canada’s Changing Climate Report.
“This rate of warming is about double the global average reported over the same time period. Warming has been occurring even faster in northern Canada and in the Arctic. A regional pattern of stronger warming in the west versus the east has been observed across North America and linked to shifts in large-scale atmosphere-ocean circulation patterns,” as reported in by Natural Resources Canada and Environment Canada. Later in this chapter the emphasis in reducing carbon from the atmosphere is in conserving nature and biodiversity with data from the IPBES Report.

Figure 1.1 B. An update of CO₂ concentration and seasonal variation of CO₂ source and sink at Mauna Loa station in Hawaii from April 2018 to May 2019 (~ 415 ppm). Note the months of sinks and sources in Hawaii. Credit to Scripps Institution of Oceanography & NOAA.

Charles Keeling used a high precision, non-dispersive infrared gas analyzer to collect his data on atmospheric carbon dioxide. The team of researchers selected
that location at Mauna Loa in Hawaii as ideal for monitoring atmospheric gases. It was originally chosen far from any continent as “the air was sampled and represents a good average for the central Pacific region. Being high up the mountain, it is above the inversion layer where most of the local effects are present” says NOAA. The contamination from local volcanic sources is sometimes detected at the observatory, and then removed from the background data. Keeling first recorded an average of 315 parts per million (ppm) by volume of CO₂ in the atmosphere in 1958 at the start of his research; in other words, it’s a volume of 315 litres of CO₂ in one million litres of air. The pre-industrial CO₂ concentrations averaged 280 ppm and by 2019 global CO₂ had climbed to 415 ppm. In a single annual cycle, Keeling noted that the average global concentration of CO₂ rose an average 318 ppm (source) and then dropped to 315 ppm (carbon sink) at the Mauna Loa station from August to October which are not comparable spring and summer months in Canada. The graph in Figure 1.1 B shows a higher level of source and sink from 2018 to 2019 data. The atmospheric concentration of CO₂ increased by an average of 1.80 ppm per year from 1979-2016, then climbed to 2.2 ppm per year during the years 2007-2016. The annual CO₂ increase from January 2016 to January 2017 was 2.9 ± 0.1 ppm quite a jump according to the Earth Science Research Laboratory. The rate of CO₂ increase has been escalating over the recent decades.

Figures 1.2. CO₂ concentrations above Mauna Loa and the “Keeling curve” as an ongoing increase. Charles Keeling shown above was a pioneering scientist on monitoring CO₂. Credit NOAA & Scripps Institution of Oceanography.
The data plotted an annual zig-zag or up and down line on the graph but with a constant mean increase in CO₂ concentrations (Figures 1.1 A & B) with each passing year. What could this zig-zag pattern represent in terms of CO₂ rise and fall? When plants are not carrying out photosynthesis or food manufacture, they absorb less CO₂ from the atmosphere, thus increasing the annual atmospheric CO₂ concentration by about 3-5 ppm. In the Hawaiian spring and summer months (about July to October) plants absorb a lot of CO₂ from the atmosphere for photosynthesis, thus lowering (sink) the atmospheric CO₂ concentration by about 3-5 ppm. Figures 1.1 A & B show that impressive rise and fall or source and sink of CO₂ levels at the Mauna Loa station and identifies the “seasonal variation” and months for sources and sinks. Plants and indeed the world’s forests and oceans contribute to the global carbon sink and provide the oxygen we breathe while fossil fuel combustion, deforestation, fires and biomass burning greatly increase atmospheric global CO₂ concentrations. Similar CO₂ measurements were recorded in the Southern Hemisphere at the Baring Head monitoring station in New Zealand. Both Mauna Loa and the Baring Head recording stations provide the longest continuous record of accurate measurements of global atmospheric CO₂ concentrations. It is interesting to note that the annual fluctuation (zig-zag representations) or source and sink of CO₂ concentrations is lower at the Baring Head station than at Mauna Loa located in the Northern Hemisphere. This data indicates that the Southern Hemisphere holds less vegetation than the Northern Hemisphere, thus the slight difference in CO₂ sources and sinks at the two stations. Examine at a vegetation or biome map of the world and compare the differences between the two hemispheres.

Additional data are recorded from four CO₂ monitoring stations shown in Figure 1.2 A with each station showing its annual source and sink but with a constant increase of CO₂ over time. Note that at Barrow, Alaska there is a high sink and source compared with other stations, the lowest being at the South Pole which is expected with no vegetation. One observation on the ‘source’ compared to the ‘sink’ at Barrow shows a blunt end (graphically visual) as a source and the sink (pointed end) for an annual rise and fall. Why a ‘blunt’ end or ‘spike’ end representing ‘source’ and ‘sink’ mean? Some explanation includes: hours of daylight/darkness, greening of ecosystems in a warmer environment, permafrost
release of GHG, photosynthesis from boreal forests, decay and respiration. Which ones represent sink and source? The blunt end also is longer in time while the spike represents less time in the annual cycle. Why are the sources and sinks at American Samoa and at the South Pole lower in Figure 1.2 A than at Barrow or Mauna Loa? As observed, CO₂ concentration is increasing in all regions of the world.

![Monthly Mean Carbon Dioxide](http://www.esrl.noaa.gov/gmd/dv/data/)

Figure 1.2 A. Monthly mean CO₂ from Barrow, Alaska, Mauna Loa, Hawaii, American Samoa & South Pole. Credit NOAA Pacific Marine Environmental Laboratory.

In 2014, NASA launched a new satellite, the *Orbiting Carbon Observatory* or OCO-2, to accurately measure regional levels of CO₂ in the atmosphere over vast region of earth. The Orbiting Carbon Observatory-2 is NASA’s first satellite designed to measure atmospheric carbon dioxide with the precision, resolution, and coverage necessary to quantify regional carbon sources and sinks. Some earlier findings over Africa discovered high levels of CO₂ from the burning of savannas and forests, decay of biomass and respiration (Figure 2.7 B). A similar event was recorded in Brazil from forest fires, deforestation, an increase in droughts and drop in photosynthesis (low fluorescence) in northwest Brazil. In southeast Asia and Indonesia forest fires and droughts persist with an increase in atmospheric carbon dioxide. The Orbiting Carbon Observatory-2 is designed to collect “global measurements with sufficient precision, coverage, and resolution to aid in
resolving sources and sinks of CO₂ on regional scales. Solar-induced chlorophyll fluorescence measuring the rate of photosynthesis, is detected in remote sensing measurements of radiance” as in the Brazilian Amazon according to NASAs Jet Propulsion Laboratory. This analysis shows more carbon was released in 2015 (an El Niño year) relative to 2011 over Africa, South America, and Southeast Asia. These three tropical regions released 2.5 gigatonnes more carbon into the atmosphere than they did in 2011.

This additional carbon dioxide explains the difference in atmospheric carbon dioxide growth rates between 2011 and the peak years of 2015–16. The OCO-2 data allowed us to quantify how the net exchange of carbon between land and atmosphere in individual regions is being affected during El Niño years,” as reported by scientist Jungji Liu at NOAA - (1Gt Carbon = 3.67 GtCO₂). Elevated levels of CO₂ from North Africa across to India and China, the US and Europe are mostly associated with burning of fossil fuels. “OCO-2 observations confirm that the tropical Pacific Ocean played an early and important role in the response of atmospheric CO₂ concentrations to the 2015–2016 El Niño” as reported in October 2017 Science journal. Earth’s record spike in atmospheric carbon dioxide at the tropical Pacific region were driven by heat and drought caused by El Niño in 2015 and 2016. In addition, solar-induced chlorophyll fluorescence is a signal emitted directly from the core of photosynthetic machinery will lead to more reliable estimates of terrestrial carbon sources and sinks. The OCO-2 satellite will shed more light on where exactly emissions are coming from and how fast the planet could warm in the future.

On May 6, 2019 another satellite was carried by a supply spacecraft to the International Space Station (ISS) – it is the new OCO-3 satellite. Canadian astronaut David Saint-Jacques took the controls of the robotics workstation with the Canadaarm to retrieve ‘Dragon’ the supply spacecraft carrying the OCO-3 satellite. The ISS circles Earth between 52 degrees north to 52 degrees south latitudes - about the latitudes of London and Patagonia. Mounted externally on the underside of the space station, “OCO-3 will collect the first dawn-to-dusk observations of variations in carbon dioxide from space over tropical and mid-latitude regions, giving a better view of emission and absorption processes. OCO-3
like OCO-2 data collects “a very faint glow that plants emit during photosynthesis, called solar-induced fluorescence.” This light is far too dim for humans to notice under normal circumstances, but it is the most accurate indicator of the amount of photosynthesis that can be measured from space. As Earth's climate changes, rainfall and temperature are changing plant growth around the globe in ways that may affect world food security. “OCO-3 will demonstrate a new technique to measure urban carbon emissions, volcanic eruptions and other local carbon sources from space” according to NASA.

From the graph in Figure 1.2, from 1958 to 2017, the global concentration of carbon dioxide increased from 315 ppm to 407 ppm; from 2017 to 2019 CO₂ levels jumped to 415 ppm, a huge rise in the last two years. Methane (CH₄) climbed by 135% followed by nitrous oxide (N₂O) at 75% posing additional environmental concerns. Both greenhouse gases and atmospheric temperature are closely linked so it is not surprising that global temperature would rise along with increases in greenhouse gases. Throughout the 20th century the global temperature rose by 0.75 °C according to the IPCC Fourth Assessment Report and now at 1.10°C from pre-industrial time. As mentioned, in the Canadian north the temperature is more than twice the global average at 2.3°C rise from 1948 to 2016.

The global CO₂ equivalent emission since 1970 to the present increased by 70%; the CO₂ equivalent is the amount of climate or radiative forcing (a measure of
warming or cooling) produced by mixed greenhouse gases, namely, CO₂, CH₄, N₂O, including the halocarbons and calculated in Watts per metre square (Wm⁻²) in the upper atmosphere. This net radiative forcing of all mixed greenhouse gases calculated by the *US Climate Science Report* is ~3.00 Wm⁻² and increasing with each passing decade. Radiative forcing is discussed later in this chapter. James Butler and his team at NOAA designed an *Index* to for CO₂ equivalent concentration as shown in the next graph. Measuring CO₂ in ppm in the atmosphere is routine but the *CO₂ equivalent* is meaningful data and must be included in global warming.

![Graph of CO₂ equivalent mixing ratio (ppm) vs. Year](image)

Figure 1.2 C. Greenhouse Gas Index of CO₂ and non-CO₂ GHGs (CO₂ Equivalent). The Index was set at 1.0 by the year 1990 (Kyoto Protocol Year) and by the end of 2016 the Index rose to 1.4 or 40% increase in GHG equivalent. Credit NOAA Earth System Research Laboratory.

By 2016 the *CO₂ equivalent* concentration was ~ 490 ppm while CO₂ measured 404 ppm (Figure 1.2 C); CO₂ in the atmosphere by mid 2019 climbed to 415
**ppm.** The *Index* compares the combined warming influence of these gases each year to its influence since 1990, the year that countries signed on to the UN Kyoto Protocol as a *benchmark* to reduce emissions. By the end of 2016, the warming influence of greenhouse gases had risen 40 percent above the 1990 baseline (Figure 1.2 C). Carbon dioxide equivalent would be higher than the percent quoted in Figure 1.2 C knowing that CO$_2$ concentration has been rising at a faster rate. Carbon dioxide rise in the atmosphere is always consistent with surface temperature rise.

Four world-class research centres that provide global-average temperature each month (Figure 1.3 B) from thousands of land and ocean stations are *Met Office Hadley Centre* in England, *Goddard Institute for Space Studies* (GISS), the *National Oceanic and Atmospheric Administration* (NOAA) and the *Japanese Meteorological Agency*. These research centres work independently to gather, analyze and calculate data. There is *high confidence* that since the 1970s global warming has been escalating. About 6,300 meteorological stations around the world include over 1200 buoys, over 2,000 land stations and 4,000 ships that provide data and checked by super computers. This research was pioneered by Charles David Keeling of the *Scripps Institution of Oceanography* in March of 1958 at a facility of the *National Oceanic and Atmospheric Administration* (NOAA). NOAA started its own atmospheric CO$_2$ research in 1974 and ran in parallel with the research of the Scripps Institute. Keeling who was the pioneer of monitoring atmospheric carbon dioxide died in June 2005, a tribute to his work in understanding climate change, CO$_2$ rise and global temperature (Figure 1.2). Ralph Keeling carries on the work of his father as the principal investigator for the *Atmospheric Oxygen Research Group* at Scripps Institute and the director of the Mauna Loa CO$_2$ program.

**A Warming Planet & Likely/Unlikely Target of 1.5°C – 2.0°C by 2100?**

Earth was supposed to be in a slightly cooling phase during the past 1,000 years in the Holocene but is negated by global warming especially since the 1950s in a more serious way. Over the past 120 years there have been pauses of cooling and
warming but since the 1970s global temperature has been steadily escalating due to higher concentrations of greenhouse gases in the atmosphere. Relative to average temperature for 1880-1920, as an appropriate estimate of pre-industrial temperature, “Earth’s 2016 surface temperatures were the warmest since modern record keeping began in 1880”, according to independent analyses by NASA and the National Oceanic and Atmospheric Administration (NOAA). El Nino in 2015 and 2016 was partly responsible for a slight spike in global temperature. The combined temperature from 2015 - 2019 years now surpass all the previous years. Every passing decade has been warmer than the previous since the 1960s as shown in Figure 1.2 D – climate change is best recorded in decades rather than individual years. During the 1961-1970 decade global temperature escalated by 0.56°C up to the 2001-2010 decade. The present decade, 2011- 2020, is expected to be warmer by a fraction of a degree than the previous. NASA GISS or GISTEMP reported that “July 2019 was the warmest global July of 1.17°C relative to 1880-1920 years.” The mean global temperature rose to 1.1°C since preindustrial time but regional variations in northern Canada and the Arctic are twice the global average.

Figure 1.2 D. Global temperatures increasing by decades especially since the 1970s. Credit NASA.
“Paleoclimate reconstruction shows that the second half of the 20th century was likely the warmest 50-year period in the Northern Hemisphere in the last 1300 years,” as reported from the 2014 IPCC Report. The 2014 *IPCC Fifth Assessment Report* stated that “warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia.” With more fossil fuel power stations in the horizon, energy-guzzling factories for coal combustion and inefficient buildings, it would be almost impossible to hold back on global warming with business as usual. Global temperature has been rising close to 0.20 °C per decade consistent with rising greenhouse gas concentrations. An increase in global temperature of 0.75 °C during the entire 20th century has not been influenced by naturally occurring systems such as solar radiation but by external anthropogenic radiative forcing from greenhouse gases. The NOAA projects that with the *best-case scenario* such as rapid growth in renewables, no new coal plants and with carbon capture and storage (CCS), a temperature rise of 1.9 °C by the year 2100 from 1990 baseline is a likely scenario. In the Northern Hemisphere from the years 1983 to the present were the warmest 35-year period in the past 1400 years. Pledges made by countries at the Paris COP 21 (Paris Accord) still project a *very unlikely* scenario on limiting the rise of 2 °C by 2100, knowing how the way the world has been consuming fossil fuel or business as usual. Details of the Paris Agreement and projecting climate change in this century are discussed later.

**For 2018–2022 years**, the probabilistic forecast indicates a warmer than normal period, with respect to the forced trend. This will temporarily reinforce the long-term global warming trend. “The coming warm period is associated with an increased likelihood of intense to extreme temperatures. Warming trend for surface air temperature and sea surface temperature is expected for the next decade” as reported in *Nature Communications* on August 14, 2018 by climate scientist Florian Sevellec and others. The study by Sevellec shows that at the global level, 2018-2022 may be an even hotter period than expected based on current global warming. The *IPCC Special Report in August 2019 on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems* added that since the pre-industrial period, the land surface air temperature has risen nearly twice as much as
the global average temperature (high confidence rating). Warming caused by greenhouse gas emissions is not linear. The latter study noted that “temperature appears to have lapped in the early 21st century, a phenomenon known as a global warming hiatus. A new method for predicting mean temperatures, however, suggests that the next few years will likely be hotter than expected. The coming warm period is associated with an increased likelihood of intense to extreme temperatures.”

Thomas Karl writing in the journal *Science* presented an updated global surface temperature analysis revealing that global trends are higher than those reported by the *Intergovernmental Panel on Climate Change* (IPCC) especially during the last few decades, and that the “central estimate for the rate of warming during the first 15 years of the 21st century is at least as great as the last half of the 20th century.” The study refutes the notion that there has been a slowdown or hiatus in the rate of global warming in recent years. The study is the work of a team of scientists from the *National Oceanic and Atmospheric Administration* (NOAA) and *National Centers for Environmental Information* (NCEI) using the latest global surface temperature data. The UK Met Office, NASA and NOAA reported that 17 of the 18 warmest years in the 136-year record all have occurred since 2001, with the exception of 1998 that was a strong El Nino year.

Warming across Canada from 1948-2018 was 1.7 °C, higher than the global average of 1.10 °C since pre-industrial time. Northern Canada’s temperature is surprisingly 2.3 °C since 1948 more than twice the global average (Figure 1.3). Canada’s Changing Climate Report (CCCR2019) also noted that British Columbia’s mean temperature has risen 1.9 °C since 1948, again higher than the global mean. In a US Climate Science Special Report in 2017 it noted “an annual average temperature over the contiguous United States increased by 1.2°F (0.7°C) for the period 1986–2016 relative to 1901–1960 and by 1.8°F (1.0°C) based on a linear regression for the period 1901–2016 (very high confidence).” NOAA and GISS posted 2015 - 2019 combined as the warmest years and with each successive year appearing to be warmer than the previous. The best projected increase in global temperatures using IPCC scenarios and from research models point to a range from 1.8°C to 4.0°C for long-term warming in this century according to William Collins, a climate scientist and a team leader for the IPCC. The data (Figures 1.3 A & B) from four world class research centres show consistent and reliable temperature data in over 150 years. The solid red line (Figure 1.3A) averages the 5-year mean collected from over 6,300 meteorological stations around the world from buoys, ships and land stations; temperature trends are never linear but continues to rise over time.

![Figure 1.3 A. Global temperatures from the period of 1880 to 2015 and never linear. Credit to NASAs Goddard Institute for Space Studies (GISS).](image)
Models project that even if CO₂ concentrations today were kept steady at the 1990 levels, by the year 2050 CO₂ concentration could still climb to 475 ppm from 415 ppm today, and by the year 2100 it could possibly reach 550 ppm based on any prolonged use of fossil fuels or business as usual. Could CO₂ levels in Earth’s atmosphere be reduced to 350 ppm for climate stability by the end of this century? If the world could stay between 1.5°C and 2.0°C warming, emissions must stay well below a projected 400 ppm. Using guarded terms since climate science has several built-in uncertainties from natural and anthropogenic influences, global temperature would likely (greater than 66% probability) be in the range of 2°C to 4.5°C with a best estimate of about 3°C, and it is very unlikely (less than 10% probability) to be less than 1.5°C according to the 2014 IPCC report. However, the 2018 IPCC Report looked at scenarios of how to achieve 1.5°C and 2.0°C by 2100. The COP21 Paris in 2015 left delegates hopeful of a planet warming of 2°C or less from pre-industrial time by 2100 only if those pledges made by countries are

![Temperature Anomaly (°C)](image)

Figure 1.3 B. Land and Sea Surface Temperatures: NASA’s Goddard Institute for Space Studies, NOAA National Climatic Data Center, Met Office Hadley Centre/Climatic Research Unit and the Japanese Meteorological Agency. Credit NASA GISS.
fulfilled over the next 5-10 years. International Energy Agency (IEA) noted encouragingly that the years 2013 to 2015 were a levelling of CO₂ emissions from fossil fuel combustion possibly due to a surge in renewables and reduced coal consumption.

**In the next chapter the global projection of climate change is detailed from the IPCC 2018 Report and the UN 2018 Gap Report.** The IEA preliminary data suggest that electricity generated by renewables played a critical role, having accounted for around 90% of new electricity generated in 2015 – all good news! Wind alone produced more than half of new electricity generated. In parallel, the global economy continued to grow by more than 3%, offering further evidence that the link between economic growth and emissions growth is weakening. In the more than 40 years in which the IEA has been providing information on CO₂ emissions, there were only four periods in which emissions stood still or fell compared to the previous year. The two biggest emitters of GHG, China and the United States, both registered a decline in energy-related CO₂ in 2015. Coal is still the highest fuel of use in China and India but declining in the USA, Canada and European nations. Nuclear power with an ample source of uranium in Canada is surprisingly in decline albeit a safer energy fuel for electricity than coal. Canada’s coal consumption is declining while natural gas as an energy source is on an upturn (Figure 1.3 C). However, Canada would still need gasoline, diesel and aviation fuel for our transportation system for several more decades (Figure 1.3 D); we now use 25% of fuel for transportation in Canada. Both India and China (Figure 1.3 E) are leading the way in carbon intensity while Sweden stands at the lowest level followed by France. The US, UK, Japan and Germany are just below the global average for carbon intensity. **Carbon intensity** is the amount of carbon by weight emitted per unit of energy consumed or billions of tonnes of carbon emitted (as CO₂ equivalent) divided by energy consumption in billions of tonnes of fossil fuel.
Figure 1.3 C. Energy usage in Canada 2014 and Projected 2040. Coal Production and use declining, natural gas increasing. Credit National Energy Board. Website: neb-one.gc.ca.

Figure 1.3 D. Energy usage in Transportation for Canada (2014) and projected to 2040. Gasoline and diesel will continue to be in the major energy mix. Credit National Energy Board Canada.
The Pembina Institute (June 27, 2019) reported that “Canada is the ninth biggest contributor to greenhouse gas emissions in the world with a 1.6% global contributor. We now know where to look to reduce Canada's contribution to this global problem, to restore balance to planetary climatic systems, to slow the frequency and intensity of costly extreme weather events like droughts, flooding and wildfires here at home, and,

![Graph on left showing the percent of GGE from Canadian provinces. On right, the use of fossil fuels for economic growth and development. Credit National Inventory Report.](image1)

Figure 1.3 D-1. Graph on left showing the percent of GGE from Canadian provinces. On right, the use of fossil fuels for economic growth and development. Credit National Inventory Report.

(a) 2016 Annual Emissions

![Graph on left showing the percent of GGE from Canadian provinces. On right, the use of fossil fuels for economic growth and development. Credit National Inventory Report.](image2)

Figure 1.3 D-2. Cumulative and Annual Emissions of major emitters. Data for annual emissions in 2016 is close to present emissions. Canada’s GHG emission is 1.6% of global. Credit NOAA.
Figure 1.3 E. Energy Consumption comparisons for China, USA, India & Germany ending in 2015. Cited from Dr. James Hansen’s research at www.columbia.edu.

through investment in clean technology and renewable energy, to position Canadian workers to profit from the global shift toward a clean economy. These graphs (National Inventory Report 2017 data) show GHG emissions by provinces and economic sectors (Figure 1.3 D-1). The provinces of Alberta and Ontario contributed 60% of GHG emissions in Canada in 2017. With reference to Figure 1.3 D-2, the emissions that accumulate from all countries are long-lasting. The IPCC stated that “after 2,000 years the atmosphere will still hold 15 - 40% of the initial CO₂” so it is a daunting task by all emitting countries past and present to reduce GHG now. In the next chapter projections and expectations are discussed from the IPCC and UN documents and the possibility of a 1.5 °C, 2.0°C or higher rise by 2100.
Natural Variability and Paleoclimatic Changes

Climate change historically has always been influenced by Earth’s changing orbit around the Sun, its changing proximity and amount of sunshine it receives. However, recent climate change or in over 100 years has not been influenced by increasing solar irradiance or from Earth’s orbital changes but by rising greenhouse gases. The 11-year solar cycle of waxing and waning sunspot numbers is perhaps the best way to understand how the Sun’s activity influences global warming or cooling. As shown in the graphs (Figures 1.3 G & H), solar irradiance remains relatively unchanged and even with decline in recent decades; NOAA projects a lowering level in the next decade and perhaps even longer. Sunspots equate with the Sun’s activity and high sunspot activity is known to raise global temperature by a mere 0.10 °C, with the last active increase being around 2014-2015. GHG have a radiative forcing of about 3.0 Watts per square metre (W/m²) of atmosphere compared to 0.25 W/m² for solar irradiance today. With no increases in GHG, Earth would be in a cooling pattern together with a decline in solar irradiance at least since the 1970s; the Holocene climate would have continued. The year 1850 saw
CO₂ concentration at about 280 ppm while CH₄ was around 770 ppb. By August 2019, the CO₂ concentration climbed to 415 ppm by volume while CH₄ level reached 1900 ppb. NASAs scientists noted that 24 of the past 25 years have been the warmest on record since instrumental records were taken. What is clear is that global temperatures would increase in the long-term and we may have passed the point of no return to stabilize global temperatures for the next 50 years. GHG concentrations in the atmosphere drives up atmospheric and surface temperatures but not from solar irradiance.

Figure 1.3 G. Relationships for Temperature, Carbon Dioxide concentration and Sunspot numbers or Solar Irradiance in over 100 years. Note the steady and declining solar irradiance. Credit to NASAs Goddard Institute of Space Studies (GISS).

Figure 1.3 G illustrates solar irradiance and the 11-year cycles are not factors responsible for the increase in global temperatures in the past 100 years but mainly from anthropogenic influences in adding more heat-absorbing greenhouse gases such as CO₂ into the atmosphere. If warming was caused by a more active Sun, then scientists would expect to see higher temperatures in all layers of the atmosphere. Instead, they have observed a cooling in the upper atmosphere, and a warming at the surface and in the lower regions of the atmosphere; that's because greenhouse gases including H₂O vapour are trapping heat in the lower atmosphere.
and re-radiating down to Earth’s surface. Scientists look at warming from one decade to the next and that each successive decade is expected to be warmer than the previous decade (Figure 1.2 D). As mentioned, research is cited from hundreds of climate scientists documented in peer review journals and from credible sources such as NASA, NOAA, EPA, AAAS, Met Hadley Centre, the IPCC, Environment Canada and many others.

Figure 1.3 H. Sunspot numbers or activity from 1995 to 2016 showing Solar Cycles at decreasing rate. Credit NASA Jet Propulsion Laboratory, California.

Earth’s climate has changed over the millennia and through millions of years from its orbit around the Sun. “We now have a better knowledge of climate variability over the past few climatic cycles as illustrated by selected paleo-temperature records dating back to 400,000 years” according to the IPCC. Changes in climate in the past millennia were based on Earth’s naturally occurring astro-physical phenomena and the solar system. These include: (1) Earth’s changing pathway around the Sun or its eccentricity (an egg-shaped pathway), (2) variations in its precession or rotational movement around the axis as Earth wobbles like a spinning top and, (3) changes in its axial tilt over tens of thousands of years. The latter three naturally occurring phenomena led to Earth’s warming and cooling or ice ages over hundreds of thousands and millions of years ago together with GHG
concentrations, volcanic activity and ocean circulation with outgassing of CO\textsubscript{2}. At present, Earth’s rotational axis is fixed to the star \textit{Polaris} and wobbles slowly (its precession) around the Sun. In about 10,000 years or so Earth’s rotational axis will point to the star \textit{Vega} in another constellation. Our planet including its polar axial direction will change and the northern hemisphere would see summers by December. Earth’s climate has changed many times from analyzing ice core data from the Antarctic and deep ocean sediments from around the world.

Milutin Milankovitch, a Serbian mathematician and scientist, had theorized that changes in Earth’s orbit and its axial tilt affect the amount of sunlight it receives; in the course of tens of thousands of years Earth would cool, another ice age would emerge, followed by a warming trend. Earth’s elliptical path (every 100,000 years), its precession (every 26,000 years) and axial tilt (every 41,000 years) occur over the millennia. A greater elliptical orbit corresponds to cooler periods while a more circular one brings about warming. Every January Earth is closest to the Sun (perihelion), a distance of about 147 million kilometres, and in July it is farthest (aphelion) by about 152 million kilometres – Earth’s pathway around the Sun is not a circular one but elliptical like the shape of an egg and changes over time. Its axis is tilted toward the Sun at 23.5\textdegree that starts the summer solstice around June 21, the longest day in the year in the Northern Hemisphere. Earth’s axial tilt varies from 22.1 to 24.5 degrees and decreasing, presently at 23 degrees-26 minutes-12.3 seconds of arc. A lesser tilt corresponds to Earth having cooler summers and increasing ice sheets. Incidentally, more solar energy or solar radiation is being experienced by people and biota in the southern hemisphere during the southern summer months from December to February since Earth is closest to the Sun by 5 million kilometres in the southern summer solstice - health issues such as a skin cancer seems to be more evident in Australia as the Sun is closer to Earth during their summer months; lifestyle factors are also part of the problem of having skin cancer. Earth will again experience changes in glaciation that ended about 20,000 years ago as the planet wobbles its way around the Sun. For more information on Earth’s orbit you can \textit{Google} ‘Milankovitch’ and also NASAs website at \url{https://earthobservatory.nasa.gov}.
During the last interglacial period about 125,000 years ago the average global temperature was around 3°C higher than the present and CO$_2$ concentration was around 275 ppm from ice core data. Sea level at that time was between 6.6 to 9.4 metres higher than today. Is Earth warming in a similar manner during the past 100 years from increasing solar activity or from changes in its axial tilt, precession or changes in eccentricity? The answer is unequivocally “NO”. The temperature increase realized since the Industrial Revolution to the present has been influenced mainly by higher concentrations of mixed greenhouse gases and minimally from natural influences such as solar irradiance, volcanic emissions, El Nino events while aerosols advance temporary cooling of the planet; radiative forcing comes directly from mixed greenhouse gases in the atmosphere. Our planet should actually be in a cooling phase without this growing greenhouse effect after the Holocene and Little Ice Age that ended about 1850.

How are scientists able to unfold the climate of past millennia, hundreds of thousands of years ago? Climatologists and glaciologists analyze ice cores (Vostok data) for the presence of tiny amounts of trapped gases such as CO$_2$ and CH$_4$, from plant and animal fossils, dust containing uranium and other elements, from heavy hydrogen or deuterium ($^2$H) and oxygen ($^{18}$O) or isotopes in water (ice) that provide some of the evidence of Earth’s past climate and temperature; all of the above were components of the atmosphere trapped as snow and then into ice. (An isotope is a heavier form of the same element). The graph in Figure 1.4 illustrates the changing concentrations of CO$_2$ and temperature over the millennia. On a reverse condition when temperatures increase more CO$_2$ is produced while lower temperatures tend to reduce CO$_2$ emissions from biomass. Was the rise in global temperatures driving up CO$_2$ concentrations or was it the other way around hundreds of thousands or millions of years ago? There is a direct correlation between temperature and greenhouse gases and that these two have been well linked for millions of years. Recent research in Nature journal (Vol. 514, Oct. 30, 2014) by Shaun Marcott et al hypothesized that CO$_2$ and CH$_4$ were increasing during the paleoclimate time from ocean circulation. Carbon dioxide has amplified the warming for thousands of subsequent years. The idea that CO$_2$ levels have risen after the temperature increases began may still be valid. Marcott reports “because we think CO$_2$ is being outgassed from somewhere in the Southern Ocean, we
hypothesized that this local Antarctic warming caused the CO2 to come out of the ocean, began warming the planet, and **drove the global climate warming.**” Scientific Enquirer summarizes thus: “while the initial warming hasn't historically been caused by CO2, **CO2 has amplified the warming for thousands of subsequent years** and is still the principal control knob governing Earth's temperature.”

A study by Jeremy Shakun and others in *Nature* (Vol. 484, April 5, 2012) looked at temperature changes 20,000 years ago (the last glacial-interglacial maximum) from around the world in identifying deep ocean sediment cores and added more detail to our understanding of the CO2-temperature change (Figure 1.4 C) relationship. They found that the Earth's orbital cycles triggered warming in the Arctic approximately 19,000 years ago, causing large amounts of ice to melt, flooding the oceans with fresh water. “This influx of fresh water then disrupted ocean current circulation, in turn causing a seesawing of heat between the hemispheres. The Southern Hemisphere and its oceans warmed first, starting about 18,000 years ago. As the Southern Ocean warms, the solubility of CO2 in water falls. This causes the oceans to give up more CO2, releasing it into the atmosphere. While the orbital cycles (Milankovitch) triggered the initial warming, overall, more than 90% of the glacial-interglacial warming occurred **after** that atmospheric CO2 increase.”

Paleoclimate temperature is determined by the concentrations measured in parts per thousand of deuterium or heavy oxygen (isotopes) that exist in tiny amounts in water or ice. **Snow or ice from colder periods is known to have less of the isotopes of hydrogen and oxygen.** During cold periods, the concentration of ²H or ¹⁸O (isotopes) in the ice is lower than during warm periods (Figure 1.4 A). The reasoning for the latter is at a lower temperature, the moisture has been removed from the atmosphere to a larger degree resulting in an increased depletion of the heavier isotopes in water forming ice. The amount of deuterium or ¹⁸O concentration in ice core samples provides the evidence of the changing temperatures over tens and hundreds of thousands of years (Figures 1.4-1, 1.4 & 1.4 A). The Vostok ice core samples in the Antarctic are being studied by glaciologists in laboratories in Grenoble, France and in Denver, Colorado.
From the graphs, warming occurred *more rapidly* than the cooling periods or glacial states. The warming of the planet over tens of thousands of years allowed the release of CO$_2$ and CH$_4$ that were stored in the ocean floor, from the decay process of biomass on land, and from the thawing of the permafrost and soil. As discussed above, the CO$_2$ outgassed from the Southern Ocean amplifies the global warming. Conversely, during the ice ages less CO$_2$ and CH$_4$ escaped from Earth’s land and ocean resulting in a lower emission of greenhouse gases. It was Earth’s natural warming or cooling trends that promoted greenhouse gas emissions in the historic past. Historically therefore, Earth has warmed and cooled by natural variability of Earth’s changing orbit around the Sun- changing its precession, elliptical pathways and axial tilt, according to the Milankovitch’s theory and confirmed by today’s scientists from deep ocean sedimentation cores.

Figure 1.4. Carbon dioxide and temperature changes over the past 400,000 years from ice core analysis in Vostok, Antarctica. The blue line on the graph represents CO$_2$ concentrations in parts per million and the red line refers to temperature changes in degrees Celsius. Credit to NOAA.
Past climate indicators are locked in ice cores, ocean sediments, tree rings, and coral skeleton that scientists have been analyzing for decades. As mentioned, tiny amounts of CO$_2$ and CH$_4$ gases become trapped in ice (Figure 1.4-1), millions to hundreds of thousands of years old that hold clues to ancient climate. The Vostok ice core samples preserved from 3,600 metres of ice in Antarctica have been studied to reveal past climate conditions dating back 420,000 years over four glacial periods (Figure 1.4-2). Scientists also discovered a large lake under the Vostok drilling site that holds clues to ancient life; in fact, hundreds of lakes and rivers have been identified under the Antarctic ice from laser satellites as explained in Chapter Two. Interpreting ancient temperature is based on sensitive measurements of the ratios of isotopes of oxygen and hydrogen (deuterium) left in ice core samples and first analyzed by climatologist Jean Robert Petit. The National Ice Core Laboratory in Denver, Colorado holds ice cores (Figure 1.4 B) under freezing temperatures for scientists around the world to study. As mentioned, **colder periods correspond to less of the isotope of hydrogen** (deuterium) or **oxygen** ($^{18}$O) and warmer periods indicate more of the isotopes as shown graphically in Figures 1.4-1 & 1.4 A. Figure 1.4 A provides data from the ‘Dome C Site’ that is the *European Program of Ice Coring in Antarctic* (EPICA) showing corresponding concentrations of CH$_4$, CO$_2$ and temperature changes in over 800,000 years; changing GHG concentrations corresponds to temperature changes.
Tiny pockets of air bubbles trapped in the ice, ash from ancient volcanic activities and remains of plants and animals preserved tell the history of the region and age of events. Plant and animal fossils have also been identified in about two kilometres below the ice sheet in Greenland. The DNA of plants and animals from ice core samples under Greenland’s ice sheet provides additional evidence of past climate as well as the existence of a boreal forest. Biologists from the University of Copenhagen uncovered DNA samples of alder, spruce, willow, pine, yew and other plants in a region known as known as Dye 3 in the south-central region of Greenland. Invertebrate DNA sequences of beetles, flies, spiders, butterflies and
moths were also obtained from the Dye 3 site. Greenland was once a boreal forest and its name seems quite appropriate. Recently on Ellesmere Island in the Canadian Arctic evidence of a boreal forest was identified under the ice sheet.

Figure 1.4 A. Past Climate from 3,270 metres Antarctic Ice. Data: Deuterium (\textsuperscript{2}H), CO\textsubscript{2} ppm & CH\textsubscript{4} ppb. Ice Core from EDC Site in E. Antarctic. Note the temperature rise 9\textdegree C since the last glacial period to recent. Credit EPICA & NOAA.

Today the vast Arctic region and Antarctic continent have been altered from increasing air and surface temperatures and a warming ocean circulation, accompanied by collapsing ice shelves, loss of sea ice, melting glaciers and diminishing ice sheets. Over 3,000 vertical metres of ice core samples have been examined and analyzed by scientists. The Russian drilling project at the Vostok Station in Antarctica identified air temperature variations that correspond to changes in carbon dioxide and methane concentrations in the historic past. A cooling period followed from about 100,000 years to about 20,000 years from the present – that is over an 80,000-year period. During the latter time period the temperature dropped about 10-12 degrees Celsius. This was representative of the last ice age. From 12,000 years ago to the present, Earth’s temperature again increased to the recent interglacial period or Holocene. It is likely that in the next
10,000 years or longer Earth would again experience global cooling from natural physical processes in changing eccentricity, precession and axial tilt as in the historic past. Planet Earth continues to be in a dynamic state internally as well as from changes in ocean circulation, changes in the chemistry of its atmosphere and from its slow but changing distance from the Sun, all playing a role in long-term climate change.

Figure 1.4 B. Sample of West Antarctic Ice Sheet holds the archive of the atmosphere including a layer of volcanic ash (dark band) that settled on the ice sheet approximately 21,000 years ago. Credit: Heidi Roop, National Science Foundation.

Carbon dioxide concentrations as a key mechanism of global warming during the last deglaciation from the research by Shakun and others using 80 oceanic proxy sedimentary cores from around the world (Figure 1.4 C). Deep-sea sediment cores first provided compelling evidence in the 1970s that Ice Ages were linked to slow cyclical changes in the earth’s orbit around the sun. Shakun explains that “these orbital cycles, however, affect the hemispheres in opposite ways, warming one while cooling the other. This seemed at odds with geologic data suggesting that the whole planet goes into and out of an ice age together. A possible explanation came in the 1980s when ice cores taken from Antarctica showed that atmospheric CO$_2$ levels also rose and fell with the Ice Ages, suggesting that CO$_2$ may have been the ‘globalizer’ of these climate changes. Temperatures recorded in these ice cores,
however, indicated that past episodes of warming began slightly before CO\textsubscript{2} started rising – apparently relegating CO\textsubscript{2} to being an amplifier of warming at best rather than a driver.” Figure 1.4 C shows difference between global and Antarctic temperatures during the last deglaciation. “The apparent lead of Antarctic temperature (red) over CO\textsubscript{2} (blue dots) in the ice-core records does not apply to global temperature (green)” according to the research findings by Shakun in *Nature* journal (April 5, 2012). Today we are seeing an Arctic temperature more than twice the global average of 1.1\degree C while northern Canada temperature since 1948 has risen 2.3\degree C to the present.

![Temperature and CO\textsubscript{2} over the last deglaciation](image)

Figure 1.4 C. Global Temperature and Antarctic temperature differ. CO\textsubscript{2} is the cause and effect of warming. Apparent lead of Antarctic temperature over CO\textsubscript{2} in the last deglaciation according to Shakun and others. Credit Jeremy Shakun *et al* (*Nature*, April 5, 2012, Volume 484).
Figure 1.4 D. Warming period following the last glacial maximum followed by cooling around 5,000 before the present. The Little Ice Age started around the year 1400 and ended around 1850 followed by global warming. Marcott et al. Science, Vol. 339, March 8, 2013.

“Marine and terrestrial proxy records suggest global cooling during the Late Holocene, following the peak warming of the Holocene until the rapid warming induced by increasing anthropogenic greenhouses gases. However, the physical mechanism responsible for this global cooling has remained elusive” according to Marcott (Figure 1.4 D). “Here, we show that climate models simulate a robust global annual mean warming in the Holocene, mainly in response to rising CO₂ and the retreat of ice sheets. We find that global temperature was rising from approximately 10,000 to 5,000 years before the present. Following this interval, global temperature decreased by approximately 0.7°C, culminating in the coolest temperatures of the Holocene around 500 years before present during what is commonly referred to as the Little Ice Age. The largest cooling occurred in the Northern Hemisphere. Slow, millennial-scale ventilation of Southern Ocean CO₂-rich, deep-ocean water masses is thought to have been fundamental to the rise in atmospheric CO₂ associated with the glacial termination” according to Shaun Marcott and co-researchers. The Little
Ice Age was a period of advancing glaciers in the northern hemisphere with loss of crops, infant mortality and other diseases that lasted over 300 years. In the Chamonix valley near Mont Blanc, France, numerous farms and villages were lost to the advancing front of the Argentiere mountain glacier. The damage was so threatening that the villagers summoned the Bishop of Geneva to perform an exorcism of the dark forces presumed responsible for the extreme and prolonged cold weather. The graph in Figure 1.4 E explains anthropogenic and natural influences in the climate system. The Holocene would have continued if humans did not contribute to global warming.

Figure 1.4 E. Following the Holocene, the Human Epoch or Anthropocene started about 100 years ago with repaid GHG emissions. Credit James Hansen, GISS – Columbia University.

The Carbon Cycle

As people work, learn, run errands, travel, and enjoy family and civic life, carbon is the common “thread,” running through their infrastructure, tools, and environment as illustrated by the tiny white threads in Figure 1.4 E-1. Thus, analysis of the carbon cycle will be enhanced by identifying human uses of and reliance on carbon. “We are made of carbon, we eat carbon; our civilizations, our economies, our homes, our means of transport are built on carbon. We need carbon, but that need is also entwined with one of the most serious problems facing us today: global climate change” writes Holli Riebeek, a researcher at NASAs Earth Observatory. The carbon cycle is more complex than is illustrated in the next few pages and still needing answers to
questions such as how much carbon can the ocean absorb and release? How much more carbon can the atmosphere hold? Carbon emissions refer to both CO$_2$ and CH$_4$ as greenhouse gases and implications in climate change. This section is meant as an introduction to the carbon cycle while throughout the text carbon dioxide and methane comprise carbon sources that are measured from the historic past and recent anthropogenic emissions that make up the *carbon cycle* as a regulating and cycling set of processes for maintaining life on earth.

![Image of carbon cycle](https://carbon2018.globalchange.gov)

Figure 1.4 E-1. We are embedded with Carbon – we don’t see carbon in transportation, electricity use, in food manufacture, at the grocery store but it’s in every “thread” of life. Credit Second State of the Carbon Cycle Report, US Global Change Research at [https://carbon2018.globalchange.gov](https://carbon2018.globalchange.gov).

Carbon dioxide is needed for life on the planet; without CO$_2$ plants would not exist, oxygen would not be produced and Earth would be a frozen planet. We are concerned today about releasing excessive amounts of carbon that is changing ecosystems with global warming. The carbon cycle is as old as Earth’s oceans and atmosphere have existed. There are two general cycles for carbon – *slow and fast* between the ocean and atmosphere, land and atmosphere (Figures 1.4 F & G). Once in the ocean, carbon dioxide reacts with water to release hydrogen, making the ocean more acidic with carbonic acid. The hydrogen also reacts with carbonate from rock weathering to produce bicarbonate ions. Winds, currents, and
temperature control the rate at which the ocean takes up carbon dioxide from the atmosphere. Research is being conducted to determine how much CO₂ is vented and absorbed by warm and cold oceans. Carbon is locked up in limestone and ocean sediments for hundreds of millions of years. Carbon is also locked up underground as oil, gas and coal deposits over hundreds of millions of years as a slow process but with a fast process in its release with combustion of that stored fossil fuel. Through a series of chemical reactions and tectonic activity, carbon takes between 100-200 million years to move between rocks, soil, ocean, and atmosphere in the slow carbon cycle. Volcanoes release that stored carbon and other gases into the atmosphere and eruptions create new land as on the Hawaiian Islands. The fast carbon flow is exchange between ocean and land with the atmosphere as sources and sinks. Photosynthesis, biomass burning and decay as well as feedback from permafrost decay and thawing release and exchange carbon dioxide and methane. Carbon dioxide and water in the presence of light with land and ocean plants or vegetation manufacture the building blocks of carbon, namely carbohydrates, and provide planet Earth with the much-needed oxygen and food sources.

Scientists would need an early warning system for potentially large, but hard to predict, changes in the carbon cycle, such as massive emissions of CO₂ from frozen carbon compounds in Arctic permafrost as it warms up. The oceans contain a very large reservoir of carbon that is exchanged with the atmosphere. As atmospheric CO₂ increases, the interaction with the surface ocean will change the chemistry of the seawater resulting in ocean acidification as mentioned. “Increasing CO₂ modifies the climate which in turn impacts ocean circulation and therefore ocean CO₂ uptake. Changes in marine ecosystems resulting from rising CO₂ and/or changing climate can also result in changes in air-sea CO₂ exchange. These feedbacks can change the role of the oceans in taking up atmospheric CO₂ making it very difficult to predict how the ocean carbon cycle will operate in the future” as reported by NOAA Pacific Marine Educational Laboratory. Regarding CO₂ and its solubility in cold and warm water, as the ocean surface warms, it emits more CO₂ or takes in less. The spikes in the sea surface temperature correspond to the spikes in CO₂ increase. A warming ocean is a subject of research since CO₂ has been steadily increasing in the atmosphere from anthropogenic activity. Simply
put, as water temperature increases, its ability dissolve CO₂ decreases. Global warming is expected to reduce the ocean’s ability to absorb CO₂, leaving more in the atmosphere which lead to even elevated temperatures. A study found that the “Atlantic Ocean absorbed increasing amounts of carbon at high latitudes and decreasing amounts of carbon closer to the Equator. In addition, the increase in absorbed carbon was greater in the Northern Hemisphere and extended farther down the water column” and noted by NOAA at www.climate.gov.

Sources and sinks that exchange carbon from one system to the next is simplified in the diagram (Figure 1.4 G) and is still an ongoing research to quantify natural and anthropogenic activities. Note the carbon storage reservoirs in land, in the ocean depths and the atmosphere; data provided are not up-to-date. Recent research indicates that about 870 billion tonnes (Gt) of CO₂ reside in the atmosphere at any given time to maintain the greenhouse effect but growing excess is putting our climate at risk; carbon dioxide is necessary for photosynthesis and should not be given a bad rap. Land plants and the oceans take up 55% of the extra carbon people have added into the atmosphere with about 45% remaining in the atmosphere; as much as 20% of CO₂ produced today may remain in the atmosphere for hundreds of years according to NOAA. The IPCC stated that “after 2000 years the atmosphere still holds 15% to 40% of the initial CO₂”. Without these GHG and clouds in the atmosphere planet Earth would be frozen at minus 18 degrees Celsius. Today the global temperature of the atmosphere is at about 15°C and slowly increasing with anthropogenic influences. Adding one ppm CO₂ to the atmosphere is equivalent to adding 7.8 billion (Gt) tonnes of carbon dioxide.

Carbon dioxide concentrations as discussed climbed from 280 ppm from 1780 to 415 ppm by volume today. All greenhouse gases climbed by about 40% from 1990 to 2016 as noted in the GHG Index graph shown in Figure 1.2 C. Do we have an excess CO₂ in the atmosphere and how does this affect climate change now and in the future? When is carbon neutrality expected, that is sources equal sinks? The CO₂ emissions data is typically expressed in gigatonnes carbon (Gt). For conversions you could use this data: One gigatonne (billion tonnes) of carbon equal 3.67 gigatonnes of carbon dioxide and 1 ppm CO₂ ~ 2.14 gigatonnes (Gt) carbon or ~7.81 Gt CO₂. The perturbation from anthropogenic influences as
shown in Figure 1.4 H for the mean of 2008-2017 years retrieved from the *Global Carbon Project*. The data from Figure 1.4 H is considered to be approximate and do not include updates to 2019 average. “It is likely that changes in ocean temperature and currents helped remove carbon from and then restore carbon to the atmosphere over the few thousands of years in which the ice ages began and ended” according to researchers from Earth Observatory at NASA. The latter source stated that “land plants and the ocean have taken up 55% of the extra carbon people have put into the atmosphere while 45% has stayed in the atmosphere.” Thus, the data for sources and sinks (Figure 1.4 G) should be considered as slightly off the current data.

Figure 1.4 F. The Carbon Cycle showing processes that move carbon from stored sites, to and from the atmosphere, ocean and land in Earth’s natural cycles with a small but significant percent from fossil fuel combustion. **Should link Land use, CO₂ flow from Ocean to Atmosphere to this cycle.** Credit [www.carboncyclescience.us](http://www.carboncyclescience.us).

**By studying the Carbon Cycle, the following questions still require answers:** What will happen to plants as temperatures increase and the climate changes? Will more carbon be removed from the atmosphere than is put back? How much extra carbon will the melting permafrost put into the atmosphere, and how much will
that amplify warming? Will ocean circulation or warming change the rate at which the ocean takes up carbon? Will ocean life become less productive? How much will the ocean acidify, and what effects will that have?” These and other questions need further investigating as suggested by NASA’s Earth Observatory. From Figure 1.4 H, the global fossil fuel industry on average from 2008-2017 produced about 34 billion tonnes (Gigatonnes or Pentagrams) of CO₂. Land use amounts to about 5 Gt CO₂ so we have a total emission of about 39 Gt CO₂ from humans per year; the amount not absorbed naturally works out to be 17.3 Gt CO₂ per year as shown in Figure 1.4 H with billions of more tonnes to be added; the revised atmospheric reservoir was about 870 Gt Carbon by 2019, higher than the 800 Gt C indicated in Figure 1.4 G as older data. With respect to the amount of carbon, and “to put this in perspective, think about a train of railroad hopper cars full of coal.

![Components of the Global Carbon Cycle](Figure 1.4 G. This diagram of the fast carbon cycle shows the movement of carbon between land, atmosphere, and oceans. **Yellow numbers are natural fluxes**, and **red are human contributions** in gigatonnes of carbon per year. (For CO₂ x 3.67 Gt). White numbers indicate stored carbon. Credit www.globalcarbonproject.org)
One hopper car will hold about 100 tons of coal which is about 80% carbon. If that hopper car is about 60 feet long then a train hauling one petagram of carbon as coal would have to be about 156,500 miles long” (Pacific Marine Environmental Laboratory)

Figure 1.4 H. Anthropogenic impact and recycling of CO₂ from fossil fuel, industry and land use/degradation with sources and sinks per year. Note that natural influences play the major role in the carbon cycle. Credit www.carboncyclescience.us & NOAA from a powerpoint (2018).

With reference to Figure 1.4 H, the carbon sinks include ‘Biosphere’ and ‘Ocean’ while carbon sources mainly include ‘Fossil CO₂’ and ‘Land use change’. For more information with useful ‘Questions with Answers’ go to these two websites: www.carboncyclescience.us, and www.esrl.noaa.gov. Noted from figures 1.4 G & 1.4 H, the natural sinks and sources have greater influences than anthropogenic but the latter is increasing and presents the climate crisis. The IPCC August 2019 report on Climate Change and Land Use puts Agriculture, Forestry and other land use as contributing 22% anthropogenic GHG emissions, much higher than cited in Figure 1.4 H.
Mixed greenhouse gases (GHG) such as CO₂, CH₄, N₂O, the halocarbons and, yes, water vapour, absorb infrared rays in the atmosphere; these GHG are activated or energized by these long waves or infrared rays and re-radiate this energy back onto Earth’s surface, causing surface temperatures to rise, thus creating the greenhouse effect. Infrared radiation from the Sun warms the planet and escapes into the atmosphere. All warm objects radiate infrared. Water vapour is the most abundant greenhouse gas while CO₂ is a mere 0.0415% in the atmosphere but more than enough for photosynthesis and keeping the planet warm or warmer; pre-industrial levels were around 0.0280% or 280 ppm including the Holocene epoch. This ability to absorb and re-emit infrared energy is what makes CO₂ an effective heat-trapping greenhouse gas. Greenhouse gases as we know are needed for the survival of the planet - for photosynthesis as green plants use CO₂ to make food, produce O₂ and for Earth’s climate stability. Mixed greenhouse gases such as carbon dioxide, methane, nitrous oxide, ozone and the halocarbons are long-lived, evenly distributed throughout the atmosphere and in higher concentrations today than in past millennia.

Environmental pollution with increasing dust and soot carried to regions of ice and snow lowers the albedo effect resulting in greater absorption of solar energy that further promotes melting of the sea ice, ice sheets and glaciers as positive feedback mechanisms. Today forest fires and seasonal burning from the tropical to the boreal forests add more soot that is carried over vast regions; the carbon loss is also evident with fires and insects such as the mountain pine beetle that is evident in British Columbia in killing pine trees. Black carbon arises mostly from the combustion of coal that travels across continents. Trans-Pacific pollution from nitrogen dioxide and ozone are also carried in the subtropical Jetstream from China to the west coast of North America. Carbon pollution elsewhere knows no geographical boundaries as our atmosphere and oceans are connected around our planet.

As an update, the atmosphere holds over 870 billion tonnes or gigatonnes (Gt) of carbon (1 Gt Carbon = 3.67 Gt CO₂) or about 3,200 Gt CO₂ and increasing every
year. From Figure 1.4 G, while figures need updating, most of the carbon storage is found in the ocean and under the soil (fossil fuel). Without greenhouse gases, Earth would be in a frozen state and kept at -20 degrees Celsius with no life except perhaps bacteria. Water vapour contributes about 50% of the greenhouse effect, a key factor in keeping temperatures in the habitable range on Earth. But as temperatures warm, more water vapour evaporates from Earth’s surface into the atmosphere, where it can cause temperatures to climb still further as positive feedback. GHG (CO₂, CH₄ & N₂O) account for about 25% of the greenhouse effect while clouds are responsible for the rest. Clouds, like greenhouse gases, also absorb and re-emit infrared energy. Low, warm clouds emit more energy than high, cold clouds. Low clouds often have nearly the same temperatures as the Earth’s surface, and so emit similar amounts of infrared energy. Clouds both reflect sunlight that cools the earth and trap heat (infrared radiation) like other GHG. Stratus and stratocumulus clouds exist about two kilometres above the surface, are grey and act like a sunscreen to cool the earth. Cumulus clouds look like cotton balls that dot the sky on clearer days that block sunlight but also trap Earth’s heat or infrared radiation. Cirrus clouds let sunlight through and have a warming effect on the surface (Figure 1.5 B). Fortunately, planet Earth is covered by clouds about 70% at any given time and generally exert a cooling effect. For more information on clouds you may access “Clouds and Radiation” at https://earthobservatory.nasa.gov.

As early as 1827 French researcher and mathematician Jean Fournier hypothesized that Earth’s temperature was being regulated by interactions of Earth’s surface and having “certain components in air.” Fournier compared the heating of Earth’s surface to that of a greenhouse but he could not explain the science of Earth’s warming or cooling. In 1859, John Tyndall, an Irish physicist, provided the first logical explanation of the greenhouse effect. Tyndall suggested that carbon dioxide in the great aerial ocean absorb the outgoing infrared or long waves radiated from Earth’s surface. Roughly one-third of the solar energy that reaches the top of the atmosphere is reflected back into space and about two-thirds is absorbed by Earth’s atmosphere, clouds, land and oceans. Clouds alone reflect about 20% of the Sun’s energy and roughly 50% is absorbed by land and oceans. Generally, clouds, greenhouse gases, and water vapour play a major role in regulating surface and
atmospheric temperatures. Lower clouds tend to reflect the Sun’s energy and keep Earth’s surface cooler while upper clouds trap and reflect more energy keeping Earth’s surface warmer. Greenhouse gases and water vapour in the atmosphere or troposphere absorb heat as long waves and are the primary agents in radiating this energy onto earth’s surface (Figure 1.5A). Higher concentrations of water vapour and greenhouse gases in the atmosphere promote higher temperatures and as well as higher precipitation levels. Some of that trapped infrared rays from greenhouse gases are re-radiated back onto Earth’s surface as long waves, warming Earth’s surface. NASAs Center for Climate Simulation puts water vapour and clouds as contributing 75% of the greenhouse effect with CO$_2$ equivalent (mixed greenhouse gases) contributing the rest.

![Figure 1.5. Relative amount of the Sun’s energy reflected and absorbed by the atmosphere, clouds and surface. Credit to NASA.](image)

In an actual greenhouse, the Sun’s radiation passes through the glass and is absorbed by plants and soil. Ninety percent of the heat is absorbed by the glass and heat energy is transferred by convection and conduction inside the greenhouse. Very little heat leaves the greenhouse; we experience this heat sitting in a hot car unless you open the windows. The term “greenhouse effect” should therefore not be confused with the actual mechanism of Earth's warming and climate control; we nevertheless loosely use this term today when discussing global warming. Earth’s surface heats up and emits infrared or long waves into the troposphere or
atmosphere containing water vapour, clouds, carbon dioxide, methane and other greenhouse gases that trap and then re-emit some of the long waves back onto Earth’s surface to warm up the Earth – that is the basis of the greenhouse effect. Higher concentrations of greenhouse gases therefore promote an increase in “climate forcing” or “radiative forcing” or “global warming” by elevating Earth’s surface temperatures. Since 1880 Earth’s temperature has risen about 1.10 °C and CO₂ concentrations in the atmosphere jumped from 280 ppm to 415 ppm and will continue to rise over time.

In 1896, a Swedish chemist Svante Arrhenius was the first to explain that carbon dioxide unlike oxygen and nitrogen absorb heat and is responsible for increasing Earth’s surface temperature. Arrhenius predicted that any rise in CO₂ concentration would elevate global temperatures. He also predicted that global warming causes the melting of glaciers and ice sheets. Arrhenius suggested that by doubling the concentration of CO₂ in the atmosphere, Earth’s temperature would rise by 5 to 6 degrees Celsius in over a century and commented that “people would live under a warmer sky and a less harsh environment than we were granted.” That prospect may indeed be pleasant for temperate dwellers in winter but not during the summer months and does not bode well for all organisms on land, ocean and freshwater as well as inhabitants in tropical and small island states and coastal ecosystems. In 1938, a British military engineer and meteorologist Guy Callendar linked greenhouse gases in promoting ‘climate change’. He hypothesized that a doubling of CO₂ concentration would result in an increase in the mean global temperature of 2.0°C. Callendar evaluated data from 600 meteorological stations and collected a long list of evidence from the world’s weather patterns. He concluded that “from the best laboratory observations it appears that the principal result of increasing atmospheric CO₂ would be a gradual increase in the mean temperature of the colder regions of Earth.” Callendar and Arrhenius both linked carbon dioxide concentrations with changes in surface temperature.

Carbon dioxide concentration is measured in parts per million (ppm) by volume in the atmosphere and increased to 415 ppm today from 280 ppm from preindustrial time, or we have 415 litres of CO₂ in one million litres of air. Methane (CH₄) concentration is measured in parts per billion (ppb) by volume and increased by
more than 40% (~1900 ppb CH₄) while nitrous oxide (N₂O) concentration increased by 50% (~320 ppb) since the 1970s. The latter two GHG have a higher potential in absorbing long waves and promoting a higher greenhouse effect than carbon dioxide. Relative to average temperature for 1880-1920, as an appropriate estimate of “pre-industrial” temperature, the year 2016 was warmer than in the base period; the year 2017 was noted as the second warmest with a mild La Nina (cooling trend) in effect as El Nino waned in 2016. Earth has definitely been warming up at a faster rate since the 1970s consistent with an increase in atmospheric CO₂ and other greenhouse gases.

![Figure 1.5 A. The greenhouse effect in general terms. Credit NASA.](image)

The IPCC projects that with a doubling of CO₂ concentrations to 560 ppm (from the year 1750) Earth’s surface temperature would likely warm between 2°C to 4.5°C and most likely (a probability of 90%) increase by 3 degrees Celsius. Climate scientists project that the lowest emission scenario gives the lowest global mean temperature increase of 2°C and its highest emission scenario projects a warming of 4.5°C by the year 2100. As mentioned, climate scientists at the Tyndall Centre
for Climate Change Research reported that “even with global greenhouse gas cuts of 3% starting in 2020 it could leave us with four degrees of warming by the end of the century.” Climate scientists and environmentalists want to see GGE return to 350 ppm to prevent catastrophic warming; at present Earth’s CO₂ emissions stand at 415 ppm. The thawing of the permafrost releases additional CH₄ and CO₂ into the atmosphere, further increasing surface temperature in the Arctic region. The latter concept known as a positive feedback is difficult to quantify in terms of how much warming is directly involved from such feedbacks. Clouds also create

![Examples of cloud feedback](image)

Figure 1.5 B. Clouds play an important role in Earth’s warming and cooling. Credit Skeptical Enquirer.

positive and negative climate feedbacks (Figure 1.5 B). Lower clouds are bright and reflect sunlight that provides more of a cooling effect or negative feedback whereas high level clouds have a net warming effect because they trap more outgoing heat (infrared radiation) - positive feedback. Volcanic aerosols also contribute to negative feedback and provide temporary cooling by reflection of sunlight from volcanic emissions or aerosols. Climate projections and updates from the IPCC and UN 2018 Reports discussed in Chapter Two for a projected range of 1.5 °C to 2.0 °C in specified years to follow.
Although CO₂ is the most abundant greenhouse gas, methane (CH₄) is considered to be about 23 times more powerful for its Global Warming Potential (GWP) - its efficiency to absorb heat more than CO₂. Nitrous oxide (N₂O) has a GWP of 300 times more powerful as a greenhouse gas than CO₂. The GWP is still higher for the halocarbons such as chlorofluorocarbons (CFCs); in fact, the CFCs and HFCs are the most powerful of the greenhouse gases; CFCs were phased out some years ago after the ruling at the Montreal Protocol. Major sources of methane come from the thawing of the permafrost, from rice paddies, from ruminants (cows) with the latter producing lots of it from belching and flatulence. As mentioned, greenhouse gases are long-lived; the ‘lifetime’ for CH₄ is about 12 years, 110 years for N₂O, while CO₂ continues to have warming effect for centuries to be recycled globally between the atmosphere and land and the atmosphere and ocean. At most times, the atmosphere holds about 870 billion tonnes of carbon dioxide as a 2018 update. Scientists at the National Oceanic and Atmospheric Administration (NOAA) and NASAs Goddard Institute for Space Studies (GISS) calculated to three significant figures that the five warmest years for global surface temperatures since 1850 except for 1998 as a strong El Nino, were 2015, 2016, 2017, 2018 and 2019. The fact remains that 24 of the past 25 years were the warmest on record since instrumental data were collected. However, temperature change over two or more decades is a more reliable statistic than comparing the hottest years by fractions of a degree.

Models that compute both natural and anthropogenic forcings from the year 1906 to the present clearly indicate that in all continents both atmospheric and surface temperatures have been increasing principally from human activities and not from natural means such as solar irradiance, as cited earlier in Figures 1.3 G & 1.4 E. The last decade (from 2001-2010) was warmer than the previous one (from 1991-2000) by 0.20°C (Figure 1.2 D). The present decade (from 2011-2020) is expected to be warmer than the last. The 2014 IPCC Report noted that “each of the last three decades has been successively warmer at the Earth’s surface than any preceding decade since 1850. In the Northern Hemisphere, the years from 1983 to 2014 were likely the warmest 30-year period of the last 1400 years.” This recent warming trend points directly to increasing greenhouse gases in the atmosphere.
**Greenhouse Gases: Natural & Anthropogenic**

**Fossil fuels powered the industrial revolution** and have greatly improved living standards in much of the world since 1850. The industrial revolution began in the United Kingdom, and until the second half of the 19th century more than half of global emissions arose from that small nation from coal combustion. Industrialization spread across Europe, then to the United States with emissions reaching about 50 percent of global emissions from that nation with about 5% of the global population in developing the biggest economy in the world today. As other nations developed, the U.S. fraction of greenhouse gas global emissions declined slowly and by 2019 was about 15% of global emission while China’s economy erupted to 29% GGE in 2019 and the second highest global economy; India is the third highest global polluter of about 8% and advancing its economy while moving tens of thousands of people out of poverty. Fossil fuels helped raise the standard of living of the average Canadian with 1.6% global polluter but carrying a very high carbon footprint. Coal is the mainstay in both China and India in generating electricity contributing to high GHG emissions and decline of the health of its people.

Greenhouse gases are considered individually or collectively when measuring the radiative or climate forcing effects that are quantified in Watts per square metre (Wm$^{-2}$) in the upper atmosphere. The incoming solar radiation onto Earth’s planet is calculated to be 340 Watts per square metre. The radiative forcings are estimates and based on the potential effectiveness for heat absorption or the global warming potential (GWP) of one GHG relative to another. The **greenhouse gases of importance are:** carbon dioxide (CO$_2$), methane (CH$_4$), nitrous oxide (N$_2$O), chlorofluorocarbons (CFCs are phased out), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), tropospheric ozone, sulfur hexafluoride (SF$_6$), nitrogen trifluoride (NF$_3$), halogenated ethers (eg.C$_4$F$_9$OC$_2$H$_5$), and other halocarbons not covered by the Montreal Protocol. Water vapour remains the most abundant natural GHG. Black carbon from pollution that settles in snow and ice reduces the albedo effect and contributes to a global warming potential higher than warming potential from the halocarbons (F-gases). As mentioned, it is difficult to quantify positive feedback into any temperature rise but it contributes to the increasing rise in Arctic temperature. For a detailed list of the sources of CO$_2$, CH$_4$, N$_2$O, HFCs,
PFCs and SF₆, you may refer to the US Environmental Protection Agency (EPA) entitled “Inventory of US Greenhouse Gas Emissions and Sinks.” Canada presently contributes 1.6% GGE globally while the US and China contribute 14% and 29%, respectively (Figure 1.3 D-1). For more information on Canada’s emissions, Google “Canada’s Greenhouse Gas Inventory” and “Executive Summary 2018”.

Methane is naturally generated from rice paddies, marsh lands, landfills, coal mining, the permafrost, the ocean floor and effluents from cattle and sheep through anaerobic bacterial means. An article in Scientific American predicts that by the year 2100 “methane concentrations would increase by 20% - 40% beyond the natural and man-made levels.” Gas hydrates on the ocean floor and the permafrost hold vast reserves of methane gas and escape when Arctic temperature rises; today the temperature in the Arctic and in northern Canada is more than twice the global mean of 1.10°C. Scientists at the Woods Hole Research estimate that 1,500 billion tonnes of carbon are stored in the permafrost and greater than 2°C would be produced from thawing from that stored carbon. The “thawing permafrost has caused the ground to subside more than 15 feet (about 5 metres) in parts of Alaska…things that normally happen in geologic time are happening during the span of human lifetime” writes Daniel Glick in National Geographic.

Ruminant animals like cows release a lot of methane gas through their enteric or digestive processes; in North America a major source of CH₄ surprisingly originates from enteric fermentation. One study in Britain found that an average dairy cow belches out some 100 to 200 litres of methane gas each day (Figure 1.6). Another study conducted in Argentina where 55 million heads of cattle graze on the famed Pampas grasslands reportedly produce a lot more methane per head than in the British study. Researcher Guillermo Berra from Argentina measured methane production from the stomach (consisting of four chambers) of cows and recorded that an animal weighing 550 kilograms could emit 800 to 1,000 litres of methane gas per day. From 2014 to at least the end of 2018, the amount of CH₄ in the atmosphere increased at nearly double the rate observed since 2007. Livestock inventories show that ruminant emissions began to rise steeply around 2002 and can account for about half of the CH₄ increase since 2007; CH₄ from wetlands also add to this increase. The UN Food and
in a report entitled “Livestock’s Long Shadow” stated that livestock emits more greenhouse gases (CH\textsubscript{4} and CO\textsubscript{2}) than emissions from all vehicles in the entire world. Livestock emissions in Canada amount to about 60 million tonnes of CO\textsubscript{2} equivalent from an earlier statistic. The Joint Global Change Research Institute found that “total livestock methane emissions have increased the most in rapidly developing regions of Asia, Latin America and Africa. In contrast, emissions increased less in the US and Canada.” Methane concentrations have more than doubled in the atmosphere mainly from leaky pipelines, coal mining, ruminant animals, rice fields and landfills, not to mention positive feedback from the thawing permafrost and ocean. The warming potential for CH\textsubscript{4} is more than 23 times higher than from carbon dioxide.

![Global Greenhouse Gas Emissions by Gas](image)

**Figure 1.5 C.** Global greenhouse gas emissions. Credit EPA, Government of USA.
We should be planting a billion trees every year around the world that act as carbon sinks and provide for a healthier environment and oxygen. Each student in China must plant one tree by age eleven. Carbon dioxide and the carbon sink both are lost from billions of trees killed by pests and from forest fires. The natural carbon sink has been reduced from the millions of pine trees killed off by the mountain pine beetle in British Columbia, Alberta, Colorado and Washington state; reforestation and afforestation (new plantings) need to be greatly expanded in Canada. Two of the worst forest fires occurred in 2017 and 2018 in BC, and similarly in 2016 in the Fort McMurray region and again in May 2019 in High Level, northern Alberta, with about one million hectares of forests destroyed, an area of about half the size of Vancouver Island. In addition to CO₂ emissions, CH₄ a potent GHG, has been increasing in the atmosphere from ruminants (cattle), rice paddies, peat lands drainage, permafrost thaw and coal combustion.

Canada has proposed cutting greenhouse gas emission by 17% from 2005 level by 2020 at the UN Copenhagen Conference but the Pembina Institute stated that “Canada is on track to miss its 2020 climate target by over 100 million tonnes.” Refer to Chapter 3 on “An Historic UN Agreement: COP21 Paris” on Canada’s Intended Nationally Determined Contributions (INDC) to reduce GGE by 2030, and INDC from other nations to keep our planet on less than a 2°C rise in this century; the world is not on track to keep GGE under 2°C rise by 2100 from their ambitious Paris Agreement INDC. Later in this chapter one initiative to reduce GHG emissions is to conserve nature and preserve on biodiversity as proposed by IPBES and the Global Change for Nature. The latter reports and mission emphasize the connection with the Paris Agreement to keep Earth’s temperature under 2°C by 2100.
Figure 1.5 D. Rise in methane in ppb from 2000 – 2018 (years not shown on graph). The “accelerated” growth started in 2014. Credit Science, June 2019 & NOAA.

Figure 1.6. Rice paddies in Java, Indonesia, source of methane gas. Photo by the author. Measuring methane gas production from a cow’s stomach from belching. Credit Reuther’s.

**Radiative or Climate Forcing**

The term ‘radiative’ refers to the energy balance between the incoming solar radiation and the outgoing infrared radiation in the atmosphere; it is a measure of how the energy balance of the Earth-Atmospheric system is being influenced when
mixed greenhouse gases interfere with the climate system. ‘Forcing’ refers to how Earth’s radiative balance is being shifted from its normal state to a higher or lower energy state in influencing temperature change. Radiative forcing (RF) is therefore a measure of the influence of greenhouse gases in changing the balance of the incoming and outgoing energy on Earth’s surface and atmosphere. Earth’s energy budget is controlled by solar irradiance, GHG, clouds, aerosols, land and ocean as sources and sinks, and other natural variabilities. The incoming solar energy at the top of Earth’s atmosphere is calculated to be **340 Watts per square metre (W/m²)** of atmosphere. To cite Wikipedia: “**Radiative forcing** or **climate forcing** is the difference between sunlight absorbed by the Earth and energy radiated back into space. The influences that cause changes to the Earth’s climate system in altering Earth’s radiative equilibrium, and forcing temperatures to rise or fall, are referred to as **Climate Forcings**.” Positive radiative forcing means Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy causes surface warming. Conversely, negative radiative forcing means that Earth loses more energy into space than it receives from the sun, which produces cooling.

Earth’s radiative forcing has been on the rise from increasing concentrations of greenhouse gases emitted into the atmosphere. Climatologists are able to quantify radiative forcing from the rate of energy change per unit area at the top of the atmosphere in a given time and expressed in Watts per square metre. Positive forcings from the influence GGE tend to warm the atmosphere while negative forcings from volcanic aerosols and lower clouds tend to cool the planet. That increase comes directly from anthropogenic influences, mainly from increasing carbon dioxide and methane. Solar irradiance is not responsible for the rise in global warming over the past century.

About one-third of the total energy from the Sun is reflected back into space at any given time; about 20% is absorbed by the atmosphere and 50% absorbed on land and the ocean (Figure 1.5). Earth’s atmosphere and surface with clouds, water vapour, greenhouse gases, aerosols, land, ocean and other bodies of water maintain a mean surface global temperature of 15°C. Carbon dioxide holds the highest radiative forcing or net warming potential followed by CH₄, N₂O, the halocarbons
and atmospheric ozone. The total global radiative forcing from all of the mixed anthropogenic greenhouse gases was calculated at 3.027 Wm$^{-2}$ from recent research by James Butler and others at NOAAs *Earth System Research Laboratory*. Radiative forcing is helpful in assessing and comparing the anthropogenic and natural drivers of climate change. According to NOAAs Butler and co-researchers: “Of the five long-lived greenhouse gases that contribute 96% to radiative climate forcing, CO$_2$ and N$_2$O are the only ones that continue to increase at a regular rate. Radiative forcing from CH$_4$ increased from 2007 to 2016 after remaining nearly constant from 1999 to 2006 (Figure 1.5 D). While the radiative forcing of the long-lived, well-mixed greenhouse gases increased 39.9% from 1990 to 2016, CO$_2$ has accounted for about 80% of this increase.” An imbalance by adding radiative forcing of 3.027 W/m$^2$ in the atmosphere directly caused a global temperature rise by about 1.10$^\circ$C in over 100 years and not from solar irradiance (Figures 1.3 G & 1.3 H).

Higher clouds act as a blanket and have a warming effect as they radiate long waves back onto Earth’s surface. We know that cloudy nights tend to be warmer than cloudless nights. Clouds close to Earth’s surface tend to have a negative forcing effect by reflectivity (high albedo) of solar energy and provide a cooling effect; lower clouds generally provide that shade umbrella. Aerosols or sulfate particles from volcanic eruptions provide a cooling effect in the atmosphere and is known to periodically reduce global temperature to a fraction of a degree; aerosols reflect solar radiation back into space resulting in a slight drop in global temperatures and a drop in radiative forcing. Suggestions of using aircrafts to bombard the upper atmospheres with sulfates to reduce warming is being considered to reduce global warming. Asteroid and meteoritic impacts in the geologic past would have reduced global temperatures and blocked sunlight resulting in serious consequences to Earth's biota that may have led to mass extinction of species like the dinosaurs. Natural aerosols in my opinion and not artificially inducing sulfates have always kept temperature in balance.
Figure 1.6 A. Radiative forcing, relative to 1750, from carbon dioxide alone since 1979. The percent change from January 1, 1990 is shown on the right axis and indicates how the direct warming influence of CO$_2$ increased by about 50% since 1990. Credit NOAA Earth Science Research Laboratory.

Figure 1.6 B. Radiative Forcing by major long-lived greenhouse gases (CO$_2$ equivalent) from 1970-2015, an increase of about 40% (1.4) from 1990 baseline (1.0). Credit NOAA.
The June 1991, Mount Pinatubo volcanic eruption in the Philippines “cooled the globe by at least half a degree and accelerated the loss of stratospheric ozone”, writes Richard Kerr’s in the journal *Science*. The National Research Council (Canada) in “Climate Intervention Reflecting Sunlight to Cool Earth” added “the eruption of Mount Pinatubo in the Philippines injected 20 million tons of sulfur dioxide into the stratosphere, which increased Earth’s reflectivity (albedo) and decreased the amount of sunlight absorbed, causing globally averaged surface air temperatures to cool an estimated 0.30°C for a period of 3 years.” The eruption of the Tambora Volcano in 1815 on the island of Sumbawa in Indonesia lowered global temperatures by as much as 2.5°C and historical accounts in 1816 in New England in eastern USA saw “the year without a summer with temperatures of 5 to 10 degrees below normal” according to the US Geological Survey. Tambora’s explosion killed about 100,000 people, ten times greater than Krakatoa and 100 times more powerful than the Mount St. Helens eruption in Washington State.

The naturally occurring phenomena and conditions in the atmosphere such as solar irradiance, clouds, water vapour concentration, naturally occurring greenhouse gases, volcanic aerosols and anthropogenic greenhouse gases regulate radiative forcing effects and provide the elements for changes in atmospheric and surface temperatures. Figure 1.6 B illustrates the amount of radiative forcing and warming influence by individual greenhouse gases based on the change in concentration of those gases in Earth’s atmosphere over the past decades. Radiative forcing is calculated in watts per square meter, which represents the size of the energy imbalance in the atmosphere. On the right side of the graph (Figure 1.6 B) radiative forcing is converted into the Annual Greenhouse Gas Index (AGGI) - also refer to Figure 1.2 C for the Index - which is set to a value of 1.0 for 1990. Since 1990 the AGGI or the CO₂ equivalent increased to an Index of 1.4 or 40% warming to the year 2016.
Regional Aquatic Ecosystems: Impacts & Awareness

“World Rivers Day is a celebration of the world's waterways. It highlights the many values of rivers and strives to increase public awareness and encourages the improved stewardship of rivers around the world. Rivers are the arteries of our planet; they are lifelines in the truest sense.” Mark Angelo “Outdoor Recreational Council of BC”

In this section you would be introduced to regional and global environmental impacts on ecosystems not necessarily tied to climate change but connected to human behaviour, specifically our impact on biodiversity and nature. Canada has environmental laws such as the Canadian Environmental Protection Act, the Fisheries Act, the Species at Risk Act, and enforcement of such laws is meant to foster good environmental stewardship. Recently we read about the Federal Appeal Court ruling against the proposed Kinder Morgan pipeline expansion and in particular the impact of tanker traffic on killer whales in the Salish Sea citing the Environmental Protection Act. The Royal Society of Canada Expert Panel (RSC) in its 315 page-report on Sustaining Canada’s Marine Biodiversity provides details on our three coastal regions and the challenges posed by a warming planet to fisheries and aquaculture. (You may have to Google the above report since RSC website does not show all reports before the year 2015 when I last checked the website www.rsc-src.ca). The Fisheries Act “requires extensive revision or replacement” and the Species at Risk Act “has yet to provide an effective legislative mechanism for the protection, conservation, and recovery of marine species at risk” as cited in that RSC report. Should more species such as polar bears that are subjected to a warming Arctic be added to the Species at Risk Act?

Legislation is still required to protect our three extensive coastal regions from oil tankers and ships carrying harmful or dangerous cargo; the regulations specified in the Transportation of Dangerous Goods Act (1992) are needed for the safe movement of chemicals by truck, rail and ship. Legislation is needed to address the toxic tailings and quality of water at the oil sands project and for responsible extraction of bitumen with as little disturbance to the ecosystems at the Fort McMurray region in Alberta. The Report from the Commissioner of the Environment and Sustainable Development (www.oag-bvg.gc.ca) is loaded with recommendations that the Government needs to enact upon in the House of
Commons on behalf of all Canadians. “According to the Canadian Environmental Assessment Agency, an environmental assessment should be conducted as early as possible in the planning stage of a major project. This is done so that the proponent can consider the analysis in the proposed plans, including incorporation of mitigation measures to address adverse environmental effects” as stated in the Fall 2014 Commissioner’s Report. The latter process was not fully executed for the Enbridge Northern Gateway and Kinder Morgan Trans Mountain applications as well as the failure of Canada’s National Energy Board to include tanker traffic and its safety at the hearing process; the NEB erred in both pipeline hearings and showed bias in its final determination. The federal Liberal government has stated the importance of consulting with First Nations on projects that impact on their territory before any planning; by not doing it has led to protests, delays and uncertainties in projects such as the Kinder Morgan Pipeline expansion from Alberta to Burnaby, BC. The Supreme Court of Canada noted that “if the Crown begins a project without consent prior to aboriginal title being established, it may be required to cancel the project upon establishment of the title.”

The Reports from the Royal Society of Canada in 2004 on “Science Issues related to Oil and Gas Activities Offshore British Columbia” document is a reminder of shipping concerns by oil supertankers. In April 2011, The Pembina Institute (www.pembinafoundation.org/pubs) produced its research and detailed recommendations on “Solving the Puzzle with 19 steps toward responsible oil sands development.” Canadians are anxious to see that the oil sands projects are developed in a responsible way for their long-term prosperity and environmental protection. No one is advocating to close down the oil sands but both government and industry must do a better job of making the environment safer for people and wildlife – for quality of water, for migratory birds, greenhouse gas emission, energy use for mining and in situ retrieval of oil, to name these important concerns. Until disturbed boreal forests are reclaimed to the satisfaction of the people of Alberta and government only then should new licenses be handed to companies for exploration. In 2016, the Premier of Alberta sent a strong message to Albertans and oil companies on changes to oil sand projects and reducing GGE while promoting development of oil sands and transport of bitumen by pipelines; the latter plan was
approved by the Prime Minister of Canada. At the time of writing political
decisions seem like indecisions.

The First Phase of water quality monitoring program on the Lower Athabasca
mainstream and its tributaries has been initiated. A team of scientists from across
Canada is conducting the research. Sadly, the non-elected Conservative Senators
defeated a Climate Bill in November 2010 that the federal opposition parties had
passed in the House of Commons. What message was the (former) Prime Minister
of Canada and his appointed Senators sending to Canadians? What message is the
present prime Minister sending to Canadians on a five-fold increase in tanker
traffic through the Port of Vancouver and purchasing the KM pipeline as
announced in May 2018? Compromises on tanker traffic and safety need to be
addressed or protests would continue as noted at the time of writing. The
Commissioner of the Environment and Sustainable Development stated that “the
federal government is not doing what it said it would do to protect the environment
and move toward sustainable development…”

In the December 2010 Report, the Royal Society of Canada Expert Panel delivered
its comprehensive and extensive findings on the oil sands operations and
recommendations to clean up the pollution and advance appropriate legislation. In
December 2010, the Federal Government’s Oil Sands Advisory Panel also
completed its review on monitoring the quality and quantity of water at the oil
sands projects and provided a number of recommendations (www.ec.gc.ca) that
former Environment Minister Jim Prentice (deceased) had commissioned. Another
former Environment Minister, John Baird, said that he acknowledged the need for
a monitoring system at the oil sands projects and the impact, and proclaimed “we
hear the panel loud and clear and we’re ready to act.” The federal government
subsequently appointed Peter Kent as the next environment minister in 2011, a
record of four environment ministers in just five years. Then in 2013, Prime
Minister Harper appointed still another Minister of the Environment in the name of
Leona Aglukkaq who represented Nunavut but was defeated by a Liberal candidate
in 2015. The follow up to the Oil Sands Panel’s recommendations on monitoring
of water quality in the Athabasca River system and tributaries is being advanced by
Environment Canada and the Alberta government. In 2014, Environment Canada
released a study citing research that estimated the rate at which water from tailings is seeping from one lake and into groundwater system connected into the Athabasca River; that rate is estimated to be 6.5 million litres per day.

The Report by the Royal Society of Canada Expert Panel (RSC) in February 2012 on “Sustaining Canada’s Marine Biodiversity: Responding to the Challenges Posed by Climate Change, Fisheries and Aquaculture” was critical of Fisheries and Oceans Canada: “We have failed to meet most of our national and international commitments to protect marine biodiversity…Fisheries and Oceans have generally done a poor job of managing fish stocks…We are failing our oceans”, the RSC report concluded. The Royal Society of Canada has produced several reports by its expert panel of scientists. Canada holds about 40% of the world’s marine species and its Arctic coastline comprises two-thirds of Canada’s entire coast. The report goes on to say that “compared to most developed nations Canada has made little substantive progress in fulfilling national and international commitments to sustain marine biodiversity.” The Fisheries Act requires extensive revision or replacement as recommended by the Royal Society of Canada. Prime Minister Trudeau announced in Vancouver in 2016 of a $1.5 billion National Oceans Protection Plan. The Oceans Protection Plan has four main priority areas:

- Creating a world-leading marine safety system that improves responsible shipping and protects Canada’s waters, including new preventive and response measures;
- Restoring and protecting the marine ecosystems and habitats, using new tools and research, as well as taking measures to address abandoned boats and wrecks;
- Strengthening partnerships and launching co-management practices with Indigenous communities, including building local emergency response capacity; and,
- Investing in oil spill cleanup research and methods to ensure that decisions taken in emergencies are evidence based.

The Oceans Protection Plan was developed based on work done over two years between Indigenous and coastal communities and various government programs implemented in 2017. But can this plan truly protect the marine ecosystems
from pollution such as oil spills? Since Canadians are keen on preserving ecosystems, the many reports from climate change to marine protected areas by the Commissioner of the Environment and Sustainable Development is worth accessing from its website at www.oag-bvg.gc.ca. These reports are generally directed to members of Parliament and the general public, and are at times critical of how government responds to issues on the environment as mentioned earlier. On the topic of ‘biodiversity’ and ‘fisheries’ for example, you can Google “Rivers in BC”. When I did so I came up with a list of rivers in BC from the Wikipedia website. I search the list and under “Thompson River” for example, found other rivers from that list. I wanted to know more about the Adams River that showed up. This is what Wikipedia provides in part: “The Adams River is a tributary to the Thompson and Fraser Rivers in British Columbia, Canada. Beginning in the Monashee Mountains to the north, the Upper Adams River flows mainly southward and eventually reaches Adams Lake. The Lower Adams River begins at the southern end of the lake and flows into the extreme western end of Shuswap Lake. The river is one of the most important sockeye salmon breeding areas in North America. The run occurs in mid-October and can bring millions of fish to a concentrated area near the river mouth.....” Now I Google “Sockeye Salmon in BC” since I wanted to know more about the sockeye. You can continue to access more information about the “Adams river sockeye run” and related information or your interest and research.

I needed to further investigate the “Sockeye Salmon in the Fraser River.” I then came up with this document: “The Uncertain Future of Fraser River Sockeye”. This is a very important government report by the Cohen Commission. It is lengthy, informative and well researched with supporting data, maps, graphs, photos. Another website of importance provides the work of the Pacific Salmon Commission (www.psc.org). The Pacific Salmon Commission is the body formed by the governments of Canada and the United States in 1985 to implement the Pacific Salmon Treaty. It is our shared responsibility to conserve the Pacific Salmon in order to achieve optimum production and to divide the harvests so that each country reaps the benefits of its investment in salmon management. In 1999 government-to-government negotiations culminated in the successful renewal of long-term fishing arrangements under the Pacific Salmon Treaty. The Thirty-
Second Annual Report 2016/2017 is available from the above website. Projected data of sockeye salmon returns up the Fraser River every 4 peak years such as in 2010, 2014 and 2018 and numbers were 28.3, 19.2, 13.9 million sockeye, respectively, according to a Pacific Salmon Commission report. The 2018 run was reported to be between 8.4 to 23 million fish according to Pacific Salmon Commission biologist Mike Lapointe. Report for 2019 has the Fraser River sockeye salmon is expected to return around 600,000 as decline has been increasing over the years. Ocean warming or extreme weather is one major cause of this decline. Figure 1.7 is a photo I took of sockeye salmon spawning in the Adams River in October 2010 which was a peak migration year.

**Fin Donnelly and Kevin Scott** are co-founders of the **Fraser Watershed Initiative** said that “projects include terrestrial and freshwater restoration, conservation of important cultural and recreational areas and preservation of critical habitat. This will provide training and critical employment for First Nations communities, and thousands of skills workers as well as diversifying the economic base of the watershed.” A major objective of the **Fraser Watershed** to a new, more culturally and economically prosperous and ecologically intact future was launched in July

![Figure 1.7. Adams River Sockeye Salmon in October 2010 and taken in Adams River. Signature runs but declining were in 2014 and 2018. Photo by the author.](image-url)
2019. Through a joint Government of Canada and Government of British Columbia Fund, the Minister of Fisheries said “we are investing in community and industry led solutions to restore the health of wild fish stocks and fish habitat across the province. This includes a focus on maintaining the integrity of the Fraser River salmon run as a crucial component of the Pacific wild salmon lifecycle.”

As a young man, Fin Donnelly, the Port Moody–Coquitlam NDP MP was a marathon swimmer, crossing the Strait of Georgia several times. But it was his journey down the length of the Fraser River in 1995 and again in 2000 that changed his life. When he came to swim in the Fraser River, he didn't care how cold or hot it was; he was doing it because he was trying to make our rivers and watersheds a better place for countless living species and an awareness of its importance to British Columbians. “It pretty much shaped me into the man I am today. It’s important to me because I’ve swam the length of the Fraser River twice. And a lot of the work I’m doing today now focuses on the Fraser River.” The journey in 1995 was a 1,400-kilometre swim, which he completed over 21 days. (I am pleased to add that Fin was one of my exceptionally bright biology students at Port Moody Secondary School).

We need to revitalize the ability to properly monitor and protect the environment and freshwater resources. The BC “endangered rivers list targets key waterways by region” – the list highlights these rivers, to name a few: Seymour, Fraser, Cowichan, Thompson, Peace and Skeena, and Shawnigan Creek. The Outdoor Recreation Council of British Columbia - 2016 Endangered Rivers provides a complete guide. The Outdoor Recreational Council of BC is headed by Mark Angelo and on “Endangered Rivers” it asks persons nominating rivers to answer the following:

✓ The name of the river or stream
✓ Impacts, threats and issues related to the river nominated
✓ Impacts on outdoor recreation and specific activities threatened
✓ The name of the group or individual making the nomination, his or her background
✓ Their experience with the area or the basis for their knowledge of the river being nominated.

The latter research and reports are coordinated by the above Council and “The Rivers Institute” at the British Columbia Institute of Technology (BCIT). For
example, the **Seymour River** in North Vancouver topped the most endangered waterways list for the Lower Mainland as a result of a December 2014 rockslide that blocked the return of early Coho salmon and summer steelhead stocks, according to a recent survey by the *Outdoor Recreation Council* of BC and headed by Mark Angelo. Angelo is an international river advocate and has paddled more than 1,000 rivers around the world and the full length of the Fraser River. A documentary entitled **River Blue** led by Angelo of rivers around the world that are being severely polluted by chemicals from the textile industry. It is quite a moving film depicting how rivers are being polluted in China, India, Bangladesh from that industry. You could Google “River Blue” for a preview of that documentary on *YouTube*.

![Fish ladder at Hells Gate on the Fraser River near Boston Bar, BC.](image)

Figure 1.7 A. Fish ladder at Hells Gate on the Fraser River near Boston Bar, BC. Salmon then swim onto the Thompson River to the Shuswap Lake and Adams River while the rest continue on the Fraser north. Photo by the author.

By the mid-1990s the El Paso’s (Texas) jeans industry was in a steep decline—a pair of jeans could be made in **Xintang, China** for a quarter of the price; today, it is the denim or **Blue Jeans capital of the world**. Some production went across the border into Mexico, but China was able to ramp up production on an unprecedented scale. Three hundred million pairs of jeans are made in Xintang
each year—that’s about 800,000 pairs a day—in both state-of-the-art factories and back alley workshops but with a severe environmental and health price to pay. Cotton, mostly imported from the United States, is cut and sewn, dyed and washed, distressed and sandblasted. The Pearl River through Guangdong province has sustained Chinese civilization for ages. It has now become a dumping ground for debris, floating among massive algae blooms and even pig carcasses. The river is the lifeblood of the "world's factory floor"- thousands of factories that produce the world's toys, mobile phones, computers, textiles and more. The process by which denim is made into blue jeans is poisoning China's rivers, lakes and ocean. Mark Angelo commented “when you see toxins of an Asian textile mill showing up in polar bears you realize how everything is connected on this planet.” This documentary is being shown across the US and Canada. As mentioned, you may Google “River Blue” for more information about the contents of this documentary.

It’s impossible to touch on the damage and pollution on all ecosystems but I hope that the above may allow you to further investigate the health of our rivers and environmental pollution that are of interest to you, your community, in British Columbia and throughout the Canadian landscape. On the fourth Sunday every September we celebrate World Rivers Day, a celebration of the world’s waterways promoted by Mark Angelo, Fin Donnelly and others; visit the website at www.worldriversday.com or BC Rivers Day at http://www.orcbc.ca to find out about school projects, habitat restoration, river clean-ups, paddle trips, art exhibitions and community festivals.

The Plastic Apocalypse

"The sea, the great unifier, is man's only hope. Now, as never before, the old phrase has a literal meaning: We are all in the same boat." Jacques Cousteau

“Realistically reducing plastics means consuming consciously. I find it helpful to keep in mind that, in reality, there is nothing actually disposable about plastics. Every single piece of plastic we have ever created is still with us now. Plastic’s indestructible nature has helped to make it pervasive in the things we use, but it also means it’s not going to break down anytime soon. Keeping that fact front of mind as you make purchasing decisions helps you to contextualize
“the effects of your decision and to make smart ones”. Céline Cousteau is an ambassador for the TreadRight Foundation and grand-daughter of the legendary Jacques Cousteau.

The world of plastic is having profound environmental impacts in our oceans and food webs from the tiny zooplankton to mammals such as whales. The June 2018 *National Geographic* magazine is a must read and presents the following 4 articles on Plastic: (1) “We made it. We depend on it. We’re drowning in it.” (2) “The World Capital of Everyday Plastic.” (3) “A Toll on Wildlife.” And (4) “A Threat to Us?” The Editorial of this issue of the magazine entitled “The Plastic Apocalypse” which I used in the heading above. If you have read these articles you may skip the next section.

There are some practical ways we could take to reduce or eliminate our plastic use by logging on to Ocean Wise at [https://ocean.org](https://ocean.org). You will be taken to other sites such as “Break Your Plastic Pattern – Protect Our Ocean” and suggests you “Take the Pledge” to “Be Plastic Wise” with information on ‘microplastics’ and circulation in our oceans and with threats from zooplankton to humans. Dr. Peter Ross has been conducting research on microplastics and you will be able to review his video clips. You will be able to check out “Our Work” from the above website on the work at Vancouver Aquarium under “Education” that includes “Online Learning”, “Children & Youth”, Research on “Species Under Threat” and “Plastics”, to name a few. In 2019, over 1,000 clean up groups collected 413,294 kilograms of plastic litter along 1962 kilometres of shoreline in Canada. We can all start at home and lessen the threat posed by plastics that end up in our ocean.

The ‘Great Pacific Garbage Patch’ (Figure 1.8) as a huge region of the world’s ocean and waters that are filled with plastic from micrometre size to giant pieces such as fishing gear. This NOAA website [https://marinedebris.noaa.gov](https://marinedebris.noaa.gov) deals with marine debris in all coastal regions of continental USA including the US Caribbean and Pacific Islands. Tonnes of plastic trash either directly dumped or washed by heavy rains and rivers into the North Pacific Ocean is a serious concern for the health of our ocean, for species small and large including humans and its impact on our food chain. Garbage is swept up in the currents of a gigantic swirling vortex known as the North Pacific Gyre as illustrated in Figure 1.8. An estimated 11
million tonnes of floating plastic covers a vast region the Pacific Ocean, 1100 kilometres northeast of the Hawaiian Island chain and 1600 kilometres off the coast of California, known as the Eastern Garbage Patch as illustrated. Humans produce 100% of the plastic pollution in the ocean — and it is entirely preventable. The latter site is only one of many around the world’s oceans from the Arctic to the Antarctic including rivers and landfills. Approximately 80% of this plastic pollution originates on land, and 20% is produced from recreational boaters, commercial operations, maritime industries, and the military. The Living Oceans Society in BC on its “Clear the Coast” program with volunteers have cleared over 40 tonnes of debris from coastal Vancouver Island. Over 10 tonnes were collected from Cape Scott region on the tip of Vancouver Island in 2016. Most of the material included Styrofoam, plastics and fishing equipment.

The 2011 Japan earthquake generated a massive tsunami that launched an extraordinary transoceanic biological rafting event. “We document 289 living Japanese coastal marine species from 16 phyla transported over 6 years on objects that traveled thousands of kilometers across the Pacific Ocean to the shores of North America and Hawaii” reported by James Carlton in Science journal. Hundreds of billions of tiny pieces of plastic are also floating in the once-pristine Arctic, according to a new study is a startling indication of how polluted the planet has become. Scientists have collected up to 750,000 bits of microplastic in a single square kilometer of the Great Pacific Garbage Patch. Most of this debris comes from plastic bags, bottle caps, plastic water bottles, and Styrofoam cups. With more than 10 million tonnes of plastic entering the ocean each year, humanity must urgently rethink the way we make and use plastics, so that they do not become waste in the first place.
The evidence in *Scientific Reports* journal (March 22, 2018) by oceanographers Laurent Lebreton and others “calibrated with data from multi-vessel and aircraft surveys, predicted at least 79 (45–129) thousand tonnes of ocean plastic are floating inside an area of 1.6 million km²; a figure four to sixteen times higher than previously reported. Over three-quarters of the Great Pacific Garbage Patch mass was carried by debris larger than 5 cm and at least 46% was comprised of fishing nets. Microplastics accounted for 8% of the total mass but 94% of the estimated 1.8 (1.1–3.6) trillion pieces floating in the area.” Dutch oceanographers will place a 600-metre-long floating barrier in the garbage patch, powered by currents, waves and wind, will aim to collect five tonnes of plastic debris each month. Moving with wind and currents in the same way plastic does, the barrier should self-adjust once deployed. It will trap large debris before it can break down into harmful microplastics. Some 92% of plastic in the region is made up of pieces larger than 5mm so that is our focus.

While most Arctic waters were found to have little plastic debris, researchers discovered two major “dead ends” – in the Barents and Greenland seas – where plastics transported over thousands of kilometres by ocean currents have been
gathering. Peter Ross of the Vancouver Aquarium has “determined that there are an average more than 3,000 particles of plastic (microplastic) in a cubic metre of water in Georgia Strait outside of Vancouver.” Pollution, be it from the air, rivers or ocean, knows no geographical boundaries. Small marine creatures consume these small fragments or microplastics carrying toxic chemicals, mistaking them for phytoplankton and pass on to the next and subsequent food chain. In a process called bio-accumulation, toxic compounds build up in an organism at a rate faster than they can be broken down, thus impacting the food chain from bottom to top. Ultimately, these harmful substances wind up in the seafood on our dinner plates and we thereby become the subjects or consumers of bio-accumulation. Other animals such as sea turtles and birds also consume larger bits of plastic mistaking them for food. These larger fragments cannot pass through an animal’s digestive systems and have no nutritional value. With no room left for their normal food, they slowly starve to death. Albatross unwittingly feed plastic to their young, causing them to also die of starvation. Once an animal dies and its body decomposes, all that remains is the plastic (Figure 1.9 A), which is then released back into the environment where it will continue to cause harm.

Celine Cousteau reminds us “while the issue of larger, visible pieces of plastic cropping up on our shores, piercing the insides of seabirds, drowning whales and dolphins and choking sea turtles is undeniable and persistent, the much smaller fragments – commonly referred to as microplastics as they are measured in mere millimetres – represent an even more significant threat to the health of our oceans and, therefore, the whole planet. These microplastics are being accidentally consumed by marine life, poisoning entire systems as they break down and release toxic chemicals.” Other harmful chemicals such as polychlorinated biphenyls or PCBs are found in fish and amphipods deep in the Mariana Trench. A science-based approach is needed to replace chemicals such as endocrine disruptors that are found in some plastics and pose a risk to human health. Researchers are puzzled how these chemicals got to that depth in the Mariana of over 10,000 metres. Toxic chemicals have reached distant places in our oceans; the deep oceans rather than being remote is highly connected to surface water. The tiny Henderson Island (Figure 1.9) in the South Pacific has the highest density of anthropogenic
Figure 1.9. Plastic abound on Henderson Island in south Pacific Ocean. It is uninhabited, about 38 square kilometres in size and home to many endemic bird species. Credit www.guardian.com.

Figure 1.9 A. Every piece of plastic above was found in the stomach of a single albatross chick. The photo was copied from pages 72-73 of National Geographic magazine, June 2018. Vertical line in photo is the mid-page break on photocopying. Credit photograph by Mandy Barker & National Geographic.
debris anywhere in the world – about 18 tonnes – source of origin is likely from ships, fishing boats, pleasure crafts and offshore from rivers and lands.

On pages 70-71 of the June 2018 *National Geographic* depicts the “Plastic Parade” on Henderson Island “cataloguing 53,000 pieces in a sample area and puts the Island’s total at 38 million pieces of plastic.” That is one tragic and terrible scene for one small island in the south Pacific. The researchers were able to read the labels from some 88 items from Henderson Island and “more than one-third came from China or Japan, more than one-quarter from South America and some had labels from Germany and Scotland. On pages 72-73 in the 2018 *National Geographic* article, the display of hundreds of plastic pieces and bottle caps “that came for the stomach of a single albatross chick laid bare outside the bird it killed” shown in Figure 1.9 A. NOAA researchers discovered that plastic trash is either directly thrown or washed by heavy rains and rivers into the North Pacific Ocean. It is swept up in the currents of that gigantic swirling vortex of the North Pacific Gyre. NOAA reported “a plastic water bottle discarded off the coast of California, for instance, takes the California Current south toward Mexico. There, it may catch the North Equatorial Current, which crosses the vast Pacific. Near the coast of Japan, the bottle may travel north on the powerful Kuroshiro Current. Finally, the bottle travels westward on the North Pacific Current. The gently rolling vortexes of the Eastern and Western Garbage Patches gradually draw in the bottle.” Approximately 80% of this plastic pollution originates on land, and 20% is produced from recreational boaters, commercial operations, maritime industries, and the military. Another *National Geographic* article in the May 2019 issue entitled a “Sea of Plastic” of ‘Little Pieces BIG Problem’ of microplastics that are found in stomachs of zooplankton, birds and fish.

Many hazardous chemicals make their way into our oceans including gasoline, motor oil, and anti-freeze from our cars; pesticides and fertilizers from agricultural operations; manure from stockyards and animal processing plants; and human waste from faulty septic systems and overloaded sewage treatment plants. American manufacturers admit to releasing 2 billion kilos of pollutants into our air and waterways annually. Once in the marine environment, scientists refer to these waste products as “persistent organic pollutants” (POPs). These POPs consist of
pesticides, PCBs (found in automobile fluids and flame retardants), and dioxins (found in herbicides and as a byproduct of waste incinerators) and many others. Collectively we humans make over 100,000 synthetic chemical compounds that take hundreds of years to break down. Many of these pollutants are known carcinogens, and are harmful to both animals and humans when ingested. Scientists call the North Pacific Gyre a “toxic soup”.

For your information and interest as quoted below, the NOAA Marine Debris Program (MDP) pillars the following:

**Prevention:** Prevention is the ultimate solution to marine debris. The MDP supports projects that prevent marine debris from ever entering our ocean and waterways through outreach and education efforts that raise awareness and change behavior. These types of initiatives, along with individual decisions to reduce, reuse, and recycle, will help minimize the impacts of marine debris.

**Removal:** The MDP supports community-based marine debris removal projects across the United States. From local shoreline cleanups to vessel removals, these projects benefit coastal habitats, waterways, and wildlife. Since 2006, NOAA has supported over 100 marine debris removal projects and removed more than 5,500 metric tons of marine debris from our coasts and ocean.

**Research:** Marine debris is a relatively new field of research, and there are many opportunities to advance our understanding of how it impacts the environment. The MDP monitors the amount and types of debris on shorelines and supports projects to help understand debris baselines, chemicals in plastics, debris detection, plastic ingestion by wildlife, economic implications, and how to minimize the impacts of derelict fishing gear.

**Emergency Response:** Storms and natural disasters that impact U.S. coasts can be an overwhelming source of marine debris. High winds, storm surges, and heavy rains drag household products, and even entire homes, into the surrounding waters. The MDP prepares for severe weather events by supporting regionally-focused emergency response planning efforts and coordinating with partners during an event.”

For more information on the Marine Debris Program: [https://marinedebris.noaa.gov](https://marinedebris.noaa.gov)

Encouraging news come from industries and governments to reduce plastic. As starters the Canadian Minister of the Environment and Climate Change said at the G7 ministers meeting in September 2018 that “we are going to eliminate unnecessary single-use plastics throughout government operations.” Companies like [Unilever](http://www.unilever.com), a massive multinational consumer products
firm, its CEO Paul Polman said that “by 2025 100% of plastic packaging will be reusable, recyclable or compostable.”

**Water: Global Resource, Storage & Hydrologic Cycle**

Viewed from space, one of the most striking features of planet Earth is the presence of water in both liquid and frozen forms with a cloud cover loaded with water vapour. Water covers approximately 75% of the Earth’s surface. It is a vital substance that sets Earth apart from the rest of the other planets in our solar system. As we are aware, water is a necessary ingredient for the development and nourishment of all life. About 97% of Earth’s water is present in the global oceans; less than 2% is stored in the polar icecaps, glaciers, and permanent snow, and the rest stored in groundwater, lakes, rivers, streams, and soil and with a small fraction as water vapor in the atmosphere. The hydrologic or water cycle illustrates the passage of water from its three states (liquid, solid and gaseous) around the planet and always distributed elsewhere. This global system is powered by energy from the Sun with a continuous exchange of moisture among the oceans, atmosphere, land, cryosphere and biosphere. In other words, the cycling of water is intimately linked with energy that determines Earth’s climate system and the cause of much of its natural variability.

Evaporation, precipitation, condensation, sublimation, volcanic emissions, runoffs, and transpiration by plants move water back and forth from the ocean, lakes, ice sheets, rivers and land. After the water vapour enters the lower atmosphere where the air is cooler it condenses into a liquid and form cloud droplets. When water vapour condenses into clouds it releases its *latent heat* into the atmosphere. This release of latent heat (energy) is an important part of Earth’s energy balance and tied to its climate balance and the water cycle. Clouds produce precipitation as rain or snow onto the Earth’s surface. Precipitation follows various routes in its subsequent paths - into the ground as soil moisture or groundwater, the ocean, into rivers and streams. All life depends on water and we humans daily use it for drinking, washing, irrigating, hydroelectricity, industrial use, transportation, recreational use, even retrieving bitumen from oil sands, and many other uses. As a
result of the processes involved in recycling water, the total amount of water vapor in the atmosphere remains approximately the same over time. Climate change is changing the abundance and location of water in the atmosphere and evaporation rates. A warming climate will have more water evaporate with increased frequency of intense precipitation events. With warmer temperatures, higher precipitation ensues but with less snow as recently observed in Canada and in northern latitudes. An earlier arrival of spring-like conditions leads to earlier snow melt and flooding in low-lying communities. Flooding in the spring of 2018 was evident in many regions of Canada and in particular in New Brunswick and southeast British Columbia. Does climate change promote extreme weather like floods? Yes. This is discussed later in Chapter Two.

Research at NOAA’s Earth System Research Laboratory (ESRL) use satellite data to document that during the winters from 1997-2016, there were 217 days on which Atmosphere Rivers (ARs) impacted the California coast. The precipitation caused by these ARs can be beneficial to depleted water supply but can also lead to devastating floods. Satellite images show that ARs can extend over a distance of 600 km wide, sometimes referred to as the Pineapple Express. Collaborative research between ESRL and Scripps Institution of Oceanography indicates that ARs are responsible for 30-50% of all the precipitation that occurs in west coast of North America from California to British Columbia and Alaska. Flooding caused by ARs will become increasingly important as costs associated with extreme weather events continue to increase. NOAA’s ESRL conducts research on precipitation and weather events and use new tools into forecasting operations.

ESRL scientists developed and prototyped an Atmospheric River Observatory (ARO) designed to further our understanding of Atmospheric Rivers (ARs) that are narrow belts of concentrated moisture transported in the atmosphere, and a key process linking weather and climate. ARs provide beneficial water supply and snowpack especially to drought-stricken regions in California. The extensive duration of ARs can also produce flooding that disrupt travel, induce mud slides, and catastrophic damage to life and property. A West Coast Network of AROs was recently implemented along the California, Oregon, and Washington coastlines
with funding from the California Department of Water Resources and the U.S. Department of Energy. What are the benefits? Improved monitoring, observation-based process understanding and predicting of ARs provide the critical knowledge needed by flood control managers, water supply authorities, and reservoir operators to mitigate the risks of major flood events while being able to take advantage of these heavy rainfall events as drought busters. NOAA’s ESRL conducts targeted field campaigns using satellite measurements, offshore aircraft reconnaissance, and land-based AROs to guide model forecast system development, leading to improvements in the prediction of AR intensity and duration to support water resource management decisions.

Figure 1.10. Hydrologic Cycle shown with processes involved in water distribution regionally and globally. Credit US Geological Society.
Hydrologist Matt Rodell of NASA’s Goddard Spaceflight Center has been investigating first-of-its-kind data from the Gravity Recovery and Climate Experiment (GRACE). Data shows big changes in mass primarily the result of the movement and trends of water storage on specific regions on Earth as shown in Figure 1.11. A team led by Rodell analyzed 14 years of observations from GRACE satellite to track trends in freshwater in 34 regions around the world. Published in the journal Nature on May 16, 2018, I selected some key findings from that research with the illustration shown and credit to NASA’s Goddard Spaceflight Center stating it is “a first-of-its-kind study, scientists combined satellite observations (GRACE) with data on human activities to map the locations where freshwater is changing on Earth. The study finds that Earth’s wet landscapes are getting wetter and dry areas are getting drier due to a variety of factors, including water management, climate change, and natural cycles.”

This global water survey by satellite from 2002-2016 is truly an eye-opener and with links to possible climate change impacts!

Water loss from ice sheets and glaciers occur from Antarctica each year with a loss of 127 billion of tonnes (Gt), from Greenland with a loss of 286 Gt/year, from Alaska with a loss of 62.6 Gt/year and from the Canadian Archipelago with a loss of 75 Gt/year where the warming climate continues to drive rapid ice-sheet and glacier ablation. Positive trends in sub-regions of Antarctica and Greenland result from increasing snow accumulation, according to NASAs research. “What we are witnessing is major hydrologic change,” said Jay Famiglietti co-author of the research at NASA’s Jet Propulsion Laboratory. “We see a distinctive pattern of
the wet land areas of the world getting wetter—those are the high latitudes and the tropics—and the dry areas in between getting dryer. Embedded within the dry areas, we see multiple hot spots resulting from groundwater depletion.”

Figure 1.10 – B. From the Middle East and North Africa to India are water stressed countries. Map for 2019 - for more information go to World Resources Institute at https://www.wri.org.

Quotes cited below were taken from the journal Nature (May 16, 2018) entitled “Emerging Trends in Global Freshwater Availability” and with reference to the illustration (Figure 1.11). In my opinion this research is of vital global importance, and is as important as the attention we pay to global climate change as the two are linked. One characteristic of the map (Figure 1.11) is that it
reveals a clear ‘human fingerprint’ on the global water cycle. Freshwater is rapidly disappearing in many of the world’s irrigated agricultural regions. Another aspect of the global-trend map is natural interannual variability from NASA’s satellite GRACE revealing considerable changes in freshwater resources occurring across the globe and quantified at regional scales.

Figure 1.11. Trends in Terrestrial Water Storage (in centimetres per year) obtained on the basis of GRACE observations from April 2002 to March 2016. The cause of the trend in each outlined study region is briefly explained and colour-coded. This detailed map retrieved from Nature journal with Credit to Nature and NASA’s Goddard Spaceflight Center.

“Northern India, the North China Plain, the Middle East and the area surrounding the Caspian Sea (#18 in Figure 1.11) are already on a perilous path, while California, in response to severe drought and alarming groundwater declines (#21 Figure 1.11) in the Central Valley, recently passed legislation to regulate groundwater consumption.” The hotspot in northern India (#7 – ‘groundwater depletion’) was among the first non-polar Terrestrial Water
Storage (TWS) trends to be documented by GRACE. It results from groundwater extraction to irrigate crops, including wheat and rice, in a semi-arid climate. “Fifty-four per cent of the area is equipped for irrigation. The increasing trend in eastern central China is caused by a surge in dam construction and subsequent reservoir filling across that region. The vast agricultural region surrounding Beijing is heavily irrigated.”

Satellite altimetry and Landsat data indicate that the majority of lakes in the Tibetan Plateau have grown in water level and extent owing to a combination of elevated precipitation rates and increased glacier-melt flows. “The negative trend that extends across East India, Bangladesh, Burma and southern China, a loss of about 23 billion tonnes (Gt) per year, may be explained by a combination of intense irrigation.” Landsat imagery reveals the appearance and expansion of crop irrigation over the past three decades, supplied by non-renewable groundwater. The Saudi Arabian government ended their domestic wheat production program as desalination process for freshwater is expensive. “Turkey’s construction of 22 dams upstream on the Tigris and Euphrates Rivers in the last three decades has considerably decreased the rate of flow into Iraq and Syria.”

A historically severe drought centred in southern California that began in 2007 and subsequent increases in groundwater demand conspired to diminish TWS at a rate of about 4 Gt per year. “Although atmospheric rivers replenished California’s surface waters during 2016–2017 and policy changes that have been enacted, it is doubtful that aquifer storage will recover completely without large usage reductions, in part because dewatering of aquifer materials can cause compaction of sediments, thus reducing aquifer capacity irrevocably.” In the Central Valley in California, which provides one-third of the vegetables and two-thirds of the fruits and nuts grown in the US, annual water demands for agriculture have exceeded renewable water resources since the early 20th century.

In a warming world, “melting of the Patagonian ice fields will continue until they are exhausted.” Eastern Brazil has recently suffered from a major drought
including well below normal rainfall in 2012, 2014 and 2015, causing TWS to plunge at a mean rate of about 17 Gt per year. In Africa, a powerful wetting trend of about 29 Gt per year is observed in the western Zambezi basin, the Okavango delta and areas west of the coast. The worst drought in over 100 years afflicted eastern Australia during 2001–2009 years. “It is likely that groundwater was more heavily consumed during that time to compensate for reduced availability of surface waters. Recovery from the drought began with heavy rains in 2010 and transitioned to severe flooding in 2011.” Trends in Canada in the mid Prairies and the Maritimes show a progression from dry to wet period. Surface water drying persist in mid-northern Canada in Nunavut. Glaciers continue to retreat from the Yukon and Alaska, and from Alberta and British Columbia.

**On the domestic front**, Canada has an abundant supply of water but we cannot be complacent and with an understanding that some regions are not well supplied with drinking water or for agriculture. Metro Vancouverites use about 270 litres per person per day. When you factor in commercial uses (to run our businesses, institutions and public facilities, for example), the average use is about 450 litres per person per day. One major use of water inside our homes is from flushing of the toilet. The Water Services Department provides clean, safe drinking water through its member municipalities for over three million residents in the Lower Mainland. The drinking water supply comes from rain and snowmelt in the Capilano, Seymour and Coquitlam Watersheds. Many regions use wells for their water supply. **Should the provincial government, Municipalities in Metro Vancouver and the Fraser Valley initiate the need for more water supply for our future needs from Harrison Lake? We can build oil pipelines so why not embark on a major water pipeline or water conduit project from the glacial-fed Harrison Lake throughout the Lower Mainland?**

Our drinking water is treated in modern, world-class drinking water treatment facilities, and meets Health Canada’s standards for quality. Over 30,000 samples of our water are tested every year. Clean, safe drinking water is a valuable resource, even in the Lower Mainland where it often rains well over a metre each year. Still, in drier months we must use our water wisely. Operating our vast drinking water system, with expansive infrastructure and a growing population, requires constant
upgrades, improvements, repairs and expansion. Metro Vancouver continues on the upgrading of Metro water treatment system to meet the *Guidelines for Canadian Drinking Water Quality* and to provide more reliable treatment. For example, the Seymour-Capilano Filtration Project is in operation and the Ultraviolet (UV) Disinfection Facility on the Coquitlam source is also in operation. The Seymour-Capilano Filtration Plant can treat 1.8 billion litres of water per day, continues to produce high quality drinking water since going into service and filtering water from the Seymour source in late 2009. In addition, the amount of chlorine required to maintain a residual in the distribution system has dropped approximately 50% from the levels required before filtration.

In February 2014, the Coquitlam UV Disinfection Facility began operating and successfully treating water from the Coquitlam source and treating 380 million litres of water per day. Ultraviolet disinfection enhances disinfection of microorganisms such as *Cryptosporidium* and *Giardia* by complementing with the existing ozone and chlorination processes. Chlorine levels in the City’s distribution system were within recommended levels in 2016. Chlorine is used to disinfect the water and safeguard against microbial re-growth or contamination. Chlorine levels are regulated by Metro Vancouver while member municipalities monitor this parameter within their systems.

Routine sampling of Vancouver’s 53 stations showed an average pH of 7.50 in 2016. This is slightly higher than the average pH 7.31 recorded in 2015. Drinking water should have a pH between 7.0 and 10.5 as per the guidelines. The region’s source waters are a combination of rainfall and snowmelt. This type of supply results in very soft water defined by low amounts of dissolved calcium and magnesium. Water which is soft and acidic (lower pH level) has the capacity to corrode plumbing and distribution system components. To reduce the corrosiveness of the water and lengthen the service of pipes, Metro Vancouver’s Corrosion Control Program increases the pH of water before it is delivered to municipalities.

For more information on watersheds, hydrogeological regions, distribution of freshwater and safety of drinking water and much more about water in Canada you
could access these two websites: https://www.nrcan.gc.ca (Natural Resources Canada) and www.ec.gc.ca/eau-water/ (Environment Canada). For provincial and municipal and cities water supply you may Google for your specific needs. For example, if I want to know about water supply and treatment for the Vancouver area, Google “Water Supply for Metro Vancouver” and several websites are displayed and you could select what you are looking for.

NASA satellites are a prominent tool for accounting for water, as it constantly cycles from water vapor to rain and snow falling onto soils, and across and beneath the landscape. As Earth's atmosphere warms due to greenhouse gases and the satellite data record continues to get longer and more detailed, scientists are studying how climate change is affecting the distribution of water. From 1958 to 2016 heavy rainfall events have increased in the northeastern states by 55%, midwestern states by 42%, and southeastern states by 27%. The western states have also seen modest increases in heavy rain events that can overwhelm the local watershed's capacity to absorb excessive water. Researchers at NASA's Goddard Institute for Space Studies and Columbia University said "Climate change is not just a future problem. This shows it's already affecting global patterns of drought, hydroclimate, trends, variability — it's happening now. And we expect these trends to continue, as long as we keep warming the world."

**Connecting with Nature**

“Nature holds the key to our aesthetic, intellectual, cognitive and even spiritual satisfaction. Destroying rainforest for economic gain is like burning a Renaissance painting to cook a meal…If all mankind were to disappear, the world would regenerate back to the rich state of equilibrium that existed ten thousand years ago. If insects were to vanish, the environment would collapse into chaos.” Edward O. Wilson – World renowned entomologist, theorist, naturalist & author

“Nature and mental health: An ecosystem service perspective” was researched by Gregory Bratman and a number of scientists in Science Advances (July 24, 2019). I would like to highlight the following from their research: “Human well-being is linked to the natural environment in myriad ways. Little attention has been given in the field of ecosystem services (see Figure 1.11 A) to the ways in which nature
experience directly affects human mental health and well-being. One is urban living. Cities are centers of prosperity, employment opportunities, access to education, health and human services, and cultural advancement, all aspects of life that may promote mental health. However, they can also be associated with decreased access to nature. Psychological well-being of a population can be associated, in part, with its proximity to green space, blue space (i.e., aquatic and marine environments), and street trees or private gardens. Research has shown that various types of nature experiences are associated with mental health benefits in many ways. Over the past century, people have been increasingly concentrated in urban areas. In many instances, modern living habits involve reduced regular contact with outdoor nature and increased time spent indoors, on screens, and performing sedentary activities.” For the full report you could find it in Science Advances cited above.

The following are well-known recreational, educational and nature sites to explore:

2) Sierra Club of BC – https://sierraclub.bc.ca  
5) Outdoor Recreation Council of BC – https://www.orcbc.ca  
9) Pacific Salmon Foundation – https://www.psf.ca  
10) Hope Mountain Centre for Outdoor Learning – http://hopemountain.org  
11) Sitka Foundation – https://sitkafoundation.org

Environment and Climate Change Canada website offers much for the inquisitive on a variety of topics at https://www.canada.ca/en/environment/
Canada has so many natural wonders to discover and manages more than 50 National Wildlife Areas across the country for wildlife conservation, research, and interpretation. Ten of them are open to the public, so that you can experience these amazing spaces, enjoy an array of activities and spend some time connecting with nature. The Provincial government, Municipalities and Cities across BC and other provinces also provide natural habitats and recreational sites so you could enjoy nature and the outdoors. For example, on Environment Canada Directory listed below, if you open “Wildlife habitat” you will be taken to “Nature Wildlife Areas” and as an example “Scott Islands Marine National Wildlife Area” as shown in the map below opens up. Discover the wonders of Scott Islands and other sites as cited below from Environment Canada website.

For “Services and Information” on Environment and Climate Change Canada website the following headings are full of information for further exploration. For example, under “Wildlife habitat” as noted above and cited below gives you a guide on the topic.

Scott Islands Marine National Wildlife Area

Arctic Polar Bear & Widgeon Valley National Wildlife area near Pitt Lake, BC

Air pollution - Atmosphere, imbalance, chemical composition, sources, levels, causes

Environmental wildlife and enforcement - Applying environmental and wildlife protection laws for cleaner and healthier communities. Environmental science and technology - Scientific and technical knowledge available to science and technology users. Biodiversity - Variety of genes, species and ecosystems that keep the living world healthy.

From Nature Conservancy Canada: “Together with Canadians, we are doubling the protection of our lands and oceans. Canada is home to one quarter of the Earth’s wetlands and boreal forests, 20% of its freshwater, the longest coastline in the world, and precious habitats for birds, fish, and mammals. We have a special
responsibility to the world. We are on our way to protecting 1,680,000 km² of our land and freshwater, and 575,000 km² of our oceans by 2020. That is 2,255,000 km² of protected land, lake and ocean—an area bigger than Greenland. We are doing it together with provinces and territories, Indigenous Peoples, cities and towns, foundations, charities and other partners from coast to coast to coast.

**What we have done:** So far, 1.66 million km² of our lands and oceans are already protected or conserved—about the size of Quebec. Over the past several years, we have increased this number by creating and supporting new federal, provincial, territorial and Indigenous protected areas, as well as areas protected by land trusts and communities.”

**Here are some recent additions:**

- **Edéhzhie Indigenous protected area**, the first Indigenous protected area established under the Canada Nature Fund.
- **Scott Islands National Marine protected area**, one of the most diverse marine ecosystems on Canada’s Pacific coast, attracting millions of migratory birds each year. Refer to the above map of Scott islands off the BC coast.
- **St Anns Bank Marine protected area** off the coast of Nova Scotia, a habitat for more than 100 species.
- **Kitaskino Nuwenënë Wildland**, an Alberta-led protected area created and managed though collaboration with local Indigenous groups, the community and industry, and supported by the Canada Nature Fund.
- **Kenauk protected area**, a unique and exceptional wetland and forest area, home to more than 170 species protected by the Nature Conservancy of Canada.”

(Environ[54x66]et and Climate Change Canada in 2019).

The "Living Planet Report 2018 – Aiming Higher” is also well worth accessing in full support of a global deal for nature and people. Its Director General, Marco Lambertini leaves us with this message in his Editorial: “*Today, we still have a choice. We can be the founders of a global movement that changed our relationship with the planet, that saw us secure a future for all life on Earth, including our own. Or we can be the generation that had its chance and failed to act; that let Earth slip away. The choice is ours. Together we can make it happen for nature and for people.*”

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Biodiversity, Ecosystem Services & Nature’s Dangerous Decline

“Across cultures, humans inherently value nature. The magic of seeing fireflies flickering long into the night is immense. We draw energy and nutrients from nature. We find sources of food, medicine, livelihoods and innovation in nature. Our well-being fundamentally depends on nature. Our efforts to conserve biodiversity and ecosystems must be underpinned by the best science that humanity can produce. This is why the scientific evidence compiled in this IPBES Global Assessment is so important. It will help us build a stronger foundation for shaping the post 2020 global biodiversity framework: the ‘New Deal for Nature and People’…” Achim Steiner, Administrator, United Nations Development Programme.

“We are the first generation that has a clear picture of the value of nature and our impact on it. We may be the last that can take action to reverse this trend. From now until 2020 will be a decisive moment in history.” Living Planet Report 2018: Aiming Higher

At the end of the last glacial maximum, the Earth entered a new geological epoch – the Holocene. This remarkably stable warm period lasted about 11,700 years and we might have expected it to continue for another 50,000 years but the ‘Great Acceleration’ changes all that – demand for energy, land, food, water and with a human population growth. This human-induced change has been so great that many scientists believe we have entered into another geological epoch: the Anthropocene. Our planet in the Anthropocene defines Earth's most recent geologic time period as being human-influenced, or anthropogenic, based on overwhelming global evidence that atmospheric, geologic, hydrologic, biospheric and other earth system processes are being altered by humans in such a short period. The word ‘Anthropocene’ combines the root "anthropo", meaning "human" with the root "-cene", the standard suffix for "epoch" in geologic time. How important is the thin layer that supports life on land? It is the biosphere the thin sphere around the planet which supports all life on Earth. It provides life-supporting ecosystems that provide us with a hospitable climate, water supply, food, fibers and numerous other goods and services. It is time for a shift in perception – from people and nature as seen as separate parts but recognized as interdependent social-ecological systems. Without the biosphere, life on Earth will cease to exist.
The Big Question: Are we now within the sixth mass extinction as a result of human exploitation and degradation of ecosystems and not paying attention to the decline of species on land (forests) and oceans? The following section includes “direct quotes” from the *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (IPBES) Report. This Report is very extensive and can be accessed from [www.ipbes.net](http://www.ipbes.net). More than 550 leading experts from more than 100 countries attached numbers to the value of specific aspects of nature in this Report. The Report provides global assessments for the Americas, Africa, Europe & Central Asia, and SE Asia & the Pacific. The Summary for Policy-Makers for each region is about 50 pages with ample details for the reader. The *Media Release* section on page 5 carries several video clips and is worth accessing for the following topics: “Land Degradation & Restoration”, “Biodiversity and Ecosystem Services”, Pollination & Food Production” and others.

Thomas Lovejoy writing in *Science Advances* (May 6, 2019, Vol. 5, No. 5) and in support of the IPBES Report emphasizes the message of protecting biodiversity with the following statement: “A scientific assessment of the state of biodiversity and ecosystems services in the context of climate reveals that all are inextricably intertwined, united yet dispersed, invaluable yet monetizable, reflecting nature in its holistic role as the bedrock of human civilization. While the planetary garden still exists, it is in deep disrepair, frayed and fragmented almost beyond recognition. Not unexpectedly, the specific findings are depressing. More species are threatened with extinction than any time in human history. Ever growing human populations and their activities have severely altered 75% of the terrestrial environment, 40% of the marine environment, and 50% of streams and rivers. Of monumental note is that, collectively, significant destructive forces arise from the actions of impoverished peoples living at the edges of society, working to eke out an existence often with little choice but to have minimal concern for environmental impact. The assessment concludes that the current course of planetary degradation can be altered only with preemptive and precautionary actions, strengthened laws and related enforcement, dramatic changes in economic and social incentives, increased monitoring of biodiversity..."
and ecosystems, and integrated decision-making across sectors and jurisdictions.”

The Global Deal for Nature (by Eric Dinerstein and co-authors in Science Advances, April 19, 2019, Vol. 5, No. 4) emphasizes conservation efforts, such as climate change policies, are being reassessed in the midst of a planetary emergency. Climate concerns rightly prompted the 2015 Paris Agreement, which has facilitated coordinated global action not only among governments but also among industries, cities, and its citizens. Research since then suggests that efforts to stabilize the climate and avoid the undesirable outcomes of >1.5°C warming will “require a rapid reduction in land conversion and a moratorium by about 2035. The most logical path to avoid the approaching crisis is maintaining and restoring at least 50% of the Earth’s land area as intact natural ecosystems, in combination with energy transition measures. Natural ecosystems are key to maintaining human prosperity in a warming world.”

The Global Deal for Nature (GDN) emphasizes the mission of the IPBES Report and the two reports stress the need to conserve and expand on natural resources such as our forests. “Our objective is to present scientific guidance for three major themes that should be included in a GDN and a short list of key milestones and targets that could underpin these themes, which would be complementary and, in many cases, reinforcing of the Paris Climate Agreement. These themes are (1) protecting biodiversity, (2) mitigating climate change, and (3) reducing threats to ecosystem intactness and persistence of species. We also propose that the GDN embrace monitoring progress from the ground, or below the sea surface, to space, using powerful new technologies, much of it publicly available.”

The IPBES Chair, Sir Robert Watson’s message: “The overwhelming evidence of the IPBES Global Assessment, from a wide range of different fields of knowledge, presents an ominous picture. The health of ecosystems on which we and all other species depend is deteriorating more rapidly than ever. We are eroding the very foundations of our economies, livelihoods, food security, health and quality of life worldwide.” The Report also tells us that it is not too late to make a difference, but only if we start now at every level from local to global. Watson concludes: “Through ‘transformative change’, nature can still be conserved,
restored and used sustainably – this is also key to meeting most other global goals. By transformative change, we mean a fundamental, system-wide reorganization.”

The following sections are findings with direct quotes from “Biodiversity and Ecosystem Services on Global Extinction – the IPBES 2019 Report” at www.ipbes.net:

• “Three-quarters of the land-based environment and about 66% of the marine environment have been significantly altered by human actions. On average these trends have been less severe or avoided in areas held or managed by Indigenous Peoples and Local Communities.
• More than a third of the world’s land surface and nearly 75% of freshwater resources are now devoted to crop or livestock production.
• The value of agricultural crop production has increased by about 300% since 1970, raw timber harvest has risen by 45% and approximately 60 billion tons of renewable and non-renewable resources are now extracted globally every year – having nearly doubled since 1980.
• Land degradation has reduced the productivity of 23% of the global land surface, up to US$577 billion in annual global crops are at risk from pollinator loss and 100-300 million people are at increased risk of floods and hurricanes because of loss of coastal habitats and protection.
• In 2015, 33% of marine fish stocks were being harvested at unsustainable levels; 60% were maximally sustainably fished, with just 7% harvested at levels lower than what can be sustainably fished.
• Urban areas have more than doubled since 1992.
• Plastic pollution has increased tenfold since 1980, 300-400 million tons of heavy metals, solvents, toxic sludge and other wastes from industrial facilities are dumped annually into the world’s waters, and fertilizers entering coastal ecosystems have produced more than 400 ocean ‘dead zones’, totaling more than 245,000 km² - a combined area greater than that of the United Kingdom.
• Negative trends in nature will continue to 2050 and beyond in all of the policy scenarios explored in the Report, except those that include transformative change – due to the projected impacts of increasing land-use change, exploitation of
organisms and climate change, although with significant differences between regions.

Since 1970 the global human population has more than doubled (from 3.7 to 7.7 billion), rising unevenly across countries and regions; and per capita gross domestic product is four times higher – with ever-more distant consumers shifting the environmental burden of consumption and production across regions. The average abundance of native species in most major land-based habitats has fallen by at least 20%, mostly since 1900. The numbers of invasive alien species per country have risen by about 70% since 1970, across the 21 countries with detailed records. The distributions of almost half (47%) of land-based flightless mammals, for example, and almost a quarter of threatened birds, may already have been negatively affected by climate change.

**Indigenous Peoples, Local Communities and Nature**

IPBES Report: “At least a quarter of the global land area is traditionally owned, managed, used or occupied by Indigenous Peoples. These areas include approximately 35% of the area that is formally protected, and approximately 35% of all remaining terrestrial areas with very low human intervention. Nature managed by Indigenous Peoples and Local Communities is under increasing pressure but is generally declining less rapidly than in other lands – although 72% of local indicators developed and used by Indigenous Peoples and Local Communities show the deterioration of nature that underpins local livelihoods.”

**Key Statistics and Facts from the IPBES Report:**
- 75%: terrestrial environment “severely altered” to date by human actions (marine environments 66%)
- 47%: reduction in global indicators of ecosystem extent and condition against their estimated natural baselines, with many continuing to decline by at least 4% per decade
- 28%: global land area held and/or managed by Indigenous Peoples, including >40% of formally protected areas and 37% of all remaining terrestrial areas with very low human intervention
- +/-60 billion: tons of renewable and non-renewable resources extracted globally each year, up nearly 100% since 1980
• 15%: increase in global per capita consumption of materials since 1980
• >85%: of wetlands present in 1700 had been lost by 2000 – loss of wetlands is currently three times faster, in percentage terms, than forest loss.

**Species, Populations and Varieties of Plants and Animals:**
• 8 million: total estimated number of animal and plant species on Earth (including 5.5 million insect species)
• Tens to hundreds of times: the extent to which the current rate of global species extinction is higher compared to average over the last 10 million years, and the rate is accelerating
• Up to 1 million: species threatened with extinction, many within decades
• >500,000 (+/-9%): share of the world’s estimated 5.9 million terrestrial species with insufficient habitat for long term survival without habitat restoration
• >40%: amphibian species threatened with extinction
• Almost 33%: reef forming corals, sharks and shark relatives, and >33% marine mammals threatened with extinction
• 25%: average proportion of species threatened with extinction across terrestrial, freshwater and marine vertebrate, invertebrate and plant groups that have been studied in sufficient detail
• At least 680: vertebrate species driven to extinction by human actions since the 16th century
• +/-10%: tentative estimate of proportion of insect species threatened with extinction
• >20%: decline in average abundance of native species in most major terrestrial biomes, mostly since 1900 +/-560 (+/-10%): domesticated breeds of mammals were extinct by 2016, with at least 1,000 more threatened
• 3.5%: domesticated breed of birds extinct by 2016
• 70%: increase since 1970 in numbers of invasive alien species across 21 countries with detailed records
• 30%: reduction in global terrestrial habitat integrity caused by habitat loss and deterioration
• 47%: proportion of terrestrial flightless mammals and 23% of threatened birds whose distributions may have been negatively impacted by climate change already
• >6: species of ungulate (hoofed mammals) would likely be extinct or surviving only in captivity today without conservation measures

**Food and Agriculture:**
• 300%: increase in food crop production since 1970
• 23%: land areas that have seen a reduction in productivity due to land degradation
• >75%: global food crop types that rely on animal pollination
• US$235 to US$577 billion: annual value of global crop output at risk due to pollinator loss
• 5.6 gigatons: annual CO2 emissions sequestered in marine and terrestrial ecosystems – equivalent to 60% of global fossil fuel emission
• +/-11%: world population that is undernourished
• 100 million: hectares of agricultural expansion in the tropics from 1980 to 2000, mainly cattle ranching in Latin America (+/-42 million ha), and plantations in Southeast Asia (+/-7.5 million ha, of which 80% is oil palm), mostly at the expense of forests
• 3%: increase in land transformation to agriculture between 1992 and 2015, half at the expense of intact tropical forests
• >33%: world’s land surface (and +/-75% of freshwater resources) devoted to crop or livestock production
• 12%: world’s ice-free land used for crop production
• 25%: world’s ice-free land used for grazing (+/-70% of drylands)
• +/-25%: greenhouse gas emissions caused by land clearing, crop production and fertilization, with animal-based food contributing 75% to that figure
• +/-30%: global crop production and global food supply provided by small land holdings (<2 ha), using +/-25% of agricultural land, usually maintaining rich agrobiodiversity
• $100 billion: estimated level of financial support in OECD countries (2015) to agriculture that is potentially harmful to the environment

Oceans and Fishing:
• 33%: marine fish stocks in 2015 being harvested at unsustainable levels; 60% are maximally sustainably fished; 7% are underfished
• >55%: ocean area covered by industrial fishing
• 3-10%: projected decrease in ocean net primary production due to climate change alone by the end of the century
• 3-25%: projected decrease in fish biomass by the end of the century in low and high climate warming scenarios, respectively
• >90%: proportion of the global commercial fishers accounted for by small scale fisheries (over 30 million people) – representing nearly 50% of global fish catch
• Up to 33%: estimated share in 2011 of world’s reported fish catch that is illegal, unreported or unregulated
• >10%: decrease per decade in the extent of seagrass meadows from 1970-2000
• +/-50%: live coral cover of reefs lost since 1870s
• 100-300 million: people in coastal areas at increased risk due to loss of coastal habitat protection
• 400: low oxygen (hypoxic) coastal ecosystem ‘dead zones’ caused by fertilizers, affecting >245,000 km²
• 29%: average reduction in the extinction risk for mammals and birds in 109 countries thanks to conservation investments from 1996 to 2008; the extinction risk of birds, mammals and amphibians would have been at least 20% greater without conservation action in recent decade
• >107: highly threatened birds, mammals and reptiles estimated to have benefitted from the eradication of invasive mammals on islands

Forests:
• 45%: increase in raw timber production since 1970 (4 billion cubic meters in 2017)
• +/-13 million: forestry industry jobs
• 50%: agricultural expansion that occurred at the expense of forests
• 50%: decrease in net rate of forest loss since the 1990s (excluding those managed for timber or agricultural extraction)
• 68%: global forest area today compared with the estimated pre-industrial level
• 7%: reduction of intact forests (>500 sq. km with no human pressure) from 2000-2013 in developed and developing countries
• 290 million ha (+/-6%): native forest cover lost from 1990-2015 due to clearing and wood harvesting
• 110 million ha: rise in the area of planted forests from 1990-2015
• 10-15%: global timber supplies provided by illegal forestry (up to 50% in some areas)
• >2 billion: people who rely on wood fuel to meet their primary energy needs

Mining and Energy:
• <1%: total land used for mining, but the industry has significant negative impacts on biodiversity, emissions, water quality and human health
• +/-17,000: large-scale mining sites (in 171 countries), mostly managed by 616 international corporations
• +/-6,500: offshore oil and gas ocean mining installations (in 53 countries)
• US$345 billion: global subsidies for fossil fuels resulting in US$5 trillion in overall costs, including nature deterioration externalities; coal accounts for 52% of post-tax subsidies, petroleum for +/-33% and natural gas for +/-10%

Urbanization, Development and Socioeconomic Issues:
• >100%: growth of urban areas since 1992
• 25 million km: length of new paved roads foreseen by 2050, with 90% of construction in least developed and developing countries
• +/-50,000: number of large dams (>15m height); +/-17 million reservoirs (>0.01 ha)
• 105%: increase in global human population (from 3.7 to 7.6 billion) since 1970 unevenly across countries and regions
• 50 times higher: per capita GDP in developed vs. least developed countries
• >2,500: conflicts over fossil fuels, water, food and land currently occurring worldwide
• >1,000: environmental activists and journalists killed between 2002 and 2013

Health:
• 70%: proportion of cancer drugs that are natural or synthetic products inspired by nature
• +/-4 billion: people who rely primarily on natural medicines
• 17%: infectious diseases spread by animal vectors, causing >700,000 annual deaths
• +/-821 million: people face food insecurity in Asia and Africa
• 40%: of the global population lacks access to clean and safe drinking water
• >80%: global wastewater discharged untreated into the environment
• 300-400 million tons: heavy metals, solvents, toxic sludge, and other wastes from industrial facilities dumped annually into the world’s waters
• 10 times: increase in plastic pollution since 1980

Climate Change:
• 1 degree Celsius: average global temperature difference in 2017 compared to pre-industrial levels, rising +/-0.2 (+/-0.1) degrees Celsius per decade
• >3 mm: annual average global sea level rise over the past two decades
• 16-21 cm: rise in global average sea level since 1900
• 100% increase since 1980 in greenhouse gas emissions, raising average global temperature by at least 0.7 degree
• 40%: rise in carbon footprint of tourism (to 4.5Gt of carbon dioxide) from 2009 to 2013
• 8%: of total greenhouse gas emissions are from transport and food consumption related to tourism
• 5%: estimated fraction of species at risk of extinction from 2°C warming alone, rising to 16% at 4.3°C warming
• Even for global warming of 1.5 to 2 degrees, the majority of terrestrial species ranges are projected to shrink profoundly.”
Sobering but Encouraging Message: “We have already seen the first stirrings of actions and initiatives for transformative change, such as innovative policies by many countries, local authorities and businesses, but especially by young people worldwide,” said Sir Robert Watson. “From the young global shapers behind the #VoiceforthePlanet movement, to school strikes for climate, there is a groundswell of understanding that urgent action is needed if we are to secure anything approaching a sustainable future.”

Figure 1.1 A. Benefits from Nature. Adapted from Millennium Ecosystem Assessment 2005. The above illustration is also cited from the Living Planet Report 2018 - Aiming Higher.

From Figure 1.11 A, **Provisioning services** are the products we obtain from ecosystems; **regulating services** are the benefits obtained from the regulation of ecosystem processes; **cultural services** are the nonmaterial benefits that people garner from ecosystems and **supporting services** are those services that are necessary for the
production of all other ecosystem services. The human well-being shares these four main components: the basic material needs for a good life, health, good social relations, security, and freedom of choice and action. Human well-being is a continuum—from extreme deprivation, or poverty, to a high attainment or experience of wellbeing. Ecosystems underpin human well-being through supporting, provisioning, regulating, and cultural services. The Millennium Ecosystems Assessment Report noted that “this new inclusive framework demonstrates that while nature provides a bounty of essential goods and services, such as food, flood protection and many more, it also has rich social, cultural, spiritual and religious significance—which needs to be valued in policymaking as well.”

Compare the graph in Figure 1.11 B with Figure 3.18 A as advanced by Climate Analytics. The Leonardo DiCaprio Foundation (LDF) is “dedicated to the long-term health and wellbeing of all Earth’s inhabitants. Through collaborative partnerships, we support innovative projects that protect vulnerable wildlife from extinction, while restoring balance to threatened ecosystems and communities.” One Earth project is an initiative of the Leonardo DiCaprio Foundation (LDF). LDF has provided over $100 million in grants to projects around the world that build climate resiliency, protect vulnerable wildlife, and restore balance to threatened ecosystems and communities.

The One Earth (https://www.leonardodicaprio.org) initiative offers a vision for the world that is possible by mid-century, a world in which humanity and nature can coexist and thrive. The state-of-the-art modeling framework offers a roadmap to stay below the threshold of 1.5°C in global temperature rise using currently available technologies and natural climate solutions (Figure 1.11 B). By logging on to this website you will discover the “Projects”, “Resources”, “Stories” and the One Earth Climate Model on climate solutions to stay well below 2.0°C by 2100 (Figure 1.11 B). RESOLVE (https://www.resolve.ngo) is a Washington, DC-based non-profit organization that forges sustainable solutions to critical environmental, social, and health challenges by creating innovative partnerships where they are least likely and most needed. RESOLVE’s Biodiversity and Wildlife Solutions Program tackles the most pressing conservation problems of our time—the approaching extinction of endangered wildlife and threats to habitats, including tropical forests where most of the world’s species reside—
through technological innovation, ambitious global agreements, and targeted land protection. You will not be disappointed in researching this website and its contribution to conservation, healthy communities and sustainable resources.

Figure 1.11 B. “The **One Earth** climate model shows the possibility of staying below the 1.5°C climate threshold. The IPCC special report calls for a carbon budget of 400 GtCO₂ to maintain a chance of staying below the threshold of 1.5°C global average temperature rise, adjusted to account for additional warming since the beginning of the industrial era. The budget for a good chance of 1.5°C is 175 GtCO₂, accounting for a buffer of 100 GtCO₂ for biosphere feedbacks in the second half of the century, such as melting permafrost, which is achieved by 2075. This is the first climate model to offer a chance of lowering global temperatures to 1.4°C by the end of the century without geoengineering.” Credit One Earth Model of LDF.

**The Global Deal for Nature** ([https://www.globaldealfornature.org](https://www.globaldealfornature.org)) with a similar message from organizations cited above warns the world: “If we fail to change course, it will take millions of years for Earth to recover an equivalent spectrum of biodiversity. **Future generations of people will live in a biologically impoverished**
world.” Adopting a Global Deal for Nature (GDN) and the milestones and targets presented above would better allow humanity to conserve intact ecosystems. Linking the mission of GDN, LDF, IPBES and RESOLVE with the Paris Agreement could solve the two major challenges facing the biosphere and all the species within it and result in a return to safe operating space for humanity in sequestering carbon while preserving nature and biodiversity.

Questions

1) How do you differentiate between weather and climate? (Also refer to Chapter Two for more information and use a Google search).
2) Why is it relatively easier to project climate change in the future whereas predicting the weather for the next week poses greater uncertainty?
3) List as many natural and anthropogenic influences that promote climate change for warming and cooling trends.
4) Refer to the graph in Figure 1.3 A & B. Why does the temperature not show an even steady rise over time? Give an explanation for the sudden increase since the 1970s.
5) Explain how the “greenhouse effect” works (Figure 1.5 A)? How does it differ from the heating of a greenhouse?
6) In the historic past, there were several mini-ice ages and warming periods without any human influence or industrial GGE. Propose a hypothesis or theory to project how the climate could change without any human interference in the next ten to fifty thousand years.
7) Research Earth’s historical precession, elliptical orbit and axial tilt from the past millennia and suggest climate projections into the future.
8) How do the atmosphere, land and oceans interact in regulating climate change (warming or cooling)? Include both natural and human influences in climate change trends.
9) Study the graphs in both Figures 1.1 A and 1.2. Why does CO₂ levels rise and fall during each annual cycle?
10) Calculate the mean annual increase and decrease of CO₂ concentrations from the data presented in Figure 1.1 A.
11) How do greenhouse gases promote global warming between the atmospheric-land interactions? Name four greenhouse gases that are attributed to human activities.

12) What is radiative or climate forcing and the contributing factors that increase climate forcing?

13) If you were the Prime Minister of Canada, what would be your focus in planning an “energy of the future” and justify some of your objectives for a Canadian audience.

14) Summarize Nature’s benefits to humans and the need to preserve biodiversity.

15) Why is it necessary to protect natural resources in a way to reduce carbon emissions? From reading the last section in this chapter, what should Canadians be doing to reduce carbon footprint – ours are the third largest in the world per capita.

16) If you feel strongly about climate change or any specific environmental issue in your community or province, write to your MLA or MP, state your opinion and ask what they can do. Ask for an acknowledgement of your letter.

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Chapter 2

Climate Impacts & Projections: Natural & Anthropogenic from the Arctic to the Antarctic

“Collective human action is required to steer the Earth System away from a potential threshold and stabilize it in a habitable interglacial-like state. Such action entails stewardship of the entire Earth System—biosphere, climate, and societies—and could include decarbonization of the global economy, enhancement of biosphere carbon sinks, behavioral changes, technological innovations, new governance arrangements, and transformed social values.” Will Steffen et al in “Trajectories of the Earth System in the Anthropocene” (Proceeding of the National Academy of Sciences, July 2018).

We start with some of our most basic needs: energy, materials, chemicals, and food. Although human population growth is escalating, we have never been so affluent. Along with affluence comes increasing use of energy and materials, which puts more pressure on the environment. How can humanity maintain high living standards without jeopardizing the basis of our survival? (Jeremy Berg, Science, 29 June 2018)

Climate Components & Projecting Climate Change

Terms such as climate, weather, extreme weather and to differentiate climate change from global warming need some clarification. Climate is the average of weather conditions taken over a long period of time, from decades to millions of years in a particular region of Earth such as from the Arctic, Antarctic or globally; regional variations exist for climate. Our climate is principally influenced by natural variabilities - the Sun’s energy, Earth’s position in relation to the Sun or its orbital changes over the millennia (Milankovitch cycles), rise and fall of greenhouse gases, the El Nino events, ocean and atmospheric circulation and recently, from human or anthropogenic influences. Weather, on the other hand, refers to the fluctuating state of the atmosphere at a given time and place, and is characterized by changes in the Sun’s intensity, Earth’s rotation and seasons, temperature, humidity, precipitation, wind, snow and ice, atmospheric and oceanic circulation, air pressure and clouds over a short period of time; simply put, climate is what you expect and weather is what you get. Any short-term variability of
weather and climate conditions promote abnormal conditions such as droughts, heat waves, hurricanes, wildfires, floods, extensive snowfall and freezing, we refer to as **extreme weather**. The next section deals exclusively with ‘extreme weather and climate change’ and connections between these two events.

**Climate change** refers to long-term temperature changes in Earth’s atmosphere and ocean, land use or changes such as deforestation and land degradation, impacts on ice sheets and glaciers, ocean circulation including changes in the Atlantic Meridional Overturning Circulation or AMOC. Changes in the chemistry of the atmosphere and oceans, global ocean circulation and Earth’s changing distance about the Sun have influenced climate of past millennia, notably during the glacial and interglacial periods. Changes in the climate today is being pushed by anthropogenic influences – we are adding GHG into the atmosphere from fossil fuel emissions and carbon dioxide concentrations have reached the highest level over hundreds of thousands of years. Changes in snow and ice, atmospheric and oceanic circulation, increasing concentrations of greenhouse gases or increasing use of fossil fuel impact on Earth’s climate. The following website is recommended for students and teachers and in explaining the “vital signs of the planet” - NASAs “Global Climate Change” at [climate.nasa.gov](http://climate.nasa.gov) allows you to explore updated climate science.

Climate change influences Earth’s biosphere, the thin layer that holds all living things. Climate is observed through the glacial and interglacial periods from ice core and deep ocean geological sediments as proxy evidence to document Earth’s climate history. One region of global concern today points to the Arctic and Canadian north because of a higher rise in temperature over several decades than the global average. With elevating greenhouse gases (GHG) in the atmosphere during the past 100 years the planet’s temperature has been gradually warming – GHG absorb long waves from Earth’s surface that radiate that energy back onto its surface as the greenhouse effect. **Global warming** on the other hand links temperature rise with increasing greenhouse gases as both are well connected in evidence of warming or radiative forcing. The planet has warmed at least 0.75°C in the last century according to most scientific reports and the IPCC. An appropriate estimate of pre-industrial temperature up to the present is around 1.10°C above the
average between 1850 and 1900. Temperature rise is well established and agreeable with the science from credible sources as cited in Chapter One, arising from rising GHG in the atmosphere. The year 2015-2016 were El Nino years and global temperature was above the average as expected during El Nino as one natural variability. However, the years 2017-2019 were non-El Nino (a mild El Nino in 2018) years but cited as the second warmest years, not from natural variability but influenced by anthropogenic GHG. Climate change and global warming are often used interchangeably with reference to temperature change.

![The Earth’s Climate System](image)

Figure 2.1. The Climate System is complex with interacting processes from natural variabilities and anthropogenic influences. Credit IPCC 2007.

The **climate system** or ‘living Earth system’ is more complex and involves interrelationships with sunlight or solar energy, the dynamics and composition of the atmosphere, cloud characteristics, the oceans and circulation, land-ocean-atmosphere interactions, the presence or absence of ice and snow, all living things in the biosphere. The climate system therefore includes natural processes such as changes in Earth’s orbit, solar radiation or irradiance, ocean circulation,
atmospheric chemistry and circulation, the water cycle, the greenhouse effect (natural and anthropogenic), the carbon cycle and all the physical and chemical interactions as illustrated in Figure 2.1. The human influence on the climate system is evident from anthropogenic emissions of greenhouse gases such as CO$_2$ (~415 ppm), CH$_4$ (>1800 ppb), N$_2$O (>320 ppb) and the halocarbons. An understanding of the changes and interactions between and among these five climate systems - **Atmosphere, Biosphere (Biomass), Cryosphere, Geosphere and Hydrosphere** - show how complex these systems interact. Many physical, chemical and biological interacting processes occur among these various components of the climate system on a wide range of space and time scales, making the system extremely complex. Although the components of the climate system are very different in their composition both physical and chemical, they are linked to Earth’s weather and climate conditions.

Linking extreme weather with climate change has been in the debate for some time and with some controversy. “A dramatic increase in forest fire damage in the western United States and western Canada is linked to climate change, a new research suggests. In the past 3 decades, acreage burned by forest fires has doubled, according to the study… human-caused climate change has lengthened the annual fire season” as published in the *Proceedings of the National Academy of Sciences*. Research from the *American Meteorological Society* makes an excellent case linking anthropogenic influences and natural variability in promoting extreme weather conditions on land and in the ocean. **“Extreme Weather and Climate Change”** is discussed later in this chapter.

The British Columbia Ministry of *Environment and Climate Change Strategy* published a “Preliminary Strategic Climate Risk Assessment for British Columbia” in July 2019. It does not provide overall adaptation measures but “characterizes the most problematic climate-related risks that could potentially occur in BC in coming decades.” Of the 15 specific events at risk the top three risks are (1) severe wildfires, (2) seasonal and long-term water shortage and (3) heat waves. The report estimated the consequences for each risk event including loss of life, psychological impacts, loss of natural resources and economic impacts. The
Projecting Climate Change

A climate model is essentially a representation of the many interactions within the climate which includes the atmosphere, oceans, land surface, and ice. Climate models are the key to making projections of future climate conditions. The National Climate Data Center stated that “models successfully reproduce temperatures since 1900 globally, by land, in the air, and the ocean.” Climate scientists incorporate past and present climate conditions and evidence from many sources with mathematical models, supercomputers and scenarios to predict what may likely happen in the future. “Computer models are essential tools in understanding how the climate will respond to changes in greenhouse gas concentrations” noted the UK Met Office Hadley Centre, a world-class climate projection research centre. Doug Smith at Met Office discussed a new modelling system to predict how climate change could proceed. NASAs Goddard Institute for Space Studies (GISS) developed three-dimensional circulation models coupled with atmosphere-ocean models for simulating Earth’s climate system. The US National Centre for Atmospheric Research has been modeling climate systems in the tropics and sub-tropics and found the “most accurate models were most likely to best reproduce cloud cover which is a major influence on warming.” Models are useful tools in predicting long-term climate change but not without some uncertainty. Climate models are based mainly on the laws of physics such as conservation of mass, energy and momentum, to simulate and quantify the climate response from projected human activities, namely greenhouse gas emissions. For more details on Models go to the free Wikipedia site.

The Climate Prediction Center at www.cpc.ncep.noaa.gov is another good site for exploring future climate on the short and long-term trends. Projections for June to August for “Temperature and Precipitation” outlooks in the US for 2018 are illustrated in Figure 2.1. Does this mean that every day between June and August will be warm and getting warmer? No. What it means is that, over a 3-month period, we expect the temperature to be above average and precipitation or drier
conditions will also vary. The El Nino in 2016 was expected to bring rain to southern California but instead that region was under drought conditions. At the time of writing, many of the events for warmer temperatures in the northwest and precipitation in eastern USA in 2018 seem to be expressed as holding true. Climate scenarios are also derived from the **Coupled Model Intercomparison Project Phase 5** (CMIP5) system. The latter carries multi-model ensemble scenarios used by climate scientists. Graphics and tables show projected climate change based on a multi-model ensemble of 29 CMIP5 models. Projections are expressed as anomalies with respect to a reference period (1986-2005, for example) for graphics and tables. The science of climate change is highly complex, global and regional in nature and subject to ongoing change.

![Figure 2.1](image)

**Figure 2.1.** NOAA Climate Prediction Center (CPC) Seasonal Precipitation (left panel) and Temperature (right panel) Outlook for June-August 2018 in the US. Color shading indicates the probability of below or above average temperature or precipitation. Data from NOAA/CPC and modified by NOAA Climate.gov.

Scientists at the Canadian **Centre for Climate Modelling and Analysis at Environment and Climate Change Canada** develop and use models of the climate system to simulate and predict changes globally and regionally over various timescales. Scientists also study the interaction between the land and atmosphere, ocean and atmosphere to further our understanding of how the entire Earth system
is changing. Models therefore represent mathematical computations of the climate system, expressed as computer codes and run on powerful computers. Climate models provide credible quantitative estimates of future climate change. There is no absolute certainty in predicting the climate in say 20 or 50 years from now; there are no absolutes in science. Models do have their limitations such as the representations of clouds and feedback relationships in projecting climate change. The fate of the permafrost in the next few decades is difficult to quantify with respect to CO$_2$ and CH$_4$ release. The Met Office for climate projection and modelling cautions that “projections from climate models are always subject to uncertainty because of limitations on our knowledge of how the climate system works.”

The IPCC Special Report concludes that that “there is medium confidence that droughts will intensify in the 21st century in certain regions; there is high confidence that changes in heat waves, glacial retreat and permafrost degradation will affect high mountain phenomena such as slope instabilities and glacial lake outburst while the frequency of precipitation will likely increase in this century.” Probabilities are built into all climate projections but scientists base future trends on past and present data; findings from several research centres are compared and the significant levels determine scientific accuracy or inaccuracy. The IPCC projects that for the next two decades a warming of 0.2°C per decade is being projected for a range of scenarios while the ‘best case scenario’ would see a rise of 0.1°C per decade even if GHG emissions are kept at 1990 levels. The emission scenarios of the IPCC Special Report on Emission Scenarios are detailed in its last edition; for example, in a simplified emission scenario for projecting CO$_2$ and temperature rise by 2100 is based on human behaviour or our consumption of fossil fuel.

Earth’s energy balance between these four components (atmosphere, land surface, ocean, sea ice) is the key to long-term climate prediction. The atmospheric component simulates clouds and aerosols, plays a large role in transport of heat and water around the globe. The land surface component simulates surface characteristics such as vegetation, snow cover, soil water, rivers, and carbon storing. The ocean component simulates current movement and mixing, and
biogeochemistry; the ocean is the dominant reservoir of heat and carbon in the climate system. **The sea ice component** modulates solar radiation absorption and air-sea heat and water exchanges. The climate modeling program at NASA Goddard Institute of Space Studies (GISS) is primarily aimed at “the development of coupled atmosphere-ocean models for simulating Earth's climate system.” It investigates climate sensitivity globally and regionally, including the climate system's response to diverse forcings such as solar variability, volcanoes, anthropogenic and natural emissions of greenhouse gases.

*Global Precipitation Measurement Satellite* launched by NASA and the Japanese Space Agency entered a new era in measuring precipitation from satellites. These measure global precipitation of all types, from light drizzle to heavy downpours to falling snow. “All this new information comes together to help us better understand how fresh water moves through Earth's system and contributes to things like floods and droughts”, writes Skofronick-Jackson at GISS. Recall the data of global surface water by *GRACE satellites* – the loss and gain of surface water, groundwater, ice melt, precipitation in Figure 1.11. The IPCC developed six illustrative emission scenarios (simplified as best case through to worse case in investigating the potential consequences of anthropogenic climate change) so as to project global warming into the future. For a more concise explanation, scenarios represent: (1) continued use of fossil fuel or business as usual; (2) efficient technologies replacing fossil fuels such as wind and solar power; (3) economic growth and human population; these are only three general scenarios of the many that the IPCC outlined.

The UK *Met Office Hadley Centre* modelling laboratory divides our planet’s atmosphere into ‘boxes’ both horizontally and vertically; it establishes square boxes with many levels in the vertical around the globe and incorporates all of the components of the climate system. The planet is then displayed as a three-dimensional grid system to which mathematical equations are applied and evaluated. At each box or grid point (Figure 2.1-1), for example, solar and terrestrial radiation, moisture content, heat transfer, snow and ice melt and runoff, and other climate systems are evaluated and calculated. **All models project that the Earth will continue to warm in this century**; there is obvious uncertainty by
how much Earth will warm. However, climate scientists claim to have a *high degree of confidence* that climate models provide credible quantitative estimates of future climate change. The Paris COP21 projects that a +2.7°C is expected in this century even after the “Intended Nationally Determined Contributions” or pledges were enacted upon by the 195 countries to reduce GGE. However, only with changes in fossil fuel consumption by mid-century (50% decarbonization), we may *likely* see a planet warming to < 2.0°C and greenhouse gas emissions (GGE) less than 400 ppm; CO₂ concentration today is around 415 ppm and CO₂ *equivalent* is above 490 ppm (Figures 1.2 & 1.2 B) with updates not available at the time of writing.

![Figure 2.1-1. Illustration of a grid point that evaluates Earth’s climate system and mathematical computations made to project climate models for the entire Earth. Credit NASA - GISS](image)

Warming needs baseline anomalies, so climatologists project a global temperature increase in the range of 1.8°C through to 4.5°C from the years 2090 to 2099, relative to the long-term average temperature from the years 1980 to 1999. A range of temperatures is always given because there is no certainty in predicting what may likely happen and always relative to other years or given as an *anomaly* or the difference in temperature from the ‘normal’. “Business as usual” scenario in fossil fuel use gives a higher temperature prediction. Rapid oil sands expansion to retrieve bitumen in northern Alberta is considered an example of business as usual. Continued and increasing use of coal in China, India, Australia, and the US, to name a few countries, for generating electricity is business as usual and
counterproductive to solving the climate crisis. The lowest projected temperature of 1.8°C is based on the best-case IPCC scenario while 4.5°C increase is for a worst-case IPCC emission scenario throughout this century. If we do not reduce carbon emissions from the present the global average temperature could very likely exceed 2°C in this century and with CO₂ climbing well-over 450 ppm before 2100 from its 415 ppm level today. As mentioned, the pledges made by countries from the Paris COP21 projects a rise of at least 2.7 °C by the year 2100 and unlikely to meet a 2-degree Celsius or less rise.

The International Energy Agency calculated that in order to keep Earth’s atmosphere from exceeding 450 ppm we have to reduce our daily global consumption of 93 million barrels per day (mbd) of crude to 80 mbd or less and to phase out coal for electricity in the next two to three decades. Coal, however remains the dirtiest fossil fuel and no new coal plants should be built to keep GGE under 2°C. As mentioned, the Intended Nationally Determined Contributions (INDC) or pledges at COP21 in Paris in 2015 from submissions by countries will not meet the global projection of less than 2.0°C before the end of this century. Canada’s INDC is insufficient and we need to resubmit another binding pledge in the next 5 years. Some climate scientists speculate that we may have already passed the point of no return of a 2°C rise well before the end of this century as time is running out.

Because of the complex nature of the climate system, climate models are adjusted from time to time. For example, a Met Office Hadley Centre in England forecasts a lower heat-carrying Atlantic current by the North Atlantic Drift or Gulf Stream and projects temporary cooling over the North Atlantic, North America, and Western Europe in the next decade. Cold water in the subpolar Atlantic correlates with high summer temperatures over Europe, and the 2015 and 2019 European heat wave has been linked to the record ‘cold blob’ in the Atlantic with a stationary high-pressure ridge over Europe. Scientists provide evidence that the Atlantic Meridional Overturning Circulation (AMOC) is weakening and could become the “main cause of future west European summer atmospheric circulation changes as well as potential on increased storminess in Europe.” The Royal Netherlands Meteorological Institute speculates that as a result of El Nino sea surface warming
in the Equatorial Pacific Ocean allows for more heat to be released into space that may cause a *pause in warming* at surface level. Skeptics would take delight and be quick to argue that any temporary cooling promotes their case that global warming is a myth; industries and some politicians too would use any temporary global cooling trend as fuel for their disbeliefs in climate science and continue to disregard linking greenhouse gas emissions to global warming. There are many unknowns about oceanic circulation and on how the climate system responds and what conditions may unfold in the long-term. Models do give very good projections of the climate but as mentioned are influenced by changes in the climate system. Later in this Chapter a section entitled “Ocean Circulation & The Atlantic Meridional Overturning Circulation” discusses at length the impact and changing circulation.

Some processes in radiative forcing (promoting atmospheric warming or cooling) are well known while other systems such as clouds, the thermohaline circulation, and regional ocean currents are less well understood in influencing climate change. Clouds near Earth’s surface generally produce a cooling influence by reflecting sunlight back into space. High clouds including the cirrus types do the opposite and tend to increase earth’s warming (Figure 1.5B). Climate scientist Williams Collins explains that “climate processes include the behavior of atmospheric aerosols, the dynamics of sea ice, and the exchange of water and energy between the land and atmosphere…large-scale patterns of temperature change are most consistent between models and observations when all forcings are included.” The present generation of models to simulate some aspects of regional climate change is limited but there is greater confidence in projecting changes at continental or global levels. Climate models are based on what we know from past decades to the present and they project that changes in future climate would very likely (greater than 90% probability) be larger than observed over the past 50 years; the prospects of any temperature stabilization look less likely in the long-term primarily based on the continued and greater use of fossil fuel, particularly with coal.

The CO₂ concentration trajectories of fossil fuel combustion assume that the future carbon cycle would continue to operate in a similar way as in the past with higher greenhouse gas concentrations of carbon dioxide, methane and nitrous oxide. Our
oceans, soil, decay processes and plants absorb and recycle billions of tonnes of CO₂, much more than from human emissions (Figure 1.4 H). Methane (CH₄) emissions from ruminants, rice paddies and the permafrost thawing add greatly to GGE. William Collins writing in Scientific American warns that “over the next 20 years global temperatures would increase by an average rate of 0.2°C per decade, close to the observed rate over the past 30 years.” Positive feedback relationship such as the thawing of the permafrost releases CO₂ and CH₄ into the atmosphere albeit difficult to quantify but definitely contribute to higher Arctic temperatures; leaking natural gas from the sites of production and delivery add substantially to methane in the atmosphere. For climate change mitigation, “the dominant uncertainties are associated with climate system processes and feedbacks, rather than uncertainties in initial conditions” as noted by Peter Cox in the journal Nature. In addition, loss of sea ice with more open water reduces the Sun’s reflectivity or albedo effect contributing to additional Arctic sea ice melting. Arctic conditions of sea ice melting, loss of mass from ice sheets and glaciers signal an increase in regional climate change. The Arctic region including northern Canada has become the ‘banana belt’ and since the 1950s the mean temperature rise in Canada was higher than the global mean (1.10°C), with most of this rise in northern Canada reported as 2.3°C since 1948 (Canada’s Changing Climate Report 2019).

Glaciologist Lonnie Thompson of Ohio State University has been researching ice cores from glaciers and he projects the impact of global warming to a high degree of certainty. The ice cores that Thompson analyzed also suggest that climate change is human-induced. Thompson predicts that in less than 10 years there will be no more “Snows of Kilimanjaro” from his studies of mountain glaciers. Ice-Cloud-Land Elevation (ICESat) and Gravity Recovery and Climate Experiment (GRACE) satellites measure changes in the ice sheets “with a laser altimetry approach and is most effective because it provides a detailed look at the overall integrated changes in the ice sheets” writes Waleed Abdalati of Goddard Space Flight Center. GRACE tracks the movement of water around our planet caused by Earth’s changing seasons, weather and climate processes, and human activities (Figure 1.11). The mission has mapped Earth’s ever-changing gravity field in unprecedented detail, showing how water, ice and solid Earth material move in or
near Earth’s surface. GRACE operates by sensing minute changes in gravitational pull caused by local changes in Earth’s mass. The Arctic ice cover is on a downward spiral and may have passed the point of no return says Mark Serreze of the US National Snow and Ice Data Center. Analysis from GRACE satellite estimates the total loss of ice mass in Greenland was about 130 billion tonnes (gigatonnes - Gt) each year from July 2002 to March 2005; in 2018 the loss increased to 286 Gt per year.

The Jakobshavn Isbrae glacier in western Greenland is about 6 kilometres wide and is losing more ice than any other glacier in that region, at least in past years until it was reportedly started to grow in the past three years. The huge Zachariae Isstrom glacier in northeast Greenland started to melt rapidly in 2012 and broke up into large icebergs where the glacier meets the sea. All glaciers on Greenland’s periphery have been constantly losing mass. GRACE also reveals unknown groundwater depletion; ice sheets are melting to better understand rates and variations of sea level rise around the world. Since GRACE (twin satellites) was launched in 2002, its updated measurements show Greenland has been losing about 280 gigatonnes of ice per year on average, a higher increase in the past five years and since 2005. For more information on the data from GRACE satellite go to http://grace.jpl.nasa.gov. Surface loss of ice sheets is calculated from laser altimeter (the ICESat satellite) on more than 16,000 locations on Greenland. NASA’s scientists report that “from 2003 to 2009, the ICESat mission provided multi-year elevation data needed to determine ice sheet mass balance as well as cloud property information, especially for stratospheric clouds common over polar areas. It also provided topography and vegetation data around the globe, in addition to the polar-specific coverage over the Greenland and Antarctic ice sheets.”

With millions more observations added each day, data from NASA’s Ice, Cloud and land Elevation Satellite-2 (ICESat-2) is providing a precise global portrait of elevation and allows scientists to track even the slightest changes in the planet’s polar ‘rise or fall in mass’ over regions. Small changes across vast areas like the Greenland ice sheet can have large consequences. “ICESat-2 will be able to measure the shift in annual elevation across the ice sheet to within a fraction of an inch. To do this, the
satellite uses a laser altimeter – an instrument that times how long it takes light to travel to Earth’s surface and back. With that time – along with the knowledge of where in space ICESat-2 is located, and where on Earth the laser is pointing – computer programs create a height data point.” The data is originally processed at NASA Goddard, then turned into advanced data products that researchers will be able to use to study elevations across the globe.

Ice sheets in Greenland flow outward “through a combination of internal deformation and basal sliding losing mass around its edges through meltwater runoff and iceberg calving” writes Sarah Das in the journal *Science*. Basal sliding is like a slippery slope and occurs when surface meltwater reaches the base of an ice sheet to create a mechanism for rapid response of deep ice displacement or flow caused by surface warming. Basal sliding also occurs under the deep Antarctic ice sheets triggered by heat from bedrock below the ice sheets and from a warming ocean circulation. The latest signs from Greenland suggest that sea levels

Figure 2.1 A. Ice sheet and ice shelf melting in Greenland. The greatest melting is on the periphery and the rate of change in ice sheets is noted in the above. Credit to NASA
could rise by as much as one metre by 2100 according to Steven Nerem at the University of Colorado who monitors sea levels using data from satellite imaging. The Met Office Hadley projects that with continued global warming it is likely that 15% of Greenland’s ice could be lost in about 300 years causing sea levels to rise by higher than one metre. It may take thousands of years or less for all of Greenland’s ice to melt; we cannot predict extended long-term conditions with any degree of certainty. No scientist or model could predict what may very likely happen in the distant future to Greenland or the Antarctic ice sheets. Greenland’s ice in the central interior region is more stable than the periphery and is not projected to melt in a hurry; the same goes for the Antarctic’s stable ice sheets except in the western Antarctic and the Peninsula that are unstable with collapsing ice shelves and glaciers.

Figure 2.1 B. Data derived from coastal tide gauge data shows sea level changed from about 1870 to 2000. Credit Commonwealth Scientific & Industrial Research Organization.
“The new maps reveal that two to four times more oceanfront glaciers extend deeper than 200 meters below sea level than earlier maps showed. That's bad news, because the top 200 metres of water around Greenland comes from the Arctic and is relatively cold. The water below it comes from farther south and is 3 to 4 degrees Celsius warmer than the water above. Deeper-seated glaciers are exposed to this warmer salty water, which melts them more rapidly” as reported by NASA's Jet Propulsion Laboratory. The warmer water enters the fjords to thin and melt glaciers. Within one year, icebergs that calve from Greenland’s glaciers arrived near Newfoundland and into Davis Strait in Labrador. The IPCC estimates a sea level rise by the year 2100 could climb to “between 19 and 58 cm from melting ice” while other climatologists suggest that the IPCC report is a conservative one and that a warming ocean needs to be part of the equation for total sea level rise.

From 1993 – 2017, sea level rose 85 mm or about 2.42 mm mean increase per year whereas from 1870 to year 2000 the rise was 200 mm (Figures 2.1 B & C); recent data indicated a rise of about 3 mm per year. From western Antarctica melting alone, sea level rise is estimated to be 30 cm by the end of this century. Melting of mountain glaciers and ice shelves from the Arctic to the Antarctic, about 1.5 metres sea level rise would likely occur by the year 2100 as one projection. The
IPCC confirms with *high confidence* that “over the last two decades, the Greenland and Antarctic ice sheets have been losing gigatonnes of ice, glaciers have continued to shrink worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent.” A sea level rise of at least *one metre* by 2100 is a projection of *high confidence* as cited from several sources.

Since the 1970s global temperatures rose by over 0.56°C to the present from the data provided by NASA and NOAA, and that the present warming trend is consistent with how the climate should respond with increasing greenhouse gases. **Twenty-four of the past twenty-five years have been the warmest in over 100 years.** The 2016 temperature was partially boosted by the 2015-2016 El Nino and almost as strong as the 1997-1998 “El Nino of the century”. The long-term trend is for wetter conditions in eastern North America at higher latitudes; drier conditions are predicted in the Sahel across central Africa, in northern China, southwest USA, mid-western India, northeast Brazil, and South Africa. The Sahara Desert is

![Figure 2.2. Satellite images of Lake Chad – 1972 & 2001. The satellite image on right shows the loss of water in almost 30 years. Credit to NASA.](image)
shifting in a northern and southern direction and continued droughts are expected in the Sahel and Mediterranean regions; it is not surprising that Lake Chad (Figure 2.2) that borders Nigeria, Chad and Cameroon has been steadily drying up mainly from climate change, desertification as well as from overuse in irrigation. The next section summarizes the work of the 2018 IPCC and UN Gap Reports in projecting climate change or global warming and what we need to do to keep our planet under 1.5°C before the year 2100. Chapter Four covers a multitude of ways to reduce global emissions.

**IPCC & UN Call for Action**

The *IPCC Global Warming of 1.5°C* publication in 2018 stated: “Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate with high confidence rating.” The UN *Emissions Gap Report 2018* report stated: “The message is clear: we need to make an almost existential change, the solutions are there, and we have no excuse. Closing the Emissions Gap means upping our ambition. Net zero must become the new mantra, and we must pursue this goal with confidence. After all, the science and data also show us that reducing and offsetting emissions does not mean cutting growth.” The *IPBES Report* is as important as the IPCC Report cited in Chapter One of the need to preserve nature and biodiversity or we face dire consequences.

*Emissions Gap Report 2018* published by the United Nations in association with the *IPCC Global Warming of 1.5°C* project the global emissions from fossil fuel and land use change, and what the world must do to reduce greenhouse gas emissions now and for projections by 2030, 2050 and 2100. “Total annual greenhouse gases emissions, including from land-use change, reached a record high of 53.5 GtCO2e (billions of tonnes of GHG emission equivalent) in 2017, an increase of 0.7 GtCO2e compared with 2016. In contrast, global GHG emissions in 2030 must be approximately 25 percent and 55 percent lower than in 2017 to put the world on a least-cost pathway to limiting global warming to 2°C and 1.5°C.
respectively” as cited from the UN Emissions Gap Report. If we project CO₂ concentration alone and not its equivalent the emissions by 2018 was about 42 Gt CO₂ per year. According to the new scenario estimates, emissions of all GHGs should not exceed 40 (range 38–45) GtCO₂e by 2030 from today’s 53 GtCO₂e, if < 2°C target is to be maintained and with about 66 percent chance at that. As mentioned, GtCO₂e refers to the sum total of all GHG: CH₄, N₂O, the halocarbons and carbon dioxide. For a 66 percent probability of keeping temperature increase below 1.5°C by the year 2100 global GHG emissions in 2030 should not exceed 24 (range 22–30) GtCO₂e. The Paris Agreement suggests that Parties should collectively aim to reach global peaking of GHG emissions “as soon as possible”, recognizing that “peaking will take longer for developing country Parties” and should be guided by the principle of equity, acknowledging common but differentiated responsibilities and capabilities. At present, the G20 countries are collectively not on track to meet their unconditional Nationally Determined Contributions (NDCs) for 2030 (Figure 2.2 A). The NDCs were advanced, albeit with little planning and too ambitious with Canada being a prime example at the Paris COP 21 attended by 195 nations in 2015; the details are discussed later.

![Figure 2.2 A. Projections of GHG for a 1.5°C and 2.0 °C by 2030 for a 66% probability and NDCs or Pledges and Current Policies. Credit UN Emissions Gap Report 2018 & Climate Action Tracker.](image-url)
The *IPCC Global Warming of 1.5°C* projects that global warming from anthropogenic emissions from the pre-industrial period to the present “will persist for centuries to millennia and will continue to cause further long-term changes in the climate system, such as sea level rise, with associated impacts (high confidence).” Climate models project robust differences in regional climate characteristics between present-day and global warming of 1.5°C, and between 1.5°C and 2°C. These differences include increases in: mean temperature in most land and ocean regions, hot extremes in most inhabited regions. Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5°C and increase further with 2°C. The IPCC estimated anthropogenic global warming is currently increasing at ~0.2°C (likely between 0.1°C and 0.3°C) per decade due to past and ongoing emissions. For limiting global warming to below 2°C CO₂ emissions are projected to decline by about 25% by 2030 in most pathways. Climate change from human activities mainly results from the energy imbalance in Earth's climate system caused by rising concentrations of heat-trapping gases. Can the human race especially in developed countries reduce GHG by the expected stated amounts for a safer planet?

About 93% of the energy imbalance accumulates in the ocean as increased ocean heat content. The ocean record of this imbalance is much less affected by internal variability and is thus better suited for detecting and attributing human influences than more commonly used surface temperature records. Recent observation-based estimates show rapid warming of Earth's oceans over the past few decades. This warming has contributed to increases in rainfall intensity, less intake of CO₂ as sink in a warmer than colder ocean, rising sea levels, the destruction of coral reefs, declining ocean oxygen levels, and declines in ice sheets and glaciers. The next section a detail picture of extreme weather and connection with climate change is being presented.

Global greenhouse gas emissions show no signs of peaking. Global CO₂ emissions from energy and industry increased in 2017, following a three-year period of stabilization. The IPCC noted that the “total annual greenhouse gases emissions, including land-use change, reached a record high of 53.5 GtCO₂e in 2017, an increase of 0.7 GtCO₂e compared with 2016. In contrast, global GHG emissions in 2030 need to be approximately 25 percent and 55 percent lower than in 2017 to put the world on
a least-cost pathway to limiting global warming to 2°C and 1.5°C respectively.” Refer to Figure 1.3 D-2 for cumulative and recent data from emitting countries and regions and compare with the graph in Figure 2.2 C.

What would we need to do to reduce GHG emissions as summarized from the UN Emissions Gap Report? First, we need to reduce global energy, materials and food demand. This could be supported by changes in behaviour and lifestyles, including food consumption such as reducing meat and dairy consumption, and food waste, and transport choices (such as flying less). In addition, better insulation of buildings would help reduce heating needs as buildings are responsible for around a third of global energy consumption. Second, we would need to use energy and materials more efficiently by, for instance, switching to energy efficient appliances or more efficient processes in industry. In the construction sector, use of low-emission building materials, such as wood, could help reduce emissions. Third, we need to improve agricultural practices so as to reduce emissions and water use, including

![Figure 2.2 B](image-url)

Figure 2.2 B. The UN Emissions Gap Report projections and time-line scenarios for a 1.5°C warming. Global mean temperature is at 1.10°C (2019) while Northern Canada’s mean is 2.3°C and the Arctic ~3.0°C since 1948, both more than twice the global average.
improving soil management and altering cattle diets. We also need to reduce deforestation which together with other changes in land use, account for 12% of CO₂ emissions. For more information on reducing emissions go to Chapter Four.

Finally, we need to transform the global energy mix. “Renewable energy production needs to be scaled up, with renewables (including biomass, wind, hydropower and solar) to supply half to two-thirds of primary energy in 2050 to achieve the 1.5°C target” according to the UN Report. We also need to transition transportation away from fossil fuels to running on low-emission electricity. Besides reducing climate impacts, switching to electric vehicles would bring other benefits, including improving air quality in cities. Together, these efforts amount to major transitions of unprecedented scale in all aspects of society. The UN Report warns that “what happens in the next ten years will be critical. Given the inertia of the global economic

![Figure 2.2 C. High global emitters of GHG Equivalent. Compare this graph with the one on Figure 1.3 D -2. Credit UN Gap Report 2018.](image)

system, it will be very difficult to achieve the emission reductions at the scale and rates required, without using methods to remove CO₂ from the atmosphere. Major investments will be needed to carry out these transitions, including developing economies. These could be complemented by government legislation on energy standards and a tax on carbon.” Most of all, protecting and expanding on nature reserves lead to saving biodiversity also play a major role in natural carbon sinks and improving the quality of lives of people; indigenous peoples are the true guardians of vast regions of rainforests that politicians must take seriously into keeping nature for all humankind. Unfortunately, much damage to forest ecosystems have been realized through deforestation, mining, agriculture and creating pastures for domestic animals.

**In summary, toward a ‘Stabilized Earth’ and avoiding a ‘Hothouse Earth’** such action entails stewardship of the entire Earth System—biosphere, climate, and societies—and should include (1) decarbonization of the global economy; (2) enhancement of biosphere carbon sinks - use biological processes to increase carbon stocks (sinks) in soils, forests (reforestation & afforestation) - changes in forest management, and wetlands as advanced in the IPBES Report; (3) behavioral changes, (4) technological innovations & advancing renewables; (5) carbon capture & storage at coal plants; (6) transformed social values & political change; (8) direct air capture currently limited by high cost; (9) **“Without healthy natural systems we need to ask whether future human development is even possible”** as a warning from the *Living Planet Report 2018: Aiming Higher.*

**Extreme Weather and Climate Change**

A definitive answer to the commonly asked question of whether climate change *caused* a particular event to occur cannot usually be provided in a deterministic sense because natural variability almost always plays a role. In the past, a typical climate scientist’s response to questions about climate change’s role in any given extreme weather event was “we cannot attribute any single event to climate change.” The science has now advanced to the point that this is no longer true as an unqualified blanket statement. The *Bulletin American Meteorological Society* (BAMS) Special Supplement (Vol. 99, Jan. 2018) reported that on “twenty-one of the twenty-seven papers presented in that edition it identified climate change as a
significant driver of an extreme event, while six did not.” The research papers in the BAMS are extensive; I will provide evidence to advance the connection and link with climate change and extreme weather events from the science. The Abstract to the 30 scientific reports in the Editorial by Stephanie Herring in that Special Supplement stated in part: “The events were the 2016 record global heat, the heat across Asia, as well as a marine heat wave off the coast of Alaska. While these results are novel, they were not unexpected. Climate attribution scientists have been predicting that eventually the influence of human-caused climate change would become sufficiently strong as to push events beyond the bounds of natural variability alone.” We are now seeing a clear connection between climate change and extreme weather events across the planet (Figures 2.3 & 2.4).

Arctic warmth most likely would not have been possible without a long-term warming contribution from anthropogenic forcing. The Earth System Science Center top climate scientist Michael Mann advanced evidence that “the events are being made more frequent and more extreme by human-caused climate change.” The observed frequency, intensity, and duration of some extreme weather events have been changing as the climate system has warmed. Such changes in extreme weather events have also been simulated in climate models, and some of the reasons for them are well understood. For example, warming is expected to increase the likelihood of extremely hot days and nights. Warming is also expected to lead to more evaporation that may exacerbate droughts and at the same time increase atmospheric moisture and the frequency of heavy rainfall. Extreme precipitation events are increasing in frequency globally over both wet and dry regions resulting in flooding as experienced in India, eastern USA and Canada in 2018. Numerous studies have found increasing precipitation, extreme events in many regions (Figure 2.4), and those increases can be attributed to human-caused changes to the atmosphere, land, cryosphere and oceans.

Soaring Arctic temperatures are ‘strongly linked’ to recent extreme weather events, scientists claim at this cutting edge of climate change research. “Human activity has been suspected of contributing to this pattern before, but now we uncover a clear fingerprint of human activity,” says Professor Michael Mann, at Pennsylvania State University who led the study and published in the journal
Scientific Reports. Professor Mann cited the “the unprecedented 2016 California drought, the 2011 US heatwave and 2010 Pakistan flood as well as the 2003 European hot spell all belong to a most worrying series of extremes. In data from computer simulations as well as observations, we identify changes that favour unusually persistent, extreme meanders of the jetstream that support such extreme weather events.” Mann says that what happens in the Arctic does not stay in the Arctic with reference to its warming and influence on the polar jetstream, forest fires in North America and polar vortex. As a result, an Arctic warming is likely the cause of a weakened polar vortex causing the southward turn of the jetstream resulting in extreme cold winters in Siberia and northeast United States and Canada. Mann reminds us that asking if climate change “causes” specific events is the wrong question. “The relevant question is: ‘Is climate change impacting these events and making them more extreme?’ and we can say with great confidence that it is.” Mann points out that the link between smoking tobacco and lung cancer is a statistical one, which does not prove every cancer is caused by smoking, but epidemiologists know that smoking greatly increases the risk. “That is enough to say that, for all practical purposes, there is a causal connection between smoking cigarettes and lung cancer and it is the same with climate change” according to Mann.

National Academy of Sciences (NAS) and The National Academy Press (NAP) in a 2016 publication on “Attribution of Extreme Weather Events in the Context of Climate Change” stated that extreme weather and climate events (e.g., heat waves, droughts, heavy rainfall, hurricanes) have always posed risks to human society. NAS emphasized “as a matter of growing interest, however, is the degree to which humans are changing these risks through anthropogenic climate change.” The consequences of this change to the climate are seemingly everywhere: average temperatures rising, precipitation patterns changing, melting of glaciers and ice sheets, and rising sea level. These changes are affecting the availability and quality of water supplies, how and where food is grown, and even the very fabric of ecosystems on land and in the sea. The US National Academy of Sciences research identifies a high confidence rating of an event such as extreme cold and extreme heat to anthropogenic climate forcing (Figure 2.3). Since the NAS research was put out it is more likely to add other events such as droughts and precipitation to a
higher level of confidence with climate change. The updated research as mentioned from 21 of 27 in the *Bulletin of the American Meteorological Society* (BAMS) Special Supplement in January 2018 adds *high confidence* on more extreme events than the NAS report and **linking extreme weather to climate change**. The *Climate Science Special Reports* in 2017 and 2018 are valuable references that outline projections of **climate extremes and confidence levels** of an event happening and can be accessed at [https://science2018.globalchange.gov](https://science2018.globalchange.gov).

The April 18, 2018 *Nature* journal’s headline: **“Great Barrier Reef saw huge losses from 2016 heat wave.”** One-third of reefs in the world’s largest coral system were transformed by warm waters, a finding from underwater and aerial survey. Researchers report that severe bleaching on an unprecedented scale triggered mass death of corals. This drastically changed the species composition of almost one-third of the 3,863 individual reefs that comprise the Great Barrier Reef (GBR). The Great Barrier Reef is home to the world's largest collection of coral reefs, with around 400 types of coral and 1,500 species of fish. It is also home to a number of endangered species, including the large green turtle. Extensive aerial surveys revealed widespread coral bleaching between March and April 2016. This phenomenon occurs when excessive heat kills or expels algae called *zooxanthellae*, which have a symbiotic relationship with reef-building corals. The algae provide the corals with energy and nutrients through photosynthesis and without them, the corals often die. Approximately one-third of the world’s coral reefs were affected by bleaching in 2016. On the GBR less than 10% of reefs escaped with no bleaching compared with more than 40% in previous bleaching events. Corals of the GBR have declined over the past 30 years. While reef state depends on the balance between disturbance and recovery, most studies have focused on the effects of disturbance on reef decline. We show that coral recovery rates across the GBR declined by an average of 84% between 1992 and 2010, according to Juan-Carlos Ortiz and others in *Scientific Advances* (July 18, 2018).
“Anthropogenic greenhouse gases likely increased the risk of the extreme Great Barrier Reef bleaching event through anomalously high sea surface temperature and the accumulation of thermal stress” as cited in the *Nature* journal. The research found that the 2016 global coral bleaching event was severe: “93% of the northern, a 700 km stretch of the Australian Great Barrier Reef coral was bleached and by June, 60% of this coral was killed in association with heat stress was severe.” John "Charlie" Veron widely known as "The Godfather of Coral" is a renowned reef expert who has personally discovered nearly a quarter of the world's coral species and has spent the past 45 years while diving Australia's Great Barrier Reef says "it's the beginning of a planetary catastrophe." Figure 2.4 illustrates the regions that are being impacted by extreme weather events taken from the *BAMS Special Supplement*. Because of that extensive research only two of the 21 papers linking extreme weather and climate change I am citing only two of the extensive research here in brief – the decline of corals in Great Barrier Reef (both in *Nature* journal and *BAMS*) and the warming of more than 2°C in the Bering Sea at a depth of 200 metres with an accompanying death toll from krill to mammals from coastal California to the Gulf of Alaska.
In another research conducted by John Walsh and others in the *BAMS Special Supplement* entitled “The High Latitude Marine Heat Wave of 2016 and its Impacts on Alaska” concluded that the 2016 Alaska marine heat wave was unprecedented in terms of sea surface temperatures and ocean heat content, and using the CMIP5 (a powerful computer modelling data system) suggest human-induced climate change has greatly increased the risk of such anomalies. The Gulf of Alaska and Bering Sea have been anomalously warm for several years with the warmth peaking in 2016 with about 2°C higher at a depth of 200 metres in the Bering Sea. As a consequence of the high marine heat content and sea surface temperature, coastal areas of Alaska had their warmest winter on record in 2016. The warmth of the Bering Sea and the Gulf of Alaska (Figure 2.5) in 2016 was unprecedented in the historical record. Both anthropogenic forcing and internal variability were necessary for that extreme warmth of the subarctic seas. “It was extremely unlikely that natural variability alone led to the observed anomalies” as reported by Walsh and colleagues.

The *National Geographic* September 2016 issue gives a similar account in the article entitled *Heat Wave* of the “giant patch of warm water known as the blob shocks the Pacific Ocean, in what some fear is a preview of our future oceans.” Since 2013 the Pacific Northwest Coastal waters have been warming and exacerbated by El Nino in 2015 and 2016 as well as the Pacific Decadal Oscillation, as explained in the next section. New species migrate to the northern Pacific region (Figure 2.5), then a massive toxic algae bloom (*Pseudo-nitzschia*) developed in June 2015 from California to Alaska that was killing off small and large species. The widespread algae containing the neurotoxin called *domoic acid* affected krill and shellfish in the food chain and carried it onto birds and mammals. Tests found the toxin was contained in anchovies, dead sea birds (murrens), sea lions, sea otters, humpback whales that washed ashore in British Columbia, all showing traces of domoic acid.
Figure 2.4. Location and extreme events throughout the planet as appeared in the BAMS Research Supplement. Credit *Bulletin American Meteorological Society* (BAMS), Special Supplement – Volume 99, No.1, January 2018.

Figure 2.4 B. Marine biologists examining corals on the Great Barrier Reef in Australia. Photo credit: Fredrik Naumann from IPCC Climate Outreach at [www.climateoutreach.org](http://www.climateoutreach.org).
Figure 2.5 Showing sea surface temperature in the Bering Sea and Gulf of Alaska. Temperature at about 200 metres in the Bering Sea was 2°C higher than normal. Warmer ocean continued to 2019. Credit NOAA.

The connection of climate change and extreme weather in many regions of the planet from the BAMS research, *National Academy of Sciences*, *Nature* journal and from scientists like Michael Mann and Jennifer Francis, must be taken seriously. **Natural variability alone cannot explain extreme events without global warming in recent decades.** In 2017 and 2018, forest fires damaged vast regions in British Columbia, about 2.6 million hectares in BC (Figure 2.7), as well as in Washington State and Napa Valley, California. Worldwide fires have also been destroying vast regions in Brazil, Africa and Indonesia. In 2016, fires in the Fort McMurray region of Alberta (Figure 2.6) devastated that region and thousands lost property. Most of the fires in BC in 2017 and 2018 (Figure 2.7) were ignited by lightning and fueled by dead trees. The Alberta and BC forest fires were also triggered by winds and an **Omega block** – a stationary high-pressure region surrounding by lows and looks like the Greek symbol; the latter illustration is shown in this section. **The wildfire Alberta region in 2016 is “one stark**
example for the potentially disastrous impact of planetary-wave slow-down and the resulting summer weather stalling” according to research by Dim Coumou and others from the Potsdam Institute for Climate Impact Research & Nature Communications journal. Stalling summer weather like that in the summer of 2018 in the Northern Hemisphere can turn into ‘extreme extremes’ from heat to drought, from rain to flood. When those conditions stall for several days or weeks, they can turn into extremes—heat waves resulting in droughts, health risks and wildfires, or relentless rainfall resulting in floods. Rains can grow into floods, sunny days into heat waves, and tinder-dry conditions into wildfires.

Figure 2.5 A. A stationary high-pressure region over Alaska in June & July 2019, with an Omega block jetstream similar to the condition in Alberta forest fire in 2016. Credit AccuWeather Meteorologist Ryan Adamson.

In 2019, during June and July in Alaska have brought extreme heat with the jetstream high over most of Alaska, another Omega block of stationary a high-pressure system. The Anchorage Daily News reported “The temperature at Ted Stevens International Airport reached 90°F (32°C) on July 4, 2019 crushing a 50-year record in Anchorage. Anchorage has now had 34 days in a row of above-average temperatures.” "Surface temperatures are above normal everywhere around Alaska. The entire Gulf of Alaska, in the Bering Sea, in the Chukchi Sea south of the ice edge, exceptionally warm waters, warmest on record, and of course record-low sea ice extent for this time of
year off the north and northwest coasts of the state” as reported by Rick Thoman, climatologist at the University of Alaska. From Greenland to Siberia, from Alaska to the Yukon, huge swathes of flame and smoke are wrapping themselves around the upper Northern Hemisphere of our planet. Since the start of June 2019, more than 100 wildfires have sparked and burned in the Arctic circle. The boreal forests in Siberia are burning at extraordinary rates. The 2019 wildfires have already burned roughly 538 square kilometres of forest in southern Siberia. While wildfires in the Arctic are not technically uncommon, in recent years, they have been getting much worse due to global warming. The World Meteorological Organization are calling them “unprecedented - the extreme intensity and sheer number of this year's wildfires.”

The El Nino and La Nina phenomena also promote abnormal long and short-term extreme weather patterns across the continents and especially around the regions of the mid-equatorial Pacific Ocean from South America to Indonesia and Australia. However, natural variability alone cannot account for many bush or forest fires, heat waves and other extreme weather events. Robert Field a climate scientist at NASA’s Earth Observatory in “Forecasting Fires” said “it’s not just one factor that causes a fire to start or spread.” For instance, if a region has not received normal precipitation for weeks or months, the vegetation might be drier and more prone to catching fire; if it gets windy, a fire could spread more quickly, both events seem obvious. “Across much of the world, tracking fires and smoke using NASA satellite data is the only way to get a consistent picture of fire activity, and our fire weather data helps us to understand the causes. That will help us to understand how fire activity might change and allows us to think ahead for different climate scenarios” said Field.

When lightning storms passed over the Canadian province of British Columbia in July and August 2018, they ignited several hundred fires in forests that were already primed to burn. The heat wave sweeping across the province with “23 daily maximum heat records cited for August 9, 2018 were broken in several British Columbia locations” according to Environment Canada. Abnormally hot, dry weather had stressed vegetation and parched the soil. And infestations of mountain pine beetles had left many forests with large numbers of dead trees. Losses from
severe weather have been rising across the planet. Extreme events, including storms, flooding and heat waves have had significant economic, health and safety impacts on people worldwide. Environment Canada reported “nearly 600 wildfires burn across the province of BC in August 2018, displacing thousands of people and forcing scores more to be prepared to leave at a moment's notice. Heavy smoke from the fires has led to air quality advisories covering the Dease Lake and Bulkley Valley regions, as well as the entire southern half of B.C., including Metro Vancouver and most of Vancouver Island.” On May 20, 2019, the Alberta fires at High River took a turn and advanced within 5 kilometers of that community. It had spread across an estimated 230,000 hectares by early June, leading the Alberta Emergency Management Agency to issue a mandatory evacuation order for residents south and southeast of the town. A state of emergency was declared for Mackenzie County. As the Canadian north grows warmer and drier for longer periods, the destruction is expected to get worse. Massive wildfires have become common in Alberta during spring, said Mike Wotton, a research scientist with Natural Resources Canada. There’s a window — after the snow melts but before vegetation grows — when there can be plenty of dry material to fuel fire. 

Maclea

n’s magazine special “The Climate Crisis’ in August 2019 carries several articles of interest for Canadians. The summer of 2019 and at the time of writing, Maclean cited over 800,000 hectares were burned in northern Alberta.

Scientists are “virtually certain” that the three-month event in 2018 which saw temperature records broken and wildfires in places such as the Arctic circle, Western Canada, Greece and California could not have happened in a world without human-caused greenhouse gas emissions. NASA’s image showed a “World on Fire” (Figure 2.7 B) taken on August 23, 2018 and reported the following: “Africa seems to have the most concentrated fires. This could be due to the fact that these are most likely agricultural fires. The location, widespread nature, and number of fires suggest that these fires were deliberately set to manage land. Farmers often use fire to return nutrients to the soil and to clear the ground of unwanted plants. While fire helps enhance crops and grasses for pasture, the fires also produce smoke that degrades air quality. Elsewhere the fires, such as in North America are wildfires for the most part. Central Chile is experiencing a mega drought and large portions of its diverse native forests have been converted to
more flammable tree plantations. In Brazil, the Amazon fires are both wildfires and man-made fires set to clear crop fields of detritus from the last growing season. Fires are also commonly used during Brazil’s dry period to deforest land and clear it for raising cattle or other agricultural or extraction purposes. Brazil’s National Institute for Space Research has recorded more than 74,000 fires by August 2019 – up 84 per cent from the same period in 2018 and the highest increase since records began in 2013. Imagine the loss of biodiversity from human-caused fires and
deforestation! The world’s oxygen is in decline while \( \text{CO}_2 \) is on the rise in Amazonia from the destruction of rainforests. Australia is also where you tend to find large bushfires in its more remote areas. Hotter, drier summers in Australia will mean longer fire seasons – and urban sprawl into bushland is putting more people at risk for when those fires break out.”

Wildfires in Alberta in 2016 and 2019 and in British Columbia in 2017 and 2018 devasted huge regions of both provinces and cost billions of dollars to property and fire-fighting. In 2016, because of human activities, insect infestation and wildfires Canadian forests released about 78 megatonnes of carbon into the atmosphere, about 10% of Canada’s GGE. The intense heat from the fire causes air to rise rapidly in the smoke plume. The rising hot air is turbulent and draws in cooler air from outside the plume, which helps cool the plume as it rises. As the plume rises to higher and higher elevations the atmospheric pressure reduces, causing the plume air to expand and cool even further. If it cools enough, the moisture in the plume air will condense and forms cumulus cloud, which, because it comes from the fire plume, it is called ‘pyrocumulus’. The condensation process causes latent heat to be released, which makes the cloud warmer and more buoyant and causes the cloud air to accelerate upwards into the lower stratosphere. Having produced a thunderstorm, the cloud is now known as ‘pyrocumulonimbus’. The smoke from these storms from 2016 to 2019 wildfires from Alberta and BC end up circling the world.

Figure 2.7 A. Pyrocumulonimbus cloud and storm reaching the lower stratosphere. Credit Wildfire Today https://wildfıretoday.com
Global heating could bring many more bouts of severe drought as well as increased
flooding to Africa than previously forecast, scientists have warned. New research
says the continent will experience many extreme outbreaks of intense rainfall over
the next 80 years. These could trigger devastating floods, storms and disruption of
farming. In addition, these events are likely to be interspersed with more crippling
droughts during the growing season and these could also damage crop and food
production. “Essentially we have found that both ends of Africa’s weather
extremes will get more severe,” said Elizabeth Kendon of the Met Office’s Hadley
Centre in Exeter. “The wet extreme will get worse, but also the appearance of dry
spells during the growing season will also get more severe.” This report appears in
Nature Communications journal in June 2019. Many countries in these regions –
including Niger, Nigeria and the Democratic Republic of Congo – are expected to
experience substantial growth in population over that time and will be particularly
vulnerable to severe floods.

![Figure 2.7 B. ‘A World on Fire’. Image on August 23, 2018. Credit NASA Worldview, Earth Observing System Data and Information System.](image)

The Natural Resources Canada published projected changes including extreme events
in the document entitled: “CANADA IN A CHANGING CLIMATE: Sector Perspectives on
Impacts and Adaptation.” The IPCC reports claim of “likely impacts of climate change include increased frequency of severe weather events such as droughts, floods and storms.” The likely projected scenario from the IPCC gives a probability of 66% that an event would occur. There is a likely connection between climate change and the occurrence of some severe weather patterns such as droughts, floods, extreme cold weather and abnormal snowfall (Figure 2.3). However, that report by the IPCC should be revised in their next review to show the connection of climate change with several extreme events; it is no longer a likely scenario but one of high confidence according to climate scientists writing in Nature, the Bulletin of the American Meteorological Society and Michael Mann of Penn State in Earth System Science Center.

Arctic temperature and polar jetstream have been associated with the changing polar vortex. The unusually cold winter weather in Britain and northern Europe in December 2010, and recent winters especially in eastern USA and Canada appear to point to heating in the Arctic and the weakening of the polar vortex with a southward shifting of the Polar Jetstream. An explanation of this process comes from NASAs Goddard Institute for Space Studies (GISS) of a warming Arctic with subsequent developments in extreme winter weather conditions. In addition to the warming Arctic, the shifting Jetstream influenced severe winter storms in Europe and elsewhere. In the Fall of 2014, the strong Polar Vortex that is a circumpolar counterclockwise low pressure of cold air was weakened by a warming Arctic causing the Polar Jetstream to drift way south (Figure 2.8) into eastern Canada and the US that brought early snowfall and cold weather to most of the mid-west USA and eastern Canada.

Soaring Arctic temperatures have been ‘strongly linked’ to extreme winter weather events in north-eastern North America as noted from a weakening polar vortex and changing jetstream. “Human activity has been suspected of contributing to this pattern before, but now we uncover a clear fingerprint of human activity,” or global warming according to Michael Mann, climate scientist at Pennsylvania State University. Mann stated: “The unprecedented 2016 California drought, the 2011 US heatwave and 2010 Pakistan flood as well as the 2003 European hot spell all belong to a most worrying series of extremes. In data from computer simulations as well as observations, we identify changes that favour unusually persistent,
extreme meanders of the jetstream that support such extreme weather events." Benjamin Santer and others in *Science journal (July 20, 2018)* reported that “a human-caused signal in the seasonal cycle of tropospheric (atmospheric) temperature can also be measured.” They use satellite data and the anthropogenic “fingerprint” predicted by climate models to show the extent of the effects and discuss how these changes have been caused. The “human influence” fingerprint matched the satellite patterns of seasonal cycle change. The match was significant – it couldn’t be explained by natural climate variability alone.

*Goddard Institute of Space Studies* (GISS) reported that temperatures in western Greenland, northern Canada, and Hudson Bay were 10°C higher than normal at the end of 2010 year. The re-freezing of sea ice in the Arctic was also delayed late in 2009 and 2010. The unusual extreme cold winter and high snowfall in northern Europe and Britain in 2010 was the likely cause from an Arctic warming according to GISS. Warming in the Arctic, the changing pattern of the normal west to east polar jetstream and disruption of the counterclockwise circumpolar air circulation or polar vortex altogether influence extreme winter conditions in northern Europe, Siberia, eastern Canada and the USA. The latter conditions showed the polar vortex and polar jetstream moving to lower latitudes as described in Figure 2.8. Some scientists suggest that the heat from the tropical Pacific has a greater influence on the polar vortex and Jetstream. With the strong El Nino event in 2015 and 2016, the northeast USA and Canada did experience two severe winters. Climate scientists coined a new term of “Warm Arctic-Cold Continent” to describe the Arctic Dipole anomaly and concluded that warming in the Arctic region promotes colder winters elsewhere.

The diversion of *Superstorm Sandy* in October 2012 that ravaged the New York and Jersey shores was likely due to a high-pressure system south of Greenland that prevented Sandy from going offshore. Sandy was fueled by a cold front from the northwest that diverted the Atlantic storm inland, not out to sea due to a “blocking ridge of high pressure over Greenland” and a shift of the Jetstream over the Atlantic. A warming sea, the weakening Gulf Stream or North Atlantic Drift, and a Full Moon intensified the damage caused by Sandy; wave heights of up to 15 metres on the New Jersey/New York coastal regions were observed. (The section
on ‘Ocean Circulation’ in this Chapter and a weakening of the *Atlantic Meridional Overturning Circulation* (AMOC) would shed more light into the changing ocean circulation and climate impacts.) Low lying communities and even the subway system in New York City were flooded. It is likely that storm surges and rising sea level would intensify and become more frequent in this century as a result of climate change and natural variability such as El Nino that will continue to influence the occurrence of extreme weather conditions.

GISS scientists found that there were “twice as many extreme regional snowstorms between 1961 and 2016 as there were from 1900 to 1960” suggesting that global warming or Arctic warming likely triggers extreme weather patterns. The sources cited in this section provide ample evidence that without climate change many extreme weather events around the planet would not occur. In *Nature Communications* (August 14, 2018), research by Florian Sevellec showed that at the global level, “2018-2022 years may be an even hotter period than expected based on current global warming.” Warming caused by greenhouse gas emissions is not linear. It appears to have lapsed in the early 21st century, a phenomenon known as a global warming hiatus. The next few years will likely be hotter than expected. The coming warm period is associated with an increased likelihood of intense to extreme temperatures.” A word of caution and not targeting climate change solely for every abnormal weather condition promoting floods and fires. However, Professor Michael Mann, a world-renowned climate scientist, reminds us that we should be asking ‘Is climate change impacting these events and making them more extreme?’ and we can say with great confidence that it is.” Yes, climate change plays a dominant role in promoting and impacting many extreme weather situations as discussed above.

Climate scientist Jennifer A Francis (Environmental Research Letters - Volume 10, Number 1, 2015) provided evidence for standing jet stream waves with large amplitude north/south undulations in response to rapid Arctic warming and “we conclude that further strengthening and expansion of Arctic Amplification (AA) in all seasons, as a result of unabated increases in greenhouse gas emissions, will contribute to an increasingly wavy character in the upper-level winds, and consequently, an increase in extreme weather events that arise from prolonged
atmospheric conditions.” A positive value of AA indicates that the Arctic is warming faster than mid-latitudes. The combination of a storm stalling over the Atlantic Ocean and stationary high pressure over central and eastern Europe act to pull very hot air from Africa northward across Europe. The latter set the stage for a dangerous heat wave experienced in 2019 over a large portion of western and central Europe with daily temperatures at and above 32°C. NASAs GISS posted the global average temperature for June 2019 at 0.93°C above the norm breaking the previous June record of 0.82°C set in 2016. In 2019, June and July were punctuated by a severe heat wave that struck Western Europe including Britain and Siberia with numerous all-time-hottest-temperature records. Notably, 13 locations in France surpassed their highest temperature ever recorded with Paris recording the highest temperature at 40.6°C.

The Science Behind the Polar Vortex

The polar vortex is a large area of low pressure and cold air surrounding the Earth's North and South poles. The term vortex refers to the counter-clockwise flow of air that helps keep the colder air close to the poles (left globe). Often during winter in the Northern Hemisphere, the polar vortex will become less stable and expand, sending cold Arctic air southward over the United States with the jet stream (right globe).

The polar vortex is nothing new — in fact, it's thought that the term first appeared in an 1853 issue of E. Littell's Living Age.

Figure 2.8. Polar Vortex showing a strong vs a weak system in its oscillation from changing air pressure, jetstream shifts and a warming Arctic. Credit to NOAA & Earth System Science Center.
Figure 2.8 A. Satellite view of the omega block over W. Europe, the cause of the big heat wave in summer of 2019. A strong ridge has formed over W. Europe, flanked by lows on both sides. Clear, sunny and very hot weather prevails under the ridge. Inset in upper right is a plot of 500 mbar jetstream, tracing out the distinct omega pattern. Credit IFL Science & The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

Figure 2.8 B. Europe 2019 Heat Wave. Credit NASA's Earth Observatory.
As Greenpeace has pointed out, the deaths in Europe are of a relatively small number compared with the “far bigger disasters already occurring in hotter, poorer countries in the global South”. After the 2003 heatwave, about 70,000 additional deaths were recorded in Europe compared with previous years, according to a scientific and medical study. In poorer countries with less advanced infrastructure, global heating is likely to bring drought and water stress, making agriculture more difficult if not impossible across large areas of land, leading to food shortages and potentially conflict and mass migration. Higher temperatures can affect anyone, but dehydration, heat exhaustion and heatstroke can have deadly consequences for people who suffer from cardiac, kidney and respiratory diseases, as well as the elderly and infants.

**NOTE:** The Following section was presented as a handout with my powerpoint presentation to students and teachers and entitled “Connecting Climate Change & Extreme Weather” and may serve as a summary.

Unprecedented summer warmth and flooding, forest fires, drought and torrential rain — extreme weather events are occurring more and more often, but now an international team of climate scientists has found a connection between many extreme weather events and the impact climate change is having on the jet stream. The Jetstream lies 8-11 km in atmosphere and 250 km/hr & hundreds of km wide.

"We came as close as one can to demonstrating a direct link between climate change and a large family of extreme recent weather events," said Michael Mann, distinguished professor of atmospheric science and director, Earth System Science Center, Penn State. **Prof Michael Mann said that asking if climate change “causes” specific events is the wrong question:** “The relevant question is: ‘Is climate change impacting these events and making them more extreme?’ and we can say with great confidence that it is.” Mann points out that the link between smoking tobacco and lung cancer is a statistical one, which does not prove every cancer was caused by smoking, but epidemiologists know that smoking greatly increases the risk. “That is enough to say that, for all practical purposes, there is a causal connection between smoking cigarettes and lung cancer and it is the same with climate change,” Mann said.
The land and lower atmosphere are warming faster in the Arctic than anywhere else on the globe. That pattern projects onto the very temperature gradient profile – less of a temperature difference between the Arctic region and sub-Arctic or sub-tropical that influences movement and speed of the planetary waves (Rossby waves) and the polar jetstream. **This is where climate change comes in.** Rossby waves help transfer heat from the tropics toward the poles and cold air toward the tropics in an attempt to return atmosphere to balance. They also help locate the jet stream and mark out the track of surface low pressure systems. The slow motion of these waves often results in fairly long, persistent weather patterns.

Northern Canada temperature rose 2.3 °C from 1948 to 2016 with the Arctic almost three times the global mean. That Arctic to mid-latitude temperature difference is getting smaller in winter and summer. The smaller differential in temperatures is causing the west-to-east winds in the jet to weaken. Strong jets tend to blow straight west to east; weaker jets tend to wander more increasing the likelihood of wavy patterns. With the smaller temperature differential, the jet stream’s waves grow larger, they tend to move eastward more slowly, which means the weather they generate also moves more slowly, creating more persistent weather patterns. The Rossby waves also slow down and get stuck or stall. This is also evident in winter with the weaker **polar vortex bringing extreme cold to Canada and the US.** The polar jetstream is wavier and the theory of a warmer Arctic in changing the jetstream with a cold continent especially to mid-east Canada and mid-east USA. Those stationary Rossby waves cause weather conditions to remain “stuck” for long periods, increasing the likelihood of extreme
heat waves, droughts and flooding events in Eurasia and North America. The persistent heat and stalled (stuck) waves allow for longer periods of hot weather with a blocking high pressure cited the climate generated as one cause of the Alberta and BC forest fires from 2016-2018.

Climate scientists point to the movement of heat from lower latitudes from the atmosphere to beyond 60 degrees N. latitude. GHG emissions are the main cause of this warming in the atmosphere. At the same time the Pacific and Atlantic oceans absorb about 93% of the excess heat caused by greenhouse gas warming and sea surface temperature in the first 10 meters of water. Significant ocean warming in the Gulf of Alaska and Bering Sea and from the Atlantic Gulf Stream brings heat to the Arctic and northern Canada. Other persistent positive feedbacks include the thawing of the permafrost to release CO₂ and CH₄; the loss of reflectivity or albedo from less snow and ice and contaminated snow add to Arctic warming. The warming of the Northern Hemisphere and Arctic set the conditions for Rossby wave and Polar Jetstream behaviour to promote extreme weather conditions of drought and cold. The Potsdam Institute stated: “The waves slow down so the weather in a given region gets stuck. Rains can grow into floods, sunny days into heat waves, and tinder-dry conditions into wildfires.”

Location and extreme events throughout the planet as appeared in the BAMS Research Supplement. Credit Bulletin American Meteorological Society (BAMS), Special Supplement.

References
2. Special Supplement to the *Bulletin of the American Meteorological Society*
   Vol. 98, No. 8, August 2017

**NOTE:** As mentioned the above section was one of my handouts to teachers at ProD Day Events and my visit to schools in February 2019.

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The *Arctic Report Card 2018* accessed at [www.Arctic.noaa.gov/Report-Card](http://www.Arctic.noaa.gov/Report-Card) provides the highlights on the Arctic; the *Executive Summary* is a good place to start for highlights. Another document, *Arctic Resilience Report 2016* of about 200 pages by the **Stockholm Environment Institute & Stockholm Resilience Centre** “builds on collaboration with Arctic countries and Indigenous Peoples in the region, as well as several Arctic scientific organizations.” To quote the opening paragraph of its *Foreword*: “Life in the Arctic has always been defined by change and uncertainty. The seasons transform the landscape, the weather is unpredictable, and conditions can shift abruptly, sometimes dangerously. Yet the Arctic is now changing at an unprecedented pace, on multiple levels, in ways that fundamentally affect both people and ecosystems.” As Canadians we should be paying more attention not only to climate change in the Arctic which holds a vast landmass and with its longest ocean coastline but also to Canada’s northern security, the Northwest Passage as a Canadian strait and transit for foreign vessels, the Inuit people and communities and how they would adapt to changes in ecosystems.

**The Severe Weather Makers: El Nino & La Nina**

The El Nino and La Nina phenomena are short-term climate systems generally occurring from the eastern to western mid-Pacific Ocean region that promote climate change and impacts worldwide. These naturally occurring climate change variabilities occur on a regular basis and generally alternate from El Nino to Neutral to La Nina conditions in that order. The El Nino puzzle was unraveled many decades ago by British scientist Gilbert Walker in predicting the occurrence and prevalence of monsoons in India. Monsoons seem to come on and off periodically over the years and Walker was attempting to link these two weather or
short-lived climate phenomena with rainfall patterns in India. Walker discovered a connection between barometric (air pressure) measurements at weather stations located at the eastern and western regions of the equatorial Pacific Ocean. Walker found that when the air pressure drops from the mid to eastern Pacific (from around Tahiti to the South American coast) it usually rises in the western Pacific (toward Darwin in Australia and Indonesia), and the pattern reverses itself from time to time. Walker called this condition of the east-west seesaw of changing barometric pressure the *El Nino Southern Oscillation (ENSO)*.

The El Nino phenomenon is also recognized with *weaker easterly trade winds* from the eastern Pacific Ocean region (from South America) and continues westward along the mid-equatorial Pacific Oceanic region; it is accompanied by a *lower air pressure* system from the eastern to mid-Pacific region. At the same time a *higher air pressure in the western Pacific* region is being observed in Darwin and all along the Indonesian region – wind and air pressure mark the two conditions of an impending El Nino plus a warming of sea surface temperature from mid to east Pacific Ocean as shown in red in a NOAA satellite enhanced image in Figure 2.10.

During El Niño regions of the western Pacific, northern Australia and Indonesia experience severe drought, while eastwards across the ocean, heavy precipitation brings flooding to the west coast of South America, wet conditions in southern California and warmer conditions as far as Alaska (Figure 2.11) accompanied by a more southern Pacific jetstream; the jetstream will not always remain as shown and is changeable depending on other weather conditions elsewhere. With an El Niño the easterly trade winds converging across the equatorial Pacific weaken from the eastern Pacific or from the South American mainland across the Pacific basin (Figure 2.13). This in turn draws warmer western Pacific Ocean warmer water and colder surface water away from the eastern Pacific Ocean, flattening out the *thermocline* allowing warm water to rise slowly to the surface - from the mid-Pacific Ocean and eastwards to the South American coast (Figure 2.9). The *thermocline* is the dividing layer between the warm surface water and the deep cold water as the bulk of warm water stays closer to the surface during an El Nino. El Nino shows a lasting warming of the ocean surface temperature in eastern and northern Pacific Ocean region in
satellite image (Figure 2.10); the last strong El Nino was during the years 2015 and 2016. By mid-2019 a weak El Nino had in effect after a brief La Nina in 2018. According to NOAA and the International Research Institute for Climate and Society “A transition from El Niño to ENSO-neutral is expected for 2019 with ENSO-neutral most likely to continue through Northern Hemisphere fall and winter.”

Figure 2.9. The Walker Circulation is the result of a difference in atmospheric pressure, trade winds and sea surface temperature over the western (Australia) and eastern tropical Pacific Ocean (South America). Credit NOAA.

The lower air pressure, weaker easterly wind direction and intensity, and a warmer ocean surface temperature are conditions that define an El Nino event. Heavy rainfall and warmer conditions are experienced in the eastern Pacific regions of South America, southern California and southern states but not always because in 2016 less rainfall and more drought conditions were experienced in southern California and was not expected. Peru seems to be the most affected country with heavy rainfall. Even the desert islands in the equatorial mid-Pacific experience torrential rainfall for months during an El Nino, a welcome sign to the residents to collect rainwater. Lower air pressure, lower clouds and higher oceanic and surface temperature trigger higher rainfall. El Nino at the same time promotes droughts to the western Pacific regions including northern Australia, Indonesia,
Borneo, and most of southwestern Asia. The waning El Nino in 2016 and a neutral ENSO in early 2017 brought excessive rainfall and snow at higher elevations to California and the west coast of North America. The atmospheric rivers were mostly responsible for the higher precipitation levels as discussed earlier.

Figure 2.10. Satellite images of the strongest 1997-1998 El Nino. Note the large expanse of warm water extending from the Pacific Ocean from South America reducing to the mid-Pacific Ocean and as far as Indonesia. Credit to NOAA.

Jacob Bjerknes of the University of California also started to research the El Nino phenomenon in 1961 and confirmed that the cause of this occurrence was due to variations of the Pacific trade winds, changes in sea surface temperature and air pressure in the western and eastern equatorial Pacific Ocean – those three conditions as mentioned signal an El Nino event. Bjerknes confirmed that “the meteorological control over the occurrence of El Nino must lie in the fluctuating strength of the Pacific trade winds…trade winds would permit a larger-than-normal volume of warm water to assemble in the eastern tropical Pacific” or toward the mainland of South America. Bjerknes confirmed that as the trade winds weaken and sea surface temperature increases, sea levels also begin to rise from natural thermal expansion. Those latter conditions with accompanying lower air pressure had signaled the start of the strong 1982-83, very strong 1997-1998 and
last strong 2015-2016 El Nino events. The year 1997-1998 saw the Oceanic Nino Index (ONI) at a high of +2.4 based on departures from normal sea surface temperature; the last El Nino was the second strongest with an ONI of +1.7 from 2015 to 2016. The year 2000 was a strong La Nina period with an ONI in the negative at -1.7 or a cooling of the sea surface temperature.

The Vancouver Winter Olympics in February 2010 saw less snowfall on the coastal mountains (at Cypress in North Vancouver) as temperatures were higher than normal from that moderate 2009-2010 El Nino period. In fact, winter temperatures in British Columbia have been mild in recent years that saw the devastation of 17 million hectares of lodgepole pine forests from the attacks of the mountain pine beetle. The Canada Changing Climate Report 2019 reported that from 1948 – 2018 the mean temperature in BC was 1.9°C and higher than the global mean; northern Canada’s mean temperature is surprisingly 2.3°C as reported in the above report. Mountain pine beetles attack lodgepole pine trees and thrive during the warm winters; only an extended cold spell would kill them. Beetles have killed over 700 million cubic metres of lodgepole pine in BC (Figure 3.12 A).

Throughout 2015 and in early 2016 was the last major El Nino episode; its effect was being experienced in western USA, Canada and worldwide. By early 2015 the Pacific or sub-tropical Jetstream (Figure 2.11) was located at a lower southern latitude toward the southeast to northern Florida and onto the Atlantic; that variable jetstream crossed over Baja California to south-eastern USA. A huge ridge of low pressure exists over the north Pacific Ocean and persisted off the northwest Pacific region. The associated pineapple express or atmospheric rivers brought heavy rainfall and snow to higher elevations in California and the northwest region in 2018. All jet streams are variable with no established but changing patterns except for conditions of a warming Arctic as with extreme weather discussed earlier. As mentioned earlier, the dissociated Polar Vortex from a warming Arctic promotes severe winter weather conditions in eastern Canada and the USA – the warmer Arctic-colder Continent scenario.

La Nina on the other hand is the sister or “opposite” of El Nino and represents the cooling of oceanic surface temperatures from the central equatorial Pacific Ocean
to the South American coast. The occurrence of La Nina or El Nino is unpredictable but a La Nina is generally followed by a short neutral period and then an El Nino. The intensity and duration of both events last from several months to up to two years; the duration of La Nina is on the average is roughly 15 months to less than two years. From the 1950s to 2000 there were 15 periods of El Nino and 11 periods of La Nina. A La Nina event started in late 2011 onto 2012 followed by a neutral period from 2013 to mid-2014, then came a strong El Nino from 2015-2016. A brief neutral period started in 2017 followed by a weak La Nina in late 2017 and continue onto 2018. From April 2018 a neutral ENSO ensued with a “70% chance of another El Nino in the winter of 2018” according to NOAA. The year 2019 saw the emergence of a weak El Nino at the time of writing.

During a La Nina event the sea-surface temperature generally drops by 1°C to 2°C below the average, and drops by 2°C to 4°C at the lower end of the thermocline – the result is a cooler ocean surface temperature in the eastern to mid-Pacific Ocean and extends to the Pacific Northwest. A buildup of a high-pressure system in a La Nina event in the eastern Pacific extending to western Canada. The Pacific Jetstream (Figure 2.12) shifts to a more northerly direction looping toward British Columbia and continuing south east to the northeast US with a blocking high

Figure 2.11. Typical El Nino winter conditions across North America. Note the general pathways of the Polar and Pacific (sub-Tropical) Jetstreams in winter. Credit NOAA.
pressure system. The **Polar Jetstream** in a typical La Nina shifts from the Arctic to Alaska and loops over northern Alberta and eastward across northern US to eastern Canada, and onto the Atlantic to northern Europe. The consequences of the changing Pacific and Polar Jetstream influence extended weather patterns across North America and Europe as with El Nino. La Nina represented in Figure 2.14 for winter with cool and wet conditions generally in the Pacific northwest including British Columbia. In 2017 during a La Nina event the Pacific northwest experienced higher precipitation levels from *atmospheric rivers* (Figure 1.10 A). The conditions that bring about La Nina are recognized by lower than average air pressure over Indonesia, northern Australia and throughout the western Pacific region, while the opposite conditions exist in the eastern Pacific – from Tahiti to the South American mainland and in the northwest Pacific. In the western Pacific region more clouds are noticeable, more water vapour persists in the atmosphere and therefore more rainfall generally to Indonesia, northern Australia and that region. A higher-than-average barometric pressure persists at the Tahiti weather station and this higher air pressure continues east toward South America. At the same time a lower-than-average air pressure is noted at the Darwin weather station in northern Australia and throughout the western equatorial Pacific region. Less rainfall and more droughts persist in Peru, California and the eastern Pacific region during a La Nina; wetter conditions persist in the Pacific northwest. The Walker and Bjerknes seesaw patterns or the *El Nino Southern Oscillation* (ENSO) for air pressure, surface ocean temperature and wind speak for both El Nino and La Nina. The air above the colder water from the mid to east Pacific is too dense to rise high enough to form clouds leaving regions of Peru and Ecuador in desert-like conditions during a La Nina.

The strong easterly trade winds are responsible for harvesting moisture in the western Pacific regions that brings monsoons to India, Bangladesh and Indonesia. In 2012 a La Nina event saw the wettest conditions and devastating floods in 150 years in the state of Queensland in Australia. In fact, Australia experienced a record 1408 mm of rainfall in a two-year period from 2011 to 2012 during that La Nina event. At the same time historical droughts persisted in East Africa, southwestern USA, and northern Mexico. During the year 2013 there was a balance between El Nino and La Nina or a neutral state to be followed by the last
major El Nino that ended in late 2016; by late 2017 a mild La Nina started with wetter conditions persisting from Oregon to British Columbia and by April 2018 was the start of a neutral ENSO and an expected El Nino to begin later in 2018 and continue in 2019.

Another natural phenomenon like that of El Nino/La Nina but weaker is the Pacific Decadal Oscillation. It is a recurring pattern of ocean-atmosphere climate variability in the North Pacific basin, south of Alaska and west of the North American continent to Japan. The years 1977-1998 and 2014-2016 corresponded with dramatic shifts in salmon production regimes in the North Pacific Ocean according to Dr. Steven Hare a fisheries scientist in Seattle, Washington. The Pacific Decadal Oscillation (PDO) is a long-lived climate variability. Natural oscillations like PDO simply move heat around from ocean to air and vice-versa and not as widespread as El Nino. Basically, the PDO is an example of internal variability that is still unexplained that oscillates from warming to cooling in 10-15-year periods. El Nino and La Nina are more regular occurrences and having greater impact on sea surface temperature changes. The PDO can remain in the
same phase for 20 to 30 years, while ENSO cycles typically only last 6 to 18 months. The PDO, like ENSO, consists of a warm and cool phase which alters upper level atmospheric winds. Shifts in the PDO phase can have significant implications for global climate, affecting Pacific and Atlantic hurricane activity, droughts and flooding around the Pacific basin, the productivity of marine ecosystems, and global land temperature patterns. Experts also believe the PDO can intensify or diminish the impacts of ENSO according to its phase. If both ENSO and the PDO are in the same phase, it is believed that El Niño/La Nina impacts may be magnified.

**Monthly PDO Index: 1900 to 2009**

Figure 2.12 A. PDO warming and cooling phases. **Cold PDO** regimes prevailed from 1900 - 1924 and again from 1947-1976, while **warm PDO** regimes dominated from 1925-1946 and from 1977 through the mid-1990's. Credit University of Washington Climate Impacts Group and climate scientist Nate Mantua.

*National Geographic* September 2016 publication cited the unusual warming of the eastern Pacific from California to Alaska as explained earlier. Toxic algae produce domoic acid carrying a neurotoxin that passes into the food chain and were found all along the coastal regions from California to Alaska. Thousands of animals became sick, starved and died as reported in the *National Geographic* article. Dead whales and sea lions showed up in coastal British Columbia and with
traces of domoic acid. PDO, El Nino, ocean circulation and a changing climate are conditions that are responsible for a warming Bering Sea and Gulf of Alaska. **Impacts from El Nino & La Nina**

Lower air pressure, low intensity of easterly winds and loaded air moisture led to heavy rainfall in California while droughts were severe in far reaching regions of the sub-Saharan in Africa, Indonesia and Australia in that strong 1998 El Nino event. “Extensive floods in drought-stricken Texas and Arizona have occurred during El Nino events. The Santa Cruz River in Arizona was flooded during and after El Nino years”, according to David Enfield in his book, *El Nino Historical and Paleoclimatic Aspects of the Southern Oscillation*. Rain and warm weather ensued through Oregon, Washington and British Columbia. There were “69 tornadoes in December 2015 in the southern states” due to instability of the weather. In 2016 and continuing into 2017 California received more rain and snow in higher elevations. El Nino ended with a brief neutral condition in early 2017 followed by La Nina that ended in 2018, bringing unusual winter storms and rain to southern and northern California onto British Columbia; as mentioned a weak El Nino started by mid-2019 and to be followed by a neutral period. The weather was also encouraged by the atmospheric rivers or the pineapple express. **“The 2016 El Nino caused havoc in Peru”** in one newspaper headline: “The number of people killed in Peru following intense rains and mudslides wreaking havoc - the death toll climbed to 67, with thousands more displaced from destroyed homes and others waiting on rooftops for rescue. Across the country overflowing rivers caused by El Nino rains damaged 115,000 homes, collapsed 117 bridges and paralyzed countless roadways.”

Of the past twenty-six El Nino events, twenty-one of them coincided with a lack of the monsoons in India. As mentioned, it was Gilbert Walker who in the 1920s on assignment in India provided the first clue to predicting monsoons and droughts. Krishna Kumar writing in the journal *Science* reported that severe droughts in India have been accompanied by El Nino events, yet an El Nino pattern does not always produce severe droughts in that region. During an El Nino, the anchovy (small fish) catch off the coast of Peru declined due to the warmer sea surface temperatures compared to a La Nina event; the thermocline shifts closer to the
warmer sea surface during an El Nino. The anchovy harvest off the coast of Peru during a La Nina period has always been higher. Occasionally off the coast of British Columbia tropical species of fish appear during an El Nino. The severe El Nino episode in 1997-1998 saw one of the warmest events globally with extensive forest fires raging through Sumatra and Borneo in Indonesia. During the recent strong El Nino in 2015 & 2016, droughts and widespread fires were again raging in Sumatra and Kalimantan from observations with NASA’s Terra satellite. Peatland fires in Borneo released a vast amount of CO₂ that lasted for several months. Forest fires also had its toll on the health of people with respiratory illnesses causing many deaths. The Alberta fires at Fort McMurray raged on in May 2016.

![El Niño diagram](image)

Figure 2.13. El Nino conditions of weak trade winds, low air pressure and increased sea surface temperature across the mid-equatorial to eastern Pacific Ocean. Credit NASA’s website – Source: Lutgens & Terbuck.

Atlantic hurricanes are more frequent during the La Nina than in an El Nino period. There was a decline of just nine North Atlantic tropical storms at the start of the last El Nino in 2015 but increased with a waning El Nino and the start of a weak la Nina in late 2017. Colorado State University hurricane scientist William Gray noted that an El Nino occurrence tends to suppress hurricanes in the Atlantic. La Niña conditions are associated with weaker upper-level westerly winds and
reduced levels of vertical wind shear over the Atlantic basin.” There was ample evidence of a lower incidence of Atlantic and the heat released is dispersed by the velocity of wind shear. Wind shear is defined as any change in the vertical wind speed from the lower to the upper atmosphere. Vertical wind shear of less than 35 km/hr between the surface and the troposphere is favoured for tropical cyclone development, making the storm stronger. A high wind shear tends to suppress Atlantic hurricanes; the storm cannot rise to its full potential and energy becomes spread out over a large area (Figure 2.15 A).

![Figure 2.14. La Nina conditions of increased trade winds, higher air pressure and lower sea surface temperature across the mid-equatorial and eastern Pacific region. Low air pressure and a warming sea with higher precipitation exist in the western Pacific region. Credit NASAs website.](image)

NASA reported an interesting scenario about hurricane Florence that emerged off the west coast of Africa near Cape Verde on September 1, 2018. As the tropical storm drifted west, it slowly intensified until achieving hurricane status on September 4 with peak winds of 75 miles (120 kilometers) per hour. Category 1 hurricanes have winds of between 74 and 95 miles (119 and 153 kilometers) per hour; Category 5 storms, the highest on the scale, have winds that surpass 157 miles (252 kilometers) per hour. By September 5, Florence rapidly intensified,
becoming a Category 4 storm with winds of 140 miles (225 kilometers) per hour. “This was followed by a few days of increasing wind shear, which forced the storm into an asymmetrical shape and began to tear it apart. By September 7, Florence’s peak winds had dropped back down to 70 miles (100 kilometers) per hour, meaning it was no longer a hurricane. Then on September 9, Florence entered a zone of particularly low wind shear and high sea surface temperatures that led the storm to rapidly intensify. By September 10, the hurricane was back to a Category 4 status. “By the time Florence made landfall at Wrightsville Beach, North Carolina, it was a Category 1 storm” according to NASA.

In 2017 there were three major hurricanes in the Atlantic, Caribbean seas and Gulf of Mexico at the end of a neutral ENSO period and at the onset of a weak La Nina. There were 15 named cyclones and major hurricanes projected up to October 15, 2017. The 2017 major hurricanes (Category 3 and higher) cited below:

1. Harvey, which hit the Texas coast August 26.
2. Irma, which hit the Caribbean and then the Florida Keys and southwest Florida September 10.
3. **Jose**, which peaked as a category 4 on Sept. 9 before moving away from the Caribbean and back out into the Atlantic Ocean.
4. **Maria**, which tore through the Caribbean before devastating Puerto Rico as a Category 4 storm on September 20.
5. **Lee**, which formed into a hurricane September 24.

**Figure 2.15** A. In the presence of vertical wind shear, a storm’s core structure will be tilted in relationship to the wind shear. This tilting will disrupt the flow of heat and moisture which inhibits the storm from developing and becoming stronger or with a high wind shear velocity. Credit NOAA’s Atlantic Oceanography & Meteorological Laboratory.

**Figure 2.16** A. Projections for the Atlantic Hurricane Season made in August, 2017, was a good prediction as noted above with a weak La Nina in late 2017. Credit NOAA
NOAA’s Climate Prediction Center is forecasting a 75-percent chance that the 2018 Atlantic hurricane season will be near- or above-normal. Compare the data with Figure 2.16 A for 2017. Credit NOAA.

One can make comparisons at the end of 2018 between what is expected for the Atlantic hurricane season and the actual outcomes. Based on the 2017 experience, NOAA’s prediction came close to the reality of the 2017 Atlantic hurricane season as noted in Figure 2.16 A. “The 2018 Atlantic hurricane season was the third in a consecutive series of above-average and damaging Atlantic hurricane seasons, featuring 15 named storms, 8 hurricanes, and 2 major hurricanes, which caused a total of over $50.205 billion in damages. The season officially began on June 1, 2018, and ended on November 30, 2018” as reported by Wikipedia. The outlook projected in Figure 2.16 B falls close to the actual outcome during a mild La Nina period in 2018; the year 2019 and at the time of writing a mild El Nino is being experienced.

**Ocean Circulation & The Atlantic Meridional Overturning Circulation (AMOC)**

The oceans which cover about three quarters of the Earth’s surface play a vital role in the global climate system by absorbing and storing over 90% of excess heat
accumulated, generating about half of the world’s oxygen, absorbing more than 25% carbon dioxide from the atmosphere, with its rich resources to sustain life and a major climate change agent. The oceans are the world’s largest store of carbon where much of the global carbon cycle is circulated through marine systems and storage – refer to the carbon cycle in Chapter One. Surprisingly, most of the CO₂ is being absorbed in a colder ocean, not from a warming ocean so as the ocean warms in the northern and southern hemispheres less CO₂ is being absorbed. Rising ocean temperatures are now a reality from the evidence of loss of Arctic sea ice, collapse of ice shelves and ice sheets at both polar regions, with challenges to biodiversity and poleward movement of some species. The increase of CO₂ comes with acidification of sea water and with consequences to species with calcium coatings and coral reefs.

The oceans have always played a major role in earth's energy balance and climate change, carbon cycles, and home to hundreds of thousands of species. “The ocean has absorbed roughly one-third of emitted anthropogenic carbon, so the ocean carbon uptake influences how much of this important greenhouse gas remains in the atmosphere. Accurately measuring and simulating ocean carbon storage is important for assessing the current environmental conditions and projecting future climate” as noted by NOAA’s Pacific Marine Environmental Laboratory.

The giant conveyor belt or thermohaline circulation (Figure 2.16 C) plays a major role in regulating global climate and weather. This global ocean circulation is controlled by temperature (thermo) and salinity (haline) and provides the conditions that create the giant thermohaline circulation. The ocean currents move vast amounts of heat across the planet much like our atmosphere. Ocean currents are movements of water in a continuous flow, created largely by surface winds but also partly by temperature, salinity gradients, Earth’s rotation, and tides. With their huge heat capacity, the ocean circulation regulates temperature fluctuations or simply put it’s the Earth’s thermostat.

Our planet without liquid water would be frozen or too hot and unable to sustain life. The oceans cover 71 percent of the planet and holds 97 percent water, making the ocean a key factor in the storage and transfer of heat energy across connecting ocean systems and the atmosphere. The movement of this heat through regional
and global ocean currents regulate weather conditions and temperature extremes, stabilize global climate patterns, control intake or output of oxygen and carbon dioxide, and movement of nutrients into marine bio-ecosystems. For more information on the thermohaline circulation and AMOC you could Google Paul Beckwith, climate scientist at the University of Ottawa, and access his Facebook and YouTube sites. Beckwith also updates his followers with the current climate research in YouTube. Additional information is listed in Figure 2.16 C as a useful summary on “salinity, surface warmer temperature and deep flow colder temperature, deep water formation” in understanding this giant circulation.

The Gulf Stream and its extension, the North Atlantic Circulation, flowing towards northwestern Europe as connecting systems of this giant thermohaline system. Thermohaline circulation, as mentioned, describes driving forces such as temperature and salinity of sea water, which determines water density differences that ultimately drives the circulation. The term 'conveyor belt' describes its function quite well. For example, in the Atlantic Ocean, an upper surface loaded with heat moves north, releasing heat to the atmosphere, while water is being evaporated continually into the atmosphere making the northern ocean saltier and denser that would then have water flow deeper (about 3,000 - 5,000 metres below the sea surface) and to start its return journey of this tremendous volume of water to the southern hemisphere from the Nordic and Labrador seas in the North Atlantic ‘Deep Water Formation’ as illustrated in Figure 2.16 C.

The heat transported to the North Atlantic in this way is enormous that influences global and regional weather, climate change as well as extreme weather conditions. Satellite images show how the warm current keeps much of the Greenland-Norwegian Seas free of ice even in winter, despite the rest of the Arctic Ocean being kept frozen. Climatologists still do not fully understand how this giant oceanic circulation system operates in regulating the global climate with its slow but deliberate flow from the vast warmer Pacific and Indian Oceans to the colder North Atlantic. There are known consequences to a weakening of the Atlantic Meridional Overturning Circulation (AMOC). Recent research uncovered the Atlantic Meridional Overturning Circulation or AMOC, and what scientists have discovered about its strength and implications on climate change.
Figure 2.16 C. Thermohaline Circulation, AMOC, Gulf Stream and North Atlantic Drift as ‘one circulation’ pattern. Note the Deep-Water Formation where surface salty water plunges into the deep North Atlantic in the Nordic and Labrador Seas. ACC is Antarctic Circumpolar Circulation counter-clockwise current to advance its circulation. Credit Dailykos.com & Google.

Figure 2.16 D. Illustration of major ocean currents. Ocean currents act as conveyer belts of warm and cold water, sending heat toward the polar regions and helping tropical areas to cool off in controlling climate change. Credit NOAA.
At higher latitudes along the Atlantic Ocean, sea water tends to be saltier because of ocean evaporation and increases in its density; sea water near the poles is obviously colder and of higher density than at lower latitudes. The interaction between water temperature and salinity affect density and density drives the thermohaline circulation. Saltier water then sinks in the North Atlantic, in the region of the Labrador and Nordic seas as noted in Figure 2.16 C ‘Deep Water Formation’. The cold and dense water flow southwards deep in the ocean (not at the bottom) and have the equivalent of a hundred Amazon Rivers passing Earth’s equator. Deep water returns to the Antarctic Circumpolar Circulation (ACC in Figure 2.16 C), Indian and Pacific Oceans and then continues its circulation back to the North Atlantic in perhaps a duration of a thousand or more years. Climate scientists believe that this “bipolar oceanic see-saw” of oceanic temperatures and density between the Southern and Northern Hemispheres within the Atlantic Ocean greatly influence global atmospheric conditions, extreme weather and global climate. The thermohaline circulation plays an important role in supplying heat to the polar regions, while anthropogenic influences or global warming impact on the cryosphere with loss of Arctic sea ice and melting ice sheets. Global warming from anthropogenic forcing of GHG emissions affect the thermohaline circulation in two ways: surface warming and surface freshening (water from Greenland melt) that reduce the density of high-latitude surface waters south of Greenland and Iceland in slowing down the ‘deep-water formation’ as shown in Figure 2.16 C.

The Atlantic Meridional Overturning Circulation (AMOC) is an extension of the thermohaline circulation. The Gulf Stream, together with its northern extension as the North Atlantic Drift, are warm and swift Atlantic Ocean currents. The Gulf Stream originates in the Gulf of Mexico and stretches to the tip of Florida then follows the eastern coastlines of the United States and Newfoundland before crossing the Atlantic Ocean (Figures 2.16 E & F). Both the AMOC and wind driven Gulf Stream are complex and fundamental systems of the thermohaline. The AMOC influences the exchange of heat between the tropics and at higher latitudes. Driven mainly by cold dense water in the saltier Nordic and Labrador seas the dense ocean water sinks to over 3,000 metres and continues on a southern flow. One big question - what happens to the AMOC with Arctic warming or amplification from GHG emissions?
In a paper in *Nature* journal (Vol. 556, 227-230) in 2018, D.J. Thornalley and other scientists present paleo-oceanographic evidence that “deep convection of surface waters in the North Atlantic — the engine that keeps the AMOC in constant motion — began to decline as early as around 1850”, from increased freshwater influx from Arctic ice and Greenland that had melted at the end of a relatively cold period or from the Little Ice Age. **The freshening of ocean waters south of Greenland and Iceland creates a less salty ocean – less dense.** This finding suggests that the AMOC was not running as normal. In a second paper, researchers **Levke Caesar** and **Stefan Rahmstorf** in a *Nature* journal (Vol. 556, 191-196) in 2018 used global climate models and data sets of sea surface temperature to date the onset of the weakening AMOC to more recent times or around the mid-twentieth century. According to their models, the slowdown of AMOC “was about 15%, and most pronounced during winter and spring and led to a cooling of sea surface temperatures in the northern Atlantic (yes, cooling), together with a slight northward shift of the mean Gulf Stream flow. The authors conclude that the weakening of the AMOC is a consequence of anthropogenic climate change, by the freshening of ocean water from melting of ice from Greenland. The **RAPID-AMOC** research facility in the UK ([www.rapid.ac.uk](http://www.rapid.ac.uk)) using moorings, measured temperature and salinity across the Atlantic Ocean at 26.5° north Latitude and observed from April 2004 to March 2014 on changes in the AMOC, and “discovered a reduced AMOC event from 2009-2010 and the overall decrease in its strength over the 10 years were all clearly visible.”

The Abstract in the April 12, 2018 *Nature* journal read as follows: “The AMOC has a major impact on climate, yet its evolution during the industrial era is poorly known owing to a lack of direct current measurements. **Here we provide evidence for a weakening of the AMOC** by about $3 \pm 1$ sverdrups (one sverdrup amounts to one million cubic metres of ocean water flow in one second) or around 15 per cent decline since the mid-twentieth century.” This weakening of AMOC is from a cooling in the subpolar Atlantic Ocean gyre (see dotted circular region in Figure 2.16 E and 2.16 F), freshening of water from melting ice sheets from the Arctic region. **Arctic sea ice, and ice sheets and glaciers surrounding the Arctic began to melt, forming a huge natural tap of fresh water that gushed into the North Atlantic. This huge influx of**
freshwater diluted the surface seawater, making it lighter and less able to sink deep, slowing down the AMOC system. The pattern can be explained by a slowdown in the AMOC and reduced northward heat transport, as well as an associated northward shift of the Gulf Stream according to Caesar and Rahmstorf as cited earlier. Given the potentially disruptive impact of a major change in the AMOC, it is imperative to better understand whether and how the AMOC is responding to modern anthropogenic warming.

The findings from Caesar and Rahmstorf seem to confirm that in recent years the AMOC may have reached a new record low, consistent with the record-low annual sea surface temperature in the subpolar Atlantic (since observations began in 1880) and reported by the National Oceanic and Atmospheric Administration (NOAA). Surface temperature proxy data for the subpolar Atlantic

Figure 2.16 E. Left: The Atlantic meridional overturning circulation (AMOC). The AMOC is an ocean circulation system that consists of warm surface currents (red & orange) and cold deep-water return flows (blue), as shown in this simplified representation. The surface currents include the Gulf Stream, which feeds a branch of the AMOC known as the North Atlantic Current. The deep-water return start from three branches (sinking regions with red dots) that merge into the North Atlantic Deep Water. At Right: Note the circular (dotted) Gyre pattern and in Figure 2.16 F of cold water (blue). Credit to Nature & Coastal Review Online & Google.
suggest that “the AMOC weakness after 1975 is an unprecedented event in the past millennium.” What is the Subpolar Gyre and why is it important? The North Atlantic subpolar region lies between roughly 45°N and 65°N, between the subtropics in the south and the Nordic Seas to the north. A ‘gyre’ is a large system of rotating currents driven by winds that circulate anti-clockwise (Figures 2.16 E dotted circle) & 2.16 F in blue). “At the southern edge of the gyre the North Atlantic current brings warm subtropical water into the eastern subpolar region; most of that warm water circulates around the gyre, but some escape and flows northwards between Greenland and into the Nordic Seas. The gyre is deep, with the whole upper kilometre of the North Atlantic circling in this way” according to the UK OSNAP research (www.ukosnap.org). The gyre is a key component of the climate system because it is a region where the ocean warms the atmosphere (keeping North Europe relatively mild) and because it draws atmospheric carbon dioxide into the deep ocean; CO₂ mixes more readily with cold water than with warm water.

![Sub-Polar Gyre](image)

Figure 2.16 F. Sub-Polar Gyre, a vast region of cold water (blue) south of Iceland in its anti-clockwise current. Note the warm Gulf Stream (small green circle) along the North American coast. Water from Greenland melt freshens the Labrador and Nordic Seas to weaken the AMOC. Credit to Sam Carana for Arctic-News Blog.

Researchers recently present multiple lines of evidence suggesting that the subpolar gyre cooling is due to a weakening in the AMOC “over the twentieth
century and particularly after 1970” as reported by Rahmstorf, Caesar and Thornalley in the journals Nature and Nature Climate Change. Because of the large heat transport associated with the AMOC, changes in sea surface temperatures can be used as an indirect indicator of the AMOC evolution. The very cold and extensive subpolar-gyre region advances the understanding of a weakening AMOC and transport of warmer surface water to the north Atlantic Ocean according to the research cited by climate scientists. Today, Earth's climate is warming, and even though sea ice in the region has diminished, the ocean circulation remains weak from Greenland's ice sheet thawing releasing fresh water into the North Atlantic. Researchers estimate that if current trends continue, the Greenland freshwater input from 1995 to 2025 may exceed 10,000 km³. “This might lead to further weakening of the AMOC within a decade or two, and possibly even more permanent shutdown of Labrador Sea convection as a result of global warming” as speculation by Rahmstorf and colleagues. Direct evidence of freshening of the ocean comes from greenhouse gas emissions, positive feedbacks and Arctic amplification or warming.

As a summary from climate scientists cited above of likely consequences from the AMOC weakening: “Cold water in the subpolar Atlantic correlates with high summer temperatures over Europe, and the 2015 European heat wave has been linked to the record ‘cold blob’ in the Atlantic that year.” AMOC weakening has also been connected to above average sea-level rise at the US east coast and increasing drought in the Sahel. Continued global warming is likely to further weaken the AMOC in the long term, via changes to the hydrological cycle, sea-ice loss and accelerated melting of the Greenland ice sheet, causing further freshening in the northern Atlantic Ocean; all of the above points to climate change or global warming enhanced in the Arctic region. The interesting (non-science) movie “The Day after Tomorrow” depicts the sudden advance of the second ice age as the AMOC stopped and the thermohaline ground to a halt. You may access the video clip on Google - “it will happen again…where will you be.” Many questions in climate science remain unanswered about the consequences of a weakening AMOC or thermohaline circulation and its future impact on climate change. What we know from several research findings is that the AMOC is weakening from global warming, in particular Arctic Amplification, and the result of GHG
emissions. With its huge heat capacity, the ocean circulation regulates temperature fluctuations and a large part the Earth’s thermostat. The oceans which cover about three quarters of the Earth’s surface play a vital role in the global climate system by absorbing and storing over 90% of excess heat accumulated, generating about half of the world’s oxygen, absorbing more than 25% carbon dioxide from the atmosphere, with its rich resources to sustain life and a major climate change agent. How will the climate system behave with a warming ocean, warming Arctic region and weakening of the thermohaline and connecting circulation in the North Atlantic?

Peril at Both Poles & Canada’s Arctic

In the first half of 2010, air temperatures in the Arctic were 4° Celsius warmer than the 1968 to 1996 average, according to NOAA. The Arctic ice cap grows during the winter months and usually reaches its maximum by early March. “But the 2017 maximum was 14.4m sq km, lower than any year in the 38-year satellite record” according to researchers at the US National Snow and Ice Data Centre (NSIDC) and NASA. “I have been looking at Arctic weather patterns for 35 years and have never seen anything close to what we’ve experienced these past two winters,” said NSIDC’s director, Mark Serreze. The Arctic saw the warmest temperature ever recorded in 2015 and 2016; air temperatures were 2°C higher than the 1981-2010 average between October 2015 and September 2016 according to NOAA. By 2018 and 2019, the Arctic temperature was more than twice the global mean. “Annual mean temperature over northern Canada increased by 2.3°C (likely range 1.7°C–3.0°C) from 1948 to 2016, or roughly three times the global mean warming rate” according to the 2019 Canada Climate Change Report (Figure 1.3). The ice at both polar regions of our planet is diminishing as Arctic and global temperatures keep rising. David Barber, Director of the Centre for Earth Observation Science in Manitoba, said that “the Arctic ice level now is unprecedented over the last 1,450 years.” During the last decade a tremendous amount of ice was lost from glaciers in mountains worldwide, from the entire Arctic region including Greenland, from the Western Antarctic and the Peninsula.
Satellite gravitational field data from the *Gravity Recovery and Climate Experiment (GRACE)* provided an estimated total rate of ice mass loss over Greenland’s ice sheets to be as much as “200 cubic kilometres per year.” Baffin and Ellesmere Islands, Greenland and Western Antarctica and its Peninsula estimated to lose over 400 billion tonnes of ice every year. Most regions the eastern Antarctic and Greenland’s interior are kept stable as more ice is being added. In 2018, NASA intensified its focus on one of the most critical but remote parts of our changing planet with the launch of two new satellite missions - *GRACE-FO and ICESat-2* satellites – that will use radically different techniques to observe how the massive ice sheets in Greenland and Antarctica are changing over time and how much they are contributing to sea level rise. NASA’s Ice, Cloud, and land Elevation *Satellite-2 (ICESat-2)* was launched in 2018, to measure surface heights of ice sheets, glaciers, ice shelves, sea ice, and even forests. The NSIDC noted that “when combined with data from the original ICESat mission and the airborne data from Operation IceBridge, users will have a decades-long, high resolution view into the dramatic changes taking place in the cryosphere.”

The revised data and graphs shown in Figure 2.19 give an update on Greenland’s ice mass from ice sheets to be between 264 - 270 Gt per year as evidence from satellite data retrieval; the latest data is now 286 Gt per year.

Arctic sea ice thickness is steadily declining in the past four decades and linked to warming from increasing greenhouse gases and from positive feedback. In addition to increasing air temperature, positive feedback occurs with lower albedo (less reflection of sunlight or solar energy) and from thawing of the permafrost to release CO₂ and CH₄ that enhance further surface warming. The Arctic should have been on slow cooling trend in over 8,000 years but is being offset by anthropogenic global warming in the past 50 or more years. Albedo loss is accelerated from loss of ice and snow, contaminated ice or snow that lowers solar reflection, allowing more solar energy to be absorbed by the vast Arctic Ocean. Less snow pack means faster melt and greater loss of albedo promoting further ice melt. According to the *Scripps Institution of Oceanography* the “albedo in the Arctic fell from 52 percent to 48 percent between 1979 and 2011.” In *National Geographic* (January 2016) scientists determined the albedo effect is estimated to be 85% reflection of sunlight. With open water, the reflectivity is only 7% with 93% of sunlight being absorbed resulting in increasing Arctic temperature as
Figure 2.17. The melting of Arctic sea ice is an example of a positive feedback loop. As the ice melts, less sunlight is reflected back to space and more is absorbed into the ice-free ocean, causing further warming and further melting of Arctic ice. Credit NOAA.

Figure 2.17 A. The graphs above show Arctic sea ice extent from April to August from the years 2012 – 2019; 2012 was a record low. Note the colour coded years – blue to July 2019 extreme melt. Extent loss in millions of square km. Credit National Ice and Snow Data Center.
positive feedback. With added soot to ice and snow the albedo effect becomes greatly reduced. “Add dust or soot, and the albedo drops below 40 percent. Slushy snow saturated by water – which gives it a gray cast, or even a bluish tint – reflects as little as 60 percent” according to NSIDC.

Scientists at *Environment Canada* in 2012 reported that “the spring snowpack in the Arctic is disappearing at a much faster rate than anticipated even with climate change models” from studies of 40 years of data across the Arctic from April to June. The *National Snow and Ice Data Center* (NSIDC) in Colorado reported that by September 2012 “the sea ice minimum was smallest since satellite records began in 1979 – it was 49% smaller than the 1979-2000 average.” In 2015, NSIDC (https://nsidc.org) researchers announced that “Arctic sea ice had already reached its maximum extent for the winter in late February, much earlier than usual. It was the lowest maximum the satellites had ever recorded.” In 2015 during a strong El Nino event air temperatures in the Arctic were 2°C higher as mentioned and summer sea ice extent was the lowest since 2007 according to the *National Snow and Ice Data Center* in Colorado. The Arctic sea ice loss is being subjected to a warming Atlantic Ocean, a warmer atmosphere, loss of albedo and positive feedback from permafrost loss of carbon dioxide and methane. The thickness of sea ice is also being reduced over the years.

In November 2010, temperatures in regions of the Arctic including Hudson Bay averaged 4°C to 10 °C higher than normal. Taking the Arctic temperature into the data, NASA claims that Earth’s temperature in the Arctic region “was the warmest in 2010 since instrumental measurements were taken.” The combination of these four years, namely, 2015, 2016, 2017 and 2018 were altogether regarded as the warmest on record. Incidentally, the melting of sea ice does not give rise to any sea level rise. The *Nimbus 7* satellite carrying a *Scanning Multichannel Microwave Radiometer (SMMR)* aboard, took several December readings from 1978 to 1986 over the Arctic Ocean to measure the extent of the sea ice. The *SMMR* can detect not only how much ice is present but the age of the ice. The *Ice, Cloud, and Land Elevation Satellite (ICESat)* stopped collected data in 2009) also measured the extent of sea ice and used lasers to detect conditions under the ice sheets in Greenland and elsewhere. A new mission of NASAs *Operation IceBridge* aircraft
research collects data on changing polar land and sea ice and maintain continuity of measurements between previous ICESat missions. The first ICESat mission ended in 2009, and its successor, ICESat-2 was launched in 2018. ICESat-2 uses laser beams to measure the elevation of sea ice floating on the ocean, which can then be used to infer its thickness, but lack of knowledge of the snow that sits on sea ice can makes sea ice thickness retrievals less accurate.

The newer Aqua satellite carries microwave sensors, captures sea ice record year-round even with clouds overhead and during the months of polar darkness. In the fall of September 2009 Arctic sea ice reached its minimum consistent with NASAs research which shows that January 2000 to December 2010 were the warmest decade on record then. The Met Hadley Office for climate change prediction identified a continuing decline of sea ice in the Arctic of about 2.5% per decade since the 1970s. The Canadian RADARSAT imagery data is used by scientists at the National Snow and Ice Data Center (NSIDC) in Colorado to monitor ice movements. RADARSAT 1 & 11 satellites are also used to locate the movements of foreign vessels in the Arctic sea and may become important when ships circumnavigate the Northwest Passage in Canadian waters. Scientific and commercial users in agriculture, cartography, hydrology, forestry, oceanography, and ice studies will greatly benefit from more readily accessible radar data. In June 2019, the Radarsat Constellation Mission (RCM) of three satellites was launched from a Space X Falcon rocket in California. The cost of RCM of $1.2 billion is owned by Canada and will improve on the work of the earlier Radarsat satellites. Maritime surveillance includes ship detection, ice monitoring, oil pollution monitoring and marine wind measurement. New data would continue to emerge on sea-ice measurements. Environment Canada reported “that the Arctic air temperatures have risen by 3°C to 4°C over the past 50 years and noted that during the past three decades the sea ice extent has been declining by 3 to 4 percent per decade.” Studies from submarine surveillance also discovered that the thickness of the sea ice has been declining. There is conclusive evidence that the Arctic ice is fast disappearing and that trend is very likely irreversible.

An Arctic Climate Impact Assessment reported that “the average temperatures in the Arctic have increased twice the rate of global temperatures over the past
decades.” German researchers on the icebreaker Polarstern measured the average thickness of the Arctic sea ice as 2.3 metres in the summer of 2001 but six years later its thickness was reduced to 1.3 metres in the same region and month. It is well known that the melting of sea ice, loss of snow or contaminated snow reduces the albedo effect which allows open water to absorb more solar energy. Cryoconite dust comprised of mineral particles from Asian deserts, from volcanic eruptions, emissions from forest fires and soot from industries greatly add to reducing the albedo effect in the Arctic and in all regions covered with snow. As mentioned, a similar positive feedback phenomenon originates from the thawing of the top metre of the deep permafrost releasing stored methane and carbon dioxide to promote additional regional warming and melting. Meltwater on the permafrost surface often forms shallow lakes. Scientists from the University of Alaska found methane gas bubbling up from the bottom of Arctic lakes. Peter Wadhams in his book A Farewell to Ice and from in the Siberian Times newspaper report that “permafrost bubbles are leaking methane 200 times above the norm.” At low sea level methane plumes are seen everywhere from underwater that add considerably to Arctic melting as positive feedback. Wadhams shows how a series of rapid feedbacks in the Arctic region are “accelerating change there more rapidly than almost all scientists have previously realized, and the dangers of further acceleration are very real.”

The ice sheet in the Antarctic and Greenland overlays bedrock and contains fresh water from the accumulation of snow in the course of tens of thousands of years. For the past few years scientists have been observing a decline in the ice sheets especially around the periphery of Greenland (Figure 2.18). A significant number of meltwater pools and crevasses are now visible over Greenland as the ice sheets melt and slide into the sea. Glaciologists observed ‘open holes’ or vertical shafts in the ice known as moulins that carry water right down to the bedrock, causing the ice sheets to further slide toward the sea; water drains downs into a moulin faster than Niagara Falls. Scientists at the Woods Hole Oceanographic Institution observed a crack in a 900 metre-thick ice in Greenland and with meltwater draining through that crack to the bedrock into the ocean.
Goddard Institute for Space Studies figured that an albedo loss of about 30% in the Arctic region was due to pollution from soot, dust, volcanic ash that settle over the years that speed up the melting of sea ice. There is near-universal agreement that we are now seeing a strong greenhouse effect in the Arctic according to Mark Serreze of the US National Snow and Ice Data Center (NSIDC). Scientists at the NSIDC in Colorado found that the Arctic sea ice extent “appears to have reached its minimum by September 2007, shattering all previous lows since satellite record-keeping began about 30 years ago.” The NSIDC concludes “all indications are that sea ice will continue to decline over the next several decades.” By 2012, Arctic sea ice decline had broken the record set in 2007; the daily loss in 2012 was 50% higher than in 2007 according to NASA. Gabrielle Walker in Nature journal reported that “there is 20% less ice cover than the 1979-2000 average” in the Arctic in over a century. Summer sea ice loss in 2016 reached its low point behind the mark set in 2012 according to the NSIDC. This trend of sea ice loss is not stopping as cited by data in Figure 2.17 A.

Figure 2.17 B. Monthly Arctic Sea Ice Extent for January 1979 to 2019 shows a decline of 2.6 percent per decade. Credit: National Snow and Ice Data Center.
Scientists from the University of Washington in Seattle analyzed data from submarine surveillance from 1987 to 1997 and concluded that the Arctic sea ice had thinned by about one metre during that period. German scientists have been measuring the thickness of the summer Arctic sea ice from the years 2001 to 2007 and also confirmed that it had declined by one metre. The last 20 years were especially warm globally with each decade being warmer than the previous. As mentioned, Arctic temperature (~3°C) about three times the global average (1.1°C). NASAs ICESCAPE scientists are undertaking research on ice melt in the Chukchi and Beaufort Seas (see Figure 2.20).

Another indicator of extreme global warming in the Arctic was reported by Canadian Professors Smol and Douglas at Queens University in Ontario. They observed the disappearance of shallow ponds the size of football fields in the tundra. The Canadian scientists discovered that many of those ponds in the Arctic were drying up. In the journal Science, Smith and investigators also reported on the disappearance of lakes in the Siberian Arctic since the 1970s through satellite imaging. Ponds, lakes and sinkholes abound in the permafrost. Hundreds and possibly thousands of lakes have completely vanished and are now overgrown with vegetation. The reason for the loss of water from lakes and ponds points to the thawing of the permafrost that increases the permeability of surface water causing ponds and lakes to drain and become covered with vegetation. About 30-70% surface permafrost loss is projected by 2100 according to Woods Hole Research Institute.

Investigators discovered that the stable ice sheets and ice shelves that remained undisturbed for thousands of years are fast disappearing from Ellesmere Island in the Canadian north and from Greenland. Using satellite imagery, “researchers catalogued more than 1,700 glaciers in northern Ellesmere Island and traced how they had changed between 1999 and 2015. The results offered a glimpse into how warming temperatures may be affecting ice in the region, from glaciers that sprawl across the land to the 200-metre thick ice shelves” a report from Adrienne White, a glaciologist at the University of Ottawa in the Journal of Glaciology. More than 77,000 km² of Ellesmere Island in Nunavut are within the Canadian Arctic Archipelago and covered with glaciers and ice sheets. In 2005 an ice shelf known
as “Ayles Ice Island” broke away from Ellesmere Island measuring 15 km long and 5 km wide. An ice shelf is floating ice that rides over bedrock and extends into the ocean. By June of 2007, the Ayles Ice Island (then an iceberg) had moved southwest and drifted 80 km from its original site; by September 2007, it had broken into two huge chunks and further drifted about 500 km from Ellesmere Island. In September 2010 the Petermann Glacier from northwest Greenland measuring 250 km² collapsed into the Arctic sea. Operation IceBridge flew over a new crack in Petermann Glacier, one of the largest and fastest-changing glaciers in Greenland on April 14, 2017 just a few days after the rift was detected in satellite imagery. Satellite images (Figures 2.21, 2.22 & 2.23) clearly indicate that the Arctic sea ice has been receding and opening up wide passages for ships to transit. The evidence is clear that the Arctic ice is in a downward spiral and will continue for decades to come.

According to Professor Trausti Valsson at the University of Iceland “Arctic warming has become a self-propelling process that could leave the Arctic Ocean ice-free during the summer months by 2040.” NOAA’s oceanographer James Overland noted “we are on a one-way trip and not going back” and predicts that “by mid-century a further rise of 4°C is all but assured” in the Arctic, presently close to 3°C above the global mean. Some climatologists predict that cargo ships will be navigating the Northwest Passage in less than 10 years during the summer months. “Satellite data show that the extent of the sea ice has decreased by about three percent per decade” according to a US Environmental Protection Agency study. The graph in Figure 2.17 B estimates a decline of 2.6 percent per decade of sea ice extent. Hudson Bay in northern Manitoba would normally be covered with ice but in November 2010 the air temperature rose to 10°C and practically no ice was visible. GPS sensors placed on sites in Greenland estimate that GRACE satellite under-estimated ice sheet loss by 7.5% or by about 20 billion tonnes (Gt) of ice loss per year. Andy Aschwanden et al (Science Advances, 19 June 2019, Vol. 5, No. 6) reported that ice sheets lose mass through runoff of surface meltwater and ice discharge into the surrounding ocean, and increases over the past two decades have resulted in accelerated mass loss from the Greenland Ice Sheet. From June to August 2019, an extensive area of the Greenland ice sheet surface melted reaching a peak of just over 700,000 square kilometers setting an early record in the melt season. Models estimate the amount of melted ice at approximately 80
billion tons for that period according to the NSIDC. In *Nature Communications* (Vol. 10, No. 2810, June 26, 2019) J.S. Bowling *et al* reported that from radio-echo data sub-glacial lakes were identified under the ice sheet in Greenland but smaller than under those under Antarctica.

Figure 2.18. Circular green represents GPS sites on Greenland & red dots relative sea level sites. Credit NASA GISS.
Figure 2.19. Mass loss of Greenland’s ice sheets from 2002 – 2018 - 286 Gt/yr. Credit NASA.

Figure 2.20. Sea ice loss in the Chukchi Sea in Barrow, Alaska, in July 2006 (left) and July 2007 (right) one year later was devoid of sea ice. Credit to US National Imagery Systems.
Figure 2.21. Arctic Sea Ice extent in 1979. Image by NASA.

Figure 2.22. Arctic Sea Ice extent in 2005. Compare with the previous image in 1979. The Northwest Passage is more visible with less sea ice. Image by NASA.
Is the Canadian north truly strong and free? The National Round Table on the Environment and Economy (NRTEE) put out a 160-page report in 2009, entitled “True North: Adapting Infrastructure to Climate Change in Northern Canada.” Adaptation includes safe buildings, roads, airports, schools, pipelines to modernize and secure communities in Canada’s North. As global warming impacts on sea ice in the Arctic Ocean, the world is watching and waiting to see if ships could navigate through the Canadian Northwest Passage. Land claims in the Arctic region by the five bordering countries have become contentious; the Russians recently announced that a greater part of the Arctic belongs to them with concerns of sovereignty and prospects for exploration of oil and gas. Time magazine October 1, 2007 cover page asks this important question: “Who Owns the Arctic?” and Michael Byers from the University of BC in a 2009 publication also asks Who Owns the Arctic is worth reading.

The Northwest Passage is a series of interconnected waterways that may become the new route between Europe and Asia, a distance of about 9,000 km shorter than through the Panama Canal. A London to Tokyo route via the Northwest Passage would be 13,000 km compared to the Suez Canal route of a distance of 21,000 km.
Countries have Exclusive Economic Zone (EEZ) of up to 200 nautical miles (equivalent to 230 miles or 370 km) from shore according to the *Law of the Sea*; it holds exclusive rights over the natural resources of the water column, seabed and ocean floor. Countries can claim up to 350 nautical miles (403 miles or 648 km) if the region proves to be an extension of a continental shelf from that country. The UN *Convention on the Law of the Sea* (Article 76) specifies states may claim rights over an “extended continental shelf beyond the EEZ.” Russia claims to have geological evidence that its continental shelf goes all the way to the North Pole from its territory. Who will oversee the vast expanse of the Northwest Passage in the Canadian north and keep the longest Canadian border secure? Canada is pushing to see that Arctic is pollution free from shipping and a mandatory shipping code to be enacted in the Arctic according to Transport Canada. Canada claims that the Northwest Passage belongs in Canadian territory but the United States challenges that fact and stated that the NW Passage should be an international strait. The Fall 2014 Report by the *Commissioner of the Environment and Sustainable Development* noted that “the Government of Canada may not be prepared to deal with increased traffic in the Arctic.” Canada and Denmark have been working on a joint venture in mapping the region north of Greenland and Ellesmere Island along the undersea Lomonosov Ridge and are anxious to map other areas to advance territorial claims.

Figure 2.24. This map shows the potential Northwest Passage and other routes for shipping and cruise liners. Credit NASA.
Canadian scientists are amassing evidence that the disputed Lomonosov Ridge extends from the Arctic Ocean to the North American continent. Canadian scientists have successfully tested a robotic mapping system off Ellesmere Island; robotic probes will assist in mapping the sea floor. Denmark in 2014 claims its territory extends to the North Pole as an extension of Greenland. Canada is also investigating the Alpha Ridge that was damaged by a meteorite and it appears to link with the Mendeleev Ridge from eastern Siberia. Sediments from the Alpha Ridge have settled in Canadian territory and may assist Canada in making claims to that region of the Arctic. The Alpha Ridge extends from Russia to Canada and by measuring offshore seabed sediments is one scientific approach to claims of undersea territory. Silt discharged from the Mackenzie River settling into the Beaufort Sea is another example of offshore claims by Canada against the United States.

The United Nations Convention on the Law the Sea specifies that any claim based on the continental shelf extensions must be supported by scientific evidence and approved by the UN. A country may claim seabed resources to the edge of its continental margin even though that boundary may be difficult to define. Natural Resources Canadian geoscientist Jacob Verhoef believes that Canada has set the stage for Arctic continental claims in their submission to the United Nations Convention on the Law of the Sea (UNCLOS). Scientist Mary-Lynn Dickson joined Natural Resources Canada in 2015 as the Director of the United Nations Convention on the Law of the Sea Program, located at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia. In 2019 Canada submitted 1200 pages of evidence to prove that its continental shelf extended 200 nautical miles from the high Arctic islands; it included in its report a section of the sea floor that stretches from Ellesmere Island (Figure 2.24 A) along an undersea ridge to the North Pole. Canadian scientists claim that Lomonosov and Alpha-Mendeleyev Ridges (Figure 2.24 B), underwater mountain ranges stretching under the Arctic Ocean from Canada to Russia, are submarine elevations, thus giving them the right to claim the seabed under the North Pole. Michael Byers suggests that the geographic pole lies on the Danish side of the Lomonosov Ridge and Canada may not have a case that the geographic pole is part of its territory. The controversy on territorial rights will
continue for some time until evidence is analyzed and determined by the UN Convention on the Law of the Sea.

The *Lomonosov Ridge* (Figure 2.24 B) is a chain of undersea mountains that extends to Eurasia through extensive seismic mapping; Russia has laid claim to a vast region outside its 200 nautical mile limit. The Russians in a risky mission planted their flag in August 2008 at the bottom of the North Pole, a depth of over 4 kilometres. The *Lomonosov Ridge* extends about 1,900 kilometres from the Siberian continental shelf through the North Pole and likely onto Greenland and Canada’s Ellesmere Island. Michael Byers in his book *Intent for A Nation*, gives an informed overview of where Canada stands in the Arctic. Byers is passionate about the “True North Strong and Free” and says that we need to defend our rights in the Arctic. Byers writes: “In the North, the Inuit and other indigenous peoples are our sentinels, soldiers and diplomats. It is time for southern Canadians to look up, way up, and provide serious support for their efforts to build a true North strong and free.”

Figure 2.24 A. A map included in Canada's UNCLOS submission in May 2019. The red line marks the outer limits of Canada's continental shelf, while the green line marks the outer extent of Canada's submission. (Government of Canada)
In *Who Owns the Arctic* Michael Byers gives extensive coverage of the jurisdiction over the Arctic and what Canada’s role ought to be or should be in the Arctic. Thomas Berger, the former BC Supreme Court judge was a conciliator retained by the federal government on Inuit life and Nunavut. He was critical of the education of Inuit children as noted on page 113 in Byers book on *Who Owns the Arctic*. “By the time they reach Grades 8, 9 and 10, they are failing…damaging to their confidence, to their faith in themselves….the curriculum becomes more dependent on a capacity in English that they do not have. In Nunavut this reinforces the colonial message of inferiority. The Inuit student mentally withdraws, then leaves altogether.” Berger continues: “Every Canadian must be aware of the Inuit achievements in art and sculpture, in film and performing arts, achievements for which the Inuits have won international renown. The Inuit are a bright tile in the Canadian mosaic.”

Figure 2.24 B. Arctic Ocean Bathymetric Map. Note the various underwater ridges as extensions of continental shelves as land claims. Credit International Boundaries Research Unit, Durham University, England.
An article in the *Vancouver Sun* on March 20, 2018 entitled “Exposed in the North” note that Canada is falling further and further behind other nations as the Arctic development heats up. Many of the infrastructure are missing or lacking: transportation, primitive airports, limited ice-breaker capacity, limited deep water ports. Byers bluntly stated that “everything in the north needs to be improved on…improving the well-being in the North, particularly when it comes to addressing high suicide rates” as a major priority. Canada has the longest coastline of any country in the world and we are not giving the support to scientific research, the education of Inuit children, search and rescue, and a full Canadian presence.

The glaciers at **Kluane National Park in the Yukon** were some of the more stable glaciers outside the Arctic region but 22% of surface area of Yukon glaciers was lost in the past few decades. Surprisingly, Peter Johnson at the University of Ottawa identified that all of the major glaciers in the St. Elias mountain region next to Kluane are retreating. Between 1956 and 2007, the Kaskawulsh glacier (Figure 2.25) retreated by 600-700m. In 2016, there was a sudden acceleration of the retreat, and the pulse of meltwater led to a new channel being carved through a large ice field. The new channel was able to deliver water to the Alsek’s tributary whose steeper gradient resulted in the Slims headwater being suddenly rerouted along a new southwards trajectory. Instead of draining northward down the Slims toward Kluane Lake to the Yukon River and eventually to the Bering Sea, the water abruptly began flowing in the opposite direction - into the Kaskawulsh River, a tributary of the Alsek, which runs southward to the Pacific Ocean. Following this route, the former headwaters of the Slims River now reach the ocean some 1,330 kilometres away from where they would otherwise have ended up. The cause of the unprecedented disappearance of one river can be unequivocally chalked up to climate change as reported in the journal *Nature Geoscience*; researchers use the term “river piracy” from glacial retreat and diverting water from one river to the next.

Figure 2.26 is evidence of glaciers of the western Cordillera stretching from the Yukon to British Columbia and Alberta are retreating and losing mass. The Peyto (Rocky Mountain), Place and Helm (Cascade and Coast) glaciers are accelerating
in shrinkage. All mountain glaciers from the Rockies to the Andes and from the Alps to the Himalayas have also been retreating. Glaciers in the Arctic and Antarctic regions have also been retreating and losing mass but at a slower rate. One of the consequences of the melting of all glaciers and ice sheets is a projected sea level rise of up to 1.5 metres by the year 2100 that takes into account thermal expansion of the ocean. Low-lying coastal cities and small island states like Kiribati, Marshall Islands, Solomon Islands and others in the south and western Pacific and Caribbean are in danger of being overtaken by a rising sea. “It is a matter of life and death” as expressed by delegates from several small island states at the Paris COP21 conference. The developed nations and developing economies are responsible to avoid this impending catastrophe of small island states and coastal cities. Developed nations and growing economies are responsible for GGE worldwide and funds have been allocated by the UN at COP21 to vulnerable states.

Figure 2.25. Kashawulsh Glacier was taken from a small aircraft over Kluane National Park in the Yukon. This is one of the world's largest non-polar ice fields and the largest UNESCO preserve. Photo by the author in year 2000 from a small aircraft.
Turning to Antarctica, a continent almost twice the size of Australia and 98% covered with ice with an average 1.6 km in thickness; regions of the interior have ice thickness over 4 kilometres as evident from the Vostok research cited in Chapter One. Air temperatures high above the Western Antarctic Peninsula have been steadily rising. The annual ice loss in Western Antarctica and the Antarctic Peninsula increased from satellite imaging data. The Potsdam Institute suggests that the western Antarctic melting of glaciers and ice shelves may have already tipped on the side of no return. The Pine Island Glacier in western Antarctic (Figure 2.30) is moving 40% faster than it was in the 1970s, discharging water and ice more rapidly into the ocean. In October 2011, NASA scientists spotted a massive crack on the Pine Island Glacier eventually calved a giant iceberg of 700 km² in size. Evidence of regional warming was noted with the breakup of the Larsen-B ice shelf in the Antarctic Peninsula (Figure 2.27). In 1987, a giant crack appeared along the edge of the Larsen-B ice shelf. Larsen -B ice shelf has been resting about 230 metres above the ocean and bigger than the state of Rhode Island! On February 2002 and within 35 days, the Larsen–B ice shelf started to break apart. “Water was indeed chiseling its way through the ice shelf by mid-March; remarkable satellite images showed that some 1,300 square miles had fragmented” writes Robin Bell in Scientific American. Terra and Ice-Cloud-Land-
Elevation (ICESat) satellites took images of that collapse that started on January 31 and ended in March 2002.

Figure 2.27. The Larsen-B ice shelf in the Antarctic Peninsula breaking up in 2002. Credit to NASA’s Terra Satellite. Note the size of this region from the scale shown in Figure 2.29.

Figure 2.28. Formation of an Ice Shelf and how Icebergs are calved. Credit AntarcticGlaciers.org
One of the world’s biggest ever icebergs – about a quarter of the size of Wales or four times the size of London - has broken off from Antarctica as new satellite images have confirmed. That massive iceberg which calved from the Larsen C Ice Shelf is about 5,800 square kilometres in size and weighs about a trillion tonnes. “The calving occurred sometime between Monday 10 July and Wednesday 12 July 2017. Its volume is twice that of Lake Erie, one of the Great Lakes” that researchers from NASA’s Modis satellite team discovered. Western Antarctic and the Peninsula extending toward the tip of South America are especially vulnerable to climate destabilization. Scientists widely consider Thwaites Glacier in Western Antarctic to be the most dangerous block of ice on planet earth. Some go so far as to term it the ‘Doomsday glacier’. For starters, its density contains 50 cm of potential sea level. But worse, Thwaites glacier is stopping four other glaciers from collapsing. Those four glaciers hold up to 3 metres of new sea level. As Thwaites glacier nears collapse, scientists worry that ramifications like the disappearance of West Antarctic are a mere decade away. It’s difficult to calculate exact timelines for this glacier to collapse, mostly because glaciers have a threshold that when met, the whole thing crumbles.

Figure 2.28 A. Recent aerial view of Thwaites glacier, which shows growth of gaps between the ice and bedrock. Credit NASAs Jeremy Harbeck
The glacier’s threshold may signal the doomsday aspect; this means that one chunk of ice crumbling could mean the entire glacier gives way. Research recently published in the *Proceedings of the National Academy of Sciences* journal found “it was likely to succumb to instability linked to the retreat of its grounding line on the seabed that would lead to it shedding ice faster than previously expected.” Researchers reporting in the *Geophysical Research Letters* stated “while the majority of the ice sheet has remained stable in the Antarctic, 24% of West Antarctica is now in a state of dynamical imbalance. Thinning of the Pine Island and Thwaites glacier basins reaches 122 metres in places, and their rates of ice loss are now five times greater than at the start of our survey.”

Eric Rignot and colleagues at NASAs Jet Propulsion Laboratory in Pasadena, California, “observed glaciers flowing up to eight times faster following the 2002 Larsen-B ice shelf collapse.” The Wilkins ice shelf in southwest Antarctica started to break up in 2009; an iceberg measuring 41 km x 2.5 km broke off the 14,000 km² size ice shelf. Several ice shelves in Antarctica, namely Prince Gustav Channel, Larsen Inlet, Larsen A and Larsen B, Muller and Jones have all collapsed.
in the past three decades. The western Antarctic and the Peninsula region are now regarded as the banana belt of the Antarctic and warming faster than any other place in the Southern Hemisphere. **Climatologists claim that the Antarctic Peninsula has warmed by 3°C in this century.** NASA's ICESat showed that “between 2001 and 2006 the glaciers that feed onto Larsen A and Larsen B ice shelves lost about 30% of ice throughout the Peninsula.” NASA is carrying out research flights over the Antarctic known as **Operation Icebridge.** Those flights study changes in the ice sheets, glaciers and sea ice. Rignot noted that “our study shows melting from below by ocean waters is larger.” **National Geographic** in a July 2017 special report on **“Crisis on the Ice”** gives an excellent account on the Antarctic Peninsula and ongoing climate changes. Rignot says that “these are the fastest retreating glaciers on the face of the Earth” referring to the Western Antarctica region. “In 2016 and 2017, a hole of open water, called a **polynya,** appeared in the winter ice of the Weddell Sea in Antarctica. It eventually grew to about 19,000 square miles; roughly twice the size of Vermont. Though polynyas are not unusual, this large and frequent of a hole was a great opportunity for scientists to figure out why, exactly, these holes were appearing” as reported in **Nature** journal in June 2019.

The Russians have been drilling through over 3 km of ice to unlock the secrets of Lake Vostok in East Antarctica; this lake is reported to be the size of Lake Erie. More than 160 subglacial Antarctic lakes have been identified so far and it is estimated that the volume of water in those lakes amount to about 30% of all surface lakes on Earth. How do scientists know that deep down below the ice sheet liquid water exists? One clue that led scientists was that ice sheets seem to float free and frictionless as it passes over water instead of bedrock; tracking movement of ice sheet by satellite is one indirect evidence of water under the ice. **Ice-Sat** satellite using lasers and radio-echo sounding instruments are able to detect sub-glacial lakes and rivers under the ice sheet (Figure 2.32). Ice movement or basal sliding is also triggered from underground heat in the bedrock. Researchers at NASA discovered a huge upwelling of hot rock under Marie Byrd Land which lies between the Ross Ice Shelf and the Ross Sea. The presence of that huge **mantle plume** could explain why the region is so unstable today. Mantle plumes are thought to be part of the plumbing systems that brings hot material up from Earth’s
interior. Its presence would explain the regional volcanic activity seen in the area, as well as a dome feature that exists there. However, there was no concrete evidence to support this hypothesis – further research is required to confirm these findings.

![Image](https://example.com/image1)

Figure 2.30. This giant iceberg of 700 km² was calved from the Pine Island Glacier in Antarctic in November 2013. Credit to NASA's Landsat 8 satellite.

The slippery slope is lubricated by geothermal energy in bedrock (Figure 2.28), a process known as *basal sliding* has been well established with ice movements. As mentioned, radio-echo soundings images aboard the *European ERS-1* satellite and laser data from the *ICESat* satellite also provide indirect evidence of lakes under the deep ice sheets. The Vostok ice cores have identified microbial life, pollen and marine diatoms located at different depths. The latest report indicates that “organisms are living and reproducing in Lake Vostok.” As mentioned from data in Figure 1.4 demonstrating the relationship between temperature and carbon dioxide through the millennia, the Vostok ice cores (Figure 1.4-2) identified several ice ages dating back in over 420,000 years from studies of the isotopes of hydrogen (deuterium) and heavy $^{18}$oxygen (Figure 1.4). “Over 35 million years ago Lake Vostok was open to the atmosphere and was surrounded by a forested ecosystem” according to the journal *PLOS One*. 
With respect to the Canadian Arctic, southern Canadians need to pay greater attention to our Inuit people of the North. The Inuit people who live in and around the Arctic are among the worst victims of global warming in Canada. The *Inuit*
Circumpolar Council (ICC) announced that “the Arctic is at the epicentre of climate change. Inuit traditions and subsistence practices have already been assaulted.” Even using snowmobiles can be hazardous. Sheila Watt-Cloutier of the ICC lives in Nunavut reminds southern Canadians that the Arctic is not a barren land but has supported the Inuit people for millennia. She was the Chair of the ICC that represents a population of over 155,000 Inuit in Canada, Alaska, Greenland and Russia. The National Round Table on the Environment and the Economy (NRTEE) put out an extensive document entitled “True North: Adapting Infrastructure to Climate Change in Northern Canada” with recommendations for adaptation opportunities for housing and engineering guidelines and other strategies to address the impacts of climate change. The NRTEE noted that “the reality is of land, sea, communities, and peoples facing both lingering and new pressures on economic growth, social conditions, and environmental integrity.”

![Graph of Antarctic mass variation](image.png)

Figure 2.33. Antarctic mass variation (ice sheet) since 2002 with a rate of change of 127 Gt/year.

Peter Taptuna the first Premier of Nunavut reminds Canadians and Ottawa that revenue-generating infrastructure is a priority – shortage of 3,000 homes and the need for roads linking Manitoba along Hudson Bay and a highway to Yellowknife.
Taptuna warns that suicide has become “an epidemic” among residents of Nunavut. The May 2009 publication of National Geographic discusses the “Arctic Land Grab” and how much of the Arctic Ocean the five Arctic countries could stake. The Arctic Polar Region regardless of continental shelf limits as well as the entire Antarctic should be handed over as an UNESCO preserve with no single country claiming title outside their 200 nautical-mile limit, and with no exploration for gas, oil or minerals. While Canada’s Environment and Climate Change Minister Catherine McKenna was on a tour of the Arctic, she recalls a story of a 14-year-old Inuit boy quietly sitting down beside her and showed her a list. It laid out all the changes that he was seeing that he thought might be caused by climate change. “He told me of getting stuck in thawing permafrost while hunting; the loss of caribou, a food that Inuit rely on; thinner polar bears; and experienced hunters no longer being able to tell the thickness of the ice and falling through.” Climate scientists confirmed that all those changes in the Arctic were all tangible signs of a warming climate.

Michael Byers reminds us of an Arctic vision in his book Who Owns the Arctic? “I have witnessed the strong protective instinct that Inuit have for the flora and fauna of the North…felt the deep love for this country. I’ve met community and territorial leaders of intelligence and integrity, all of whom have a clear sense of all that Nunavut could, and must, be. There is so much that can be done – with foresight, a relatively small amount of money, and a genuine effort to listen and cooperate.” Former Supreme Court Justice Thomas Berger is critical of the lack of education among Inuit children in Nunavut and said that “every Canadian must be aware of the Inuit achievements in art and sculpture, in film and performing arts, achievements for which the Inuits have won international renown. The Inuit are a bright tile in the Canadian mosaic.”

**Species Decline at Polar Regions**

Krill are shrimp-like tiny organisms or crustaceans that live off the phytoplankton or algae in cold water. It is an essential component of the second level of the food chain and food web that provides nutrition for larger species of consumers such as fish, seals, Polar bears, Emperor penguins, Adelie penguins and the Humpback
whales in the food web system. Ecologist Bill Fraser who has been studying Adelie penguins in Antarctica observed that one colony size was reduced from 320 breeding pairs to 54 between 1990 and 2004 at one location; he claims that they are the toughest animals he has ever encountered, swimming over 5,000 kilometres during a winter migration and thrive on the harshest environment on earth. On the Antarctic island of Litchfield the Adelie penguin population was seen to be noticeably reduced. Penguins must swim long distances in search of food and then return to feed their young. Meredith Hooper who wrote *The Ferocious Summer* about climate change in the Antarctic and its effects on Adelie penguins worked with scientists like Bill Fraser in observing the summer population of Adelies and has documented their declining population.

The average winter air temperatures where penguins inhabit have increased by nearly 6°C in over five decades. Climate change has been responsible for the decline and distribution of animal population in both the Arctic and Antarctic. Fraser also discovered that the Adelie population on Biscoe Island in Antarctica declined from about 32,000 breeding pairs to 11,000 within 30 years. “The Adelies are the canaries in the coal mine of climate change in the Antarctic,” says Fraser and predicts that the Adelies may become extinct on Palmer’s inner islands in Antarctica within the next decade. Tim Flannery in *We are the Weather Makers*, reported that the population of Emperor penguins in Antarctica declined by about 50 percent. In *An Inconvenient Truth*, Al Gore wrote that the Emperor penguin population declined by as much as 70 percent in the past 50 years.

The Arctic animal biodiversity includes 36 species of fish, 36 species of land mammals, 9 species of marine mammals and more than 160 species of migratory and resident bird species. In the Arctic Ocean, the tiny crustaceans or krill are the primary consumers in the food chain that indirectly provide nutrients for the higher consumers such as the seals, polar bears, and bowhead and beluga whales. The reduction of the krill population coincides closely with an increase in ocean temperature. Phytoplankton or algae are the producers of food for the krill and there is speculation that an ozone decline over the Antarctic may lead to a decline in phytoplankton. Climate change therefore poses a significant effect on the flora.
and fauna in the Arctic and Antarctic ecosystems from increasing oceanic and atmospheric temperatures.

NOAA (www.climate.gov) reported that marine ecosystems in the Barents Sea—a sub-arctic shelf sea bordering the Arctic Ocean—are warming faster than the global average, according to the 2018 Arctic Report Card, contributing to a northward shift in fish species. Not only are there now bigger fish to fry in the region, but scientists predict the natural marine ecosystem will undergo a transformation. “There is a significant change in the locations of fish communities between the beginning of the annual Joint Norwegian/Russian Ecosystem Survey in the Barents Sea in 2004 and in 2012.” Since the survey began, warm-water fish species from the Atlantic and central Barents Sea have taken over northern and eastern parts of the Barents Sea. Local cold-water fish species have been almost pushed out of the shelf area.

Polar bears in the Arctic need sea ice for their habitats to feed on seals whenever they come up for air and stay on the ice. The September sea ice extent since 2007 to the present has been on a steady decline from the many credible reports cited including updates from the US National Snow and Ice Data Center. Mark Serreze, the senior scientist at the Center speculates that all of the summer Arctic sea ice could be gone by the year 2030. Most of the predictions made about Arctic sea ice disappearance in the summer are likely to occur between 15 to 40 years from the present. Polar bears are often found stranded on ice flows, some not surviving having to swim a long distance; they need sea ice in search of food. The US government listed the polar bear as a threatened species under the Endangered Species Act; the government of Canada has not yet listed it under the Federal Species at Risk Act in spite of the fact that thousands of polar bears live in the Canadian Arctic region and are being threatened with extinction. In December 2010 polar bears were not able to hunt across the Hudson Bay region in northern Canada because the ice was too thin with an unusual high 10ºC average air temperature.

With a loss of summer sea ice and biodiversity from Arctic warming, the population of polar bears, narwhal whales and walruses has been on a decline. Ian
Stirling at the University of Alberta who has been studying polar bears for over 45 years discovered that the early ice breakup in spring is depriving bears of critical time to prey on seals. As a result, Stirling found that polar bears today are known to carry 15 percent less body mass than in previous years. Tim Flannery cautions of a projected significant decline in polar bear population in the Arctic ice by 2030 and possibly when all of the summer sea ice has disappeared. Polar bears are being fitted with satellite collars to study migratory patterns and survival rates; some have been tracked and known to migrate up to 240 kilometres across the ice and ocean in search of food. Paul Nicklen who has been studying polar bear habitats in the Lancaster Sound region in northern Canada off Greenland and on the Svalbard Islands 600 kilometres north of the Norwegian mainland, concludes that “an Arctic without ice would be like a garden without soil” for the survival of mammals such as the polar bears. Animals like the Adelie penguins in the Antarctic and polar bears in the Arctic are two of the many species that are in peril from climate change and sea ice thinning.

Temperatures are rising in all ocean basins in both polar regions and at much greater depths according to scientists at the National Oceanic and Atmospheric Administration. Robert Gagosian of the Woods Hole Oceanographic Institution believes that the oceans hold the key to any dramatic change in Earth’s climate. There are still many unknowns about how the climate system operates and with changes from a weakening of the Atlantic Meridional Overturning Circulation or AMOC. What seems certain is that the planet has been warming at a faster rate in the past few decades and especially in the entire Arctic region and Antarctic Peninsula. In November of 2010 the world’s governments met in Nagoya, Japan, to discuss the catastrophic decline of wildlife on the planet. One positive outcome from that conference was an expansion of land reserves to 17% of the world’s areas, up from less than 10% today, and to extend an area of protected oceans from 1% to 10% by 2020.

About 55 million years ago the Arctic was a subtropical paradise with an average temperature of 23°C with lush vegetation and animals such as crocodiles and the wooly mammoth roaming about. Today unlike several decades ago the Arctic is becoming the banana belt of the north from global warming and extreme weather.
The Inuit people in northern Canada have lived for thousands of years in the region but today their traditions and subsistence are being threatened like that of the polar bears. The Canadian government must demonstrate its presence and defend its territorial claims in the Arctic. In 2017 Canada’s **High Arctic Research Station** opened in Cambridge Bay in Nunavut. Scientists from around the world invited to carry out research there. This station is joined with existing research stations in Inuvik, Kluane, Churchill and on Ellesmere Island. Southern Canadians need to support the Inuit people who according Michael Byers are our “sentinels, soldiers and diplomats” in the Canadian north. As mentioned earlier, Michael Byers two books *Who Owns the Arctic* and *Intent for a Nation* provide an insightful look at changing conditions in the Arctic and the life of the Inuit people, and urge what southern Canadians ought to do for a true north strong and free.

**“No Man is an Island”**

We see connections in nature all around us – the climate system is a good example of how conditions on earth changes among interactions with the atmosphere, the cryosphere, land mass and hydrosphere. The water cycle recycles the same substance (H$_2$O) from bodies of water and from all living things into the atmosphere and to be carried away to distant locations. Water is cycled from plants, animals, humans, soil, the atmosphere and from aquatic ecosystems. Water is returned elsewhere as the same chemical substance and unchanged as a substance since the origin of the planet. The water molecules we drink have originated from the bodies of plants, animals, ocean dwelling organisms and even from the human species both living and dead. We share molecules of oxygen, water, and carbon dioxide with all forms of life. The carbon cycle recycles CO$_2$ from the oceans, from all living things, from decay processes, from fossil fuels, in and around the atmosphere far and wide. We are connected to a greater whole and there is no escaping our biological, chemical and even economic connections with local and distant places.

Sulfate particles from the eruption of Mt. Pinatubo volcano in the Philippines in 1991 was carried over India within 12 days; air temperatures dropped by a fraction of a degree globally. Radiation from the Chernobyl nuclear plant disaster in the
former Soviet Union was monitored and its fallout polluted distant regions. Cows on European farms were found to have high levels of radiation in their milk days after the Chernobyl disaster. Dust from the Sahara Desert is known to reach Caribbean islands from across the Atlantic Ocean; when fields are being ploughed in China some of the dust is carried across the Pacific Ocean to the Hawaiian Islands. Black carbon pollution or soot in western US and Canada is known to have its origin in Asia that affect climate change and the albedo effect in the Arctic. From 2005 to 2010 emissions of nitrogen dioxide in China increased by 21% and is a key ingredient in producing ozone. China’s ozone travelled across the Pacific Ocean to western North America and “it offset American reductions of ozone pollution by 43%” according to an article in National Geographic in October 2016. Toxic substances such as mercury from the Gulf of Mexico are found in the Arctic Ocean. Microplastics travel in all oceans and reach the Arctic sea and deep in the Mariana Trench as discussed in Chapter One. The oceans are interconnected with the thermohaline circulation and North Atlantic Drift having a profound influence in regulating global and regional climate and weather.

Figure 2.34. The map above shows dust crossing the Atlantic from the Sahara Desert. deposited on Caribbean islands as illustrated by the Goddard Earth Observing System Model (June, 2018).
Small marine creatures consume small fragments or microplastics carrying toxic chemicals, mistaking them for phytoplankton and pass on to the next and subsequent food chain. In a process called bio-accumulation, toxic compounds build up in an organism at a rate faster than they can be broken down, thus impacting the food chain from bottom to top. Ultimately, these harmful substances wind up in the seafood on our dinner plates and we thereby become the subjects or consumers of bio-accumulation. Other animals such as sea turtles and birds also consume larger bits of plastic mistaking them for food. These larger fragments cannot pass through an animals’ digestive systems and have no nutritional value. With no room left for their normal food, they slowly starve to death. Albatross unwittingly feed plastic to their young, causing them to also die of starvation. Once an animal dies and its body decomposes, all that remains is the plastic, which is then released back into the environment where it will continue to cause harm. Other harmful chemicals such as polychlorinated biphenyls or PCBs are found in fish and amphipods deep in the Mariana Trench. A science-based approach is needed to replace chemicals such as endocrine disruptors that are found in some plastics and pose a risk to human health. Plastic consumption becomes part of the ‘food chain’. Researchers are puzzled how these chemicals got to these depths of over 10,000 metres. Toxic chemicals reach distant places in our oceans; the deep oceans rather than being remote is highly connected to surface water. The tiny Henderson Island (Figure 2.11) has the highest density of anthropogenic debris anywhere in the world – about 18 tonnes – the origin of plastic came from Asia, Europe and other countries as discussed earlier.

The United Nations Conference of Parties (COP) acknowledged the damage being caused by the higher polluters from greenhouse gas emissions and the need to compensate those who are affected in less developed countries. Historic and present day high atmospheric polluters or consumers of fossil fuels need to compensate countries that are affected by climate change caused by higher polluters; we are a part of that problem. China and India would also have to compensate others if they fall short of their pledges at COP21 in Paris. Greenhouse gases know no geographical boundaries and the bigger polluters who do the damage should compensate the ones who do not pollute and are affected. The problem is who decides who pays and by how much. Will China be responsible for
climate change impacts as the biggest polluting country and to compensate others? Australia, the USA and Canada are the number one, two and three per capita of GGE globally as developed countries. What about Saudi Arabia, Qatar and Kuwait who are some of the biggest polluters in so-called ‘developing countries’. Should the rich Arab states compensate poorer countries including small island states threatened with sea level rise? Rising sea level is one of the consequences from global warming that small island states such as Kiribati, Cook Islands, Marshall Islands in the central Pacific and in coastal cities, and will need funding for protection and adaptation. Our planet is a relatively average size one with countless examples of global interconnectedness as no man is an island. Whatever happens in a distant region be it sea ice decline in the Arctic Ocean or deforestation in Amazonia or pollution at the oil sands projects in Canada, will have lasting environmental and even economic impacts elsewhere.

*Extreme weather* such as heat or cold spells or abnormal snowfall in Eastern Canada, the US, Northern Europe and Britain is known to be influenced by other conditions far away in the Arctic from higher temperatures (Arctic Amplification) and a changing Jetstream influencing the polar vortex, stationary high-pressure regions as discussed earlier. The recent extreme winters in eastern USA and Canada were likely triggered by a warming Arctic and wavier jetstream. Arctic warming would continue to bring more extreme winters in the central and northeast USA, central Canada and northern Europe when the Polar Jetstream becomes more amplified or wavier in a north to south direction. These changing weather patterns in the Arctic and over North America, Central and Northern Europe, Siberia influence extreme weather conditions elsewhere and is partly responsible for the weakening *polar vortex* and changes in the jetstream. El Nino and La Nina also have their climate and weather influences over extensive regions across the equatorial Pacific, and from western regions of North and South America to Southeast Asia and Australia. Climate scientists speculate that the influence of the mid-tropical Pacific Ocean warming is much stronger than the source of heat from the Arctic to influence the Polar Jetstream and polar vortex. The planet is interconnected in its weather, pollution and climate systems and will always experience impacts from natural variability such as El Nino but also from
the added anthropogenic influences of increasing greenhouse gases, positive feedback such as loss of albedo to promote further warming.

NASAs former climate scientist James Hansen stated that “global warming increases the intensity of droughts and heat waves, and promote forest fires. With a warmer atmosphere that holds more water vapour, global warming must also increase the intensity of the other extreme of the hydrological cycle with heavier rainfall, more extreme floods and more intense storms driven by latent heat including tornadoes.” The Superstorm Sandy that affected the northeast US in October 2012 was made worse by changes in the Jetstream and a cold front from the north. Extreme weather conditions have become more frequent in the past decade. Mega heat waves were experienced in Texas, Russia and Europe in 2010 with loss of lives; 70,000 deaths were noted in Europe. Professor Michael Mann of Pennsylvania State University, said: “The unprecedented 2016 California drought, the 2011 US heatwave and 2010 Pakistan flood as well as the 2003 European hot spell all belong to a most worrying series of extremes. In data from computer simulations as well as observations, we identify changes that favour unusually persistent, extreme meanders of the jetstream that support such extreme weather events…and a fingerprint of human activity.”

“Dangerous Climate Change in Brazil” was published in April 2011 by the Met Hadley Office and the Brazilian Instituto Nacional. In 2009, record high levels of rainfall followed record low precipitation in 2010 in Amazonia. “The Amazon forest plays a significant role in regulating local, regional and even global climate systems” as noted in the above Met Hadley report. The carbon sink from the Amazon and its oxygen production from photosynthesis sustain both animals and humans. In 2006-2007 in the southeastern Amazon region 10,000 km² of forest was devastated by fires. Large scale deforestation is responsible for warmer and somewhat drier climate conditions by altering regional water cycle. In Chapter one, data from the Observational Carbon Observatory (OCO-2) provide evidence of additional carbon dioxide loss from the Amazon, Africa and South East Asia based on those three regional conditions. Deforestation worldwide is the third largest cause of carbon emissions after energy production and greater than in all of transportation. The long-term projection models from Met Hadley Office and
Brazilian Instituto Nacional confirm that air temperatures would continue to increase; the last 25 years have been the warmest since instrumental measurements were taken. Deforestation, land degradation and increasing use of fossil fuel have altered the natural climate evolution of planet earth. Two hundred years ago our planet from space would have looked quite differently from what we see today from the Arctic to the Antarctic and across many regions. The impacts of global warming are truly global but regional as well.

As cited earlier, Thomas Friedman in Hot, Flat and Crowded, summarizes: “The world has a problem…global warming, the stunning rise of the middle classes all over the world, and rapid population growth have converged in a way that could make our planet dangerously unstable.” Garrett Hardin in his 1968 ‘Tragedy of the Commons’ in Science journal, wrote that “the population problem has no technical solution; it requires a fundamental extension in morality…and the pollution problem is a consequence of population.” Jeremy Berg in ‘Tomorrow’s Earth’ (Science, 29 June, 2018): “Our planet is in a perilous state. The combined effects of climate change, pollution, and loss of biodiversity are putting our health and well-being at risk. Given that human actions are largely responsible for these global problems, humanity must now nudge Earth onto a trajectory toward a more stable, harmonious state. Many of the challenges are daunting, but solutions can be found.” We live in our small niches without realizing how dependent we are on the living and non-living world. Every organism plays an important role in keeping ecosystems and niches in balance; we humans are connected to all creatures large and small, from bacteria to plankton, from corals to krill, from bees to food production, as ‘no man is an island’ should be heeded in our inter-connectedness with nature. Human connection to Nature and Biodiversity has been and always will be our salvation.

**Visionary Leadership Needed**

Reports from the Auditor General of Canada are transparent, credible and provides guidelines while identifying the “weaknesses in how the federal government is managing environmental and sustainability issues…this report identifies a pattern of unclear and uncoordinated actions. This has been aggravated
by the overriding problem of a lack of sustained leadership.” Such leadership was lacking in Ottawa with a reference to the federal government lacking initiatives on environmental matters. Will this government in Ottawa and the provinces move quickly to advance renewable forms of energy like European nations, China and the US? The message of transparency is clearly repeated in other reports such as in the Oil Sands Advisory Panel (www.ec.gc.ca) on what needs to be done for responsible development at the Alberta oil sands. In October 2017, the Commissioner of the Environment and Sustainable Development, Julie Gelfand, wrote “the government has failed to implement successive emissions-reduction plans, and is not prepared to adapt to the life-threatening, economically devastating impacts of a changing climate.”

The Royal Society of Canada (RSC) Expert Panel (www.rsc.ca) puts out credible reports based on science and research that should be read by politicians and the public. The December 2010 extensive Report from the Royal Society of Canada Expert Panel entitled “Environmental and Health Impacts of Canada’s Oil Sands Industry” leaves a great deal for government and industry to digest and for their response. Similarly, the February 2012 RSC Report on “Sustaining Canada’s Marine Biodiversity” was critical of the Department of Fisheries and Oceans in not being more vigilant in promoting and sustaining marine biodiversity and the need to change sections of the Fisheries Act. The Oil Sands Advisory Panel ended its “Concluding Remarks” with this one sentence: “Visionary leadership is required” in reference to our federal politicians from the Prime Minister down to Opposition members in the House of Commons. Reports from the Federal Commissioner of the Environment and Sustainable Development and Auditor General of Canada can be accessed at www.oag-bvg.gc.ca. Several references from the Commissioner of the Environment and Sustainable Development and those listed above are cited throughout this text. Fisheries and Oceans Canada website today provides some useful information and accessed at www.dfo-mpo.gc.ca.

The time is now for a renewed vision on energy production including renewables, economic dependency not solely on fossil fuel as proposed by One Earth, the IPBES and Global Deal for Nature reports as cited in Chapter One. First Nations
pleaded for “our rights, lands, waters, and cultures” and respect for the environment that is being threatened by oil pipelines and tanker traffic. The federal government and the National Energy Board had approved the Enbridge Northern Gateway project with 209 conditions to be met and approved by a previous federal government at the time. Then Prime Minister Trudeau made it clear that tankers will not be allowed on coastal northern BC and was not in favour of the Enbridge Northern Gateway pipeline before he was elected. He was true to his word in rejecting the Enbridge project in 2016 while giving the green light to twinning the Trans Mountain Kinder Morgan pipeline and increase in tanker traffic in Metro Vancouver waters and in Georgia Strait. First Nations including the Inuit in communities throughout Canada are asserting their constitutional rights to protect their lands and waters from any negative impacts to the environment that threaten their survival. Aboriginals have been the true guardians of their territories for thousands of years. The federal government stated that they will consult with First Nations on any major developments that affect their territories.

Reports from *Federal Commissioner of the Environment and Sustainable Development* deal with major environmental considerations throughout Canada and our three surrounding Oceans. The Commissioner in one report stated that “Canada does not have a national plan to ensure that the federal government is ready to respond to major incidents” of oil spills from ships and the readiness of the Canadian Coast Guard to respond appropriately. One report stated that *Environment Canada* “does not know whether the greatest risks to water quality and quantity are being monitored” and is critical of the department for not being more transparent with its monitoring procedures, a reference to water quality at the oil sands projects and the adjacent Athabasca River. *Environment Canada* needs to clarify how it will meet its responsibilities that seems long overdue in the federal monitoring of fresh water throughout the Canadian landscape. It further concludes that parliamentarians and the Canadian public do not know the status of our rivers and lakes and how they are protected and conserved. The government of Canada therefore must have a vision and an action plan based on the Commissioner’s report on water safety, its quality and quantity, not only at the oil sands projects and the Athabasca River but throughout Canada from coast to coast to coast.
Visionary leadership has been lacking by Federal government past and present as expressed by the Royal Society of Canada Expert Panel report some years ago.

As mentioned in Chapter One, oil tankers are presently loaded with Alberta crude oil at the Westridge Terminal in Burnaby, BC, then navigate through the Burrard Inlet, the Georgia Strait and the Salish Sea before entering the Juan de Fuca Strait. Kinder Morgan (KM) would twin the Trans Mountain pipeline to Burnaby, BC, and tanker traffic will increase from 6 to 34 per month. The Trans-Mountain pipeline presently delivers 300,000 barrels per day to supply us with fuel for our vehicles, for air transport and for export; we will continue to need this resource for a few more decades. A second pipeline is being planned to carry 580,000 barrels of Alberta crude per day. Should Canadians risk movement of loaded tankers through Port Metro Vancouver? Safe transit of supertankers in our waters must be a priority. Should we limit the number of tanker transits from 6 to 12 and not 34 per month? Are British Columbians aware of the safety measures that KM have put forward to the NEB and is the federal government satisfied with the conditions from the NEB? If not, can the NEB still advance compromises, for example, in reducing tanker traffic through Port Metro Vancouver and Georgia Strait and the number of storage tanks at the foot of Burnaby Mountain.

By 2020, 3.2 million barrels of bitumen per day would be in pipelines. About 5 million barrels per day would be produced by 2035 according to the Canadian Energy Research Institute. Canada exported conventional crude, synthetic oil and bitumen crude to the US by as much as 2.78 million barrels per day (mbd) in 2014 by rail and pipelines. The Canadian Association of Petroleum Producers (CAPP) projects that Canada would increase its oil production by 43% over the next 15 years or by 5.3 mbd by 2030. CAPP added that “the total Western Canadian supply including diluent volumes expected to reach 6.34 million barrels by 2035 from 4.66 in 2018.” The Keystone XL pipeline may get approval from the US and to deliver close to over 600,000 barrels of bitumen per day. The Climate Action Tracker calculates that “Canada will miss its intended target (Paris Agreement) by a large margin” but only time will tell if GGE could be reduced with the proposed carbon tax and cap and trade with the proposed but contentious Pan-Canadian Framework on Clean Growth and Climate Change.
Turning to Canada’s historical obligations and participation with the UN conferences on climate change as Conference of Parties (COP). In 2007 Parliament passed the Kyoto Protocol Implementation Act to ensure that Canada takes effective and timely action to meet its obligation under the Kyoto Protocol Agreement. As is now known, Canada had since abrogated its responsibility of the signed agreement with the UN Framework Convention on Climate Change (UNFCCC) on the Kyoto Protocol. Former Environment Minister Baird at the COP16 in Cancun, Mexico, did not add anything of substance to see that Canada reduces its GGE but instead wanted to end the Kyoto agreement to follow what the Russians and Japanese were advocating. One year later that plan became a reality in Durban, South Africa (COP17) when Environment Minister Peter Kent announced that Canada will abandon Kyoto. The Government of Canada then said that it believed that climate change will likely have a major impact on the health of Canadians and in all ecosystems but its ability to act in this regard was lacking – visionary leadership was missing in Ottawa and with concrete plans to reduce GGE in the next 10 years. The projected reduction of GHG emissions by 2030 at COP21 in Paris will not materialized (Figure 3.16 B) and noted in Chapter Three - “From Kyoto to Paris and Canada’s Role on Climate Change.”

The Government of Canada under former Prime Minister Harper was not obliged to report on GGE to the UNFCCC since that Canada had abandoned the Kyoto agreement. The Federal Commissioner’s Report on the Environment stated that Canada needs to “develop more effective and efficient ways of managing climate change risks…to adapt to the impacts of a changing climate…” Canadians expect their elected representatives to act on their behalf and not for big oil industry. The former Federal Commissioner, Mr. Scott Vaughan, stated that his job is “to provide objective reports to Parliament…and to provide members of Parliament with the information they need to hold the federal government to account.” Another telling Report by the National Round Table on the Environment and the Economy (www.nrtee-trnee.ca) dealt with the almost forgotten vast region of northern Canada and the Arctic. It addressed the need for adaptive infrastructure from climate change in our ‘True North’.
The Report by the Royal Society of Canada Expert Panel in February 2012 on “Sustaining Canada’s Marine Biodiversity: Responding to the Challenges Posed by Climate Change, Fisheries and Aquaculture” was critical of Fisheries and Oceans Canada. The report states: “We have failed to meet most of our national and international commitments to protect marine biodiversity…Fisheries and Oceans have generally done a poor job of managing fish stocks…We are failing our oceans.” The above reports insinuate or support the view that the Canadian public wants transparency, continued prosperity, improved human health but also environmental security. A National Oceans Protection Plan was established by the federal government in 2016 and designed “to help Canada achieve a world-leading marine safety system for our country’s unique context that will increase the Government of Canada’s capacity to prevent and improve response to marine pollution incidents.”

Another major global resource that must be addressed is the safety of our water for human consumption and health! Everywhere I travelled and worked in Africa, Asia and northern China, the west and southwest USA or in the Middle East where I worked for a short time, I witness a demand for water in agriculture and a lack of safe drinking water for human consumption. In Canada we are fortunate to open our taps and consume water at least in many jurisdictions. The water bottling industry sells us water at much higher prices than gasoline at the pump; bottled water is often not necessary when clean water is readily available in most homes; boiling water from the tap is sometimes recommended in some jurisdictions. Some bottling companies like Nestle take our water from aquifers in the Hope area in BC at a minimum price and makes huge profits. A special issue in the April 2010 National Geographic deals exclusively with water and global implications and worth researching. Maude Barlow’s book, Blue Covenant - The Global Water Crisis and Coming Battle for the Right to Water addresses the state of the world’s water crisis. In Chapter 6 of Barlow’s book, “Is Canada’s Water for Sale?” provides several myths about our beliefs about Canada’s water supply and reminds Canadians that there is “no national leadership” in “protecting the rights of Canadians” regarding this vital resource. We need a national water policy to protect our water resource, safety and supply in Canada. There is a lot more talk from government about oil and gas but little on water. Barlow puts it well by
saying that “our responsibility is to be stewards of this precious resource so it will be here for all generations to come.”

*Canada in a Changing Climate* document added this piece of information: “Canada is considered to have an abundance of water resources with over 8,500 rivers and 2 million lakes covering almost 9% of the total land area. Yet over three quarters of the volume of river flow is to the north, where the density of people and development is sparse. Most watersheds in Canada are influenced by snow accumulation and melt patterns. Maximum snow water equivalent is projected to decline in coastal British Columbia, the Atlantic Provinces and the Great Lakes - St. Lawrence region, while increases are projected for the Arctic coast of Nunavut.” For watersheds that contain glaciers, glacier retreat has already been observed in British Columbia and Alberta and projected to continue as the climate warms. On researching “Water supply and sanitation in Canada” to cite a piece for Metro Vancouver, *Wikipedia* noted “there are three watersheds - the Capilano, Seymour and Coquitlam. Watersheds are the water source for more than two million residents in the most populated urban region of British Columbia. Each watershed supplies about one-third of the region’s tap water. With water restrictions in Metro Vancouver in the past few years we should have the vision to plan for supplies from the glacier fed Harrison Lake to all regions of the Fraser Valley and Metro Vancouver. The Site C Dam in BC has been approved for clean energy (electricity) for the next 100 years and we need to think about water supply also for the next 100 or more years. In July 2019 the BC Ministry of the Environment released its 400+ page report *Preliminary Strategic Climate Risk Assessment for British Columbia* that covers 15 risk events, the top three being water storage, wildfires and heat waves. The report did not go into details of adaptive measures or the science of climate change of events occurring.

2017 Fall Reports of the Commissioner of the Environment and Sustainable Development in “Adapting to the Impacts of Climate Change” concluded that “Environment and Climate Change Canada, in collaboration with other federal partners, did not provide adequate leadership to advance the federal government’s adaptation to climate change impacts. Although the Federal Adaptation Policy Framework and the recent Pan-Canadian Framework on Clean Growth and Climate
Change provided a foundation, there was no action plan nor clear direction to ensure that the federal government would integrate climate change considerations into its own programs, policies, and operations... **Stronger federal leadership is needed.**

Internationally, many nations including Canada and in particular the United States, China and India must rethink their strategy at future UN Conference of Parties to reduce GGE for a sustainable planet. The combined effects of climate change, pollution, and loss of biodiversity are putting people’s health and well-being at risk given that human actions are largely responsible for these global problems. Many of the challenges are daunting, but solutions can be found. “We need to think creatively and use behavioral science to find solutions...though the planet faces daunting problems I believe that action by even a few people can make a significance difference” writes Dylan Selterman in “Greed vs the Common Good” in the June 2018 National Geographic. Visionary leadership is needed by political leaders that could escalate onto others in the public for the common good.

Progress and an awareness of the need to expand on nature and preserve biodiversity are mandatory considerations and advocated by the United Nations, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), One Earth (https://www.leonardodicaprio.org), Global Deal for Nature (https://www.globaldealfornature.org), the IPCC and United Nations. “The health of ecosystems on which we and all other species depend is deteriorating more rapidly than ever. We are eroding the very foundations of our economies, livelihoods, food security, health and quality of life worldwide” a message from Sir Robert Watson, Chair of IPBES. The Living Planet Report 2018: Aiming Higher summarizes: “We are the first generation that has a clear picture of the value of nature and our impact on it. We may be the last that can take action to reverse this trend. From now until 2020 will be a decisive moment in history.”

**Questions**

1) Predict what may likely happen to Earth’s climate and the impact on ecosystems if greenhouse gases keep on rising well above 450 ppm CO₂ from today’s 415
ppm? You may also consider the Arctic or Antarctic regions based on what you have read in this text or elsewhere.

2) Carbon dioxide is a good absorber of long waves unlike oxygen and nitrogen. By how much has Earth warmed since 1880 and what are the likely temperature projections by 2030, 2050 and 2100?

3) Review the graphs in Figures 2.2 B and 2.2 C. What conclusions can you arrive at from the data shown from each graph?

4) What are some of the practical things you could do to reduce your carbon footprint? Brainstorm with others. Suggested references for further study: March 2009 issue of National Geographic, The Pembina Institute, David Suzuki Foundation.

5) How does positive feedback relationship further increase regional or global warming? Provide two examples of how this process operates in the Arctic region.

6) Explain the importance of clouds and aerosols including volcanic activities in regulating global or regional temperatures.

7) Why is the Arctic region of importance to Canadians? What should the Canadian government do to secure its true sovereignty in that region? For further research, refer to the book, Intent For A Nation by Michael Byers and National Geographic May 2009 publication.

8) Define the terms: Ice sheet, ice shelf, moulin, basal sliding. Locate the Antarctic and Arctic on an atlas or National Geographic map. Compare and comment on the size of Antarctica with Canada and continental USA. Locate the Northwest Passage and follow its path and length in the Canadian North. Estimate the length of the Canadian border in the North and compare it with our Southern border to the USA.

9) Why is the thermohaline circulation or AMOC important in climate change? What evidence do we have to indicate that the AMOC is slowing down?

10) Cite the evidence that the climate in the Arctic has been rapidly changing. Compare the three photos from 1979, 2005 and 2012 on the Arctic sea ice extent and changes (see Figures 2.8 A, B & C).

11) Cite the technology and methods being used to identify sea ice thickness and loss in the Arctic?

12) What is the albedo effect? How does it influence Arctic air temperature and Arctic sea ice extent?
13) From the illustrations of the Larsen-B Ice Shelf in this chapter, calculate its size. Carry out an internet search on one piece of research by Mark Serreze at the US National Snow and Ice Data Center on the Arctic. You may also Google his work.

14) Describe the climate and environmental impact brought about by El Nino and La Nina events in the eastern and western equatorial Pacific regions.

15) What evidence was advanced to link climate change with extreme weather events? List as many of these extreme events, locations and projections in the coming years.

16) When an El Nino is in full swing, describe some of the physical changes (conditions that exist) in the west and east equatorial Pacific Ocean region. 

Suggestion: Cite the findings by Gilbert Walker and Jacob Bjerknes in this chapter.


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Chapter 3

The Bumpy Road Ahead

“Our planet is in a perilous state. The combined effects of climate change, pollution, and loss of biodiversity are putting our health and well-being at risk. Given that human actions are largely responsible for these global problems, humanity must now nudge Earth onto a trajectory toward a more stable, harmonious state. Many of the challenges are daunting, but solutions can be found.” Jeremy Berg in “Tomorrow’s Earth” (Science, 29 June, 2018).

“It was always going to be difficult for us – Homo sapiens – to deal with the long-term, slow-burning problems that threaten us today: climate change, population growth, increasing environmental toxicity, and the impact of all these three on the future ability to feed the 11 billion people projected for 2100…Thirty years ago the dire predictions of leading climate scientists were laughed at. Now we watch these predictions coming true and ignore the data or pretend to. So, as the world starts to burn up, we twiddle our thumbs and talk about ‘just another heat wave!’” Jeremy Grantham in “The Race of Our Lives Revisited” (2018) at www.gmo.com

Oil Sands in Alberta - Environmental & Economic

The oil sands projects are historically a key driver of the Canadian energy and economy, creating at the best time over 400,000 jobs, and new businesses especially to Albertans. Alberta’s bitumen is needed to fuel our vehicles and supply aircraft fuel for our airports. “Not all environmental groups want to kill the oil sands” says Simon Dyer of The Pembina Institute. On the contrary, The Pembina Institute and most Canadians want the oil sands to be developed in an environmentally responsible way. However, there is an environmental price to pay for water quality and quantity, accumulation of toxic tailings ponds, threats to wildlife and human health, greenhouse gas emissions, reclamation of land, and excessive use of energy such as natural gas and water to retrieve bitumen in the vast oil sands region of northern Alberta. Information on Canadian oil industry, Oil Sands development, products, revenues and much more can be assessed at Canadian Association of Petroleum Products (CAPP) https://www.capp.ca. For
example, did you know that from one barrel of Alberta’s crude it produces 35% gasoline, 26% diesel and 4% jet fuel? “Canada’s Oil Sands” and “Crude Oil Forecast, markets and Transportation” both published by CAPP carry updates on the industry and recommended for your interest. By 2017, oil sands were producing 2.8 million barrels per day and all crude in Canada including oil sands amount to 4.2 million barrel per day. By 2035, oil sands expected to produce 4.4 million barrels per day.

The uncertainty at the oil sands is based on the global price of oil and from 2104 to the present the price per barrel seems to fluctuate. In his book, The Carbon Bubble, Jeff Rubin gives an accurate account of what happens when the bubble bursts, when the demand for oil drops in the US market, our biggest exporter. The price dropped to around $40 per barrel in 2015 and in January 2016 it was even lower at $31 a barrel. In late 2017 the price per barrel was about $56.00 and in July 2018 it rose to $73.00 per barrel. Rubin summarizes that “the carbon bubble that has pretty much encapsulated the Canadian economy for the better part of the last decade has burst.”

The oil sands lay under 142,000 km² with active mining and in situ process to retrieve deep bitumen deposits. Much has been said by industries, environmentalists and politicians about the oil sands projects of the good, the bad and the ugly. The Royal Society of Canada Expert Panel in its 438-page Report in 2010 stated that “Our governments – federal and provincial – need to show some leadership in not only clearly demonstrating responsibility in how the oil sands are currently being developed and its future, but also to look ahead to a time when the economy based on fossil fuels may no longer be viable.” The Alberta government has initiated policies and guidance to be more responsible in oil sands extraction and with little disturbance to the ecosystem. In November 2015, Premier Rachel Notley announced a reduction GGE with these measures: (1) the phasing out of coal-fired plants by 2030; (2) 30% of Alberta’s power will come from renewables by 2030; (3) imposing a price on carbon emissions at $20/tonne in 2017 and increasing to $30/tonne in 2018 that would increase the price of petroleum products and reduce consumption; gasoline at the pump would increase by 7 cents per litre much like in BC but with plans to assist lower income families; (4)
capping oil sands emissions 25% of Alberta’s GGE, and (5) by 2030 up to 30% of renewables will be on the electrical grid system. The latter plan would reduce GGE to compensate for oil sands development. But then in 2019 Conservative Premier was elected and plans to change a few things including the proposed carbon tax for Alberta.

The October 2011 report of the Commissioner of the Environment and Sustainable Development reminds Canadians that “for over a decade, Environment Canada and Fisheries and Oceans Canada have warned that key environmental information regarding the effects of oil sands projects has been missing….and makes it impossible to understand the combined effects in the lower Athabasca region and on the impact on ecosystems that are farther away, including the wider Mackenzie Basin of the Northwest Territories.” That report emphasized that environmental assessments under the Canadian Environmental Assessment Act should be enforced at an early stage of a major project such as any expansion of oil sands projects, building of highways, pipeline construction or marine port construction, to name a few. “While initial steps have been taken to integrate monitoring results across air, water, and biodiversity components, further work remains to be done to understand cumulative environmental effects of oil sands development. Although Environment Canada plays an important role in its current monitoring, its future role in oil sands monitoring after March 2015 has not been decided” as stated in the 2014 Fall Report of the Commissioner of the Environment and Sustainable Development.

The province of Alberta is the biggest contributor of greenhouse gas emissions in Canada because of its industrialized base, oil sands production and a consumer of coal to generate electricity. Former Premier Notley announced that coal-fired plants in Alberta would be phased out by 2030 and renewables increased to 30 percent; the Premier while promoting the economy from oil sands development has initiated controls on carbon and an advocate on the 2016 Pan-Canadian Framework. Coal worldwide contributed to the highest increase in greenhouse gas of any fossil fuel. China is the biggest contributor of GGE worldwide with 29% global emissions of GHG by 2018, mainly from the combustion of coal; the US is responsible for 15% global emissions and has been lowering emissions more than
Canada. The province of BC has one of the lowest emitters of GGE per capita in Canada (~14 tonnes of CO₂ equivalent) mostly due to hydro-generation of electricity, having no coal consumption for electricity and a small percent from its carbon tax. Both Alberta and Saskatchewan carry a per capita carbon footprint of about 66 tonnes of CO₂ equivalent because of coal use to generate electricity and emissions from the oil sands projects.

Canada’s economy is partly defined by Alberta’s oil sands export to the US, from mining and from other energy-consuming resource industries. **Projections by 2020 will see GGE at the oil sands exceeding 14% of the total emission for Canada according to the Canadian Energy Research Institute (CERI).** The **Canadian Association of Petroleum Producers (CAPP)** estimated that GGE from oil sand in 2015 was around 10 percent of Canada’s emissions. The CERI projects that by 2035 bitumen production is estimated to exceed 5 million barrels per day; these are only projected figures and could likely change for a number of reasons be it economic, environmental or political. In 2016, CERI provided a more plausible view of the oil sands production stating a “projected production volume will

Figure 3.1 Oil Production in Canada in million barrels per day from Western Canadian Sedimentary Basin (WCSB), Eastern Canada and Bitumen (oil sands). Credit National Energy Board 2016.
increase to 3.4 million barrels per day (mbd) by 2020 and 4.8 mbd in 2030, peaking at 5.5 mbd by 2036.” Such data may not be accurate as CAPP seems to cite other projections as mentioned above. Figure 3.1 shows the total Canadian crude oil and equivalent production and projections to 2040 by the *National Energy Board* (NEB).

“Canada is the #6 nation in the world in energy consumption! Because of its large hydro and nuclear power it is #10 in fossil fuel CO₂ emissions. The “cap” approach of the Kyoto and Paris agreements is doomed to failure. We cannot successfully beg each of 200 nations to reduce their emissions. Until we get the fossil fuel price to begin to reflect its costs to society, we are unlikely to solve the problem” as authored by Jim Hansen at Columbia University GISS Centre and data from Figure 3.1 A. The NEB document entitled “Canada’s Energy Future 2016: Energy Supply and Demand Projections to 2040” can be accessed from its website: [neb-one.gc.ca](http://neb-one.gc.ca). Canadians will use and export more bitumen from all forecasts. The majority of future growth is
expected to come from in situ projects, which are smaller in scale than mining projects. In 2015, oil sands mining projects produced over 1.4 million b/d while over 1.4 million b/d came from in situ projects (Figure 3.1). The Pembina Institute noted that the “oil sands can continue to grow but much more slowly under carbon constraints, not the uncontrolled growth we have now.” The oil sands in Alberta are the third largest reserve of fossil fuel in the world, behind Saudi Arabia and Venezuela.

A statement from the NEB Chair & CEO, Peter Watson, regarding Canada’s energy future reads as follows: “One thing that is clear amidst this uncertainty is that the link between energy and the environment is stronger than ever, and will continue to strengthen in the future. This stems from the fact that a majority of greenhouse gases emitted in Canada result from the combustion of fossil fuels and that those fossil fuels provide the vast majority of energy currently used to heat homes and businesses, transport goods and people, and power industrial equipment.” In the document, Canada’s Energy Future 2016: Energy Supply and Demand Projections to 2040 hydrocarbon energy use would continue to increase, which implies increasing GHG emissions.

In April 2011, The Pembina Institute recommended 19 steps toward responsible oil sands development in its report, Solving the Puzzle: Environmental Responsibility in Oilsands Development, and can be downloaded at www.pembina.org. This well-researched document covers five areas for action to be undertaken by the government of Alberta. “It’s time to move away from defending the status quo. It’s time to set higher standards and improve the rules governing oil sands development” as told by The Pembina Institute that published several reports over the years on oil sands development and with solutions for lowering pollution. Two other major reports of significance were published in December 2010 that sent a clear message to industries, to the Canadian Association of Petroleum Producers (CAPP), and to the Federal and Alberta governments. The first one was a comprehensive report by the Royal Society of Canada entitled “Environmental and Health Impacts of Canada’s Oil Sands” published in December 2010 and covers a wide range of issues for industry and government to respond and act upon. The Minister of the Environment then was John Baird and he announced that a “new system will be in place, guided by science and not by politics and public relations.”
The Federal government then seemed ready to act following the message from the scientists who prepared the *Oil Sands Advisory Panel* report. The previous Minister of the Environment, Jim Prentice, had commissioned that Panel to focus on the environmental impact from oil sands development, specifically dealing with water quality and quantity following the research conducted by Alberta’s scientist David Schindler and others who reported the presence of heavy metals and pollutants in the Athabasca River system emanating from oil sands development. *Environment Canada* scientist, David Muir, found pollutants like polycyclic aromatic hydrocarbons (PAHs) from oil sands operations in the bottom of lakes 100 kilometres away! Lakes that are 35 km away reported higher levels of PAHs.

The *Oil Sands Advisory Panel* reported extensively on monitoring water quality and quantity in the mining and exploration regions of all oil sands projects. Following the review of the report from the Panel’s recommendations, Environment Minister Peter Kent (yet another federal Environment Minister) and *Environment Canada* established “the first of several phases in the design of an integrated, comprehensive and holistic monitoring program for the Lower Athabasca system” that will be “scientifically rigorous, adaptive and robust, inclusive and collaborative, transparent and accessible.” The latter plan was to monitor the water quality of the Athabasca River mainstream and major tributaries in the vast region from south of Fort McMurray and to the north to Lake Athabasca and Lake Claire in Wood Buffalo National Park. “Lower Athabasca Water Quality Monitoring Plan” (Phase 1) can be accessed from *Environment Canada* website at [www.ec.gc.ca](http://www.ec.gc.ca). One major question asked was “how much of the contaminants entering and leaving the Athabasca River arise directly from oil sands operations”?

Phase 2 was designed to expand beyond the scope of the Athabasca River to include the entire Athabasca Basin. On February 2012 Environment Minister Peter Kent and his counterpart from Alberta announced a “Joint Canada-Alberta Implementation Plan for Oil Sands Monitoring” with Kent saying that “it is critical we get the development of Canada’s oil sands right” and this plan will provide us with the scientifically rigorous data for oil sands to be developed in an environmentally sustainable way. Perhaps both governments should have been more transparent with the data and procedures already available from documents
such as “Duty Calls: Federal Responsibility in Canada’s Oil Sands” published by the Pembina Institute at www.pembina.org and from Dr. David Schindler’s research on the presence of heavy metals in the Athabasca River.

In January 2013, new research revealed the most conclusive proof that oil sands development in northern Alberta was polluting surrounding lakes. The co-author of that study, Dr. John Smol, at Queen’s University stated “this shows very conclusively that at least in the lakes we looked at, we cannot see any way we can attribute this to natural causes.” Dr. David Schindler cautioned that in his research heavy metals were found in water far from the sites of operations. As mentioned, research in 2013 by Environment Canada conducted by scientist Richard Frank and colleagues found that “oil sands processed-affected groundwater is reaching the river system.” Industry can no longer use the argument that pollution was emanating natural systems but only from processing industrial bitumen. More monitoring and research continue from Phase 2 of the government’s project. Leakage from oil sand tailing ponds covers an area greater than 182 km² and has been an ongoing concern.

Albertans and indeed all Canadians want to see that the vast reserves of oil sands develop in a more responsible way that would do the least harm to the environment or affect the health of people including First Nations; the need to improve reclamation of the disturbed land systems from mining and to reduce toxic tailings ponds are two major priorities. Alberta legislation requires that all disturbed lands must be reclaimed to an equivalent original land capability. Legislation is still needed to protect the water quality and quantity in the Lower Athabasca River and its tributaries. Eric Newell, a former oil executive, cautioned: “If we want to expand oil sands production as planned – and get all those economic benefits for Canada and Alberta – we have to reduce emissions absolutely, not just per barrel.” It seems that industry and government may be making some headway in this regard.

The Canadian Association of Petroleum Producers (CAPP) must be more transparent in reporting environmental problems with the companies that operate at the oil sands on the chemistry and outflow of toxic tailings, wildlife management
including the presence of waterfowl in settling ponds, the presence of heavy metals in rivers and lakes, and to promote carbon capture and storage. CAPP once claimed that the heavy metals and runoff are the result from “natural runoff” from the oil sands and from natural bitumen into the Athabasca River. “It is reasonable to assume that toxic bitumen has always naturally leached into surface water” suggests the Oil Sands Advisory Panel. CAPP spends millions of dollars in advertising that portrays the “good” side and gives the impression that all is well at the Oil/Tar Sands projects; some advertisements are for public relations consumption and are quite misleading. I recall a few years ago on a full-page advertisement that circulated in Canadian newspapers with CAPP portraying one biologist (her name given was Megan Blampin) and saying that it is her “job to understand the chemistry of the lakes and streams around our oil sands drilling site, so we don’t affect it. It’s a matter of frequently collecting samples…” That is completely false advertising; it is impossible for anyone one biologist to do that impossible job of testing and monitoring the water in the rivers, lakes and streams in such an extensive region. A research team of dozens or more scientists will be needed for many years. CAPP did not answer two of my emails when I asked for their biologist’s findings and an explanation about their advertisement.

CAPP and government need to be guided by the reports of the Oil Sands Advisory Panel, the Royal Society of Canada Expert Panel, the Commissioner of the Environment and Sustainable Development and The Pembina Institute. We must be guided by science as former Prime Minister Harper spoke about in one of his public relations speeches but little action was forthcoming having little regard for the science in muzzling government scientists. The findings released by Dr. Schindler and others finally got government’s attention on water pollution; the then Environment Minister Jim Prentice did act when he met with Dr. Schindler who discussed his findings of heavy metals in water far removed from oil sands operations.

The Royal Society of Canada noted that “the (previous) Government of Alberta has a government-wide portal on its website to address oil sands operations, but the current content is largely public relations documents regarding the industry.” The environmental impact cannot be over stated and greater responsibility is needed;
disclosure of the impacts would emerge once the research on water quality monitoring plan is complete; air quality is another concern as well. The public and international interests would be better served with transparency. One advertisement that appeared in the *Vancouver Sun* newspaper from Syncrude Canada and CAPP claims that “new equipment installed at our Mildred Lake facility will help reduce total emissions of sulfur compounds by 50%...” Canadians want environmental stewardship at the oil sands projects for the recovery and delivery of crude across Canada and to the United States for the prosperity of all Canadians. Pipelines across sensitive ecosystems and territories of First Nations both in Canada and in the US are still ongoing considerations.

Companies that operate at the oil sands are required to return disturbed land to equivalent land capability status but reclamation to its original state is almost impossible in any reasonable period of time; *reclamation* of disturbed land from mining the oil sands to its former state is not an easy task but credit to oil companies that spend millions of dollars in an attempt to do so, and by Alberta’s law they must comply. “In more than 40 years of oil sands operations less than 0.2% of disturbed lands are certified as reclaimed” says *The Pembina Institute* that contradicts the CAPP advertisements on its “reclamation claims”. CAPP claims that 65 km² have been reclaimed. The *Alberta Environmental Protection and Enhancement Act* states that post-mining landscapes must be reclaimed to an “equivalent land capability.” In 2008, Syncrude Canada received a reclamation certificate for 104 hectares of land known as Gateway Hill about 35 km north of Fort McMurray. The Gateway project did not contain tailings but was a mined boreal forest. In one Suncor advertisement in January 2011, the company claimed that “1,182 hectares of land reclaimed to date and 3.5 million trees planted since 1967.” Suncor’s Pond One was reclaimed to solid surface and undergone reclamation certification. Prior to mining, rivers and streams were being diverted, timber harvested, the debris are piled and burned. Wetlands are drained and excavated but the topsoil was being salvaged for land reclamation; wetland and storage pond reclamation are most difficult to restore to an original state. The Alberta government has been bearing some of the costs on land reclamation.
Andrew Nikiforuk who has written extensively on the oil sands fears that “we have become a petrostate without any of the safeguards that a petrostate should have.” Oil wealth in most countries seems to hinder democracy; this practice is evident in the Middle East and Persian Gulf countries. The previous Conservative government of Alberta was not aggressive on environmental stewardship prior to the administration of Premier Rachel Notley. So too was the federal Conservative government under Prime Minister Harper until the wakeup call for action by the reports from scientists like Dr. David Schindler on water pollution, and from the reports of Oil Sands Advisory Panel and Royal Society of Canada. John Dernbach in his book, Sustainable Development and the United States, summarizes that “when projects and activities pollute or otherwise hurt the environment, they almost always harm other people sooner or later. Similarly, when we make serious progress toward a sustainable society, we will make ourselves and future generations better off.”
These images (Figure 3.1 B) from Landsat satellites show the growth of surface mines over the Athabasca oil sands between 1984 and 2016. The Athabasca River shown runs through the center of the projects, separating two major operations. To extract the oil at these locations, oil producers remove the sand in big, open-pit mines, which are tan and irregularly shaped. The sand is rinsed with hot water to separate the oil, and then the sand and wastewater are stored in tailings ponds, indicated by smooth tan or light green surfaces in the Landsat satellite images. In July 2018, Bob Weber in Canadian Press reported that the director of sustainability for the Fort McKay First Nation - a community surrounded by oilsands developments (Figure 3.1 C) - said he doesn't understand how the Alberta Energy Regulator can say it's going to enforce one thing, then allow industry to do something else. “The challenge is what to do with 1.3 trillion litres of toxic tailings that have been accumulating since oilsands mining started more than 50 years ago. The tailings water holds minuscule particles of chemically tainted silt. Industry has been
working to find a way to deal with that $27 billion cleanup without ultimate success. Nobody has a proven, acceptable way to get these tailings ponds ready to reclaim,” said Mark Taylor, the regulator's vice-president of operations.

Figure 3.1 C. Map showing major oil sands projects and three Communities in the region provided by Oilsands Developers Group.

To recall, CAPP once reported that “over several decades of monitoring (the Athabasca River) there has been no significant change in water quality… no increase in concentrations of contaminants and …that contaminant sources in the area are natural.” CAPP should retract that statement based on the science that was advanced. The Tar Island Dyke impoundment at the Suncor site consists of permeable sand to low permeability clay. “In 2007, total discharge from Suncor’s wastewater pond system was 11.9 billion litres” into the Athabasca River according to research by Kevin Timoney of Treeline Ecological Research. At Syncrude’s Mildred Lake Settling Basin water samples collected showed that
wastewater reached Lower Beaver Creek. *Environmental Defence* estimates that oil sands process of wastewater from tailings is leaking at a rate of 11 million litres per day. As mentioned, University of Alberta researchers Erin Kelly and David Schindler in 2010 discovered levels of heavy metals such as cadmium, copper, lead, mercury, nickel, silver and zinc in water and snow near or downstream far from oil sands development and exceeding federal and provincial guidelines for the protection of aquatic life. The researchers took samples of water upstream and downstream within 50 km of the oil sands projects and in undeveloped oil sands sites. The pollution in the Athabasca River of heavy metals that exceeded government guidelines did not originate for natural runoff as claimed by CAPP and industries but directly from the operations of industries.

As mentioned, the *Oil Sands Advisory Panel* Report was published in December 2010. “All of the federal leaders are saying that we need to do a better job at managing the oil sands but very little seems to be done…if the federal government fails to live up to its legal and constitutional duties in the oil sands, it opens up itself to ongoing court challenges regarding oil sands development…” according to Rick Smith, Executive Director of *Environmental Defence*. The then Minister of the Environment, Peter Kent, followed up on the *Phase One* proposed water quality monitoring program for the Lower Athabasca River. As mentioned, a new oil sands implementation plan between Ottawa and Alberta was being advanced and implemented in 2015.

The oil sands projects and operations are extensive with several big oil companies extracting the tarry substance that is processed into heavy crude. Upgraders that operate at the mining sites crack the tarry bitumen and convert it into synthetic crude that travels down the pipeline mixed with a diluent (dilbit) to refineries in Edmonton and elsewhere; in 2016, about 45% of bitumen was upgraded or partially refined. Bitumen is a sticky, tar-like mixture of highly condensed polycyclic hydrocarbons containing many organic constituents. Upgraders reduce the density, viscosity and molecular weight, and increase the ratio of hydrogen to carbon, thereby increasing the market value of bitumen as crude oil. The oil companies found that it was cheaper to dilute bitumen (known as dilbit) with a condensate for pipeline transport and do less of the costly upgrading. A vast
amount of water and natural gas is used to produce that crude by \textit{in situ} means and with higher GGE than from conventional oil production. CAPP in 2018 stated that 2.51 barrels of water are used for every barrel of bitumen from mining while \textit{in situ} method uses 0.21 barrels of water for every barrel of bitumen. \textit{National Geographic} reported that “hydrogeologists at the University of Waterloo estimated that 45,000 gallons a day of contaminated water could be reaching the river” to process the bitumen.

About 40\% the City of Toronto’s water consumption for the year is being used by the oil sands operations; that works out to be 158 million cubic metres used to extract bitumen. \textit{Environment Canada} estimated some years ago that Tar Sands release of benzene was about 100 tonnes per year. In “Turning the Corner” \textit{Environment Canada} stated that “we have a responsibility to future generations to ensure that they (oil sands projects) are developed in an environmentally responsible way…and to meet tough new emission standard…” These words and that message coming a few years ago from former Environment Minister John Baird seem to have empty meaning as no tough emissions’ standards or regulations had yet to be in place in spite of all the talk. Reports in \textit{National Geographic}, \textit{Canadian Geographic} and \textit{The Pembina Institute}, the \textit{Royal Canadian Society} and the \textit{Oil Sands Advisory Panel} all promote tougher environmental standards.

The Mikisew Cree First Nation is concerned about water pollution in their territory. The health of the Chipewyan residents was being investigated as well as decline of caribou herds and other species in their region. There are concerns about low water levels affecting the livelihood of aboriginal hunting, fishing, and trapping. Treaty rights are a federal responsibility and the oil sands use of the Athabasca River may affect some treaty rights. “Alberta’s Toxic Tar Sands: The Most Destructive Project on Earth” published in 2008 by the \textit{Environmental Defence} organization based in Ontario claims that toxic pollution is now found in fish having “tumours and mutations from rising levels of mercury, arsenic and polycyclic aromatic hydrocarbons.” In September 2010, it was reported that whitefish caught in Lake Athabasca had tumours, some having no snout and reduced fins. (Dr. David Schindler, the scientist who investigated heavy metals in water, was shown in one photo holding one of those deformed fish). Some
chemicals or combination thereof in bitumen may be causing those deformities. Research by Drs. Kevin Timoney and Peter Lee published in the *Open Conservation Biology Journal* deserves attention on investigating the extent of pollutants affecting ecosystems and public health. Their findings also noted that levels of contaminants from industries are known to be hazardous to fish and humans. Pollution from the washed tailings enters groundwater and likely seep into the Athabasca River and downstream. One cannot argue that the oil sands project may not necessarily be the most environmentally destructive but it gives that impression from the extensive operations, high air pollution indices, contaminants in water downstream from industries, high energy use to extract bitumen, and the vast toxic lakes.

During the last decade, the downstream community of Fort Chipewyan documented cases of rare cancers. Fort Chipewyan has a population of about 1,200 so there is cause for alarm with a higher number of cancer cases in such a small population. The *Alberta Cancer Board* stated that there was a three-fold increase in leukemia and lymphoma and a seven-fold increase in bile duct cancer possibly linking to petroleum and polycyclic aromatic hydrocarbons; cancers could also be due to chance and/or increased detection of increased risk in the community. “The cancer rate overall was higher than expected” according to the *Royal Society of Canada* in its 2010 Report but they fall short in linking pollutants and the incidence of cancers in Fort Chipewyan. Dr. John O’Connor has been treating First Nations for several years also reported abnormally high rates of rare forms of cancers in Fort Chipewyan. Another physician, Dr. Esther Tailfeathers, treating patients in 2014 at Fort Chip also commented on suspiciously high cancer rates there.

On April 28, 2008, a flock of ducks landed in what they thought was an inviting pond. Unfortunately, the pond was a settling basin (Aurora tailings) of Syncrude’s toxic wastes; a report of “500 ducks” perished from the toxic chemicals and from hydrocarbon residues that float on the surface. That number was later revised to 1,606 dead ducks. Syncrude Canada was faced with provincial environmental charges from the deaths of waterfowl under the Alberta *Environmental Protection Enhancement Act*. In June of 2010, Syncrude was found guilty of depositing “a
harmful substance” in waters or in an area frequented by migratory birds, and on October 22, 2010, Syncrude was fined $3.2 million, the biggest environmental fine handed down in Canadian history. The proceeds of that fine went to avian research and waterfowl habitat conservation. More ducks landed on November 1, 2010, and many more will need a place to transit. “Syncrude Canada is facing two new federal charges for allegedly destroying or disturbing a nest or egg, following the deaths of 31 great blue herons in August 2015. The oilsands company has been charged with two counts under the Migratory Bird Convention Act for allegedly depositing, or allowing the deposit of, a substance harmful to migratory birds into waters frequented by them” as reported in the Calgary Herald in November 2017. Alberta Energy Regulator also charged Syncrude for allegedly “failing to store a hazardous substance in a manner that ensures that it does not come into direct contact with, or contaminate, animals.” The Field Museum in Chicago conducted a study on bird migration and stated that the Alberta Mines in the boreal forests affect some 300 species of birds including the blackpoll warbler and whooping crane; the oil sands development and lack of safety threaten migratory bird population not to mention water quality, air pollution, other wildlife, and the health of First Nations downstream.

The current practice of protecting waterfowl from the lethal risks posed with tailings ponds is inadequate. Installed in ponds are radars that scan for incoming birds and fake falcons that flap their wings to scare off waterfowl. Toxic tailings are produced at a rate of 1.8 billion litres a day and cover an area of more than 182 km², an area greater than the size of the City of Vancouver; future settling pond operations are planned that would expand to an area of 220 km². In the meantime, the oilsands’ tailings ponds have grown so massive they impound a globally unprecedented 1.3 trillion litres of toxic waste according to a 2017 release from the Pembina Institute. Open tailings ponds now cover over 250 square kilometres of the northern Alberta landscape, an area equivalent to 62 Stanley Parks in Vancouver. Companies like Suncor have developed a “Tailings Reduction Operation” technology by adding a polymer solution to the tailings to quickly advance the drying process from years to weeks. The accompanying photos were obtained from Suncor Canada (Figure 3.2 B & C). Oil companies have leased over
Figure 3.2. Tailings ponds consisting of toxic chemicals and hydrocarbons north of the Syncrude facility and upgrader. Photo credit by David Dodge, The Pembina Institute (www.pembina.org).

Figures 3.2 B & C. Left (B) shows TRO with polymer solution being added and C (right) shows drying of tailings weeks after adding the polymer solution. Permission by Suncor Canada.

4,800 km² of boreal forest in the region and prospectors have already staked an extensive area of the forest that stores the hydrocarbons. About 80,000 km² have been leased for in situ deep underground retrieval of bitumen; about half of the oil produced today comes from in situ drilling and the rest from mining. In situ in future would be used in 80% of the oil sands as claimed by industry but with a high
energy price to retrieve bitumen. About 25 cubic metres of natural gas and 0.4 barrels of water are needed to produce one barrel of bitumen from in situ according to the National Energy Board. CAPP has revised water use to be 0.21 barrel for each barrel of bitumen.

The current area disturbed by oil sands at the time of writing is about 715 km$^2$ according to CAPP. By 2007 oil sands companies had mined over 470 km$^2$ of the boreal forest but only a fraction of mined land was reclaimed to any stable state. As mentioned, CAPP claims that 65 km$^2$ have been reclaimed by 2010 from mining. Suncor Energy Pond One is undergone reclamation more than 40 years later; in 2010 Suncor reported that the pond had achieved a “solid surface.” Suncor now treats fine tailings with a common waste-water treatment chemical known as polyacrylamide so that tailings could settle more rapidly (Figures 3.2 B & C).

Figure 3.2 D. The above photo (right) shows mining at Syncrude’s Mildred Lake operations in the 1980s. The photo (left) in 2010 shows reclamation in progress from that mining site. Permission by Syncrude Canada.

A Canadian Geographic report entitled “Scar Sands” and researched by Curtis Gillespie illustrates “mismanagement” of the boreal forests by the oil companies that operate there. Separating the bitumen from sand produces massive volumes of toxic tailings mixed with an enormous volume of water drawn from the Athabasca
River. Water from the Athabasca River is used to flush the tailings consisting of naphthenic acids, polycyclic aromatic hydrocarbons, heavy metals (lead, mercury, cadmium, copper, zinc), and fine clay that resemble watery porridge. There is concern that the walls (dykes) from those ponds could break from tornadoes that are known to hit the region periodically. Groundwater seeps ever so slowly and closer monitoring of ground water seepage is needed. The Royal Society of Canada in its Report stated that there is a need to study the long-term effects of ground water as well as land reclamation “beyond what is currently evident in published research.”

A procession of Caterpillar 797B heavy haulers, the world’s biggest trucks, each costing four million dollars and weighing about 650 tonnes carry 400 tonnes of the oily sand from mining sites; about 35,000 tonnes of the oily sand are mined each day that would produce about 17,000 barrels of heavy crude. Giant shovels five stories high dig the bitumen-laced sand from the bottom of those mines (Figure 3.3). The boreal forests are stripped bare and a landscape is erased, a terrain stretching hundreds of square kilometre in area. Reclamation takes more than 40 years to an acceptable level but not to its original state. To extract one barrel of crude from the deforested area, two tons of peat and dirt above the oil sand must be first removed, then two tonnes of sand are excavated. it takes 2.5 barrels of water to produce one barrel of bitumen from mining process according to CAPP. “The overall amount of water used by companies is currently estimated to be about 200 million cubic metres. That volume of water is the equivalent to about 40 percent of the yearly water consumption of the City of Toronto” writes Gillespie in Canadian Geographic. CAPP claims that “over 80% of the water we use is recycled.” In 2015 from mining of oil sands produced over 1.0 million barrels per day. Updates on mining and in situ are published by CAPP and CERI.
As mentioned, the *in situ* method used to process bitumen is steam assisted that consumes an enormous amount of natural gas; gravity drainage of the bitumen is then pumped to the surface from deep underground. Oil sands buried more than 100 - 150 metres underground employ this method as mining deep underground is uneconomical. The bitumen is heated by steam generated at 300 – 340 °C temperature and injected deep into the oil sands formation. Each oil well from steam assisted gravity drainage produces about 1,000 barrels each day. There is “less pollution of water and less GGE” from this method in a CAPP report. With so much energy needed to produce steam GGE should be higher and is not calculated as emissions by CAPP. The companies claim that *in situ* drilling and extraction of bitumen deep underground is cleaner but GGE and SO₂ emissions are higher than from mining. “As the era of surface mining draws to a close, oil sands operations will become dominated by *in situ* projects” as reported by the *Oil Sands Advisory Panel* but mining is expected to continue for another 10 to 20 years. In 2015 *in situ* projects generated over 1.3 million barrels of crude per day.
Andrew Nikiforuk concluded that “to mine or steam the bitumen, the tar sands industry burns enough natural gas every day to heat four million homes.” Each barrel of oil extracted from the oil sands emits “between 3.5 to 4.5 times higher greenhouse gas per barrel than conventional crude oil produced in Canada” according to *The Pembina Institute*. Nine upgraders are expected to be operating between 2015 and 2020 but many may be put on hold because of the huge costs to build and with lower price of oil; it is cheaper to dilute bitumen with a condensate for pipeline transport. Those planned and operational upgraders consume about ten times the amount of water that the City of Edmonton uses, require as much natural gas as all of the households in Edmonton, use more electricity than all of the households in Edmonton, and will produce about 45 megatonnes of greenhouse gases, emissions equivalent to 10 million vehicles. The cost is high and companies are reluctant to build more Upgraders.

Shell-owned facility near Fort Saskatchewan plans to remove 1.2 million tonnes of CO₂ per year. Royal Dutch Shell says that it will begin to test the possibility of carbon capture and storage (CCS) from its Scotford Upgrader near Fort Saskatchewan in Alberta. It will take many more years before CCS projects become operational in spite of what the oil companies and the government promise. Another site that is being planned as a repository for carbon is in the mature oilfields near the city of Red Deer, Alberta, about 240 km from the North West Upgrading facility. Enhance Energy in Alberta is planning to embark on a CCS project - carbon dioxide injected into depleted oil reservoirs that result in recovery of oil. The Alberta Government has committed $1.24 billion over 15 years to two commercial-scale carbon capture and storage projects. The two projects are moving forward to help reduce the CO₂ emissions from the oil sands and fertilizer sectors. When both projects are completed, they will reduce Alberta's greenhouse gas emissions by 2.76 million tonnes each year. This is equivalent to the yearly emissions of 600,000 vehicles.

The record of oil spills is not without incidents over the years; one major Enbridge spill of 20,000 barrels of dilbit occurred in Marshall, Michigan in the Kalamazoo River in 2010. The US *National Transportation Safety Board* severely criticized Enbridge for the accident that could have been prevented had safety measures been
enacted at the Edmonton Computer Centre or from a corrosive pipeline that needed repairing. The Canadian Commissioner’s Report in 2010 on the risks of oil spills from vessels stated that “Canada still does not have a national plan to ensure the federal government is ready to respond to major incidents. Canada lacks a formal framework with clearly defined roles and responsibilities for responding to chemical spills…and emergency management plans for the Canadian Coast Guard and Environment Canada are out of date.”

Cited below are ten major projects and initiatives, albeit incomplete, that the oil sands companies and governments should undertake to reduce environmental pollution and the amazing thing is that all of these are achievable according to the research. These include: (1) carbon capture and storage, (2) reduce the creation of liquid toxic tailings, (3) reduce the overall water usage, (4) clamp down on the level of acidifying emissions, (5) restore the oil-sands mines to a functioning boreal forest as rapidly as possible, (6) set a cap for total disturbance area, (7) require environmental compensation to offset mining impacts, (8) establish large areas of boreal forest that are off limits, (9) monitor closely the quality and quantity of water in the Athabasca River system and some of the tributaries that flow through oil sands, and (10) show complete transparency in all reports and enact legislation where and when necessary to prevent environmental violations. The elaborate and comprehensive report produced by The Pembina Institute in April 2011 on “Solving the Puzzle – Environmental Responsibility in Oilsands Development” is meant to improve on the rules governing oil sands development for the prosperity of all Canadians. All of the above is expensive and with the price of bitumen companies are not rushing to satisfy those requirements.

The Oil Sands Advisory Panel’s key statement reads: “A credible, trusted monitoring system be founded on accepted scientific principles, most prominently a continuous and independent peer review of results. Policies and decisions are influenced by many considerations, but in environmental matters, science is central. A science culture will ensure the integrity of the system. A system respected by scientists would give evidence of the use of robust indicators and consistent methodology and peer review resulting in independent, objective, complete, reliable, verifiable and replicable data…” As Canadians we must do a
better job in protecting the environment while improving the economy; the
technology exists to reduce the ongoing pollution in our land, rivers, lakes and the
atmosphere throughout Canada but human behaviour needs attention. The
*Canadian Biodiversity Strategy* reaffirms that in Canada “governments must create
the policy and research conditions that will lead to the conservation of biodiversity
and sustainable use of biological resources.” The *Royal Society of Canada* found
little evidence that implementation of meaningful improvements has begun or will
be achieved in an adequately rapid time frame. The Alberta government in 2015
announced the reduction of GGE and transitioning to renewables in that province;
at the start of this chapter a more detailed account of the (former) Alberta
Premier’s intended plan was highlighted. The Federal and Alberta governments
must take the necessary steps to see that Alberta develops its oil industry for
the prosperity of all Canadians in a responsible way.

**Oil Pipelines to British Columbia & the Controversy Wages On**

The Enbridge Northern Gateway pipeline was *rejected* by the Government of
Canada. In 2013, another pipeline project was submitted by Trans Mountain
Kinder Morgan to the National Energy Board to twin its pipeline from
Edmonton, Alberta to Burnaby, BC. In 2016, Prime Minister Trudeau gave the
green light for the twinning of Trans Mountain Kinder Morgan pipeline
among protests from some First Nations, the NDP government in BC, and some
municipal and city politicians, notably the Cities of Vancouver and Burnaby. On
May 2018, the Prime Minister of Canada upon pressure from Kinder Morgan
(KM) to abandon the project decided to purchase the pipeline for $4.5 billion
and now owned by Canadian taxpayers

However, a new twist emerged in the ongoing KM dispute. On August 30,
2018 the Federal Court of Appeal in the decision written by Justice Eleanor
Dawson, the court found the National Energy Board's (NEB) assessment of
the Trans Mountain Extension pipeline was so flawed that it should not have
been relied on by the federal cabinet when it gave final approval to proceed in
November 2016. Federal Court of Appeal ruling noted that Canada fell ‘well short’ of its duty to consult First Nations and on environmental regulations based on tanker transit and wildlife such as killer whales in the Salish Sea. When the NEB reconsiders its recommendation to approve the Trans Mountain Pipeline expansion, it could include new rules for tanker traffic, spill response and protection of endangered orcas.

The **Energy East Trans Canada** project was to be a 4,500 km pipeline to transport about 1.1 million barrels of oil per day from Alberta and Saskatchewan to the refineries of Eastern Canada and with a marine terminal in New Brunswick; the estimated cost was $15 billion but **Trans Canada Corporation decided to scrap the project in 2017 with opposition in some regions of Quebec.** Some argue that the NEB and the Federal government had put restrictions that included greenhouse gas emissions and climate change as part of the review as ‘new rules’. Federal politicians argue that it was a “business decision by Trans Canada and not the NEBs new rules.” Crude oil from OPEC countries and the USA (yes, we import oil from the US as well) deliver over 650,000 barrels every day to the Maritimes and Quebec. Without the Energy East pipeline Canadians will continue to import oil to eastern Canada.

![TransCanada Energy East Pipeline Project](image)

**Figure 3.4** The proposed and abandoned 4,500 km Trans Canada Energy East Pipeline to transport 1.1 million barrels of crude per day. Credit to NEB.
There have been growing opposition to the Keystone XL pipeline but not from US Republicans or former Prime Minister Harper. **In November 2015, President Obama rejected Keystone XL** based on three key issues: (1) to improve climate change that dirty Canadian oil presents; (2) it is not a long-term contribution to the US economy; (3) lower gas prices with more oil reserves in the US, were some reasons given. [The US has been leading by example in fighting climate change and a commitment prior to the UN conference in Paris in November 2015 with its Intended Nationally Determined Contributions (INDC) that exceeded that of Canada and discussed later]. President Trump and US Congress then gave approval to build the Keystone XL pipeline but a few hurdles remain with pipeline safety on aquifers in Nebraska. At the time of writing work has not started on that pipeline and modifications were made by Trans Canada.

According to the *Canadian Energy Research Institute* (CERI) based in Calgary more than 3.4 million barrels of pipeline capacity per day is available for export to Canadian and US markets; oil sands operations produced 1.7 million barrels of crude per day by the end of 2011 so pipelines are not delivering to full capacity. The Canadian Association of Petroleum Products (CAPP) forecasts that by 2020 and 2025 oil sands production would grow from 3.2 to 3.7 million barrels per day. “Production of bitumen is expected to increase to 5 million barrels per day by 2035 and GGE would escalate to 232% from 2009 level” according to the CERI report. **All those predictions are just what they are as the price of oil, its demand, its mode of transport by rail or pipelines, and holding down GHG (from the COP21 Paris Agreement) play into the final decision by the federal government.**

The federal government has a duty to consult First Nations on any resource development that passes through or resides in their territory. This was not done to the satisfaction of First Nations prior to or after Enbridge’s application. In 2014, the then Chief Justice Beverley McLachlin and the Supreme Court of Canada ruled that “all territory in question should fall under their ownership…holds exclusive right to decide how the land is used and the right to benefit from those uses.” The Supreme Court has given First Nations the right to negotiate with
industry in that ruling. The proposed Kinder Morgan pipeline also includes discussions with First nations for approval.

The following three reports on transporting bitumen have been well researched: “Vessel Traffic Risk Assessment (VTRA) – Preventing Oil spills from Large Ships and Barges in Northern Puget Sound & the Strait of Juan de Fuca” by George Washington University for the Puget Sound Partnership. The other well documented Canadian report: “A Review of Canada’s Ship-Source Oil Spill Preparedness and Response Regime – Setting the Course for the Future” was prepared for the Transport Canada by Maritime experts. Another report emerged from Resource Works in Vancouver that compiles several sources and a recommended document, entitled “Citizens Guide to Tanker Safety & Spill Response in British Columbia’s South Coast” published in May 2018. The latter three reports advise caution and cite several reviews from maritime experts that hold true for tankers transiting from Westridge Terminal in Burnaby through Vancouver Harbour, English Bay and the Salish Sea. Kinder Morgan expects to twin the Trans Mountain pipeline and bring an additional 500,000 barrels of bitumen per day to the Westridge Terminal storage tanks for tanker shipping. As mentioned, the latter project was approved in 2016 by the Government of Canada but rejected by the Federal Appeal Court ruling in 2018.

A revised cost of $7.4 billion to build the twin pipeline, tank farms and marine terminal. Aframax tankers now load about 600,000 barrels of oil sands crude from the Kinder-Morgan Burrard Inlet Westridge Terminal in Port Metro Vancouver each week. Presently about 6 tankers per month pass through the Vancouver Harbour under the entrances to the First and Second Narrows, through the Strait of Georgia and the Salish Sea around the Gulf and San Juan Islands to Juan de Fuca Strait (Figure 3.7) The two narrow passageways are transit challenges under the
Figure 3.5 Tanker Transit under Second Narrows Bridge in Vancouver. Photo Credit to CBC.

Figure 3.6. Kinder Morgan Twinning Pipeline Route from Edmonton, Alberta to Burnaby, BC.
two bridges (Figure 3.5 - First Narrows bridge) in Vancouver Harbour and tankers must follow very strict rules by *Port Metro Vancouver, Transport Canada* and by Kinder Morgan’s new regulations itself. Fog and windy conditions are frequent in these waters and pose a threat if movement of oil tankers. All Canadians, not only Vancouver residents, are worried if a tanker becomes grounded or an accident were to happen releasing thousands of barrels of bitumen. In the year 2009, 3.9 million tonnes of crude oil were shipped in 65 Aframax tankers from Burrard Inlet at the Westridge Terminal to Salish Sea without an incident. Trans Mountain confirmed that there were 43 tankers loaded with crude from Westridge in 2018 – 14 went to Asia, and 29 to the US.

![Routing of tanker transit from Burnaby onto Juan de Fuca Strait. Credit Kinder Morgan.](image)

The proposed pipeline (Figure 3.6) would transport 580,000 barrels per day in a new 987 kilometre route and a total of 630,000 barrels per day will be delivered to the Westridge Terminal in Burnaby from the two pipelines. Simon Fraser University and the City of Burnaby submitted their reports to the National Energy Board (NEB) on the risks of the 14 new crude oil storage tanks. The Burnaby Fire
Department has published a damning report on Kinder Morgan's new tank farm, warning that the proposed expansion could put the public and the environment at serious risk. The report outlines a number of worst-case-scenarios for the Burnaby Mountain tank farm facility, including earthquakes, flammable crude leaks, poisonous gases, fires burning for days and exploding tanks that spray molten crude, igniting other nearby tanks.

Figure 3.8. Existing Tank Farm on Burnaby Mountain. Kinder Morgan is proposing to triple tank capacity at the Burnaby Mountain tank farm. Photograph by Jennifer Moreau.

Kinder Morgan’s risk assessment for the Burnaby Mountain tank farm contains serious deficiencies, and “the proposed expansion would not pass muster in the U.K” according to an expert hired by the City of Burnaby. Consultants founder Ivan Vince, a chemist, engineer and scientist specializing in industrial hazards authored a report on Kinder Morgan’s proposed expansion for the tank farm. Vince said that “the application for expanding the Burnaby terminal would, in my opinion, have failed in the U.K. and, in all probability, throughout the EU.” The cost of damage to ecosystems is difficult to quantify and may run in the billions of dollars. Recall the one spill of 20,000 barrels in Kalamazoo cost just under one billion dollars and cleanup continued until 2014, four years later.
Enbridge, Trans Canada and Kinder Morgan Trans Mountain pipelines have long transported crude oil to the US and across Canada for decades. Kinder Morgan Trans Mountain present pipeline capacity carries 300,000 barrels a day to the Westridge Terminal in Burnaby, BC. The smaller Aframax tankers (245 metres in length) presently carry crude from Port Metro Vancouver and supported by pilotage under strict Canadian regulations; marine conditions in the Vancouver Harbour and onto the Salish Sea are not as severe as in northern BC between Haida Gwaii and Kitimat but extreme caution is still needed. Any additional tanker traffic at Port Metro Vancouver from the present may not be welcome as voiced by the (former) Mayors of the cities of Vancouver and Burnaby and local residents.

Many environmentalists and some Municipalities in British Columbians believe that the process on Trans Mountain Kinder Morgan (TMKM) Hearings by the NEB was flawed since Intervenors could not cross-examine the proponent. Intervenors complained that many of the questions submitted were not answered or simply ignored. The NEB also decided to exclude the public from any open forum at the Hearings. The government of Canada purchased the assets of KM for $4.5 billion dollars as KM saw that it was no longer financially viable. There is no word on how the project would continue amidst the ongoing protests from the BC government, Cities of Vancouver and Burnaby, some First Nations and the general public in BC. The latest news as mentioned, the Federal Court of Appeal has nullified the KM project.

In my opinion, not all relevant sources were reviewed and discussed by the NEB. For example, the Vessel Traffic Risk Assessment (VTRA) prepared by George Washington University for the Washington State Department of Ecology and Puget Sound Partnership entitled: “VTRA 2015 FINAL REPORT UPDATING THE VTRA 2010 - A Potential Oil Loss Comparison of Scenario Analyses by four Spill Size Categories” was published in January 2017. A second document published in 2013 by the Government of Canada and Tanker Safety Panel Secretariat for Transport Canada entitled: “A REVIEW OF CANADA’S SHIP-SOURCE OIL SPILL PREPAREDNESS AND RESPONSE REGIME - Setting the Course for the Future” is of importance but never considered at the Hearings. Transparency seems to be
missing with the NEB’s decisions while a number of Intervenors did not have the opportunity to participate.

We need workable alternatives for Kinder Morgan Trans Mountain pipeline now owned by Canadians that require compromise, consultation and patience. The proposed pipeline does not have to be of full capacity of 500 million barrels per day and not with a seven-fold increase in tanker traffic that multiplies a potential ocean oil spill in Port Vancouver, Georgia Strait or the Salish Sea. These three documents: (1) Vessel Traffic Risk Assessment 2015 final report for Washington State, and Transport Canada’s (2) A REVIEW OF CANADA’S SHIP-SOURCE OIL SPILL PREPAREDNESS AND RESPONSE REGIME - Setting the Course for the Future and (3) Citizen’s Guide to Tanker Safety & Spill Response on British Columbia’s South Coast by Resource Works (May 2018) need the attention of the National Energy Board (NEB) and stakeholders. The NEB enforces 156 conditions for KM to proceed.

More bitumen could also be exported to refineries in Washington State. Why? YVR purchases additional aircraft fuel to service the Vancouver airport from Washington State refineries since the Burnaby refinery cannot fill the demand. The NEB and Prime Minister made the situation worse without prior consultation with First Nations for major projects that the Supreme Court of Canada and the Commissioner of the Environment and Sustainable Development advocated. In the opinion of many, the safety of the proposed pipeline itself from Edmonton to Burnaby, BC is not of a major concern but we need to limit the size of the tank farm in Burnaby, its safety from an earthquake, and limit the number of tanker transits; about 5 tankers presently transit Port Metro Vancouver with fortunately no incidents. The aging KM pipeline will need replacing sometime in the near future so this KM expansion should be built.

At the time of writing the Canadian public has been made aware that the certificate approving construction and operation of the Kinder Morgan Expansion pipeline was nullified by a ruling from the Federal Court of Appeal on August 30, 2018, leaving the project in legal limbo until the energy regulator (NEB) and the federal government reassess their approvals to
satisfy the court’s demands. In June 2019 the government of Canada again gave its approval of the KM pipeline to proceed and work is expected to begin but there could be stumbling blocks.

**Coal: Cheap but Costly Fossil Fuel**

The word ‘coal’ comes from the old English word *col* and is a mineral of fossilized carbon with variable quantities of hydrogen, sulfur, oxygen and nitrogen. It is a highly combustible sedimentary lignite rock of plant origin left underground for tens of millions of years ago. It has been the most widely available and cheapest energy source that can be safely transported by trucks and trains from the sites of mining and conveniently by ships to factories and countries in need. Port Metro Vancouver at Roberts Bank loads coal coming from the US and Canadian sites by train to Asian countries. Coal is the main source of the world’s energy supply providing 40% of the world’s electricity resulting in 44% of global CO₂ emissions and growing over the past years (Figure 1.3 F). **Canada in 2014 used 6.5% of its energy needs in coal combustion and the good news is that its use has been declining.** But coal consumption has been growing in developing economies like China and India (Figure 1.3 E) and worldwide (Figure 1.3 F). Many developing

Figure 3.8 A. Global use of coal of selected countries to generate electricity. ROW is rest of the world. Credit IEA.
and developed countries need electric power not only for household use but for manufacturing of industrial chemicals, liquid fuels and other uses. The top six countries, in the following order, that use coal to power electricity are: China, USA, India, Germany, Russia and Japan. Both Germany and the US have been cutting back on its coal use for electricity. No new coal plants will be built in Canada but we continue to export coal to Asian countries. The *International Energy Agency* (IEA) lists coal demands by countries in 2016 in Figure 3.8 A.

World coal consumption rose by 54% from 2000 to 2011 and rising at present as noted by IPCC and IEA especially in Asian countries but declining in the US, Canada, Europe and China. According to the *Energy Information Association*, coal consumption would still creep up to 33% on its own by 2040; that outlook would be a bleak one for the world to stay within 2°C rise by 2100. The outlook for future American coal industry looks bleaker, and good news, as they shift to more natural gas and renewables. The number of coal plants in the US dropped from 619 in 2005 to 427 by 2015 and despite what President Trump has been preaching about advancing the coal industry - it is a failing one unlike advancing renewables for job creation. Coal combustion greatly increases GGE and atmospheric pollution, contributes to millions of deaths per year from respiratory illnesses. Newspapers headlines on an “airpocalypse” referring to air pollution in China being linked to 1.2 million premature deaths annually. A comprehensive study led by Tsinghua University and the *Health Effects Institute* found that coal combustion is the single largest source of air pollution-related health impact, “contributing to 366,000 premature deaths in China in 2013”. In India, coal burning results in an estimated 115,000 premature deaths annually from cancers and respiratory illnesses. In his book *Climate of Hope*, Michael Bloomberg writes “coal pollution is killing 13,200 Americans a year mainly through respiratory disease and cancer, while another 20,000 Americans had heart attacks related to coal pollution.” The good news in the US is that 273 out of 530 coal plants were closed and despite President Trump’s climate change denial the American public, 400 Mayors and many Governors support climate change initiatives and that the US would still meet its GHG goal by 2025 according to Bloomberg.
Particulate matter (PM) is the tiny solid or liquid particles that float in the air. Some particles are large or dark enough to be seen as smoke, soot or dust. PM is emitted directly into the atmosphere by wood and fossil fuel burning; it also includes pollen, spores and road dust or formed in the atmosphere through chemical reactions involving nitrogen dioxide, sulphur dioxide, volatile organic compounds and ammonia. PM2.5 is responsible for almost half of air pollution–related deaths, most of which are in Asia. **PM is particulate matter and 2.5 refers to its size in micrometres (0.0025 mm).** PM2.5 easily penetrate into the lungs and into the blood as a result of its small size; the human hair has a diameter of about 50 – 70 micrometres as comparison. China’s coal-based energy-intensive development path has led to a steep increase in PM2.5 emissions and its precursors, resulting in 1.6 million deaths from heart and lung diseases or stroke, approximately accounting for one in six premature deaths in China. Of the 10 most polluted cities in the world, nine are in India. The city of Kanpur (listed as # 1 in world) in northern India recorded an annual mean of 173 micrograms per cubic meter (ug/m³) of ground level air of PM2.5 (Figure 3.15 A), way higher than the WHO’s recommendation. The Canadian standards (see Environment Canada website) vary but a “low to moderate” **PM2.5 range from 0-26 ug/m³ of air**; smoke particles from forest fires have concentrations of over 30 ug/m³. A PM2.5 cited as ‘hazardous’ is over 170 ug/m³. World Health Organization (WHO) reported that outdoor air pollution was responsible for the premature deaths of some 3.7 million people in 2012. One in eight premature global deaths is related to air pollution exposure, demonstrating that air pollution is now the single largest environmental health risk worldwide.

About 80% of those deaths are due to heart disease and stroke, while another 20% are from respiratory illnesses and cancers related to exposure to fine particulate matter (PM2.5), the most health-harmful air pollutant. Most recent survey of 4300+ cities worldwide, only 20% of the urban population live in areas that comply with WHO air quality guideline levels for PM2.5. Average particulate air pollution levels in many developing cities can be 4-15 times higher than WHO air quality guideline levels, putting many at risk of long-term health problems.” Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as of lung cancer. Air quality measurements are typically reported in terms of daily or annual mean concentrations of PM2.5 and
PM10 particle sizes in micrometres per cubic meter of air or its concentration. The Air Quality Index (AQI) on the other hand includes concentrations of particulates (PM2.5), carbon monoxide, sulphur dioxide, nitrogen dioxide and ground ozone by the EPA and Environment Canada; an AQI of 0-50 is ‘good’, ‘moderate’ as 51-100 and ‘hazardous’ above 300. Air Quality Health Index of 1-10 gives the risk level on any given day (1-3 being ‘low’) and can be accessed from Environment Canada.

Famous landmarks in Shanghai (Figure 3.9A) and Beijing are barely recognizable because of daily smog and haze; people regularly wear surgical masks as they go about their daily lives. Both these megacities are home to over 40 million people with a modern transportation system but roads and highways are clogged with millions of vehicles that add to the pollution. “Beijing issued an alert for severe air pollution…thick smog forced the airport to cancel 227 departures…particles that pose the greatest health risks was 503 micrograms per cubic metre” as reported in the Vancouver Sun on December 2015. Legislation is expected to pass a ban on coal use in the city of Beijing by 2020 but one should not hold one’s breath. China consumed 1.5 billion tonnes of coal in 2000 and by 2016 that figure escalated to 2.7 billion tonnes as annual consumption. At the same time China invested billions of dollars in renewables such as wind turbines and solar panels and making much progress in such renewables. Reports claim that China added 160 new coal plants by 2016 and India with 46 new ones even as both countries made pledges to cut GGE at the Paris COP21 conference.

Coal is pulverized and fired in a combustion chamber to convert water in tubes lining a boiler into steam; the high-pressure steam is passed into a turbine with propeller-like blades with the shaft rotating at high speed. A generator with wire coils rotates in a strong magnetic field to generate electricity. This is a simplified version of the main use of coal to produce high voltages and later transformed to safe use for the domestic market. Worldwide, coal consumption is up by 50% over the past decade and remains the biggest contributor to global warming. Coal is humankind’s thorniest problem but supplying many millions with electricity to advance their standard of living, create more jobs and more goods at cheaper prices for (western) consumption; the downside is obvious as mentioned. Countries like China and India need vast amounts of steel to build their fast-growing cities and
coal supplies that need. These are the realities of economic development as well as growing affluence among its people. Carbon capture and storage, a very costly venture, would reduce emissions of CO$_2$ but burning coal the dirty old way would not keep global temperatures under a 2°C rise in this century; it’s considered business as usual.

Figure 3.9 A. Air pollution in Shanghai taken from a landmark hi-rise building in November 2016 by the author. The Shanghai TV Tower on the left photo and the Huangpu River in foreground.

The April 2014 publication of *National Geographic* magazine gives an insightful overview of **coal and its global impacts**. From the latter article and others researched, the following are some of the facts about coal and its growing consequences:

- It’s the dirtiest of the fossil fuels
- We burn eight billion tonnes of it a year
In 2012 the world emitted a record 34.5 billion tonnes (Gt) of CO₂ from fossil fuels; it grew to 37 Gt/year by 2014. Coal already produces two-fifths of the world’s energy supply, and another 1,600 coal plants are in the works as reported in 2017. And by 2040, Southeast Asia will get half its power from coal plants.

- The ‘coal footprint’ or daily consumption of the average US citizen is 8.18 kilograms while each Australian person consumes 15 kilograms as one of the highest in the world.
- Canada’s ‘carbon footprint’ per person is third in the developed world at 15 tonnes per capita CO₂ equivalent or 20 Gt CO₂ by 2015.
- Almost 70% of global steel production is dependent on coal
- Eight biggest coal consumers in the world are: China, India, USA, Russia, Germany, South Africa, Australia and Japan
- Top seven coal producers in the world are: China, USA, India, Indonesia, Australia, Russia and South Africa
- Top seven coal exporters are: Indonesia (383 million tonnes), Australia, Russia, USA, Columbia, South Africa and Canada (35 million tonnes) per year.
- The following provinces: Alberta, Saskatchewan, Nova Scotia, New Brunswick, and Ontario use coal to generate electricity; there are 35 coal fired-plants in Canada.
- The USA generates 45% of electricity from coal while in Australia it is 78%; Australia has the highest carbon footprint per capita as a developed country.
- Coal provides cheap power but kills millions from respiratory illnesses and other health-related diseases every year worldwide.

From 2005 to 2014, greenhouse gas emissions across the province of Ontario declined by 7 percent. This trend was driven by a nearly 20 percent reduction in greenhouse gas emissions in Ontario’s energy sector. In other words, it was driven in part by a coal phase-out, which reduced emissions by an amount equivalent to taking 7 million cars off the road. In fact, Ontario’s leadership on coal reduction has been recognized and replicated in other jurisdictions such as Alberta, Saskatchewan and Nova Scotia. Provinces and the federal government are implementing plans to limit and phase out coal-fired power in Canada. Building on the results from the 2012 Environment Canada analysis, the Pembina Institute concluded that “accelerating the retirement of Canada’s 35 coal-fired units by 2030
could save as much as 1,008 Canadian lives, avoid 128,800 asthma episodes, and prevent an estimated nearly 5 billion dollars in health-related costs between now and 2035.” Coal-fired power plants are a contributor to a range of harmful air pollutants. When compared to other electricity generating options, coal power produces unmatched volumes of sulphur dioxides, nitrogen oxides, fine particulate matters and mercury — to name only the most harmful pollutants associated with coal.

The outlook is a bit bleak for keeping the global temperature on the planet below 2°C from pre-industrial time in this century. If developing nations like China and India want to reduce their GGE as they pledge to do at COP21 in Paris, coal use must be greatly reduced and renewables widely expanded. Chinese President Xi Jinping announced that “China’s emissions would peak by 2030 and that the country’s reliance on nuclear, wind and solar would jump from 10% to 20% of the nation’s energy mix over that time period” according to Jeff Rubin in his book, The Carbon Bubble. According to a Washington Post article in March 2017 industry experts say “coal mining jobs will continue to be lost, not because of blocked access to coal, but because power plant owners are turning to natural gas. At least six plants that relied on coal have closed or announced they will close at the time of writing. Another 40 are projected to close during the Trump’s Presidency in spite of his support to expand the coal industry.” Coal continues to be the cheapest fossil fuel but in the long-term it will cost us billions on its impact on climate change and the health of citizens.

**Deniers of Climate Change**

“We are speaking out to support the cumulative scientific evidence for climate change and the scientists who continue to advance our understanding. Scientists have known for some time, from multiple lines of evidence, that humans are changing Earth’s climate, primarily through greenhouse gas emissions. The evidence on the impacts of climate change is also clear and growing. The atmosphere and the Earth’s oceans are warming, the magnitude and frequency of certain extreme events are increasing, and sea level is rising along our coasts.”

There are a growing number of disbelievers of climate change with most of them emerging from the United States including many Republican politicians in the US Congress, President Trump and his Administration. The Trump administration is disregarding the science and evidence from very reliable sources. Trump officials are censoring warnings about the climate crisis, moving critical agencies out of Washington. One former climate scientist for the National Park Service, Maria Caffrey, filed a complaint on July 2019 and testified to Congress that she was blocked from publishing data about how coastal parks could flood as the seas rise. Recall that former Prime Minster Harper had also muzzled government scientists from publishing their findings. A very small number of disbelievers exists in Canada, Europe and Australia while most of them are tied to the petroleum industry as lobbyists for financial interests. “Skeptical science is based on the notion that science by its very nature is skeptical. Skepticism is not a doubt! Skepticism is the open-minded consideration of something based on the evidence” as told by scientist John Cook from *Skeptical Science* publication. The latter publication is one place to start to compare what science says and what the denier says. Go to “Arguments” then to “Print Friendly” at [www.skepticalscience.com](http://www.skepticalscience.com) for updates on climate science, with loads of “Resources” and frequently asked questions (FAQ) with answers.

Many misconceptions and misleading information about climate science and global warming originate from well-paid organizations including a handful of scientists who have retired or not actively doing research on anything related of climate science. They represent the lobbyists who collect large sums of money from fossil fuel companies to spread propaganda; they also have an influence on the right-wing politicians of the Republican Party of the United States Congress. Some of them even condemn the work of the IPCC and often quote scientists out of context, falsify data and graphs from established research conducted by scientific organizations such as NASAs *Goddard Institute for Climate Studies*, NOAA and many others. The IPCC reports may be a few years behind the current research but its reports are credible and supported by overwhelming evidence in the literature and developed by over 2,000 scientists and authors. Supporters of debunking climate change science are being financed by big businesses such as Exxon Mobil, Phillip Morris tobacco company, J.R. Reynolds Tobacco Company, and the Charles Koch Foundation, to name the major subscribers. “Pope Francis rebukes
pervasive climate change deniers over rejection of science behind global warming” in a headline in the UK Independent newspaper on November 2017.

The cause of lung cancer from smoking cigarettes has been under fierce discussion many decades ago by cancer specialists but denied by the tobacco companies; we know the answer today of the main contributing cause of lung cancer. Is second-hand smoke just as dangerous as cigarette smoke? Both were deemed false by the tobacco industry. Ignorance of the science and debunking good research is not helpful to those who are dedicated and honest in having their work scrutinized by peer review and only to be manipulated by a few uninformed and ignorant individuals. Imagine the president and vice-president of the United States disputing the science and how citizens of that country react or believe in their leaders! Yes, we need to question what scientists write and tell us but when a few individuals or leaders of a state blatantly ignore or falsify the science it amounts to unethical and dishonest behaviour. Scientists correct any false data when any new evidence emerges to the contrary. Skeptical science investigates what scientists write and publish and would question the full body of science itself. The website www.skepticalscience.com is highly recommended for students and adults and written by well-known scientists and fully referenced.

Scientific tenets are not carved in stone but one is very likely to accept scientific evidence that is reproducible by other scientists as proof at the time of discovery or even years later; that is the basic premise of how science works. Temperature rise since the 1970s exhibit a sort of ‘hockey stick’ curve compared to previous years (Figure 1.3A); temperatures tend to rise greatly during the past 50 years compared to other years from credible and independent data by NOAA, NASAs GISS, Met Office Hadley Centre and other scientific organizations (refer to the graph in Figures 1.3 B & 1.3 C). The research by Charles Keeling and his team cite increasing CO₂ levels that is consistent with increasing atmospheric temperatures since the 1960s; increasing CO₂ concentrations and increasing temperatures are well linked. Michael Mann, professor at Pennsylvania State University is an outspoken scientist like many others fighting those climate science deniers. His published book: “The Hockey Stick and Climate Wars” had deniers in combat with Mann with regard to the universal graph of increasing temperatures like that of a

Deniers of climate change in publications such as “Climate Change Reconsidered” never cite scientific references like peer review journals but contain edited versions to suit their argument. The Climate Change Reconsidered is authored by three individuals with doctorates but who are not involved in active research and are not climate scientists. Dr. Madhar Khandekar, a retired Environment Canada scientist was paid a monthly sum by the Heartland Institute to falsely climate change data. Another contributing author is Dr. Susan Crockford, an anthropologist from the University of Victoria in British Columbia and not doing any research on climate science but promotes herself as an ‘expert’. Khandekar claims that “CO$_2$ does not induce climate change” and “there is no correlation between CO$_2$ and temperature.” The latter statements are false and he knows that but promotes false information for money. Here are a few quotes from the book cited above: “The evidence shows that greenhouse gases are not playing a substantial role”; “the latest available research shows a warmer world would be a safer and healthier world for humans and wildlife alike”; “1,000 years ago when there was about 28% less CO$_2$ in the atmosphere than there is currently, was warmer than today”; “the doubling of atmospheric CO$_2$ will result in only 0.4 or 0.5 °C rise in temperature”; “the warming of Greenland was 33% greater in magnitude in 1919 – 1932 than it were in 1994 – 2007”. It is time for our scientists and institutions to confront those deniers like Professor Mann, John Cook and others have done on bogus climate change claims and to set the record straight. Students are encouraged to study the graphs from the scientific organizations throughout this book and the summary illustration (Figure 4.8) in my concluding remarks as evidence to refute the deniers.

How about the Inquisition that the Church once questioned the famous astronomer Galileo on his observations and beliefs about the solar system with observations from the primitive lens of a telescope? If you go to Florence, Italy, you will see Galileo’s telescope at the Science Museum which he used in his observations of the solar system that got him in trouble with the Church for his scientific research
and proclamation. On another topic, some schools and school districts in the US want teachers to teach *scientific creationism* alongside with the theory of evolution by natural selection. Is scientific creationism or natural selection the process by which evolution proceeds a process of science or non-science investigation? I did not have any concerns with my students or parents in explaining how evolution proceeds by natural selection, the fossil record and the processes involved in micro- and macro-evolutionary change. I respect any beliefs my students held about the supernatural or God but believing in evolution by natural selection and God are not controversial or even at odds as proclaimed by the Vatican and many religious bodies.

Some school districts (Los Alamitos Unified in California, Texas Board of Education and in South Dakota) require teachers to teach “controversial subjects such as global warming and climate change but to provide a political balance” - school officials believe that there is more than one point of view on the subject of climate science! Sounds like those school officials have a complete disregard for the teaching of science to satisfy some parents, politicians or lobbyists and the opportunity for re-election to the board. “*We examine how this societal debate affects science in classrooms and find that most U.S. science teachers include climate science in their courses but their insufficient grasp of the science may hinder effective teaching. Mirroring some actors in the societal debate over climate change, many teachers repeat scientifically unsupported claims in class. Greater attention to teachers' knowledge is critical*” as cited in *Science* journal in its February 12, 2016 publication. From the latter citation, only about half of U.S. adults believe that human activity is the predominant cause, which is the lowest among 20 nations polled in 2014.

It appears that organizations such as the *Heartland Institute* and the *Institute for Scientific Creationism* have some influence in the curriculum and teaching of science in a number of school districts in the US. The *Heartland Institute* is funded heavily by oil companies such as Exxon Mobil and provides funding to their lead skeptic authors such as Craig Idso, a geographer from Arizona, Fred Singer, a retired rocket scientist from the University of Virginia, and Bob Carter, a marine geologist from Queensland, Australia. You may check the website
(www.skepticalscience.com) to learn more about climate change myths and how many organizations fund the *Heartland Institute* and their scientific disbelievers. Fortunately, in Canada we do not have such extensive lobbying and school districts teach what is required in the curriculum and teachers are free to include updates in the science being offered; this resource cites the evidence of climate science and is meant to update teachers and students on this critical subject.

Science and technology have made advances for the benefit of mankind but we know that not all technological advances have been beneficial. Science is not a holy scripture and does not claim to have the complete answer to many questions; most scientists work honestly in trying to solve problems and advance their knowledge on a particular subject and report in peer review journals. For example, anyone may examine a collection of data that is consistent with the findings from other scientists to better understand a problem that is being investigated. There is reason to believe that a condition is deemed correct when researchers working with different scientific organizations or research centres anywhere in the world advance similar or identical results to demonstrate reliability of data. For example, when greenhouse gas concentrations increase in the atmosphere it follows that temperature would increase, not decrease. The latter concept has been linked from the research by thousands of climate scientists worldwide and we should not deny the fact that increasing CO$_2$ concentrations in the atmosphere increase atmospheric and surface temperatures as has been the case over thousands of years or more; other natural variabilities such as ocean circulation and Earth’s orbit around the Sun also affect climate change. The reports by the IPCC is one of the many documents on climate and the environment and supported by scientists and non-scientists alike.

Using commonsense in problem solving is something we do every day. We may make a prediction that it may rain on a given day based on a weather forecast so we carry an umbrella or dress appropriately. However, investigating a problem such as global temperature trends from the years 1900 to the present, requires a collection of data from thousands of weather stations, buoys, ships, satellites at different locations from around the world; that is exactly what scientists do to develop credible data and graphs of temperature fluctuations over the decades.
This extensive data of temperature collected over those years, and for every month up to the present at different global locations are tabulated and graphically represented. You may refer to Figure 1.3B that represents global temperatures and data that are consistent with four world-class scientific research organizations - the Met Office, NOAA, NASA and the Japanese data. The global mean temperature is 1.10°C from pre-industrial time to the present but regional differences exist now and in the past. Northern Canada for example from all data show a mean rise of 2.3°C since 1948 and well over the global average.

Climate research and projecting climate change are routinely carried out by centres such as the National Research Centre and Environment Canada in Canada. International research centres include the Met Office Hadley Centre in the UK, and the NOAA, NASA, Scripps Institute, National Snow and Ice Data Center, and EPA in the USA. Findings from different research centres are agreeable to a fraction of a degree that Earth’s temperature has been rising; the research claims that the combined years 2015, 2016, 2017 and 2018 were the warmest on record. Any graph representing temperature increases could never be represented as a straight line from month to month or from year to year as temperature fluctuations occur from natural influences but with a steady increase over time as documented in Chapter One from increasing GGE over the decades. The data collected has to be credible and we accept honest reporting from a large number of credible scientific researchers. The last 21 of the past 25 years have been the warmest ever recorded since instrumental measurements were taken and consistent with increasing greenhouse gas emissions as researchers have indicated.

Each research facility publishes its own findings and one can compare the data and results from other sources for reliability or consistency. When all data are analyzed and published scientists are more confident in proposing a hypothesis and draw a conclusion, however tentative, as the scientific method applies. Research laboratories publish their findings routinely and often compare findings with others. Projection of climate models, for example, from the Met Hadley Office, Goddard Space Institute for Space Studies, NOAA, NASA are compared and are often found to be consistent and significant. The IPCC compiles such research in their reports and publishes its three volumes of research to the world community. You may Google IPCC for the official site or at www.ipcc.ch. The last IPCC issue
in 2018 in conjunction with the *UN Emissions Gap Report* is a warning to the world about climate projections and what we need to do to hold GGE under 2°C before the year 2100. The denial industry with a handful of scientists and paid by big oil money has no interest in establishing the facts about global warming or climate change from anthropogenic activities. We should not give credence to any reports claiming that global warming is a hoax and that the planet is not warming.

In the book, *Heat*, George Monbiot has devoted an entire chapter on the “Denial Industry” of individuals, politicians and even a handful of scientists who manipulate the science or make false statements that global warming is a myth. The pseudo-documentary entitled “The Great Global Warming Swindle” that aired in Britain is itself a fraud and a swindle. The producer, Martin Durkin, showed reckless disregard for the truth by misrepresenting the data on climate change. The pseudo-documentary portrays graphs that are distorted, mislabelled and just plain wrong. When consistent data through research and observations are known, then one should openly accept, however tentative, the findings from those investigations. Statements made by some unbelievers claim that “there is no convincing scientific evidence that the human release of carbon dioxide, methane, or other greenhouse gases is causing or will, in the foreseeable future, catastrophic heating of the Earth’s atmosphere and disruption of the Earth’s climate” as cited on page 29 in Monbiot’s book. The website *Monbiot.com* carries a number of articles on the ‘denials’ who refute the science that greenhouse gases increase global temperatures; he is a regular writer for the UK *Guardian* newspaper.

The *Royal Society* in the United Kingdom was founded in 1660 and registers over 1,600 of the most eminent scientists, engineers and technicians from Britain and Commonwealth countries on a variety of topics for educators on its website: [https://royalsociety.org](https://royalsociety.org). The *Royal Society of Canada* carries several reports such as oil spills and oil sands under “Expert Panel Reports”. In an Editorial in the February 8, 2007 journal *Nature*, in discussing the importance to curtail greenhouse gas emissions it stated: “This requirement has been disputed by a collection of money-men and some isolated scientists, in alliance with former President Bush of the United States and a handful of like-minded ideologies such as former Prime Minister John Howard from Australia.” US Republican Senator
James Inhofe said “I have long believed that claims of consensus that man is causing global warming is the greatest hoax perpetrated on the American people.” When the former CEO Lee Raymond of Exxon retired with a package of $400 million, President Bush quickly named him to head a committee to examine America’s alternative energy future. Exxon Mobil has funded hundreds of millions of dollars into a network of organizations such as the Heartland Institute that seeks to confuse children in schools and the public on climate change science. President Trump also hired Scott Pruitt a climate denier to head of all departments, the Environmental Protection Agency.

The US still has major problems today in advancing clean energy and by not passing its Climate Bill in spite of the leadership of former President Obama on climate change; Canada did likewise when the non-elected Conservative Senators voted against a Climate Bill that was passed in the House of Commons some years ago. One former Conservative Federal Minister of Natural Resources pointed fingers at environmentalists and labelled them as “radicals” who spoke against projects such as the Enbridge Northern Gateway pipeline from Alberta to British Columbia that could harm ecosystems and watersheds from a likely massive oil spill; that pipeline project was later rejected by Prime Minister Trudeau in 2016. The Sierra Club in the US reported that “only 13 percent of congressional Republicans in the US believe in human-caused global warming.” In a shareholders meeting of Exxon Mobil in Texas, a number of environmentally-minded investors asked about the goals of the company in reducing greenhouse gas emissions and to commit to greater investment in renewable sources of energy, but they received little hearing at their own meeting. The Charles Koch Foundation and Koch brothers have funded a few scientists to dispute global warming. Friends of Science, an oxymoron, received a donation of $175,000 from Talisman Energy in Alberta to refute the Kyoto Protocol and in linking human activity to climate change. The Friends of Science group founded by retired oil industry workers and academics do not represent the views of Canadian scientists and have its own agenda as climate change skeptics.

The book, Merchant of Doubt, authored by two science historians, Naomi Oreskes and Erik Conway, they write that a handful of politically conservative scientists
with strong ties to industries have challenged the scientific consensus about the dangers of smoking, effects of acid rain, the existence of the ozone hole and that humans are not the cause of climate change. Fred Seitz and Bill Nierenberg were physicists who worked on the atomic bomb and were influential in “deliberate obfuscation” of the issues of climate change. Fred Singer was a rocket scientist and retired from the University of Virginia and has not had a single article accepted for peer-review in over 40 years and “his main work has been as a hired gun for business interests to undermine scientific research on environmental and health issues” while receiving funding from Exxon, Shell, Unocal and ARCO. Singer replied “of course I am not funded by the fossil fuel lobbies” when asked. Fred Singer is a co-author of the “Climate Change Reconsidered” published by the Heartland Institute. Another prominent climate denier is Dr. Patrick Michaels who received direct funding from “German Coal Mining Association, Edison Electric Institute and Western Fuels Association”. Citations above from www.durangobill.com/Swindle_Swindle.html entitled “Debunking the Deniers of Global Warming”.

The list of climate change deniers keeps growing and serves as a threat to honest scientific research conducted by honest scientists. The sitting President Trump is a denier of many things including climate change. Michael Mann whose book “The Hockey Stick and Climate Wars” said: “There may have been an overdue amount of complacency among many in the scientific community” and it is time to stand up for science. To paraphrase Michael Bloomberg in his book Climate of Hope, that the best way to reach skeptics is to tell about climate success stories - how it helps us save money, how it helps create new jobs in promoting wind and solar technology, how renewables are less damaging than fossil fuels, how it makes us healthier, how new technology such as electric vehicles reduce GGE, and how you feel about reducing your own carbon footprint and sending less CO₂ and pollutants into the atmosphere – all for a healthier planet and its people.

George Monbiot rightly claims that “man-made climate change denial is about politics” that support the industrial lobby groups. James Hansen, NASAs top climate scientist and now retired, claims that the lobbyists in Washington played a major role in stalling the Climate Bill. Heads of state and delegates have met at the
UN Conference of Parties (COP) to discuss climate change and work on ways to reduce GGE in their respective countries; it often seemed like ‘hot air’ or inactions that continued from 1992 at the Rio Summit onto the UN Conference of Parties (COP) meetings. You would recall that Canada in 2011 announced in Durban, South Africa at a COP that it was abandoning the Kyoto Protocol. The good news is that in December 2015 in Paris at COP21 about 150 heads of state attended the conference and after two weeks of discussions and compromises came out with a determined plan to reduce GGE. The IPCC and climate scientists may not have fully convinced politicians on reasons why it is important to reduce GGE and about their responsibilities to the health of the citizens they represent. There is increasing universal support for climate change proposals and in combatting global warming; the media should also be praised for their efforts in informing the public but readers should be cautious on what is true and false.

Do you trust the 2,500 scientists that contribute to the IPCC and three volumes of over 1000 pages in advancing our knowledge of the world’s climate and future? Major professional associations and scientific research laboratories in the USA such as the American Association for the Advancement of Science, NASA, NOAA, National Science Academies, and the National Research Centre in Canada, to name a few, fully support the claims of climate change science with sound scientific evidence. As mentioned, the website www.skepticalscience.com is helpful in explaining how disbelievers operate and to strengthen the science of climate change. Friends of Science is not a science-based organization and delivers misleading information; for example, its graph shows a straight line of temperature trends from only the years 1998 to 2012 and concludes that “earth is cooling” ignoring long-term trends as how scientists view climate change. They say that CO₂ increase and temperature increase are not congruent. Man-made or anthropogenic climate change is real and global temperature is expected to increase in the range of 1.8°C to 4.5°C by the end of this century from a range of projected scenarios. This range of temperatures is based on human behaviour in reducing GGE or from business as usual. The 2014 IPCC Report concludes that “each of the last three decades has been successively warmer at the Earth’s surface than any preceding decade since 1850”. There is no denying that each decade has become warmer than the previous one since the 1970s as documented in Chapter One.
The task now is to lower GHG emissions by decarbonizing the world and such a mission is not impossible to keep out planet well under 2°C by 2100. In Chapter 4 on Reducing Emissions, the goal of the Paris Agreement, the IPCC 2018 Report, the IPBES Report and the UN 2018 Gap Report make it abundantly clear what we must do to reduce GHG emissions from now to the year 2030 or risk a planet with continued extreme weather, rising seas, loss of biodiversity, decline in human health, increase child mortality, depletion of water and food resources and instability among nations.

China and India: Facing the Environmental Challenge

Aside from the issues of increasing greenhouse gas emissions by China and India of about 35% globally, both countries are identifying their position as economic giants in Asia and an increasing transition from poverty to a middle-class lifestyle. “China does not conform to the present conventions of the developed world and global polity. It is a civilization-state masquerading in the clothes of a nation-state, its underlying nature and identity will increasingly assert itself” writes Martin Jacques in his book When China Rules The World. It seems to be ruling the world’s economy for some time now. Some concerns have been uncovered with computer hackers or cyber-spying in China (as well as in Russia) and allegedly giving the green light to continue this illegal activity. So is China playing by the rules? A full page article written by Stephen Hume in the Vancouver Sun a few years ago cites a number of incidents of ‘looting secrets’ taken from Nortel Networks in Canada. There is “evidence of a massive Chinese network actively spying and reporting on the activities of Canadians and engaging in economic cold war” according to former Defense Minister Peter Mackay and remarks made in the Canadian Parliament.

Petro China and Sinopec acquired large shares in the Athabasca Oil Sands Corp and Syncrude Canada. Chinese companies own huge shares in the oil sands projects and may have some say in bitumen export from Canada to China. The economic footprint of China is everywhere and especially in Africa with loans to major projects; if these loans cannot be repaid guess who will own those projects! We see the daily concerns with high air pollution indices in major cities like
Shanghai (Figure 3.3A) and Beijing. Water pollution is a growing problem in both China and India; the Yellow River is unfit for human consumption. The major problem facing China and India today is that they are home to more than 2.5 billion people or almost 35% of the world’s population with expanding economies and an emerging middle-class society. Reports have China planning to build 160 new coal-fired power stations. Other reports claim that China is implementing significant policies to address climate change, most recently aiming to restrict coal consumption, which may well have already peaked, based on recent estimates. China burns 1.2 billion tonnes of coal a year according to the *Economist* and **responsible for 50% of the world’s coal consumption**. China is refining 10 million barrels of crude oil each day according to the *Canadian Association of Petroleum Producers* (CAPP). Affluence, population growth and a demand for more energy for both China and India make them the biggest polluters of GGE which is evident in many of their cities. China has well surpassed the US in global GGE and by 2018 was responsible for 29% of global emissions with the US at 15% (Figure 1.3 D-1). However, on a per capita basis, Australia, the US and Canada in that order carry the biggest global carbon footprints in the developed world.

China’s CO₂ equivalent annual emission by 2014 was 9 billion tonnes compared to the US of 5.5 billion tonnes; Canada’s emission was 700 million tonnes of CO₂ equivalent and updated data in Figure 3.16 A. Global **carbon emissions** from the energy sector topped out at about 32.5 billion tonnes in 2017, an increase from 2016 mainly from China’s emissions. The majority of millionaires in China surveyed say that they would sacrifice health and safety for money; the economy seems more important to them. To China’s credit, it has been developing, using and exporting renewable sources of energy, notably solar generating power and says it would reduce its GGE as per COP21 ‘pledge’ in Paris. The *Climate Action Tracker* reported on the ongoing reduction in coal use for the third year in a row has had a major impact, and, if they were to continue at similar rates in the next decade, total Chinese GHG emissions will only show a very slight increase in the period 2015–2030, and essentially plateau at close to 12.0 billion tonnes of carbon dioxide equivalent per year (GtCO₂e/year). China’s policies and actions appear ambitious enough to potentially overachieve the CO₂ goal in its *Nationally
Determined Contribution (NDC) made in Paris COP21 as well as its national targets. The NDC itself, however, is not ambitious enough to be consistent with holding warming to below 2°C, let alone limiting it to 1.5°C as required under the Paris Agreement. The latter conclusion was provided by the Climate Action Tracker after the Paris conference. The President of China and former President Obama signed a bilateral agreement in 2014 at the G-20 conference in Brisbane, Australia, to reduce emissions by specified amounts.

As mentioned, China is responsible for 29% of global CO₂ equivalent emissions, followed by the US at 15%. India’s emissions amount to 6% globally about the same as Russia. However, India’s GGE is expected to increase by as much as 70% by 2025 from the present with increasing coal combustion. China now gets about 80% of its primary energy from coal. However, to cut reliance on coal, China needs to derive 20% of its energy from renewables including nuclear by 2030 or double the current number of renewables. China is hungry for oil and coal to run its factories, its elaborate electrical grid and for transportation; imports of fossil fuels have increased six-fold in the past decade, with oil mostly coming from the African continent and the Middle East.

It takes oil to make toys and similar products; customers have been warned that some toys produced contain toxic chemicals. The percent of unsafe toys recalled in the US and Canada including Thomas the Tank Engine were made in China. Toxic heavy metals like lead in toys and jewelry are a concern especially with children; lead can cause permanent brain damage when children place toys in their mouths during play and get into their digestive tract. Canada has now limited its lead content to 0.0009% in products that may come in contact with children. Take an inventory at your favourite stores where ‘Made in China’ products are sold and what you purchase and its safety; read the labels for content of a product you buy. Canada needs to carefully label products for points of origin and not where they are packaged as is often the case with food products. The textile industry in countries like China, India and Bangladesh do not have strict regulations on water pollution in producing products like blue jeans for export; refer to Chapter One and the documentary River Blue for details of pollution from the textile industry. For Canadians, the flip side of lost factory jobs is an abundance of ‘good deals’ of
'Made in China’ products at Wal-Mart, ‘Dollar’ stores and others across Canada, US, Europe and around the world.

The European Union with 13% of the world’s GGE is doing a much better job than North Americans or Asians in keeping down GGE. Canada with a much smaller population than Britain emits the same amount of GGE of about 1.6% globally every year. Both China and India are starved for energy and consumption of electricity has more than doubled in over 20 years; this translates into increase combustion of coal to produce electricity. One major problem facing India and China is the lack of efficient equipment in their industries and the need to seek greater fuel efficiency. In the June 2011 National Geographic Bill McKibben noted that in the city of Rizhao in Shandong Province, 95% of the tops of all buildings had an array of solar panels. To give credit to China, it is expanding its electrical grid system with hydro, nuclear, biomass, wind, and solar power but dependence on coal is likely to remain for decades. In China, two wind turbines are erected every hour of every day. In 2016, they added roughly enough solar panels to cover three soccer fields every hour. China recently announced that by 2020, it aims to have five million clean energy vehicles on the road. Traffic seems to be a nightmare in China’s major cities as evident when I visited Beijing and Shanghai in 2016. Our guide said that there are 7,000 ‘fender benders’ each day in Beijing!

The city of Linfen of 4 million people in Shanxi Province in China is a major coal mining town and cited as “the world’s most polluted” city; the entire city smells of waste gas and sewage and often covered in smoke. Harbin in the north may be a close second and perhaps tied with Shanghai and Beijing for high air pollution indices. China needs to fast track its carbon capture and storage of greenhouse gases and pollutants from its coal fired plants but it is an expensive venture; they have the resources to put this technology in place since they can well afford to send astronauts into space and possibly on to the Moon. China’s ongoing ‘environmental plans’ have failed in the past and lack of action to phase out coal plants will only exacerbate the situation. It called for a 10% reduction in sulfur dioxide in 2001 and when the plan ended in 2005, the sulfur dioxide concentration in China’s air had increased by 27 percent; the increase in nitrogen oxides is also evident. A growing urban population an increase from 40% to 60% by 2020 is
expected, and with severe demands for more energy in construction of buildings and infrastructure. The concrete jungle is everywhere in Hong Kong, Shanghai and Beijing to name three large cities with over 70 million people. The environmental prospects for China and India still look hazy in spite of what they pledged at the COP21 Paris UN convention.

![Figure 3.10 B. A typical view of a small section of Hong Kong with its residential hi-rises.](image)

Shanghai and its air pollution shown in Figure 3.9 A. Photo by the author in 2016.

Regulations for safety of workers in China are not as stringent as in Canada. There are flaws in safety regulations of miners who die every year in coal and mineral mines; hundreds of thousands die prematurely annually from respiratory illnesses in both India and China because of polluted air. “China has the world’s highest number of annual deaths triggered by air pollution” as reported in *National Geographic*. India is believed to have exceeded China in recent years in deaths from air pollution. “Air pollution is killing an average of 4,000 people a day in China” writes Alex Morales in a *Vancouver Sun* article. The World Bank reported a few years ago that over 750,000 Chinese citizens die each year from respiratory illnesses while about 130,000 in the US suffer the same fate. Environmental pollution — from air pollution and contaminated water — is killing more people every year than all war and violence, more than from smoking, hunger or natural disasters, AIDS, tuberculosis and malaria. One out of every four premature deaths in India in 2015, or some 2.5 million, was attributed to pollution. China's
environment was the second deadliest, with more than 1.8 million premature deaths, or one in five, blamed on pollution-related illness according to a 2017 study by the *Lancet Commission* on pollution and health. A number of sub-Saharan countries are also listed as having some of the highest rates of pollution-related deaths.

As mentioned, a major concern is the safety of coal miners in China; about 6,000 miners were reportedly killed in 2005 and another 4,700 in 2006 and 1,049 in 2013; reports on coal mining accidents are not accurate and difficult to obtain. China’s coal industry is deadlier than in any other country; during the first seven months of 2007 about 2,163 coal miners were killed in 1,320 accidents. Many more accidents are never reported by the Chinese media and government. On human rights issues, China has a thriving ‘slave business’ and sweat shops that make cheap goods that we in the West purchase at lower prices – from blue jeans to toys to electrical equipment. The Chinese refuse to have verification of GGE at the Copenhagen UN Conference of the Party (COP) in 2009 and bluntly stated that they do not want outsiders interfering in their own affairs and continue to play by their rule; they were a bit more conciliatory at the Cancun COP one year later perhaps owning up to high air pollution and with rivers that are unfit for human
health. By 2014 in Brisbane, Australia, both China and the US agree to significantly reduce their annual GGE. In Paris 2015 at COP21, China decided to become an active player in reducing GGE by 2030 and thereafter but like most nations those INDC or pledges are not reliable. You will later read a statement from the Chinese delegate at COP21 in this chapter and China’s pledge or its Intended Nationally Determined Contribution (INDC) to reduce GGE. In terms of absolute emissions for China by year 2030, the models project a range from 9.6 billion tonnes of CO₂ equivalent (Gt CO₂e) to 17 Gt CO₂e, with a median of 14.6 Gt CO₂e as reported in Open Climate Network.

Figure 3.12 D. Photo at the Great Wall taken on November 2016 showing clearer skies 100 km from Beijing’s city centre. Photo by the author.

Martin Jacques in his book, When China Rules the World writes: “China’s need for raw materials and oil, and in a few decades will be greater than the entire world can produce” while depending on an economic growth rate of 8% so that employment and the standard of living can keep pace with population growth and a rising middle class society. Air and water pollution are everyday growing health concerns in both China and India; rivers smell of sewage and the hazy sky over Beijing, Shanghai, Harbin, Delhi, Calcutta, Mumbai and many others are polluted
with soot, oxides of sulfur and nitrogen. “Air pollution in Beijing is so dense it appears to be snowing and that the city got worse after the Olympics” says David Wagner, a former advisor to the Chinese government. One headline in a *Vancouver Sun* newspaper read “Pollution thick enough to cancel flights” and it is not uncommon for visibility to be less than 100 metres. An MIT study reported that the cost to China from worsening air pollution was $112 billion in 2005. Particulates such as sulfur and mercury from industrial wastes and all air pollutants have had and having its toll on the health of its people. When I was visiting as a tourist in 2016 the roads were clogged with vehicles and looked like any big North American city of having a ‘car culture’.

Figure 3.13 A. Water supply was cutoff in the northern city of Harbin in China after a massive benzene spill into the Songhua River. Residents lining up for water. Photo by Nila Gopaul in Harbin.

When the Songhua River in northern China became polluted with a massive benzene spill of approximately 100 tonnes in November 2005, the Chinese government did not report that incident immediately and did not inform its people of water contamination in the city of Harbin with over 4 million people; news from the BBC service was blocked. The Chinese are in a habit of blocking news to its people from foreign media; such as blocking news from the protests in Tibet and
Hong Kong to the carrying of the Olympic Torch in 2008. My daughter who was teaching in Harbin during the Songhua river incident telephoned me and asked me to check out a story about the Songhua River pollution of an unknown chemical spill as there was no news of this serious accident. I then checked out the news from a BBC here in Vancouver that the Songhua River was indeed the source of pollution; in fact, I learned later that the Songhua had more than 130 water pollution incidents in previous years. My daughter took this photo (Figure 3.13 A) showing residents lining up for water after the incident was later reported to the public.

I feel obliged to tell the next story about my daughter’s ordeal in another incident when she was living in Harbin and teaching at the University. The television set had “exploded” in her apartment. The explosion caused a fire, resulting in some damage to her lungs from the toxic emissions and she lost some of some of her personal belongings. Fortunately this accident occurred while she was about to be awakened; it was the sound of the exploding television that alerted her that something was wrong. The television set was not turned on but was obviously plugged into the outlet; my speculation was that because of so much coal dust and soot in the air its accumulation over the years may have short-circuited triggering that explosion. I cannot think of another reason except for some unknown malfunction of the TV but it was not turned on. The police arrived before the firefighters and asked her why she did not unplug the TV before going to bed. It seems customary to do this in China or perhaps in Harbin? The lesson: when in China, unplug your TV and perhaps other appliances before retiring. I also believe that the toxic fumes that she inhaled came from an accumulation of the pollutants and melting circuits in the TV. The next day my daughter was on her way home to Vancouver for medical treatment. This is a warning to tourists or workers who visit and live in China!

The Huai (Huai-he) River and its tributaries in China’s central and eastern region are extremely polluted, unfit for human consumption and agricultural use; this river enters Lake Hongze (Hung-tse) that empties into the Yangtze River. Another river, the Huang He or Yellow River as we know it, has temporarily run dry from low precipitation and over-use in irrigation; it is the sixth longest river in the world
that trickles into the Bo Hai Sea. Increasing pollution in China is known to
decrease trends in precipitation by 10 to 25 percent according to the IPCC. The
Yellow River has lost its water potential with many diversions, pollution from
industrial use and from many failed dams. The Yellow River in China’s northern
region is poisoned, stained with pollution, tainted with sewage, and crowded with
ill-conceived dams. About 50% of the Yellow River is considered to be
biologically dead and its water is deemed undrinkable. The May 2008 special issue
of National Geographic gives an insight into China’s growing environmental
decay and identifies the path of pollution of the Yellow River in over 2,500
kilometres length before it oozes into the Bo Hai Sea.

China is planning to divert water from the Yangtze River, just north of Shanghai,
through a tunnel to the north under the Yellow River for agricultural use; this is a
massive 62 billion-dollar project with a network of concrete conduits. This “South-
to-North Water Transfer Project” will siphon some 40 trillion litres of water a year
from the Yangtze Basin. “Eighty percent of the rivers are so degraded they no
longer support aquatic life and an astonishing 90% of groundwater systems under
the major cities are contaminated” writes Maude Barlow in her book, Blue
Covenant. The World Health Organization reports that 700 million people in
China drink water that does not meet safety standards set by that world body. We
were advised to brush our teeth with bottled water even at a five-star hotel in
Beijing!

Shortage of water is common in the north where nearly half of China’s population
lives but with only 15% of water reserves. The Yangtze River is 5,600 km long
with its origin in the Tibetan plateau has become the single largest polluter flowing
into the East China Sea carrying untreated sewage and other chemical pollutants;
irreversible pollution is found in one-third of its length. In May 2011, cargo ships
were left stranded and the river was closed to navigation because of the worst
drought in 50 years and low water level. A BBC report on March 2008 showed that
the Yangtze was at its lowest level in 140 years with many sand bars clearly visible
and with severe depletion of fish stocks; loss of fish comes from pollution and over
fishing. The internet carries several sites on the health of the Yangtze, its
importance to commerce and tourism.
A four-hour documentary aired by CNN a few years ago and billed as “Planet in Peril” examined the state of some of the rivers in China; it showed one river with a pronounced rust colour from iron mining carrying high levels of lead and cadmium and flowing through a community known as “cancer village” in northern Guangdong province. A high incidence of colon and other cancers is known in that region. Farmers use the polluted water to irrigate their crops but the locals refused to eat any of the crops grown in those fields. Chinese scientists have discovered a link between water pollution and the country’s high rates of hepatitis A, diarrhea, liver, stomach and esophageal cancers. In a National Geographic article by Brook Larmer, he reported that in “nearly two-thirds of China’s rural population or more than 500 million people use water contaminated by human or industrial waste.” It is no wonder that gastrointestinal cancer is now the number one killer in the countryside. Electronic wastes from computers and monitors end up in China from other countries according to one CBS ‘60-minute’ telecast. Tens of thousands of electronic units are recycled in cities like Guiyu and workers are being poisoned with lead, many developing sores on their hands according to that CBS report. As mentioned earlier, you would recall the TV set that exploded in my daughter’s apartment in Harbin, China, and caused her to suffer from respiratory problems. Children in Guiyu have also been affected with other heavy metals escaping into the atmosphere and water according to analysis of blood samples taken.

In July 2007, a massive spill of ammonia in the industrialized province of Jiangsu left many without water; you recall the incident in the Songhua river in Harbin. Lake Taihu east of Shanghai in Jiangsu province is extremely polluted and workers have to regularly remove the growth of algal bloom. Today about 70 percent of China’s lakes and rivers are reported to be polluted, unsafe for drinking or for recreational use. Factories and cities dump some 40 to 60 billion tonnes of wastewater and sewage into lakes and rivers every year causing massive algal growth and pollution. China is indeed paying a heavy health and environmental price for its rapidly growing industrialized economy and the government faces its biggest challenge to reduce pollution and secure the health of its citizens; that is the Chinese dilemma and it may be too late to enact strict regulations on polluters. The sailing venue from the 2008 Summer Olympics in Qingdao had to be cleared
of over 200,000 tonnes of blue-green algae; algal growth is a result of industrial and farm chemicals containing residues of toxins, nitrates, that are harmful to fish and other wildlife. Untreated sewage, excessive nitrogen from industrial run-off, and agricultural fertilizers promote algal bloom. The growing levels of nitrogen dioxide, sulfur dioxide and other pollutants were a few of the major concerns at the 2008 Summer Olympic Games. Satellite and ground data showed that air pollution in Beijing improved during the Olympics perhaps from the removal of a couple millions of vehicles before and during the games; it made for good politics and then it seems like business as usual thereafter as per my experience in 2016 in Beijing.

The number of vehicles in Beijing doubled in the past 10 years; by 2008 this number had increased to 3 million. The number of new cars added to Beijing’s roads every day is over 1,000. China now adds about 14,000 new cars each day and a total of about 130 million cars could be a reality by 2020 when China’s population is expected to reach 1.5 billion. By 2025, China is expected to have more cars than in the US. The good news is that China is producing more electric cars than the rest of the world. In 2009, China sold 13.5 million vehicles, more than all vehicle sales in the US in that year. Credit to China in its transit system of trains, the underground system and bullet trains. China like India wants to have the lifestyle that we enjoy in the West adding to affluence and a rising middle-class society. There are long lines of vehicles every day to purchase gasoline and traffic jams happen to be a living nightmare in major cities from my experience in Shanghai and Beijing. China and India are advancing the technology to produce plug-in hybrids and possibly hydrogen powered vehicles when they embark on more solar and wind to produce electricity.

Droughts and desertification have been increasing in frequency and duration in China. The depletion of water in China’s largest rivers has forced hydroelectric power plants to reduce power output from failed dams. As mentioned, water shortage in northern China over the past three decades led to the construction of the South-North Water Diversion project; more water will be diverted from the Yangtze River basin to the north. At the time of writing this project was not completed. Droughts that are more common in China’s north are also noticeable in
southern Guangdong province. It was reported that in the latter province, home to 110 million people, rainfall levels declined by about 40 percent. As mentioned, high pollution indices seem to reduce precipitation levels according to the IPCC. More than 60 percent of China’s water is used for agriculture and about 75 percent of the crops grown in the northern regions are through irrigation systems. China’s agricultural output is expected to decline from 5 to 10 percent by 2030. China’s Environmental Pollution Administration surprisingly reported that more than 70% of its lakes and its five longest rivers are polluted and unsuitable for human contact. The scary fact is that about 300 million people have little access to drinking water and additional 500 million people drink ‘treated water’

![High speed train](image.jpg)  
Figure 3.14 B. High speed train. Credit TravelChinaGuide.com file photo.

On a positive note, China has increased its forestry from 12% since the 1980s to 18% and is projected to expand on afforestation; this initiative was in part to reduce CO₂ levels and increase the carbon sink. Some 24,000 villages in northern and western China have been entirely or partly abandoned as a result of being overrun by drifting sand. China defends itself against the Gobi desert by planting a 4,480 km wide corridor of trees from outer Beijing to Inner Mongolia. China is developing, exporting and using more renewable sources of energy; its target is to increase renewables of hydro, wind, solar and biomass from 7% to 16% by 2020.
China is also building more rapid trains and underground systems to reduce vehicular traffic, to save on fossil fuel and reduce lengthy traffic jams on major highways. The high-speed bullet train (Figure 3.14 B) is in service between Beijing and Shanghai, a distance of 1,318 km and takes about 5 hours with an average speed of 300 km/hour. The rise of China may well prove to be the defining economic and political change in our lifetime. Martin Jacques in his book, *When China Rules The World*, cites “the rise of the middle kingdom and the end of the western world by giving an illuminating analysis of the future of China. China will remain highly distinctive and ultimately the major global power.”

**Turning to India**, the largest democracy in the world with a population of about 1.34 billion in a 2017 estimate, would likely surpass China’s 1.41 billion within a few years. The life expectancy in India in 1952 was 38 years compared to 64 years today while China’s life expectancy in 1952 was 41 years then jumped to 73 years by 2014. More people are moving out of poverty and are living longer in India and China. The population growth in India is expected to exceed that of China before 2035. Food production is improving in India but malnutrition is still widespread. India has the largest number of births each year at 27 million, about two-thirds of the entire population in Canada. Agriculture is the means of livelihood of almost two-thirds of the working force. India’s wheat production has increased with improved mechanization and fertilizer production. Every year in India two million children die from a number of health-related causes and more than 50% of them during the first month after birth, and in addition, 400,000 children each year die in the first 24 hours of birth. Roughly 30 percent of children less than five years of age are malnourished and the World Bank estimates that 20 percent of communicable diseases are linked to unsafe drinking water. The Ganges River is not the only river in India that suffers from environmental degradation; several rivers including the Yamuna are severely polluted.

According to the *World Health Organization* virtually all of India’s surface and ground water harbour polluting substances. Pollution emanates mainly from agricultural runoffs of pesticides, fertilizers, toxic chemicals and sewage. “Seventy five percent of India’s rivers and lakes are so polluted, they should not be used for drinking or bathing” writes Maude Barlow in her book, *Blue Covenant*. Hindus
believe that the Ganges water will wash away their sins and to be cremated on the banks of the Ganges River (Figure 3.15) guarantees that the soul will escape the world’s cycle of suffering. But the holiest of India’s river, the Ganges, is one of the most polluted in the country. The Yamuna River arises in the lower Himalaya and leaves Delhi as a sewer containing pesticides and other chemical wastes. Barlow wrote that the “fabled Yamuna River is clinically dead.” Drinking water from the Yamuna River that flows from Delhi to Agra and beyond to Allahabad before emptying into the Ganges poses a serious health risk. Health problems also arise from arsenic and fluoride in groundwater that seep into wells that are commonly used in rural India. “Twenty-three million tube wells operate around the clock in India and going so deep they are taking up water at the time of the dinosaurs” writes Barlow. Like China, India is building a massive pipeline from the Tehri Dam in the outer Himalaya to divert water from the Upper Ganga Canal (main source of the Ganges) to supply the city of Delhi. The Indus River in Pakistan, the Ganges and Brahmaputra Rivers in India supply drinking water, for irrigation to 1.5 billion people in Asia. The Indian government in 2017 approved a budget of $4 billion for the Ganges (Ganga) rejuvenation project. Indian Prime Minister Narendra Modi said “it is my duty to serve Maa Ganga (Mother Ganges)” in the cleanup project.

The day I arrived in New Delhi the haze and pollution were quite extensive and learned that it was normal occurrence. In fact, air pollution indices have been escalating at an alarming rate for many years. The level of air pollution in major cities in India is classified as “dangerous.” Air pollution and contaminated water contribute to 2.5 million premature deaths annually; it is a hidden crisis with no immediate solution. “On a typical weekday in Kolkata, a city of 14 million people in the Indian state of West Bengal, the streets are clogged with vehicles and the air is thick with exhaust. Soot coats the leaves of trees along the sidewalks and the skin tingles. Snot turns black…the annual average concentration of nitrogen dioxide is nearly double the regulatory threshold level” writes Yudhijit Bhattacharjee in Science journal. India’s former Prime Minister Manmohan Singh said that his vision is to make India less dependent on fossil fuel and to advance a non-fossil fuel economic activity. The work on transition to renewables is slow but deliberate while India still relies heavily on coal for electricity. Vestas a large wind
A turbine company in Europe has installed nearly 5,000 turbines in India and employs approximately 900 people there. Renewables are making some headway in India and more so in China today.

Two headlines on Delhi’s air pollution in the *UK Guardian* newspaper on November 7, 2017 read: “**Delhi’s air pollution rises to nearly 50 times the London average**” and “**New Delhi pollution hits dangerous level, putting residents at risk.**” Tests by Greenpeace indicated that fine pollutants are composed of carcinogenic chemicals such as lead, arsenic, cadmium and mercury. Levels of pollutants for particulate matter for PM2.5 were more than 11 times the World Health Organization’s (WHO) safe limit. The *Air Quality Index* (AQI) on the other hand, includes pollution from **particulate matter (PM2.5)**, **ground ozone (O_3)**, **CO, NO_2 and SO_2**; a “good” AQI has a range of 0-50, “moderate” 51-100 and “hazardous” 300-500. The Delhi *Air Quality Index* (AQI) had reached 403 at peak hours on that November day. An AQI above 300 is ‘hazardous’ while for PM2.5 greater than 170 ug/m^3^ is ‘hazardous’. Low to moderate concentrations of PM2.5 range from 0 - 26 ug/m^3^ of air. Flights were cancelled and schools closed with that severe air pollution crisis. Cited earlier under the “Coal” section, a particulate matter (PM) and size of 2.5 micrometers (PM2.5) or 0.0025 mm – both PM2.5 and PM10 are particle sizes that are inhalable and measured in concentrations of micrograms per cubic meter (ug/m^3^) of air. A human hair has a diameter size of about 50-70 micrometres, much larger than PM2.5.

One encouraging bit of news is that in the city of New Delhi compressed natural gas is being used on buses but with cheaper cars becoming increasingly widespread and sold by India’s Tata Motors for $2,500 each. Any gains made in curbing air pollution are negated with additional vehicles and from diesel-run light trucks. The two-stroke and four-stroke three-wheelers used as taxis also contribute to air pollution in all of India’s cities. As income rises and with an emerging middle-class Indians purchased more than 1.5 million new passenger vehicles are sold and sales are expected to double at the time of writing. There are over 300 million people without access to electricity and mostly in the state of Bihar, the poorest state in India. Worldwide about 1.2 billion people are without electricity. The bad news is that like China, India relies on its 125 coal firing plants...
to generate electricity; many more plants and coal production are inevitable as people rise up from poverty. India has the fifth largest coal reserves in the world and still imports more to meet its needs. Carbon intensity is higher than in most countries and defined as the amount of carbon (pollution) by weight emitted per unit of energy (fossil fuel) consumed.

Figure 3.15. The Ganges River at Varanasi in India where Hindus wash away their sins. A cremation site was located in the background where people congregate - the sacred the cow wanders everywhere. Photo by the author.

China and India are developing economies that could well afford to advance and implement renewable sources of energy and they have working towards that end. Thomas Friedman in *Hot, Flat and Crowded*, bluntly stated that the “Chinese Communist Party will not be able to deliver on its promise to its people of the freedom to breathe unless it gradually but steadily starts to grant more of them the freedom to speak.” China’s human rights abuses are among the worst in the world. The 2010 Nobel Peace Prize was awarded to Chinese citizen, Liu Xiaobo, who could not speak his mind while he was campaigning for democracy and free speech in China; he was serving an 11-year sentence as a political dissident and in July 2017 died after he was granted medical parole. He committed no crime but was considered a threat to the Chinese political regime. When the Nobel Peace Prize was announced, China warned countries to stay away from the award ceremony in
Oslo, Norway, where an empty chair accepted Liu Xiaobo’s Nobel Peace Prize. The ceremony was dignified with most nations in attendance and defying China’s request; the world had earlier called for Xiaobo’s release from prison as he did not violate any law in China. (At the time of writing, China is holding two Canadians who have committed no crimes as retribution in holding a Huawei executive in Canada wanted for extradition to the USA.)

Both India and China naturally wish to advance their standard of living just as we enjoy in the West but with an environmental and health price to pay especially to the poor with both countries contributing GGE by over 35% globally. The irony is that moving from poverty to middle-class or affluence increases GGE in putting more carbon into the atmosphere and increasing pollution. There is no quick fix for the health and food security of the growing economies of China and India. Both countries hold one-third of the world’s population and as noted there is no ‘technical solution’ to human growth. In ‘Tomorrow’s Earth’ by Jeremey Berg in a 2018 Science journal, he wisely questions our future: “Although human population growth is escalating, we have never been so affluent. Along with affluence comes
increasing use of energy and materials, which puts more pressure on the environment. How can humanity maintain high living standards without jeopardizing the basis of our survival?

Trouble Spots and Too Crowded

Excerpts from the “The Tragedy of the Commons” by Garrett Hardin:

"Population, as Malthus said, naturally tends to grow "geometrically," or, as we would now say, exponentially. In a finite world this means that the per capita share of the world's goods must steadily decrease. Is ours a finite world? A fair defense can be put forward for the view that the world is infinite; or that we do not know that it is not. But, in terms of the practical problems that we must face in the next few generations with the foreseeable technology, it is clear that we will greatly increase human misery if we do not, during the immediate future, assume that the world available to the terrestrial human population is finite. "Space" is no escape. A finite world can support only a finite population; therefore, population growth must eventually equal zero. The most important aspect of necessity that we must now recognize, is the necessity of abandoning the commons in breeding. No technical solution can rescue us from the misery of overpopulation. Freedom to breed will bring ruin to all." Garrett Hardin’s “Tragedy of the Commons.” Science journal, 13 December 1968.

The human population today is climbing over 7.6 billion and “going on a predicted 11 or so billion by 2100. Such a large population can only be sustained by continued heavy, heavy use of energy. Fossil fuels will run out, destroy the planet, or do both. The only possible way to avoid this outcome is rapid and complete decarbonization of our economy. Needless to say, this will be an extremely difficult thing to pull off. It requires the best of our talents and innovation, which miraculously, it may be getting. It also needs much better than normal long-term planning and leadership, which it most decidedly is not getting yet. In theory, Homo sapiens can easily handle this problem; in practice, it will be a very closely run race. We should never underestimate technology but also never underestimate the ability of us humans to really mess it up.” Jeremy Grantham (2018): “The Race of Our Lives Revisited.” (www.gmo.com)

The carbon footprint of the average Chinese or Indian is lower than the average Westerner but both countries today emit 35% of the global GGE. By 2017 there were about 2.75 billion people or more than one-third of the world’s population of 7.7 billion living in China and India; both countries now emit more greenhouse
gases than the US, all of Europe & Britain, and Canada combined. North Americans, Europeans, Japanese and Australians who make up 20% of the world’s population consume more than 75% of the world’s resources. It is obvious that consumerism and affluence add to climate change and global warming but population increase plays a big part of the equation. The book *Limits to Growth* by Donella Meadows in 1972 and revised some 30 years later, warned that by the year 2100 “the world might be on a collision course with catastrophe if growth in resource use, industrial output, food production and population expansion continue on the present course.” The authors in making recent computer model projections in their revised study of *Limits to Growth* came to the same conclusions as were in 1972 edition that “continued growth would lead to overshoot and catastrophe for human civilization.”

In limits to growth and carrying capacity, does planet Earth have a total carrying capacity to maintain sustainability of humans and the biosphere in which we live? Carrying capacity is complex and involves many factors that can be changed over time. In a concept of a pasture supporting grazing of cattle where that pasture could support indefinitely a particular number of cattle. If the threshold level to sustain a certain number is exceeded, the supporting pasture may no longer sustain that increase. Only one product is considered in this example – the number of cattle in which the pasture could support. In reality the carrying capacity of any ecosystem involves a range of other factors that places sustainability at risk as a number of products and services must come from the same ecosystem. Limits to growth or overshoot is a warning on the impact of population increase in any community or region or country and we see the limits today on the carrying capacity – the needs and wants of any community.

Garret Hardin in a *Science* journal article some 50 years ago defined ‘*The Tragedy of the Commons*’ as many individuals acting together in their own self-interest without regard for society. The effects can be catastrophic. Hardin warned of a coming population-resource collision based on individual self-interested actions adversely affecting the common good. In 1968 when Hardin composed his piece, the global population was about 3.5 billion; since then, the human population has more than doubled (7.7 billion), a rise that has been accompanied by large-scale
changes in land use, resource consumption, waste generation, and societal structures. However, through collective action, we can indeed achieve planetary-scale mitigation of harm. A case in point is the Montreal Protocol on ‘Substances that Deplete the Ozone Layer’, the first treaty to achieve universal ratification by all countries in the world. The UN Conference of Parties, in particular, the Paris COP 21 or Paris Agreement aims to keep a global temperature rise in this century well below 2°C and to strengthen the ability of countries to deal with the impacts of climate change. Jeremy Berg writing in *Science* (June 29, 2018) noted that “technology alone will not rescue us. For changes to be willingly adopted by a majority of people, technology and engineering will have to be integrated with social sciences and psychology.” Jeremy Grantham in *The Race of Our Lives Revisited* wisely puts it: “We must also find inspirational leadership, for without it this race, possibly the most important struggle in the history of our species, may not be winnable. It is about our very existence as a viable civilization. We will need all the leadership, all the science and engineering, all the effort, and all the luck we can muster to win this race. It really is the race of our lives.”

More than 250 million people in China and India have emerged from poverty in the past 35 years and tens of millions more will advance to a middle-class lifestyle. This is a credit to both China and India in economic terms but with a heavy environmental price to pay. Much more needs to be done to provide clean water and expand its use in agriculture; water use for human consumption and agriculture remains a scarce commodity worldwide. India’s population grew by 156 million in the past decade but lifted 95 million out of poverty during that time. More Indians are enjoying access to electricity with expanding coal fired plants (that need to reduce) but millions more are without it. There are 1.3 billion people worldwide today without access to electricity, with 662 million living in Africa and another 622 million in Asia. By 2030 about one billion people may still have no access to electricity unless renewable energy sources such as wind and solar are fast advanced. The bad news is that more coal-fired plants are being built in China and India and GGE will keep on rising in the next 10-20 years. Kenya, for example, is doing a good job by using solar power to harness electricity for many; having electricity always improve the quality of life and health of all people. *Vestas*, a large wind turbine company in Europe, has also committed to investments in
Kenya by participating in the development of a wind park. The goal is to supply 15% of the electrical needs for Kenya, a country that is plagued by expensive and unreliable energy sources. Kenya is a good example of how to harness clean electricity as a primary goal. Kerala in the southern state of India is also a good example of how they reduce their population and improve their standard of living and education especially of girls and with an improved medical care.

Reports of ongoing conflicts and unrest around the world seem to be a common occurrence especially in the Middle East, East Asia (Afghanistan and Pakistan), Yemen, and regions of Africa such as Sudan, Mali, Niger and northern Nigeria. The wealthy oil producing “petrodictators” in the Middle East who collect billions of dollars do not pass on their wealth to the less fortunate. Thomas Friedman in *Hot, Flat and Crowded* and Lawrence Wright in *The Looming Tower* both wrote about the support of Al-Qaeda and terrorist groups like ISIL who benefit from oil revenues from individuals in the Gulf and Middle East countries. The emerging terrorists, the Islamic State or ISIL, obtain revenues from some states and evidence of arms retrieved from the battlefield. Those ‘friendly’ Middle Eastern States, all dictatorships and ruling families of Kings, Sultans and Emirs, have advanced their standard of living not only from the oil and gas revenues they hold but also from the expertise of foreigners and cheap labour of millions of workers from Asia. I spent three years in the state of Qatar and have seen first-hand how migrant workers from Asia are being treated. There is a big human price to pay for the infrastructure and construction of stadiums for the World Soccer Tournament in 2022 that should never be given to Qatar but only from bribery to some FIFA officials.

The message in *The Looming Tower* gives an insight in understanding the continuing terrorist threat and the main players behind Al-Qaeda and ISIL or ISIS. Thomas Friedman noted that Saudi Arabia had banned one edition of *Forbes* magazine from revealing the wealth of King Abdullah and other Arab leaders. The families of the Kings, Sultans and Emirs in the Middle East and Arabian Gulf are all multi-billionaires and control the country’s wealth. The unborn to those families are also guaranteed wealth for life and the pyramid extends to thousands of family members. There is a silent and vocal discontent among the citizens of those
countries but the petrodictators have the final say and with their rule of law; the Arab Spring changed some of that discontent in North Africa but still with ongoing displacement of humans, suffering, killings and ongoing poverty, notably in Syria.

Food production has been declining in developing countries especially in sub-Saharan Africa, North Africa and in regions of Asia and Latin America. Prices for grain crops such as soy, wheat and corn have been rising. Extreme weather is more frequent in all regions resulting in shortage of food, low water levels for agriculture and the rise in food prices such as rice and wheat. Soy prices are expected to increase as a result of lower precipitation in regions of northeast Brazil where soy is grown extensively. Food riots have been common in poorer countries. Russia, the Ukraine and Argentina have blocked the export of wheat. China, India and Indonesia are not exporting rice any more. Our wealthy province of British Columbia imports under half of its food mostly from the US with most of it coming from California. The agriculture land reserve in Canada and especially in BC is being threatened with development for housing; we should be growing and exporting more of our own food in Canada. The impact of climate change in Africa is expected to affect between 75 and 250 million people mainly from the lack of safe drinking water and lower food production. Yields from rain-fed agriculture could be reduced by 50 percent in sub-Saharan Africa. A major problem facing the continent of Africa is its escalating human population, the highest growth rate in the world. Conditions in northern China as mentioned have worsened and agricultural production declined by as much as 10 to 15 percent from lack of water and continuing desertification.

In about 12 years, Earth will be home to 8.6 billion inhabitants, an increase of less than a billion from today’s 7.7 billion, assuming that the birth rate continues to decline from the present. Demographers project that the human population would likely reach 9.8 billion by 2050, give or take half a billion and by 2100 it would climb to around 11 billion as cited in Wikipedia and other sources. “The IPCC best-case scenario projects that the global population would peak at 8.7 billion in 2050 and with less globalization and co-operation, global population is expected to increase until 2100, reaching between 10.4 billion and 15 billion” for a worst-case scenario. Food production would have to triple for everyone to have an
adequate diet says Nobel Laureate Henry Kendall with present population rate of growth. China's population growth rate was reduced to less than 1% compared with India's 2.1% increase during the 1990s. Today those rates are more encouraging for China and India with population growth rates of 0.60% and 1.6%, respectively, and by 2025 those rates are expected to further decline to 0.20% and 1.2%, respectively. Forty five percent of Chinese women say that they do not want to give up their careers to get married; culturally, India is different from China where most women with less education marry at a younger age and with no restrictions unlike in China on the number of births per family. China recently changed its one-child policy to two per couple but there is a cost levied to the family. Education is the key to reducing family size and the Chinese family prefers to stay with one child as the cost of the overall education a child is high. In the state of Kerala in India where education and especially that of girls has been in the forefront with the population growth the lowest in India while at the same time health care has greatly improved.

From 2000 – 2010 India’s population grew by 180 million. By 2025, India’s population is expected to reach 1.40 billion with China’s population stabilizing at about 1.43 billion. By 2050 close to one-third of China’s population will be over 60 years of age and more would continue to enjoy a middle-class lifestyle. The USA would remain the third most populated country by 2050 with 400 million, from 321 million in a 2015 census. Canada’s population from Statistics Canada reached 37 million by April 2018. For more information on global population growth and projections, visit the US Census Bureau website at www.census.gov/ipc/www/idb; for Canada visit http://www.statcan.gc.ca. With accompanying population pressures come increased air and water pollution, greater poverty, malnutrition, loss of agricultural productivity, water scarcity and social unrest; we only have to look at events from 50 years ago to the present to understand how global environmental conditions including the climate have changed. Both China and India are home to many air polluted cities and rivers that are unfit for human consumption. Even with less fossil fuel use, if countries cannot safeguard its water and air quality the health of its citizens would be worsened as cited earlier for air pollution.
An estimated one billion people in developing countries live in slums; slums are defined as areas that lack clean water, sanitation, and durable housing, increasing malnutrition, and with children having no primary education. Factors that lead to poverty generally include a lack of arable soil, poor water quality for human consumption and agriculture, no access to electricity, little or no medical care, political unrest and little or no education. Making contraception and family planning more widespread, postponing marriage and promoting education especially among girls would reduce the number of children in any household; educated and developed societies and economies are known to have smaller families and have become more prosperous. As mentioned, the state of Kerala in India has the lowest birth rate and education of girls is higher than elsewhere in India. Sterilization is the dominant form of birth control in India today. Japan and European countries have negative or neutral population growth. Poverty contributes to environmental degradation, and environmental degradation contributes to poverty and hardship for both developed and developing economies. The good news according to a UN report is that the average number of children per woman has gone from 6 to 2.5 over the past 60 years. Population, environmental, and social-justice issues are inextricably linked. Giving women more rights over their own bodies, more respect for human rights, making education and family planning more widely available would stabilize population growth and create greater benefits and opportunities to families and societies.

**From Kyoto to Paris & Canada’s Role on Climate Change**

It has been quite a roller-coaster ride with Canadian politicians over climate change decisions or indecisions at the international level since the Rio 1992 UN Earth Summit. Canadians learned that the Kyoto Protocol became history when Environment Minister Peter Kent and Prime Minister Harper announced in 2011 the decision to terminate Canada’s binding agreement at the United Nations (UN) Conference of the Parties (COP) in Durban, South Africa. The purpose of the *Kyoto Protocol Implementation Act* was “to ensure that Canada takes effective and timely action to meet its obligations under the Kyoto Protocol…” Canada signed on to Kyoto in 1998, ratified it in 2002 and it became legally binding in 2005 for Canada. We failed to uphold that agreement then signed on to the Paris Accord in
2015 with a greenhouse gas emission reduction plan that is ambitious but would likely fail to be implemented before 2030.

The report from the Commissioner of the Environment and Sustainable Development in 2011 stated that “the 2009 and 2010 climate change plans are not in compliance with the Act as they do not include all of the information required by subsection 5(1).” Canada has been making little progress under (former) Prime Minister Harper’s government to reduce GGE and allowing emissions to rise about 30% above Canada’s Kyoto target; not all blame should be placed on the Conservatives as past Liberal administration should also shoulder some of the inactions to keep GGE under control. Canada had an obligation to the following measures: (1) to promote and cooperate in the development and transfer of technologies to control and reduce anthropogenic GGE; (2) to reduce greenhouse gases by 6% below the 1990 baseline of 600 million tonnes per year from the years 2008 to 2012; (3) to provide new and additional financial resources to help developing countries comply with their obligations under the United Nations Framework Convention on Climate Change (UNFCCC) and, (4) to support the Copenhagen and Cancun agreements of established funding for developing nations on adaptation measures to climate change. Canada failed to meet many of its obligations, showed little progress to reduce GGE and received the Fossil of the Year Award.

The former federal government of Canada then stated it would align with the USA in reducing GGE of “17% below 2005 level by 2020” and would harmonize with the US but the US forged ahead with carbon reductions and left Canada behind to this day. That proposed Canadian target would never meet its intended goal by 2020. In fact, Canada’s GGE climbed by 2% whereas in the US GGE dropped by 2% since 2011. The US had no obligation under the Kyoto Protocol since they did not sign that Treaty but has been doing a better job than Canada in reducing its GGE, reducing its coal use, using more natural gas and producing more renewables. Canada has been lacking leadership under former Liberal and Conservative governments while the European Union (EU) was and is setting a good example in reducing its GGE. The present federal Liberal government in 2015 promised to put climate change on the forefront and added a “Climate
Change” component to the Environmental Minister, Catherine McKenna’s portfolio but in name only. The Paris COP21 and Canada’s role will be discussed later in this section.

In retrospect, the 2011 report from the Commissioner of the Environment and Sustainable Development confirms that “it is unclear whether the federal government will be able to achieve the reduction targets” of 17% from 2005 levels by 2020 unless we advance renewable forms of energy, slow down on oil sands developments and abandon coal combustion for electricity. Time has basically run out for the 2020 deadline. All of the latter were ignored by the federal Conservative government. The Fall 2014 report of the Commissioner also stated “our most recent audit of climate change showed that little has changed over the last two years” to reduce GGE in Canada. By 2020 emission at the oil sands is projected to be 104 megatonnes or 14% of the total emissions for Canada when production of bitumen would likely exceed three million barrels per day according to the Canadian Energy Research Institute. Bitumen production by 2018 was about 2.4 million barrels per day (mbd) while present pipeline capacity could accommodate over three mbd.

Alberta has the highest emission of greenhouse gases in Canada from the petroleum industry and from coal to power 55% of its electricity. The daily world production of oil is over 85 million barrels at the time of writing and this supply needs to drop if GGE is to be kept below 2°C in this century from pre-industrial time. OPEC (Organization of Petroleum Exporting Countries) also sets no limits on the price of oil. The USA is still the world biggest consumer of oil with China as a close second; coal is the cheapest fossil fuel and the primary use in generating electricity for many countries but mainly in India and China. Canada is one of the biggest suppliers of conventional, synthetic and bitumen petroleum products to the USA; we also ship trainloads of Canadian and US coal mainly through Roberts Bank in BC to overseas market. Eastern Canada imports about 600,000 barrels of oil each day from the USA and OPEC countries; this may not change since the $15 billion Energy East pipeline was terminated by Trans Canada Corporation. More bitumen is expected to be in the pipeline to the US if and when the TransCanada Keystone XL gets official approval by the US administration. At the time of
writing Trans Mountain twin pipeline has been given approval by the federal government and National Energy Board but delays are expected.

From 1990 to 2007, GGE in Canada increased by 34% above the Kyoto target baseline. By 2009, Canada’s GGE was still 31.5% short of the Kyoto target. According to the Climate Action Tracker of four research organizations including the world renowned Potsdam Institute, “Canada had pledged to reduce its GGE by 17% below 2005 level by 2020 which now translates into a 7% increase from1990 baseline…Canada intends to achieve an economy-wide target to reduce our greenhouse gas emissions by 30% below 2005 levels by 2030.” Environment Canada keeps telling Canadians “Canada is making progress in reducing our emissions – from 2005 to 2013, and Canadian greenhouse gas emissions decreased by 3.1% while the economy grew by 12.9%”. The Intended National Determined Contribution (INDC) by the Canadian government at the Paris COP21 in 2015 pledged to reduce emission by 30% from 2005 level by 2030 and this reduction will not happen!

The Climate Action Tracker believes that “Canada will miss its 2030 INDC by a large margin” – refer to Figures 3.16 A & B for projections. Since the Kyoto GGE target was a dismal failure for Canada, setting targets on emissions are not as important as laying out an achievable energy plan. Canadians expect that the Trudeau government will have an achievable plan after COP21 and in consultations with the provinces to reduce greenhouse gas emissions; unless we move to 25% renewables before 2030 and abandon all coal plants the INDC by 2030 will not be realized. The 2016 Pan-Canadian Framework on Clean Growth and Climate Change document outlines proposals to hold down emissions by all provinces. Provinces are embarking on cap and trade and carbon tax plans that the federal government has proposed but not provinces are in agreement especially since the newly elected Conservative government in Ontario took office. British Columbia has been on the forefront for some years now with a carbon tax levied at $40 per tonne of CO₂ equivalent in 2019 and increasing modestly every year. The Canadian Chamber of Commerce (www.chamber.ca) document “A Competitive Transition” on how to get Canada’s climate policy right is more realistic than the government plan and should be linked with the Pan-Canadian Framework.
*The Pembina Institute* noted that “three consecutive environment ministers under Prime Minister Harper have failed to implement a single major policy to cut our growing emissions.” Catherine McKenna, the present Minister of the Environment and Climate Change, emphasized the following point before the COP21 in Paris: "It means ending the cycle in which federal governments of both stripes have set arbitrary targets without a corresponding plan, without adequate consultation and partnerships, without the commitment and the will required to make those targets achievable." That was encouraging news from Canada’s climate minister but will Canada achieve its intended plan that will coordinate in a 1.5°C before 2050? **It seems highly unlikely at the time of writing.** Canada plans to phase out coal-fired plants to generate electricity and reduce GGE in passenger vehicles and light trucks. Investments in renewables such as wind and solar as well as hydro are in the plan. The provinces of Alberta, Saskatchewan and Ontario are contesting the *Greenhouse Gas Pollution Pricing Act* enacted in 2018 by the government of Canada in an ongoing dispute at the time of writing. The good news is that Alberta plans to phase out coal by 2030 among other emission controls and by advancing renewables.

On the basis of greenhouse gas emissions in Canada, carbon dioxide (CO₂) contributes 78% of the total output while methane (CH₄) accounts for 15%, and the rest coming mainly from nitrous oxide (N₂O) and the halocarbons. Not all of the GGE comes from the energy industry but from agriculture, buildings, cement production, transportation, land use and deforestation, and forestry. *Environment Canada* reported that transportation in Canada by road, rail and sky contributed 33% of greenhouse gas emissions from fossil fuel combustion, while about 56% originated from energy industries like stationary combustion sources of electricity, manufacturing and construction, and about 11% from fugitive emissions, such as coal mining, oil and gas, venting and flaring. Electricity in Canada that originates from hydro-generation represents 78% mainly in the provinces of British Columbia, Manitoba, Quebec, and Newfoundland and Labrador.

Coal-fired plants for producing electricity are still being generated in Alberta, Saskatchewan, Nova Scotia, New Brunswick and Ontario with the latter province reported as having no new coal plants built. From 2005 to 2014, greenhouse gas
emissions across the province of Ontario declined by 7 percent. This trend was
driven by a nearly 20 percent reduction in greenhouse gas emissions in Ontario’s
energy sector. In other words, it was driven in part by the coal phase-out which
reduced emissions by an amount equivalent to taking 7 million cars off the road
according a Pembina Institute report. Nova Scotia placed a cap on coal power
plants after 2012. Nuclear power provides 15% of the electricity needs to Ontario,
Quebec and New Brunswick. Most of Ontario’s electricity is generated from
nuclear power while BC, Newfoundland, Quebec and Manitoba use hydro for over
90% of its electricity. New and smaller nuclear power plants are likely to be in the
future. As mentioned, new measures were being implemented in Quebec, British
Columbia, Alberta, Manitoba and Ontario to curb greenhouse gas emissions with a
carbon tax and cap and trade. BC implemented its carbon tax of $30 per tonne of
CO₂ equivalent on all fossil fuels and has the one of the lowest per capita carbon
footprint in Canada mainly from generating electricity from hydro power and
natural gas for heating. Under the federal plan, provinces have the right to develop
their own carbon prices but every province (except BC) must have a carbon price
of at $20 per tonne of GHG in 2019; the carbon pricing or tax in BC is $40/tonne
of CO₂ equivalent. Not all provinces are in agreement with the federal plan to
reduce GGE while Alberta, Saskatchewan and Ontario are taking the federal GHG
initiative or carbon tax ruling to court. The carbon fuel tax in BC is the highest in
Canada at 8.89 cents/litre of gasoline in 2019 and applied unequally across
Canada.

On emissions control, the good news is that a number of developed countries in
Europe has been on track in meeting their post Kyoto targets and plan to support
further reductions. Canada now contributes under 1.6% of the total global
greenhouse gas emissions (GGE) worldwide as much Britain with more than twice
the population of Canada. The United Kingdom (UK) has almost met its Kyoto
target in reducing greenhouse gases and future reductions look more promising; the
UK has switched mainly from coal to natural gas and the US has been doing
likewise (Figure 1.3 E). France, Spain, Germany, Iceland, Norway, Denmark,
Sweden and ten eastern bloc countries have also reduced their emissions
significantly. Sweden is committed to a “Sweden free of fossil fuels” by 2020 and
has the lowest air pollution in the world. Iceland is already using its geothermal energy resources for 72 percent of its primary energy needs. Under the *Clean Air Act*, the US has been making progress on many environmental fronts including transportation and continuing to lower GGE. The US under President Obama was committed to reducing GGE and expanding on renewables. At COP21 the US pledged to reduce its emissions by 26 - 28% below 2005 levels by 2025, a more robust plan than Canada’s; President Trump is likely to abandon the Paris Agreement by 2020 but Mayors and Governors across the US will continue to reduce GGE in spite of Trump. A plan was also endorsed by all 27 leaders in Europe (EU) to cut GGE by 20% from the 1990 level by 2020, and with 20% of Europe’s energy mix to come from renewable energy sources such as wind and solar. The government of Canada must develop a strategic plan with all stakeholders to embark on wind, solar and other renewables while at the same time create new jobs as evident in Europe, USA and China. The *Pan-Canadian Framework* does not go far enough on renewables. As mentioned, Canada will not meet its intended target by 2020 or 2030 as cited in Figures 3.16 A&B even with current measures.

The not so good news coming from *The Climate Action Network* (www.climateactionnetwork.ca) and obtained in a report under the *Access of Information Legislation* reveals that the (former) Conservative Government of Canada was pursuing an orchestrated strategy to undermine European and US efforts to combat climate change and reduce greenhouse gas emissions. The (former) Government of Canada established an “Oil Sands Advocacy Strategy” in the Department of Foreign Affairs to kill clean energy policies and promote the interests of oil companies according to that report. Between 2007 to 2009 the Canadian government lobbied against a California clean energy goal to reduce carbon intensity in transportation. Three former Conservative Ministers of the Environment did not pass a single legislation to regulate industrial GGE or oil sands pollution.

*Environment Canada* claims that a substantial increase in GGE between 2010 and 2020 will come from Alberta’s oil sands operations. Oil sands produce more than
1.6 times more GGE than conventional oil production. The oil companies and the Canadian Association of Petroleum Products (CAPP) must factor in the use of electricity and natural gas when calculating GGE from production of bitumen with in situ means, thus making emissions higher than the 5% they claim as oil sands emissions. As mentioned, British Columbia is one of the lowest emitters of GGE per capita in Canada (14 tonnes of CO₂ eq) fortunately from hydro-generation for electricity, no coal consumption and from its carbon tax. Both Alberta and Saskatchewan carry a per capita carbon footprint of 66 tonnes of CO₂ equivalent since coal is used to generate most of their electricity and its high energy production.

![Graph showing Canada's greenhouse gas emissions projections to 2030](Image)

Figure 3.16 A. Canada’s greenhouse gas emissions projections to 2030 in millions of tonnes (megatones) of GHG in CO₂ equivalent minus land use, land-use change and forestry. Credit Environment Canada.

Following the Copenhagen Conference, the Government of Canada announced that it would invest $400 million as agreed upon in Copenhagen to assist the poorest countries to adapt to climate change impacts, develop clean energy technology, and cut emissions by reducing deforestation. Environment Canada said that 72% of
that money will be in the form of *loans* and only 11% will go directly as a grant to helping developing countries adapt to climate change. Canada obviously overstated its initial pledge to assist poorer countries as not all funding will be in the form of grants. Developed countries at Copenhagen agreed to contribute to an international fund of $30 billion for adaptation and other measures for developing countries and small island states. Many small island states, sub-Saharan countries and other poorer nations did not receive the required funding a year later for adaptation or what was agreed upon in Copenhagen.

![Canada's Emission Projections in 2020 and 2030 (Mt CO₂ eq)](image)

Figure 3.16 B. Realistic Projections of GGE by 2020 and 2030 for three scenarios. The 2020 and 2030 targets would likely not be realized. Credit Environment Canada.

The intended goal at Copenhagen was to limit global warming to 2°C from pre-industrialized time and more ideally to keep temperatures below 1.5°C that the developing countries were demanding with the exception of China and India. In an effort to avoid calamitous impacts of climate change, the global emissions of all greenhouse gases must be stabilized at less than 40 billion tonnes (Gt) of CO₂ equivalent per year by 2020; by 2018 the total global anthropogenic GGE was 52 Gt. of CO₂ equivalent. China’s policies and actions appear ambitious enough to
potentially overachieve the CO$_2$ goal in its *Nationally Determined Contribution (NDC)*, as well as its national targets. Refer to Figures 2.2 A & 2.2 C for projections of GHG for a 1.5°C and 2.0 °C by 2030 for a 66% probability and NDCs (pledges) as well as “Current Policies” provided by the UN 2018 Gap Report.

![GHG Emissions, 2010](image)

Figure 3.16 C. GHG CO$_2$ equivalent per capita in selected developed countries. Emissions per capita of 20 tonnes of CO$_2$ eq. for Canada have not changed since 2017. Credit United Nations.

The *Climate Change Performance Index (CCPI)* rated Canada’s performance in Copenhagen and Cancun as fourth to last and was again given the “*Fossil of the Year Award*”. The categories for ranking countries that were effective in promoting reduction in GGE were based on “Emissions Trends”, “Emissions Levels” and “Climate Policy”. National leadership in Canada was lacking on climate change talks at both the Copenhagen and Cancun conferences. Norway came in sixth and well ahead in the CCPI rating, a country that is similar to Canada in terms of climate and oil and gas production and exports but not in size; Canada’s size adds greatly to energy consumption and transportation that amounts to 25% of GHG emissions. The former UN Secretary General Ban Ki Moon said that “the Copenhagen Accord may not be everything everyone had hoped for, but this
decision is an important beginning.” Surprisingly Copenhagen did not fulfill its planned mandate.

As mentioned, there was an agreement on a $30 billion fund supported by developed countries to tackle deforestation, promote and share low-carbon technologies, and deal with the impact with adaptive measures. After two weeks of meeting, a mere two-page document of 12 items emerged as the Copenhagen Accord submitted to the UN Framework Convention on Climate Change (UNFCCC). The goal of the Accord read in part: “To stabilize greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system…that the increase in global temperature should be below 2 degrees Celsius…” Politicians continue to meet and debate on what course of action was best for their country; developing and poorer countries are those who are most vulnerable with climate change impacts such as increased droughts and sea level rise. The developing economies of China and India should be obliged to monitor and report greenhouse emissions to the UNFCCC like developed nations that signed on to Kyoto but they refused to allow monitoring and reporting of national GGE at that time. Delegates were concerned about how the money allocated to poorer countries would be spent on green technology, adaptation and in curtailing deforestation. As mentioned, a year later in Cancun some countries did not receive the approved funding.

The Cancun Agreement was held in December 2010. Christiana Figueres, the Executive Secretary of the UNFCCC like her predecessor, was hopeful of progress in Cancun, Mexico. Delegates from 192 countries met for 12 days. No country provided any data on reductions of GGE and nothing of substance was agreed upon to keep global temperatures below 2°C from pre-industrial time by the end of this century. Japan, Russia and Canada rallied to put the final nail on Kyoto and on any new agreement on GGE reduction. In Cancun, a Green Climate Fund was proposed and “by 2020 a $100 billion a year would go to countries to prevent deforestation, promote and transfer low-carbon technologies, to shield the more vulnerable countries from climate change.” It was also agreed that all major emitters including China and the US must have their emission pledges to an inspection regime. The ‘hot air’ continued in Durban, South Africa in December
2011 after only modest gains were made after Cancun. As mentioned, Canada was no longer party to the Kyoto Protocol as announced by the then Environment Minister Peter Kent while in Durban with a number of countries and participants showing disdain for Canada’s action. A new agreement in Durban for the 2015 COP21 in Paris was expected to see the major emitters in both developed and developing economies working toward a reduction of annual megatonnage of GGE but promises never seem to be binding as we see today.

Canada needs to gain its respect as a nation that promotes environmental governance and to create a plan for renewable energy that would create new jobs. Strong climate policies at home would give Canada the credibility it needed for success on the world stage as promised by the Federal Liberal government. The Federal Commissioner of the Environment and Sustainable Development in his December 2011 report, urged that federal environmental laws and regulations need to be enforced to foster good environmental stewardship under the Canadian Environmental Protection Act, the Transportation of Dangerous Goods Act and the National Energy Board Act. The Royal Society of Canada in its 2010 report listed six strategies that the Alberta government says that it is committed to do to extract bitumen in an environmentally responsible way. Environmental sustainability and stewardship must work together for economic development.

James Hansen, the former NASA top climate scientist, said that in addition to renewables there must be a rising flat fee or tax on carbon emissions – a “carbon fee and dividend” to be collected that should go to development of renewables and the dividends to be distributed to residents. Citizens Climate Lobby of Canada is also advocating the “Carbon Fee and Dividend” and details its plan into 4 steps at its website www.canada.citizensclimatelobby.org. Citizens Climate Lobby Canada is a non-profit, non-partisan, grassroots advocacy organization with a twin focus: “to create the political will for a livable planet and to empower people to claim their political and personal power.” Each state should embark on climate change initiatives of carbon tax and less so on cap and trade; the government of Canada has laid out a plan in 2016 with the Pan-Canadian Framework on Clean Growth and Climate Change document for the next five years. As mentioned, the Canadian Chamber of Commerce (www.chamber.ca) put out a sensible plan
entitled *A Competitive Transition*, on how Canada could reduce its GGE and continue its prosperity. At the time of writing some provinces in Canada are fighting the federal carbon tax and sections of the Pan Canadian Framework.

**An Historic UN Agreement: COP21 Paris**

After more than 20 years of abject failure at UN conferences to agree on a new global climate deal, rich, developing and poor countries had agreed to differ and had finally adopted 31 pages of dense, legal text which, just possibly, could set the world on a different, cleaner and safer, energy path. Listed below are summary statements, and in my opinion, including some major breakthroughs but with more determination needed to reduce GGE. The final document can be viewed at the UNFCCC website. I also included statements following the Paris conference from a few well-known politicians and climate scientists. Scientists and policy experts say topping the 2°C threshold would require the world to completely rid of fossil fuels between 2050 and the end of the century. **To reach the more ambitious 1.5°C goal, some researchers say the world will need to reach zero net carbon emissions by 2050 and with an atmosphere of less than 400 ppm of CO₂ equivalent before 2100.** The task is challenging but attainable. Today, the CO₂ level sits at 415 ppm and CO₂ equivalent above 490 ppm. “Almost all nations give priority to their own development and to the well-being of their citizens. Nations therefore choose emission ‘targets’ consistent with their economic goals. **It should surprise no one that the Kyoto and even the Paris agreements were ineffectual in restricting global fossil fuel emissions**” according to James Hansen, the retired NASA climate scientist. Canada’s fossil fuel CO₂ emissions remain stubbornly high, despite decreased coal use. Emissions in 2018 were 7% greater than in 1997, the year of the Kyoto Protocol.

The Paris Agreement doesn't mandate by how much each country must reduce its greenhouse gas emissions. Rather, it sets up a bottom-up system in which each country sets its own target. That pledge or goal referred to as **"Intended Nationally Determined Contributions"** (INDC), with each country needing to explain how it plans to reach that objective after the Paris treaty. Those pledges made must be reviewed and improved over time, and starting in 2018 each country
will have to submit revised plans every five years. **Canada’s INDC is to reduce greenhouse gas emissions “by 30% below 2005 level by 2030” but this intended target is highly unlikely.** The Canadian government committed $2.65 billion in total investment — $800 million a year — by 2020 for international climate finance “to support the efforts and actions of the poorest and most vulnerable countries to adapt to the adverse effects of climate change” according to a *Pembina Institute* report. The *Climate Action Tracker* questions Canada’s reduction plan and stated that “it will miss its 2020 and 2030 INDC by a wide margin (Figures 3.16 A & B).

![Figure 3.17. Canadian Youth Climate Coalition in Copenhagen (2009) shown sending their message “Represent Canadians Or Go Home” to Jim Prentice, a former Minister of the Environment and his delegation in response Canada’s inaction at the Copenhagen Conference. Photo credit by R.J. Partington, The Pembina Institute.]

**A long-term goal is to limit global warming from 1.5°C – 2.0°C**

On December 12, 2015, COP21 in Paris ended with an Agreement from 195 nations and 150 heads of states who attended and participated in the proceedings. All quotations herein originate from the formally signed Agreement. The
agreement aims to limit the increase in global average temperatures to “well below 2 °C above pre-industrial levels” – the level beyond which scientists say we will see the worst extremes of global warming. It also aims to “pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change.” Since pre-industrial time to the present the global temperature increased by 1.10°C but regional temperatures vary such as in northern Canada with an increase of 2.3°C since 1948 and slightly higher to the present.

In order to actually limit warming to the ‘intended level’, the aim is to “achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century” – in other words, net carbon emissions to be zero. To get there, countries should aim to “reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing countries and to undertake rapid reductions thereafter in accordance with best available science. Much greater emission reduction efforts will be required than those associated with the intended nationally determined contributions in order to hold the increase in the global average temperature to below 2°C above pre-industrial levels by reducing emissions to 40 gigatonnes.” With 2,440 new coal plants planned around the world, the prospects for 1.5°C look less promising.

Ahead of (and even during) the Paris summit, countries have made their "Intended Nationally Determined Contributions" (INDCs) – pledges setting out how they plan to limit their greenhouse gas emissions during the 2020s. Each Party shall communicate a nationally determined contribution every five years starting in 2023; a plan to make countries realize deeper emissions needed in future and by improving their plans every five years. The emissions cut and proposed INDC would still leave the world on track for at least 2.7°C warming in this century as cited in Figure 3.18 and projected by the Climate Action Tracker (CAT). While the challenges are significant, limiting warming to below 2.0°C by the end of the century it is still feasible from present global emissions levels – 415 ppm CO₂ and ~500 ppm CO₂ equivalent. “The emissions pledge pathway that includes Nationally Determined Contributions (NDCs) has over 90% probability of
exceeding 2°C. The current policy pathways have a higher than 97% probability of exceeding 2°C” according to CAT projections. Figure 2.2 A from the UN Gap 2018 Report projects a 1.5°C and 2.0 °C by 2030 for a 66% probability. In Chapter One, the IPBES and Global Change for Nature provide pathways to hold global temperature under 1.5°C by 2100.

One official statement arising from the Paris COP 21 and supporting the role of the IPBES reads as follows: “Policy approaches and positive incentives for activities relating to reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries. Parties recognize that adaptation is a global challenge faced by all with local, subnational, national, regional and international dimensions, and that it is a key component of and makes a contribution to the long-term global response to climate change to protect people, livelihoods and ecosystems, taking into account the urgent and immediate needs of those developing country Parties that are particularly vulnerable to the adverse effects of climate change.” Can world leaders promote preserving nature and rainforests from being commercialized as is the case in the Amazon today?

Quotes that follow are taken from the official COP21 report.

The thorny question of how much money rich nations must give has now been moved into the non-legally binding 'decision text'. Currently, developed countries are obliged to 'mobilize' $100 billion a year of public and private finance to help developing countries by 2020 – a target set in Copenhagen in 2009. The Paris decision "intends to continue their existing collective mobilization goal through 2025" - in other words continue the $100B a year, and then by 2025 set a new goal "from a floor of $100B". The Canadian government is expected to deliver its historic commitment of $2.65 billion by 2020 to help the poorest and most vulnerable countries to mitigate and adapt to the adverse effects of climate change.
A PLAN TO MONITOR PROGRESS AND HOLD COUNTRIES TO ACCOUNT:

“There is to be a global ‘stock-take’ in 2023, and every five years thereafter, to assess progress toward the aims of the agreement and to encourage countries to make deeper pledges.” The text sets out plans for a new transparency framework to see whether countries are actually carrying out their pledges, in order to hold them to account and inform the stocktake. Countries will have to disclose an inventory of their emissions and information to track their progress in hitting their national target, while developed countries should also give information on the finance they are providing or mobilizing. The Potsdam Institute and the Climate Action Tracker stated “the current emissions reduction pledges of most countries, that the INDCs are insufficient and have to be adapted to the new level of ambition in the next few years. Still, this is a turning point in the human enterprise where the great transformation towards sustainability begins.”

![Global warming above pre-industrial levels](image)

Figure 3.18. Scenarios calculated by the Climate Action Tracker and a likely 2.7°C on the pledges made at COP21 in Paris. Credit Climate Action Tracker (climateactiontracker.org), 2015.

According to climate model calculations on Promises and Perils of the Paris Agreement (Science Journal - May 31, 2019) in order “to have even a 50% probability of staying under 1.5°C, global net CO₂ emissions would have to
decrease by \(~5\%\) per year, starting now; this is in stark contrast to the average global increase of nearly 2\% per year over the past several decades. Keeping global warming below 2°C would require a reduction of CO\(_2\) emissions by at least 3\% per year. Even if all these countries were to fulfil their NDCs, global CO\(_2\) emissions would stay about the same or even increase slightly until at least 2030.”

The document entitled “Insights from the IPCC Special Report on 1.5°C for preparation of long-term Strategies” produced by Michiel Schaeffer \textit{et al} from Climate Analytics in a 24-page document (April 2019) is found at www.climateanalytics.org. The following are direct quotes from the latter Report including the accompanying illustration. Do we have the determination to embark upon a plan as outlined below to keep within 1.5°C before 2100?

“Taken together, key global benchmarks of pathways consistent with the Paris Agreement can be identified based on these criteria:

• Peaking of greenhouse gas (GHG) emissions and of CO\(_2\) by around 2020
• Rapid decline of GHG and CO\(_2\) emissions by around 45\% by 2030 (from 2010)
• Net zero CO\(_2\) emissions by around 2050, negative thereafter
• Net zero GHG emissions by around 2070, negative thereafter
• Net zero AFOLU emissions by around 2030 (between 2025 and 2040) then negative
• Bioenergy with Carbon Capture and Storage (BECCS) deployment by around 2040.”

Achieving the Paris Agreement Long-term Temperature Goal requires transformative systemic change across the whole economy and society that is integrated with sustainable development. The key characteristics of 1.5°C consistent sectoral transformations are:

• Fully decarbonised primary energy supply by mid-century (including with CCS)
• Large energy demand reductions across all end-use sectors by 2030
• Large reductions of fossil fuel use, in particular coal (-64\% by 2030, -75\% by 2050) and oil (-11\% by 2030, -60\% by 2050)
• Rapid increase in use of renewable energy
• Bioenergy is used in many 1.5°C pathways, both with CCS (BECCS) and without, with uncertainties regarding limits to sustainable use
• Full decarbonisation of electricity generation by 2050, mainly through increased use of renewable energy reaching shares of over 50\% by 2030 and over three-quarters by 2050 globally
• Coal use for electricity reduced dramatically by around 70\% in 2030 and complete global phase out
by 2050. Due to high carbon intensity, no role for coal even with CCS by 2050.
- Electrification of end-use sectors (transport, buildings, and some industry processes) and decarbonisation of final energy other than electricity, for example through the use of biofuels, hydrogen or other energy carriers (aviation, shipping, and some industry processes)

**Figure 3.18 A.** “Illustration of the three benchmarks in Paris Agreement (dark blue boxes) and global decarbonization benchmarks (white box). This representative pathway is the median across all 1.5°C compatible pathways from the IPCC that reach levels of Carbon Dioxide Removal (CDR) below the upper end of estimates for sustainable, technical and economic potential around 2050 in the sector of Agriculture, Forestry and Land-Use (AFOLU), as well as via Bioenergy combined with Carbon Capture and Storage (BECCS). Credit Climate Analytics.” (April 2019) ([www.climateanalytics.org](http://www.climateanalytics.org))

- Net-zero land-use emissions between 2025 and 2040, requiring a steep reduction in deforestation and the adoption of policies to conserve and restore land carbon stocks and protect natural ecosystems. By 2050, negative emissions will already need to be on a multi-Gigatonne scale
- All these sectoral transformations imply a major and timely shift in investment patterns:
  - Investment in low-carbon energy technologies and energy efficiency needs to be
doubled in the next 20 years, and investment in fossil-fuel extraction and conversion needs to decrease. This represents a major shift in investments, where global annual investments in low-carbon energy technologies overtake fossil investments already by around 2025.

- There is an opportunity to address presently underinvested assets such as infrastructure and buildings, and redirect financial flows in a timely manner to achieve the transformation needed without creating stranded assets.”

**NOTE:** Review and compare the projections from the graphs in Figure 1.11 B and Figure 3.18 A on how GGE could be reduced with timelines.

**What Politicians & Scientists said at COP21 in Paris:**

Address by the Right Honourable Justin Trudeau, Prime Minister of Canada at COP21 in Paris: “I am honoured to represent Canadians at this historic meeting. My message is simple. Canada can and will do more to address the global challenge of climate change. We will do so because the science is indisputable, and tells us that our planet is already changing in ways that will have profound impacts on our future. And we will do so because it’s the right thing to do, for our environment and our economy, and as part of the global community. Our government is making climate change a top priority, and our actions will be based on five principles….”

*The full speech was not provided.* The details of each of these five principles outlined by Prime Minister Trudeau are not provided, only the headings listed below:

- Canada will act based on the best scientific evidence and advice
- Canada will support and implement policies that contribute to a low-carbon economy
- Canada will work with our provinces, territories, cities and Indigenous leaders
- Collaborating with Provinces and Territories
- Investing in Clean Energy and Clean Technology

**Pembina Institute (Canada):** “Canada was well represented in Paris: our negotiators intervened on numerous occasions to raise the level of ambition within the text, and played a critical role advocating for the inclusion of Indigenous Rights in the final agreement. We applaud the constructive efforts of the Hon. Catherine McKenna, Minister of Environment and Climate Change, and the government’s climate negotiations team.”
**Elizabeth May, Leader Green Party Canada:** “It will be legally binding. It sets a long-term temperature goal of no more than 1.5 degrees as far safer than the (also hard to achieve) goal of no more than 2 degrees. In doing so, it may save the lives of millions. It may lead to the survival of many small nations close to sea level. It may give our grandchildren a far more stable climate and thus a more prosperous and healthy society. It clearly means the world has accepted that most known reserves of fossil fuels must stay in the ground…Paris threw us a lifeline. Don’t let it slip between our fingers.”

**US President Obama:** “This new global framework lays the foundation for countries to work together to put the world on a path to keeping global temperature rise well below 2.0 degrees Celsius and sets an ambitious vision to go even farther than that. This Agreement sends a strong signal to the private sector that the global economy is moving towards clean energy, and that through innovation and ingenuity, we can achieve our climate objectives while creating new jobs, raising standards of living and lifting millions out of poverty and progress that will accelerate as a result of the Agreement’s provisions on mitigation ambition, transparency, and climate finance.”

**China’s Delegate:** “It is true that the agreement is not perfect, and there are some areas in need of improvement, however, this does not prevent us from taking historic march forwards. The Pairs climate conference is a critical point in global efforts against climate change, its success is critical for the global future in response to climate change. Agreement is fair and just, comprehensive and balanced, highly ambitious, enduring and effective.” China says the Agreement sends a strong and positive signal the world is moving to a low carbon economy.

**French President Francois Hollande:** As the final text of the agreement was released, the French president, François Hollande, said: “This is a major leap for mankind. The agreement will not be perfect for everyone, if everyone reads it with only their own interests in mind. We will not be judged on a clause in a sentence, but on the text as a whole. We will not be judged on a word, but on an act.”

**Lord Stern** - Renowned Economist added: “This is a historic moment, not just for us but for our children, our grandchildren and future generations. The Paris agreement is a turning point in the world’s fight against unmanaged climate change which threatens prosperity. It creates enormous opportunities as countries begin to accelerate along the path towards low-carbon economic growth.”

**The President of the World Bank, Jim Yong Kim:** “The world has come together to forge a deal that finally reflects the aspiration, and the seriousness, to preserve our planet for future generations. First, it leaves no one behind – protecting the poorest people and the most vulnerable countries by calling on all of us to hold the increase in temperatures to well below 2C
and to pursue efforts to limit the temperature increase to 1.5C. Second, it sends the much-needed signal to trigger the massive sums of public and private sector investments needed to drive economies toward a carbon neutral world as advised by science. While doing this, we will strive to ensure that there is the necessary finance to provide resilience for developing countries. Third, it changes development. We agree there is no development without tackling climate change. We cannot poison the planet and thrive.”

**Dr. James Hansen:** The former NASA climate scientist criticizes the talks, intended to reach a new global deal on cutting carbon emissions beyond 2020, as ‘no action, just promises… as long as fossil fuels appear to be the cheapest fuels out there, they will be continued to be burned.” He again called for a price to be placed on each tonne of carbon from major emitters. “The danger that Paris may mimic Kyoto is heightened by the ‘guard rail’ concept, which allows governments to promise future emission reductions rather than set up a framework that fosters rapid emissions reductions.”

**Hoesung Lee, Chair IPCC:** “We know how to tackle climate change and we have the means – economic, technological and institutional. But the longer we wait the harder and more expensive it will be to overcome. If we act now, we will be able to create opportunities for a new economy and better environment now and for the future.”

**Dr. Bill McKibben, Co-founder 350.org:** “Every government seems now to recognize that the fossil fuel era must end and soon. But the power of the fossil fuel industry is reflected in the text, which drags out the transition so far that endless climate damage will be done. Since pace is the crucial question now, activists must redouble our efforts to weaken that industry. This didn’t save the planet but it may have saved the chance of saving the planet.”

The election of President Trump has become a disaster since he decided to withdraw from the signed Paris Agreement by President Obama. In June 2017 the European Union (EU) rejected Trump’s offer to renegotiate the Paris climate agreement and pledged instead to bypass the White House to work with US business leaders and state governors to implement the historic accord’s commitments. EU officials will instead cut out the Trump’s Administration to deal directly with the US states and major corporations, many of whom who have already pledged to live by the terms forged in Paris. Despite President Trump’s climate change denial and planned withdrawal from the Paris Agreement the American public, over 400 Mayors and many state Governors support climate
change initiatives and that the US would still meet its GHG goal target by 2025 according to Michael Bloomberg as covered in his book, *Climate of Hope.*

**The Alarm Has Been Sounded**

Sounding the alarm is no doom and gloom scenario for planet Earth but let the overwhelming evidence speak for itself; we still hold hope for the future generation and we cannot leave them to fend for themselves. The planet has undergone several periods of glaciation and warming over the millennia as well as mass extinction of species throughout its history. Eighteen of the 19 warmest years in the 136-year record all have occurred since 2001, with the exception of 1998. The year 2016 ranks as the warmest on record according to NASA’s *Goddard Institute for Space Studies* (GISS). The years 2015 and 2016 were strong El Nino years and responsible for a slight rise in global temperature. Earth’s combined global surface temperatures from 2015 – 2019 are ranked as the warmest since 1880. Continuing the planet's long-term warming trend, globally averaged temperatures in 2017 were 0.90 degrees Celsius warmer than the 1951 to 1980 mean, according to scientists at NASA/GISS. In a separate, independent analysis, scientists at the *National Oceanic and Atmospheric Administration* (NOAA) concluded that 2017 as a non-El Nino year was the third-warmest year in their long record-keeping. Warming from one year after the next is not as important as warming through the decades and each decade has been warmer than the previous (Figure 1.2 D).

An IPCC Special Report published in August 2019 on *Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems* provided many risk factors: “Agriculture, Forestry and Other Land Use activities accounted for around 13% of CO₂, 44% CH₄, and 82% N₂O emissions from human activities globally during 2007-2016, representing 23% of total net anthropogenic emissions.” The world cannot avoid the worst impacts of climate change without making serious changes how we grow food, raise livestock and manage forests, it examines how land use around the world contributes to the warming of Earth’s atmosphere. But it also details how climate change is already threatening food and water supplies for humans: turning
arable land to desert, degrading soil and increasing the threat of droughts, floods and other extreme weather that can wreak havoc on crops. **Climate change, including increases in frequency and intensity of extremes, has adversely impacted food security and terrestrial ecosystems as well as contributed to desertification and land degradation in many regions (high confidence).**

Healthy land provides the food, timber and fresh water essential to humanity’s survival, but the IPCC report says the climate crisis is damaging this precious resource with potentially irreversible consequences. The abuse of land by razing forests, intensive farming and loss of soils also produces a quarter of global emissions, further worsening the climate emergency. Ending the degradation of land can play an important role in securing a liveable planet by cutting emissions, providing sustainable food and reducing poverty. The 2019 IPCC reported that “global population growth and changes in per capita consumption of food, feed, fibre, timber and energy have caused unprecedented rates of land and freshwater use (very high confidence).” Data available since 1961 shows the per capita supply of vegetable oils and meat has more than doubled and the supply of food calories per capita has increased by about one third (high confidence).” *Green Alliance* thinktank, said: “The key message from the IPCC is urgency: we need to act now to plant new forests, restore our ecosystems, and, yes, to eat less meat.”

An international team of scientists has published a study in *Proceedings of the National Academy of Sciences* showing that “even if the carbon emission reductions called for in the Paris Agreement are met, there is a risk of Earth entering in what the scientists call ‘**Hothouse Earth**’ conditions. The study suggests that human-induced global warming of 2°C may trigger other Earth system processes, often called ‘feedbacks’, that can drive further warming - even if we stop emitting greenhouse gases,” says lead author Will Steffen of the Australian National University and Stockholm Resilience Centre. **What are these feedbacks?** The list is long: permafrost thaw releasing CO₂ and CH₄, loss of methane hydrates from the ocean floor, weakening land and ocean carbon sinks (from extreme conditions and data from the OCO-2 satellite), increasing bacterial respiration on land and in the oceans, Amazon rainforest dieback, boreal forest
dieback, reduction of northern hemisphere snow cover, loss of Arctic summer sea ice, loss of albedo, and reduction of Antarctic sea ice and polar ice sheets.

"These tipping elements (Figure 3.19 A) can potentially act like a row of dominoes. Once one is pushed over, it pushes Earth towards another. It may be very difficult or impossible to stop the whole row of dominoes from tumbling over. “Places on Earth will become uninhabitable if ‘Hothouse Earth’ becomes the reality," warns co-author Johan Rockström, former executive director of the Stockholm Resilience Centre (www.stockholmresilience.org) and incoming co-director of the Potsdam Institute for Climate Impact Research and continues: “Maximizing the chances of avoiding a Hothouse Earth’ requires not only reduction of carbon dioxide and other greenhouse gas emissions but also

Figure 3.19 A. Global map of potential tipping cascades. The individual tipping elements are color-coded according to estimated thresholds in global average surface temperature. Arrows show the potential interactions among the tipping elements which could generate cascades. Credit Proceedings of the National Academy of Sciences and Stockholm Resilience Centre.
enhancement and/or creation of new biological carbon stores, for example, through improved forest, agricultural and soil management; biodiversity conservation; and technologies that remove carbon dioxide from the atmosphere and store it underground.” The goal of the IPBES, One Earth and Global Deal for Nature being advanced as discussed in Chapter One would prevent a hothouse earth before 2100.

The ambitious COP21 UN Conference in Paris relies on countries to hold warming between 1.5°C - 2.0°C by the end of this century. Can we keep greenhouse gases from escalating and can we keep dirty fossil fuel such as coal in the ground after 2030? The climate has changed many times over the millennia from natural influences as discussed throughout the text. Extreme weather patterns such as droughts, cyclones, snowstorms, forest fires, coral bleaching and floods occur more frequently. You would recall that Professor Michael Mann of the Earth System Science Center that asking if climate change “causes” specific events is the wrong question: The relevant question he suggests should be: ‘Is climate change impacting these events and making them more extreme?’ and “we can say with great confidence that it is” according to Mann and climate scientists. The evidence is clear and discussed at length in Chapter Two.

In the Rift Valley in Kenya, for example, farmers plant a third less of their land because of the cost of fuel and fertilizers. Subsidies by government on fuel costs have artificially helped the production of food in some countries. With an improved lifestyle and affluence there is a greater demand for energy to power more vehicles, purchase luxury items and consume more animal protein like many in the Western world. There is a price to pay for affluence and it comes down to increasing greenhouse gas without renewables and greatly reducing the use of dirty fuel such as coal. Canada still has a long way to go to reduce its carbon footprint; Canadian GGE or carbon footprint was 15 tonnes of CO₂ equivalent or 20 tonnes of CO₂ per capita in 2017 and has not changed to this day. Energy is needed to run machinery, for farming in raising livestock and food production. Water is needed to raise animals and in irrigation. The hidden water consumption in a human diet consisting of a meat diet requires 60% more water than a diet of a vegetarian; it takes a great deal more water to produce a kilogram of beef than a kilogram of
potatoes. Refer to Figure 4.1 in Chapter Four for a meat to vegetarian diet and GHG emissions. Each Canadian ‘consumes’ as much as 32 Kenyans when it comes to energy use; it is no wonder that our carbon footprint is among the highest in the developed world.

In 2008, Indonesians protested the high prices of soybean and other food items; Tunisia, Egypt and Cameroon had food riots and more unrest is expected around the world. An Egyptian family’s food bill is about 60% of their total income. In January 2011, major protests against the Mubarak government erupted in Egypt following an earlier uprising in Tunisia or the emergence of the Arab Spring; food prices and soaring fuel costs only made the situation worse against the Mubarak dictatorship and unrest followed in Libya and Syria. The Food and Agriculture Organization of the UN noted that unexpected price upswings threaten food security and “the poor countries spend as much as 70% of their income on food.” The Food Price Index (FPI) is based on commodities such as meat, dairy, cereals, oils & fats and sugar. In the year 2000, the FPI was 90 base points and increased to 215 by the end of 2010. Food prices have more than doubled in the last decade and still rising today. British Columbia (BC) imports about 40% of its food mostly from the USA. Thousands of hectares of land that are not returned in the agricultural land reserve in BC reduce its productivity; housing development hinders agricultural productivity in many countries with less land being used for agriculture. We must improve on our agricultural productivity in BC and rely less on produced in USA products.

Canada presently produces 68% of its own food, exporting mostly grain products; the Canadian Agri-Food Policy Institute believes that we have the potential to double our dollar value in food exports. Production of wheat and sugar declined worldwide mainly from floods, fires and droughts; many wheat producing countries such as Russia and Argentina (with the exception of Canada and the USA) are not exporting grain. The devastating floods in Queensland, Australia, in 2010 and 2011 have ruined wheat and sugarcane fields. Will the population growth outstrip its ability to feed itself that Thomas Malthus had warned the world long ago with massive famine? Malthus wrote that unchecked population growth leads to famine as well as malnutrition as evident in India, sub-Saharan Africa and other
regions in Asia. Jared Diamond in his book *Collapse* said that Malthus “worst-case scenario may sometimes be realized” and that “the 800,000 Rwandans who died in 1994 were not solely from ethnic hatred but from overpopulation.” Garrett Hardin in his 1968 ‘Tragedy of the Commons’ in *Science* journal wrote that “the population problem has no technical solution; it requires a fundamental extension in morality… a finite world can support only a finite population; therefore, population growth must eventually equal zero and the pollution problem is a consequence of population.” The message by Jeremy Grantham at the start of this Chapter in the *Race of Our Lives Revisited* is another warning “to deal with the long-term, slow-burning problems that threaten us today: climate change, population growth, increasing environmental toxicity, and the impact of all these three on the future ability to feed the 11 billion people projected for 2100.”

What we know is that there is cumulative evidence of anthropogenic greenhouse gas emissions that promote global warming since the pre-industrial era; the evidence is abundantly clear. *Extreme weather* promotes droughts, floods, forest fires, ocean warming, coral bleaching, hurricanes and storms have been more frequent in the past decade. Studies show that extreme weather patterns are driven by many natural events such as El Nino and La Nina and other natural variability conditions but adding *climate change* into the equation it is known to alter the intensity, frequency and geographic extent of some types of extreme events and very likely to increase in the future. We could expect more floods, intense heat waves, droughts, forest fires, intense hurricanes, coral bleaching, and sea level rise triggered by both natural and anthropogenic influences in different regions around the world. The unusually high snowfall and ice conditions in Europe in late 2010 was suspected to have been triggered by a region of high pressure over the north Atlantic and Arctic that blocked westerly winds from the southeast that normally warm northern Europe. Instead, a changing Polar Jetstream prevailed that allowed very cold Arctic air to move into southern latitudes and caused the heavy and prolonged snowfall and extreme cold conditions. This condition was also evident in 2014 through to 2016 with the weakened *Polar Vortex* taking the Polar Jetstream into the Mideast USA. The Arctic warming conditions may have set the stage for the changing counterclockwise circumpolar air circulation (polar vortex) and a subsequent elimination of the normal west to east Jetstream. The El Nino
effect triggers warming in the eastern to mid Pacific that is known to alter the Pacific Jetstream over North America and likely influencing the shifting polar vortex. In Chapter Two, a detailed review of extreme weather including the changing jetstream was presented.

In addition to Earth’s warming, air and water pollution are having serious adverse consequences on the health of millions of people in growing economies such as China and India. Industrialized countries, including growing economies of China and India in particular, must reduce emissions by 25 to 40 percent below 1990 levels by 2030 to keep temperatures from rising above 2°C from pre-industrial time in this century – India and China now contribute 35% of global GGE. Our planet is interconnected by its atmosphere, land and oceans as emissions in one country affect distant regions. Sea levels are expected to likely rise 1.4 metres by 2100 from thermal expansion of sea water and from collapsing ice shelves, loss from ice sheets in the Arctic region, in particular from Greenland and Western Antarctica, and from all mountain glaciers. The city of Venice built around water would likely have to be abandoned in the future unless the Moses Project is successful as a barricade. In December 2008, the city was flooded by windstorms from the Adriatic Sea. In October 2009 when I visited Venice tourists were unable to walk on some streets and the famous St. Mark’s Square was flooded; raised platforms were put in place for tourists and residents. The proposed Moses Project employs mobile barriers was completed in 2014 to save the city. In Bangladesh, some 10 million people who live within one metre of sea level would have to vacate their villages. In 2007, Bangladesh was inundated with floods, a year that was bordering on a La Nina system; in November 2007, a cyclone devastated coastal Bangladesh and thousands perished. Small island states especially in the Pacific region are vulnerable to sea level rise and from contamination of freshwater resources.
If sea levels were to rise by one metre as predicted in coastal Bangladesh by 2050 about 20 million people would have to be displaced; that projection is not to be ignored. The New Moore Island in the Bay of Bengal was in a territorial dispute between India and Bangladesh but it is no longer an issue since the rising sea took care of the problem and it is now completely under water. Hundreds of millions of people worldwide live within one metre of sea level. The Carteret Islands of a population of 2,600 people in the South Pacific and located east of New Guinea, have a maximum elevation of 1.5 metres. Storm surges, global warming and high tides continue to wash away homes and vegetation in low lying island states. The inhabitants of Carteret, the Marshall Islands, Kiribati Islands, Cook Islands, Solomon Islands and others in the Pacific and some in the Caribbean will most likely have to be evacuated to other regions; leaders from those countries made their voices heard at COP21 in Paris about “a life and death situation” for their citizens. In May 2009, the first ‘climate change evacuation’ began from the Carteret Islands, part of Papua Guinea, and it is the first time on record that an
entire population had to abandon its territory and homes as a result of global warming from a rising sea.

Figure 3.11 A. A & B Illustrations from *Science Advances*. Overwash by storms and sea level rise in most Atolls like the ones on Marshall Islands – Kwajalein Atoll affecting groundwater and livelihood of residents. Credit *Science Advances*.

Residents of Kiribati chain of islands and other small island states may have to relocate just like from Carteret because of rising sea levels that threaten their safety, their entire livelihood and culture. Already in Kiribati 1.3% of residents have migrated and 7.7% moved locally within Kiribati; Fiji says it would welcome those ‘climate refugees’. The **Battle of Kwajalein** was fought as part of the Pacific campaign of World War II in 1944 on the Kwajalein Atoll in the Marshall Islands. The Japanese defenders put up stiff resistance, although outnumbered and under-prepared. The determined defense of Roi-Namur left only 51 survivors of an original garrison of 3,500. Today another battle is being waged on Roi-Namur Island on Kwajalein Atoll of the Marshall Islands from sea level rise and wave driven overwash in depleting its fresh water supply and survival of residents. *Science Advances* (2018) carries this headline: **“Most atolls will be uninhabitable by the mid-21st century because of**
**sea level rise exacerbating wave-driven flooding.**” Simon Albert and researchers reporting in *Environmental Research Letters* in May 2016 present the first analysis of coastal dynamics from a sea-level rise hotspot in the Solomon Islands. “Using time series aerial and satellite imagery from 1947 to 2014 of 33 islands, along with historical insight from local knowledge, we have identified five vegetated reef islands that have vanished over this time period and a further six islands experiencing severe shoreline recession. Shoreline recession at two sites has destroyed villages that have existed since at least 1935, leading to community relocations.”

The pine beetle epidemic seemed to have subsided by 2017 with removal of dead trees while reforestation has been well on the way in BC. The affected timber can be used for standard framing and to produce wood products such as glue-laminated and cross-laminated panels. The epidemic in British Columbia is also creating opportunities for the emerging bio-energy industry. The panel beams at the *Olympic Oval* in Richmond BC for the 2010 winter Olympics provided an opportunity to use lumber from forests killed by the mountain pine beetle. Heat is used to remove the fungi from the infested wood.

Figure 3.12 A. Mountain pine beetle devastation near Prince George, BC. Trees are in red stage. Photo by Dr. Peter Jackson studying pine beetle migration on aircraft. Permission by Dr. Peter Jackson, University of Northern British Columbia.
The warmer winters in British Columbia have had a devastating impact on the forests with over 17 million hectares of pine forest being killed off by the mountain pine beetle, an area of about four times the size of Vancouver Island. The photo (Figure 3.12 A) was taken by Dr. Peter Jackson of the University of Northern British Columbia while researching the migration of the mountain pine beetle. Alberta was subsequently affected with beetles having ‘migrated’ over the Rockies and carried by the wind. The tiny beetles, about 5 mm in size, are transported long distances and at higher altitudes and ‘fly across’ the Rocky Mountains to Alberta. The boreal forest in BC has become less of a carbon sink from millions of dead lodgepole pine trees with an estimated 74 million tonnes of carbon dioxide equivalent released into the atmosphere in 2009 alone. The evergreen forests would normally act as a carbon sink. Warmer winters are more common in the northern hemisphere and in the entire Arctic region. Between 1948 and 2016, the best estimate of mean annual temperature increase was 1.7°C for Canada and an “annual mean temperature over northern Canada increased by 2.3°C (likely range 1.7°C–3.0°C) from 1948 to 2016, or roughly three times the global mean warming rate” according to the 2019 Canada’s Changing Climate report. Warmer winters, dead trees, lack of precipitation and changing jetstream add to extreme weather conditions that promote forest fires.

As discussed above, we see evidence of warming with continuous loss of the Arctic sea ice, melting of ice sheets and glaciers, collapse of ice shelves and from permafrost thawing in the first metre of soil to release stored carbon dioxide and methane. Evidence of positive feedbacks elevates Arctic temperature - loss of albedo and release of methane from hydrates in the ocean floor and the thawing permafrost. All non-polar glaciers are melting at a faster rate. The Columbia Glacier in Alaska has been receding in the past 20 years and retreated by over 12 kilometres. The Muir Glacier in Alaska covered a vast region in 1941 but in 2004 a giant lake had replaced it. The Hubbard Glacier that originates in the Yukon has been moving for decades and its front regularly collapses into Disenchantment Bay (Figure 3.13 B). It has become a good tourist site from cruise ships going to Alaska. The Helm Glacier in southwest British Columbia (BC) has receded more than 200 metres in 20 years while the Wedgemont Glacier (Figure 3.14 C) near Whistler BC, has retreated hundreds of metres in the past two decades. The
Porcupine Glacier, for example, in the Hoodoos in northern BC has been calving. Some of the more stable glaciers in the Kluane in the Yukon are also melting and receding; glaciers losing mass cited from Nunavut to the Yukon to British Columbia and Alberta are shown in Figures 2.25 & 2.26.

Refer to Figure 2.26 for some selected glaciers in Canada from Nunavut to British Columbia that are losing mass and fast-retreating. The Qori Kalis Glacier in Peru has all but disappeared – a lake now sits at the base where the glacier rested some 30 years ago. An aerial photograph in 1928 of the Upsala Glacier in Patagonia, Argentina, was visibly covered with ice and snow but by 2004 a large lake has replaced it; the latter glacier had been receding by about 50 metres per year. The Athabasca Glacier in the Rockies is fast disappearing; the glacier currently recedes at a rate of about 5 metres per year and has receded more than 1.5 km and lost over half of its volume in the past 125 years. Glacial melting is evident in Canada’s Arctic Islands, the Rocky Mountains, Coastal mountains, western United States, along Greenland’s periphery, the Arctic Islands, the Antarctic Peninsula, Alaska, the Andes, the Himalaya, Patagonia, the Swiss and Italian Alps. Lonnie Thompson is one of the world’s leading glaciologists who studies ice cores from locations around the world predicts that in a few more years there will be no more “Snows of
Kilimanjaro”. Glacier-fed rivers hold the key to surviving populations especially in Asia for agriculture and domestic use.

According to Tim Flannery in his book, *We Are the Weather Makers*, he noted that glaciers in Greenland in the past decade were melting twice as fast as was earlier estimated. Reports in 2019 show an increase melt in Greenland from ice sheets as a result of extreme heat even at higher elevations atop ice sheets. Canada’s Northwest Passage is now open to shipping in the summer as was evident when one cruise liner in the summer of 2016 took passengers from Anchorage to New York with stops in Cambridge Bay and along the Canadian Arctic. There is a growing crisis in the Himalayas with over 3,000 known glaciers and most of them retreating several metres per year. However, the *Gravity Recovery and Climate Experiment* (GRACE) satellite measures Earth’s gravitational field and from its data it projected that the Himalayan glaciers are melting at a “far slower rate” than predicted by scientists. According to the data obtained from satellites, the Himalayan glaciers are melting at a rate of 4 billion tonnes annually in contrast to the 50 billion tonnes per year predicted earlier by scientists. Of the 680 glaciers that Chinese scientists monitor closely on the Tibetan Plateau, 95 percent are shedding more ice than they are adding. However, J. M. Maurer *et al* (*Science Advances*, 19 Jun 2019, Vol. 5, No. 6) now report that ice loss
across the Himalayas has been accelerating: “To robustly quantify the regional sensitivity of these glaciers to climate change, a reliable Himalaya-wide record of ice loss extending back several decades is needed. We provide an internally consistent dataset of glacier mass change across the Himalayan range over approximately the past 40 years.”

“Many Himalayan glaciers are receding—and a new study of 32 glaciers around Mount Everest found that those terminating in lakes have lost more ice mass than landlocked glaciers. That’s a worrying trend because many glacial lakes form behind unstable debris dams that are poised to collapse and send disastrous floods hurtling down valleys” as reported in *Science* journal in February 2017. New lakes are being formed from the melting glaciers in the Himalayas that pose a danger of water collapsing upon some villages in Nepal. Imja Tsho is one such lake that was formed 50 years ago and is now 100 metres deep and 1.5 kilometres long, and located at an elevation of about 5,000 metres in the Himalaya. Should that wall holding back the lake collapse it would drown the Sherpa villages in the valleys below. The melting Himalaya glaciers normally feed into the major rivers of Asia, namely, the Ganges, Indus, Brahmaputra, Mekong, Yellow and Yangtze. The meltwater from glaciers in the Hindu Kush flow into the Indus, Ganges and Brahmaputra rivers. Water from glacier fed regions play a vital role in sustaining the livelihood of hundreds of millions of people throughout the world. About one-sixth of the world’s population lives in glacier fed river basins.

The UK *Guardian* newspaper in June 27, 2018 headlined “*Climate change has turned Peru's glacial lake into a deadly flood timebomb*” referring to Lake Palcacocha that is swollen with water from melting ice caps in the Cordillera Blanca mountains. Below the mountains 50,000 people live directly in the flood path. A handful of residents of Huaraz, the city below the lake, can recall its destructive power. In 1941 a chunk of ice broke away from the glacier in an earthquake tumbling into the lake. The impact caused a flood wave which sent an avalanche of mud and boulders cascading down the mountain, killing about 1,800 people when it reached the city. “Today the lake is even more potentially dangerous, swollen with glacial meltwater like an almost-overflowing bathtub. A
A temperature rise of 0.5 - 0.8°C between the 1970s and the 2000s has seen a third of Peru’s ice caps vanish in the last four decades” as reported in the Guardian article.

The Commissioner of the Environment and Sustainable Development warned that Environment Canada should be more vigilant about water safety. “Canadians regard fresh water as the country’s most important natural resource, more important than oil and gas and forestry. Understanding the status and long-term trends in the quality and quantity of the country’s fresh water resources is of vital importance to Canada’s future prosperity” as stated in a 2010 report by the Commissioner (www.oag-bvg.gc.ca/). The Commissioner at that time was Scott Vaughan who was critical of the federal government’s failure to adequately monitor the quality and quantity of fresh water in Canada. It seems as though water is everywhere in the Canadian landscape from east to west to north but the quality and monitoring of fresh water from the Gander River in Newfoundland to Campbell River in Vancouver Island, to the Mackenzie River in the north and tens of thousands of lakes and rivers in between, but Canada needs to maintain the health of its rivers and lakes, and the Royal Society of Canada in one of its reports has also been critical of how the federal government’s monitoring our water supply and safety.

Climate change is not only having its impact on the ocean and sea level rise but also on warming of lakes around the world, threatening freshwater food supplies and ecosystems, according to a new NASA and National Science Foundation funded study of more than half of the world’s freshwater supply. “Using more than 25 years of satellite temperature data and ground measurements of 235 lakes on six continents, this study - the largest of its kind - observed that lakes are warming an average of 0.34 degrees Celsius in each decade.” The scientists say this is greater than the warming rate of either the ocean or the atmosphere, and it can have profound effects, not just for human consumption, but in manufacturing, energy production, and irrigation of crops. That new NASA research confirmed those observations; the study also discovered that the average warming rate of lakes of 0.72°C per decade occurs at high latitudes.
The Twente Water Centre in the Netherlands present a dire warning about global water supply and availability. The University of Twente Centre warned that “freshwater scarcity is increasingly perceived as a global systemic risk. Previous global water scarcity assessments, measuring water scarcity annually, have underestimated experienced water scarcity by failing to capture the seasonal fluctuations in water consumption and availability. We assess blue water scarcity globally at a high spatial resolution on a monthly basis. We find that two-thirds of the global population (about 5 billion people) live under conditions of severe water scarcity at least 1 month of the year.” Nearly half of those people affected live in India and China. Half a billion people in the world face severe water scarcity all year round. Putting caps to water consumption by river basin, increasing water-use efficiencies, and better sharing of the limited freshwater resources will be key in reducing the threat posed by water scarcity on biodiversity and human welfare as one advice from the Twente Water Centre.

In Maude Barlow’s book, Blue Covenant, she writes exclusively about the global water crisis and the coming battle for the right to own water. Chapter 6 in her book, entitled, “Is Canada’s Water for Sale?” poses an important question to all Canadians. That report by the Commissioner of the Environment and Sustainable Development further recommended “expanding monitoring parameters to include pollutants related to oil sands development” in the Athabasca River in Wood Buffalo National Park and “to protect the environment in the oil sands.” The alarm has been sounded and the Canadian Government has been duly informed of the need to pay greater attention to our precious water resource, safety and supply. In Chapter One (Figure 1.10 B) water stressed countries include the Middle East and North Africa to India - for more information go to World Resources Institute at https://www.wri.org. Figure 1.11 indicates trends in Terrestrial Water Storage (in centimetres per year) obtained on the basis of GRACE satellite observations. The cause of the trend in each outlined study region is briefly explained and colour-coded in that illustration.

“The latest UN Report says 68.5 million people had been forcibly displaced by the end of 2017” according to the August 2019 National Geographic Editorial on “Humanity in Motion.” Millions are fleeing violence such as war, persecution,
criminality and political chaos. A recent World Bank study calculates that “by 2050 more than 140 million people in sub-Saharan Africa, South Asia and Latin America could be tumbled into motion by catastrophic effects of climate change” as climate refugees. There are ever more refugees fleeing the effects of climate change, be it floods, hurricanes, rising sea levels or expanding deserts. By the middle of this century, experts estimate that climate change is likely to displace between 150 and 300 million people, a population nearly as large as that of the United States. The impacts of climate change are numerous. Limited natural resources, such as drinking water, are likely to become even scarcer in many parts of the world. Crops and livestock struggle to survive in climate change ‘hotspots’ where conditions become too hot and dry, or too cold and wet, threatening livelihoods and exacerbating food insecurity. Climate change affects people inside their own countries, and typically creates internal displacement before it reaches a level where it displaces people across borders. The August 2019 publication of National Geographic, it gives a detailed account of the “World on the Move” with reference to migrants past and in the future from Africa, Asia and Latin America seeking work and a better life.

**Young People’s Movement**

Our youths have been sounding the alarm of late and should continue to demand that our politicians listen and act; their lives are in danger of the impacts of global warming in all ecosystems and their future health and well-being. This movement of young people started back in 1992 when Severn Cullis-Suzuki at the age of 12 silenced the world for six minutes at the first UN Earth Summit in Rio de Janeiro: *Do not forget why you are attending these conferences, who you’re doing this for - we are your own children…. My Dad (David Suzuki) always says, ‘You are what you do, not what you say.’ Well, what you do makes me cry at night. You grown-ups say you love us, but I challenge you. Please make your actions reflect your words.*

In *Young People’s Burden*, Sophie Kivlehan (grand-daughter of climate scientist James Hansen) spoke at the COP in 2017 in Germany:
“I will make my own plea to today’s adults, but I will argue that young people must do more than plea, we must demand our rights...Why has the temperature increased almost linearly since 1975?”

The recent movement again started with a Swedish teenager Greta Thunberg 15 years of age, pictured below who reignited a worldwide movement earlier this year at first protesting in front of the Swedish Parliament and later carried her protest to the European Union capital in Belgium and joining with other European students. Young people have reason to be concerned how their lives would be affected by global warming and delays in advancing reduction of GHG emissions so they will live in a world of less than 1.5°C by 2100. It’s time to heed the world’s youths, our children and grandchildren. The recent documentary Anthropocene shows just the kind of future the young people who rallied at the legislature are hoping to avoid. On March 15, 2019, in what may be the largest youth-led protest in history, an estimated 1.6 million students in 300 cities around the world walked out of school to march for climate action. In the span of just months, children around the world have pushed climate change discussion into the heart of policy debates, the mainstream media and public conversation.

The 16-year-old Swedish climate activist Greta Thunberg is an inspirational yet unlikely leader of weekly school strikes that have become perhaps the largest global protest movement. Thunberg stopped going to school to protest inaction on climate change, saying there was little point in studying for a future that may not exist. Within months, Thunberg urged immediate action from business leaders at the World Economic Forum and she told the UN’s Secretary General and others at the global climate summit in Poland that they are “stealing children’s future in front of their very eyes.” In Davos, Switzerland, Thunberg said: “Adults keep saying: ‘We owe it to the young people to give them hope.’ But I don’t want your hope. I don’t want you to be hopeful. I want you to panic. I want you to feel the fear I feel every day. And then I want you to act.” Greta is expected to meet with UN Secretary-General again in New York at the Youth Climate Summit and she is expected to head to South America for the COP conference later this year.

It was the first sitting day of the new parliament in Israel. There were over 500 students marching and shouting slogans in front of the Knesset in Jerusalem. One
student said “we had Arab Palestinians and Jewish Israelis participating together. We have multiplied our following on social media and we have started to plan social media campaign with celebrities. We have also been asked to do a bunch of television and newspaper interviews. **We feel that in order to defeat something much bigger than us, we must put the unfortunate hatred aside and focus on what actually matters the most: saving the world from an ongoing climate breakdown.**” Protests continue in many countries even in Russia but with restrictions.

![Protesters at Sweden’s Parliament](image1.png)  
**Figure 3.15.** Greta Thunberg (15 years) protesting at Sweden’s Parliament and started the movement. Right: Greta in Belgium now 16 with students from Belgium & Germany in 2019. Credit UK Guardian newspaper.

It is a time for new learning and to emphasize updates on climate change science in Canadian schools. The revised BC Curriculum for Science 8-12 courses for climate science is inadequate and disorganized and I have since written the BC Minister of Education and submitted a suggested *Module for Climate Change* for all secondary school students but to this date I have had no reply. “We have seen that in several regards Canadian climate change education is not consistent with scientific understanding” in a publication in *Plos One* journal (July 18, 2019) by a UBC researcher, Seth Wynes. Please share this resource that you are now reading; it will be updated annually as the Canadian curricula in all provinces as cited in *Plos One* journal is lacking in details and updates for our students; this resource is primarily meant to empower our youths with the tools necessary to make wise decisions about their future and to continue to take the message to politicians and decision-makers. **Our youths are on a wise march today and tomorrow who will live longest with the climate crisis.**
Summary: Global Climate Change Impacts & Projections

The following is a summary of global projections supported by scientific evidence and the *likely* (greater than 66% probability) or *very likely* (greater than 90% probability) scenarios for attention. These projections are *not* listed in any order of priority. ‘Summary statements’ were gleaned from the scientific literature and major established organizations such as NASA, NOAA, EPA, the IPCC, IPBES, the *American Association of Science, American Geophysical Union, American Meteorological Society, Environment Canada, Natural Resources Canada* and others.

➢ The past twenty years were ranked among the warmest from instrumental records of global surface temperatures. Every decade is getting warmer than the previous. The second half of the 20th century was *very likely* (greater than 90% probability) the warmest period globally in over 1,300 years. For the next two decades, a warming of close to 0.2°C per decade is being projected and an additional 0.1°C per decade only if the concentration of greenhouse gases and aerosols are kept constant at year 2000 levels. By 2018, the global temperature rose to 1.10°C since pre-industrialized time and may not seem to be much but we only have to look at frequent extreme weather events and the loss of Arctic sea ice, ice sheets and retreating glaciers worldwide. Fewer frost days are associated with increased warming in most mid-latitude regions. During the past 40 years, cold days, cold nights and frosty days have become less frequent. More frequent extreme weather such as droughts, forest fires, storms, higher precipitation in some regions, and floods are expected. Arctic and Northern Canada temperature is more than twice the global average of 2.3°C as reported by Environment Canada.

➢ IPCC Special Report on Emission Scenarios projects a *likely* increase in global GGE equivalent and continued ‘hothouse’ in the next five years from positive feedback even if GHG are reduced. Following any likely doubling of CO₂ concentrations since pre-industrial time, the global temperature is *likely* to increase in the range of 2°C to 4.5°C and it is *very unlikely* (less than 10% probability) to be less than 1.8°C. By 2019, CO₂ concentrations climbed to 415 ppm, an average increase of 2.1 ppm per year. With the “Intended Nationally Determined
Contributions” by countries at the Paris COP21 (Paris Agreement), GGE would likely fall short for the 2.0°C range by the end of this century.

- Increase in precipitation in eastern regions of North and South America, northern Europe, and central Asia would be more frequent with rising GGE. The annual mean precipitation is very likely to increase in Canada and the northeast USA but would likely decrease in the southwest USA. In the Northern Hemisphere reduced snowpack, retreating mountain glaciers and impact on biodiversity will be more frequent. Drought conditions would persist in the Sahel, the Mediterranean region, Middle East, Southern Europe, Southern Africa, Northern China, throughout India, Australia, northeast Brazil in Amazonia, Peru, and the Southwest USA.

- Water stress is projected to double in most regions of the world. In the developed world, an average household of five people uses a minimum of 120 litres of water per day to meet the basic needs – for drinking, food preparation, personal hygiene, laundry, house cleaning. Canadians use an average of 320 litres of water per day according to a BC Water and Waste Association study. Water for agriculture in the USA and especially in California, Africa, Asia including northern China, India, and Australia would become a growing concern in the 21st century. As mentioned, climate change is rapidly warming lakes around the world and at higher latitudes pose concerns for aquatic life. Around 1.5 - 2.0 billion people already live in water-stressed regions including hundreds of millions from glacier fed rivers principally from the Andes and Himalaya. More children will die from drinking contaminated or polluted water than from a combination of war, malaria, HIV/AIDS, and traffic accidents.

- Crop productivity is projected to increase slightly at mid-to-high latitudes but would decrease at lower latitudes and in all drier tropical regions. Crop yields would likely increase in Europe, North America, East and Southeast Asia but decrease in Australia, Africa, Northern China, Central, Central America, Brazil and South Asia. Food production will have to increase by 40% by 2050 to adequately feed 2 billion more people when the population is expected to reach 9.5 billion from today’s 7.7 billion. Fertile soils only cover 11% of the global surface and loss of arable soil is a major concern. The UN Food and Agricultural Organization reported that 75 billion tonnes of soil or 10 million hectares are lost from erosion, water logging and salination, and another 20 million hectares are abandoned.
because of poor soil quality. The world faces a serious threat of food shortage now and would worsen in future. By 2050 the number of people at risk from hunger from global warming and extreme weather would increase by 10 to 20 percent.

- Our well-being is threatened by more frequent and intense heat waves, floods, storms, wild fires and droughts around the world. From the latter conditions, the health status of tens of millions would be affected especially in Africa and Asia; morbidity and mortality will become more widespread in Africa and Asia and diseases such as diarrhea, malaria, and cardio-respiratory diseases would continue to increase.

- The naturally occurring event of the El Nino/La Nina Southern Oscillation will continue to affect the location and activity of tropical storms and climate systems. An upward trend of potentially destructive hurricanes since the 1970s has been well documented. The number of category 4 and 5 hurricanes increased by about 75% since the 1970s. Both El Nino and La Nina would continue to directly impact on global climate in the west, central and east Pacific equatorial regions. Volcanic eruptions and aerosols would continue to slightly offset global warming but with no lasting impact. Changes in the Gulf Stream and the Atlantic Meridional Overturning Circulation or AMOC would affect climate in northern Europe, the Arctic as well as global climate from its weakening state. The thermohaline circulation has been weakening with profound impacts in regulating global and regional climate. The Polar and Pacific jet streams change course during El Nino and La Nina that impact on regions across North America, Europe and Siberia. A warming Arctic has its impact on the Polar Vortex with shifting and wavier Polar Jetstream resulting in extreme weather.

- Ozone concentrations still persist in the stratosphere and slowly recovering as more halocarbons are being phased out. Climatologists confirm that ozone depletion or the ozone ‘hole’ over Antarctica is still extensive but slowly reducing in size. In 2015, the Antarctic Ozone showed widespread depletion from September to November months. The World Meteorological Organization noted that depletion of the ozone level over the Arctic in the spring of 2011 reached “an unprecedented level” of ozone depletion. One can expect some increase in ultraviolet radiation worldwide and a likely increase in skin cancers since ozone is a protective barrier of much of the harmful UV-B & C rays. For updates on the status of the Antarctic ozone layer, visit: http://ozonewatch.gsfc.nasa.gov.
Loss of biodiversity, poleward movement of species and species extinction will continue and intensify in rain forests, oceans and coral reefs including the Great Barrier Reef. Scientists speculate we might be heading into a sixth mass extinction of species from global warming and land use changes. After weeks of aerial and underwater surveys, the study by James Cook from Australia found that two-thirds of the 2,300km stretch of the Great Barrier Reef had suffered serious bleaching, mainly due to extreme heat. Coral bleaching would continue to impact around small island states from temperature changes and acidification. Small island states are vulnerable to rising sea level and contamination of underground freshwater reserves.

The Arctic sea ice has been declining at a faster rate since the 1970s and summer losses of ice have been increasing at a rate of 7.4% per decade. Several ice shelves in the Arctic including the once stable Ellesmere Island’s ice shelves and in Greenland are collapsing. At this rate of ice loss, the US National Snow and Ice Data Center projects that there will be no summer Arctic sea ice left by the year 2060; the Arctic Ocean is likely to be ice free or almost during the summer months within a few decades. The Northwest Passage has been open to shipping in late summer as was noted in 2016. Since 2007 to the present, Arctic air temperatures have been well above the average and twice the global mean. Current climate studies project that most of the Antarctic Ice Sheet will remain too cold for any widespread surface melting but ice sheets, ice shelves and glaciers on the Western Antarctic, the Peninsula region will continue to lose more mass as ice shelves collapse and glaciers retreat. The loss of ice and snow lowers the albedo effect resulting in greater absorption of solar heat especially during the summer months, promoting further melting of the Arctic sea ice, collapse of ice shelves and loss of mass from ice sheets and glaciers in Greenland and Arctic islands. The warming of the Arctic permafrost will continue to release more methane and carbon dioxide (as positive feedback) and further contribute to higher Arctic surface temperature.

Global sea level is rising at a rate of 3.1 mm per year. Millions of people in low lying regions are projected to be flooded before 2050. Sea level is projected to rise at a higher rate during this century. Stefan Rahmstorff at the Potsdam Institute of Climate Impact Research believes that the IPCC underestimated sea level rise of up to 58 cm by the end of this century. Thermal expansion alone is expected to increase sea level between 0.4 to 1.4 metres in this century. The eight-nation Arctic
Council including Canada warned that due to increasing Arctic warming in the past 30 years, sea levels could rise up to 1.6 metres by 2100 and with less protected hunting and fishing areas affecting the lives of Inuit people. Small island states in the Pacific are particularly vulnerable to sea level rise.

➢ The temperature at the top of the permafrost increased since the 1980s by up to 3°C. The permafrost base has been thawing at a rate of 4 centimetres per year in Alaska releasing stored CO₂ and CH₄ that further increase the greenhouse effect as a positive feedback phenomenon. The maximum area covered by seasonally frozen ground decreased by 7% in the Northern Hemisphere since 1900. Researchers estimate that by year 2100, 30-70% of the surface permafrost will be gone.

➢ Loss of ice mass from all mountain glaciers, ice sheets and shelves in Greenland and Western Antarctic contribute to sea level rise; water shortage in countries surrounding the Andes, Alps, Himalaya and Cascades is being projected. Hundreds of millions of people could be affected that depend on glacier fed rivers. Snow season length and snow depth in North America are decreasing except in the northernmost part of Canada where maximum snow depth is likely to increase. The warming of the western mountains in the USA and Canada is projected to have decrease snowpack; disturbances from fires, and insect pests such as the mountain pine beetle would continue to impact the boreal forests in BC and Alberta due to milder winters.

As mentioned, the ‘Summary Statements’ above were obtained from the many references cited in this book with guarded term such as likely, very likely, low or high confidence in determining an event occurring. These governmental and scientific organizations such as NASA, NOAA, EPA, the IPCC 2014 & 2018 Reports, UN Emissions Gap 2018 Report, the IPBES Report, and the evidence from American Association of Science, American Geophysical Union, American Meteorological Society, Environment Canada, Natural Resources Canada, and the UK Met Office, to name a few are reliable and credible.
Questions

1) What are some of the environmental issues emanating from the oil sands? Suggest ways the province of Alberta and government of Canada could undertake to reduce air and water pollution in that region? For further reading and teacher references: *National Geographic* (March 2009), *Canadian Geographic* (June 2008), CAPP website, *Royal Society of Canada* (2010), and *The Pembina Institute* website at www.pembina.org.

2) If you were the Chair of a ‘Conference on the Environment’, create an Agenda for a two-day event in the order of priority for discussion. You may be creative and suggest any names of your presenters and specific topics or presentations.

3) From this chapter, what are your opinions about the agreement reached at the COP21 in Paris? What should Canada do to improve on its pledge to reduce GGE?

4) List some initiatives to indicate China and India are reducing GGE while at the same time increasing emissions? What is the main source of emissions?

5) The next time you go shopping, take an inventory of the goods/items you observe or bought that is “Made in China.” Are you part of their carbon footprint? Discuss this concept.

6) Some people, some politicians and a handful of scientists still doubt that our climate is changing as a result of human intervention. How could you educate the unbeliever that climate change is real? For additional information you may access these two websites: www.royalsociety.ac.uk and www.skepticalscience.com.

7) The “Summary” on Projections in this chapter was researched from many sources. What aspects on climate change projections would you question, deny or support? Your answer should be supported by research or from what you may have read from any reliable source.

8) From the “Summary” above how would you prioritize the top five global problems that could directly affect future generations? Provide a brief note on why you listed them in that order.

9) “In Young People’s Movement” cited in this chapter, what are your main concerns in this climate crisis and how do you think it would affect your life?

10) From “Sounding the Alarm” in the above section, list those alarm bells and what do you think we can do to alleviate those concerns.
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Chapter 4

The Way Forward: Reducing Emissions

“We are the first generation that has a clear picture of the value of nature and our impact on it. We may be the last that can take action to reverse this trend. From now until 2020 will be a decisive moment in history.” Living Planet Report 2018: Aiming Higher

“Thirty years ago the dire predictions of leading climate scientists were laughed at. Now we watch these predictions coming true and ignore the data or pretend to. So, as the world starts to burn up, we twiddle our thumbs and talk about “just another heat wave!” God help us. For we appear incapable of, or are at least unwilling to, help ourselves, and our great scientific skills increasingly appear insufficient on their own.” The Race of Our Lives Revisited – Jeremy Grantham (www.gmo.com)

“With the pace of urgent climate warnings now increasing, it’s clear that our planet cannot wait for meaningful action. This ambitious and necessary pathway shows that a transition to 100% renewable energy and strong measures to protect and restore our natural ecosystems, taken together, can deliver a more stable climate within a single generation.” One Earth – Leonardo di Caprio Foundation.

Lowering Emissions: Plans & Actions

Many provinces seem to be making progress for a greener Canada and encouraged under a federal administration with the 2016 Pan-Canadian Framework on Clean Growth and Climate Change initiatives. Canadian Parliament enacted the Greenhouse Gas Pollution Pricing Act in 2018. The Act assesses fees on carbon-based fuels and on industrial facilities that exceed prescribed CO₂ emission limits. The fees apply in provinces that do not already have sufficient carbon pricing, which includes Ontario, New Brunswick, Manitoba and Saskatchewan (and Alberta, commencing in 2020). However, some provinces have been critical of the federal plan and the carbon tax. British Columbia is progressing toward a much greener society albeit not without criticisms by some to advance the economy with environmental compromises. The province is historically ‘green’ by generating electricity from hydro power, using natural gas and no coal for home and commercial heating. The carbon footprint for BC by 2012 was 61 million tonnes (Mt) of CO₂ equivalent and by 2014,
increased slightly to 62.7 Mt CO₂ equivalent or mixed greenhouse gases. Like many cities and municipalities across Canada, Metro Vancouver’s green waste diversion is working well and the total waste produced by single family homes was down by 66,000 tonnes from 2012 to 2013; more compostable wastes and biomass are under way for generating electricity, albeit at a small scale. BC has one of the lowest GGE in Canada per capita and intends to reduce it by 33% below 2007 levels by 2020 and by 80% by 2050. Pledges are always subject to the politics of the day with uncertainty, and in how Canadians deal with energy and the economy at any given time.

Rylan Urban used the Pembina Institute’s Energy Policy Simulator to create a winning vision of how Canada can reach its 2030 international climate targets. Rylan's winning policy package includes carbon pricing, a zero-emissions vehicle sales mandate, and dedicated funding to stop deforestation. The report entitled An Emergency Climate Policy Plan For Deep-Decarbonization In Canada is worth accessing for a five-plan of recommendations at https://www.pembina.org; go to “Publication” of Pembina for this report.

To quote Rylan Urban’s introduction in his Report: “Canada has recognized the need to reduce its greenhouse gas (GHG) emissions by 80% in 2050 from 2005 levels. However, current policies that have emerged from the Pan-Canadian Framework (PCF) fall short on meeting this target. This report identifies five complementary policy recommendations that strengthen and add to the PCF, each targeting a specific concern not addressed by the others. The analysis performed shows that no single policy is sufficient in meeting Canada’s GHG reduction targets. It also shows that each policy plays an important and unique role and that when policies are enacted together, their environmental, economic, and social impacts are greater-than-additive – they are synergistic. Ultimately, the policies recommended in this report create an optimal pathway to reduce 341Mt of GHG emissions, and save an additional $56 billion and 1,472 lives per year by 2050 when added to the PCF. The political feasibility of implementing such policies is supported by their strong social and economic impact, as well by the recent trend of municipalities in Canada declaring a climate emergency.”
In Chapter Three, “Insights from the IPCC Special Report on 1.5°C for preparation of long-term Strategies” by Michiel Schaeffer et al from Climate Analytics, a 24-page document developed in April 2019 and accessed at www.climateanalytics.org; the illustration in Figure 3.18 A projected to keep global temperature under 1.5°C in the Paris Agreement was taken from the above report. Details are summarized in Chapter Three. In Chapter One, the Leonardo di Caprio’s Foundation One Earth, the IPBES Report and Global Deal for Nature, all proposed initiatives to keep global temperature under 1.5°C before 2100 in conjunction with the IPCC Special Report 1.5°C; compare the graphs in Figure 1.11 B with Figure 3.18 A and intended projections to 2030, 2050 and 2100.

In Storms of My Grandchildren, former NASA climate scientist James Hansen said that a better way to reduce ‘offsets’ is by a gradually rising carbon fee that should be collected from fossil fuel companies with money distributed uniformly to legal residents or property taxpayers; this would not only stimulate the economy but put an honest price on fuels and money to be used for renewables. What about cap-and-trade and offsets in practice in California, Ontario and Quebec? Hansen has a pragmatic take on offsets and urges there should be “no offsets because this sort of monkey business is exactly the type of thing that politicians love and will try to keep. Offsets are like the indulgences that were sold by the church in the Middle Ages.” At the time of writing in Ontario with an elected Conservative Premier may scrap the cap-and-trade system but with no plan in place to reduce GGE.

BC Sustainable Energy Association (www.bcsea.org) “empowers British Columbians to create clean and a renewable energy through education and research.” Several small projects are underway for solar and wind power in hospitals, schools, colleges and universities in BC and across Canada. The following companies and organizations are a few examples with plans to lower fossil fuels and GGE: Lower Mainland Greenhouses, La Farge Canada Cement plant in Richmond, West Coast Air, Helijet, Sempa’s Hybrid Heating systems installed in 10 hotels, and a landfill in Salmon Arm that generates natural gas from its methane emissions and hooked up with Fortis to supply over 300 homes is a first for Fortis. “The methane capture in Salmon Arm is expected to generate 10,000 tonnes of offsets annually, equivalent to taking 2,626 cars
off the road in one year.” Lafarge Canada is planning to recapture CO\(_2\) in cement manufacturing and pass it through an “electro-reduction of carbon dioxide reactor” and with the aid of a catalyst convert into formic acid which is used in manufacturing of materials such as pulp and paper, cleaning products and in de-icing runways. Sun Mine in Kimberley is one of Canada’s biggest solar power plants. In Cranbrook at the College of the Rockies solar panels have been installed to reduce fossil fuel while at the University of Northern BC wood pellets and sawdust reduce fossil fuel by 72 percent in heating bills. Harbour Air in BC plans to be the first airline with an all-electric and zero-emission fleet and its prototype plane is expected to be in the air in November 2019. The airline flies about 30 minutes duration to local destinations and in 2007 was the first airline to go 100% carbon neutral. Fisher River Cree Nation teamed up with Dusk Energy Group, an Indigenous-owned firm based out of Vancouver, to build a project of 3,000 panels solar farm generating enough energy to power up to 400 homes, making it the largest solar farm in Manitoba.

British Columbia implemented a **carbon tax** for fossil fuels such as natural gas, gasoline, and diesel at the pump since February, 2008. People questioned why a carbon tax should be imposed on the public and especially with economic uncertainty, higher gasoline prices, and higher unemployment at that time. A carbon tax is intended to reduce GHG pollution, business will benefit and jobs created if the revenue from that tax is directed to investments in projects such as expanding public transport and in renewable forms of energy such as wind and solar. The revenue generated from this carbon tax is “returned to British Columbians through reductions in other taxes” but not in advancing renewables as it should have included. After eight years “the carbon tax has encouraged modest reductions in the fossil fuels burned in our province with negligible impacts to the economy”, says Matt Horne formerly of the Pembina Institute. The tax on gasoline at the pump was 6.67 cents /litre in July 2012 and by 2019 it rose to 8.89 cents/litre and the highest in Canada. The tax rate in 2012 was based on $30 per tonne of CO\(_2\) equivalent (tCO\(_2\)e). On April 1, 2019, B.C.'s carbon tax rate rose from $35 to $40 per tonne of CO\(_2\) equivalent. The tax rate will increase each year by $5 per tonne until it reaches $50 per tonne in 2021.

What will it cost individuals and families with a carbon tax of $50 per tonne of CO\(_2\) equivalent in a few years from now? Professor Trevor Tombe at the
University of Calgary in an article in *Maclean’s Magazine* figured that “a carbon tax will increase the price of gasoline, fuel for home heating, and (in some provinces) the electrical bill. The effect of this is fairly easy to quantify using data on gasoline spending, gasoline prices, electricity emissions intensity, and average household energy use. The average household for example uses about 2,000 litres of gasoline per year. A $50 per tonne carbon tax adds 11.2 cents per litre of gasoline, for a total carbon tax cost of $224. To heat the average home, Canadians use just over 90 gigajoules of natural gas. The hating carbon tax adds about $230 per year to those costs.” The maximum carbon tax would likely increase expenses per household by $454 per year. How much money would a household or individual receive in lower taxes after these carbon taxes is a subject to consider!

More people are being encouraged to take public transit and less use of personal vehicles thus lowering their carbon footprint; again, this decision is personal, for one’s convenience as well as economic options and so we have people having these personal choices. Norway and Sweden enacted a carbon tax in 1991 at an initial moderate cost. Norway’s greenhouse gas tax has realized economic growth and has lowered its GGE; more jobs have also been created. As mentioned, the province of British Columbia implemented its first phase of the carbon tax of 2.41 cents per litre of gasoline at the pump and increased to 8.89 cents in 2019. A poll taken by *The Pembina Institute* in 2011 indicated that the majority of British Colombians (69%) are worried about climate change and supports the carbon tax with revenues to be spent on health care, education and transit; this idea of spending the carbon tax was not being entertained by the former BC government. The total revenue from collecting the carbon tax in 2017 was $1.252 billion. The carbon tax is used to reduce other taxes in BC such as income tax to individuals and industry. “By 2020 up to 3 million tonnes of CO₂ equivalent would be reduced and equivalent to the GHG emissions of 787,000 cars per year” according to the BC government in continuing this carbon tax. The *Pan-Canadian Framework (PCF) on Clean Growth and Climate Change* is a federal document with input from provinces and designed to reduce GGE and to improve on the economy. The *Greenhouse Gas Pollution Pricing Act* of 2018 passed by Parliament assesses fees on carbon-based fuels and loosely called the carbon tax.
The *Pan-Canadian Framework* sets a target for all new buildings codes to be “net-zero energy ready” by 2030. The amount of energy used in such buildings on an annual basis could be generated on site by renewable energy systems such as solar panels. Vancouver has gone one step further; its Zero Emissions Building Plan means most new buildings in the city will have zero operational greenhouse gas emissions by 2030. Vancouver is the first major city in North America to establish specific targets and actions to achieve zero emissions in all new buildings by 2030. The phased approach aims to reduce emissions from new buildings of 70% by 2020 and 90% by 2025. "This plan is more than just about reducing our carbon pollution in Vancouver," said Sadhu Johnston, the Vancouver City Manager. "This is about building better quality homes for the people who live in Vancouver. It's ambitious yet achievable and will benefit everyone as we work towards our Greenest City, Renewable City, and Healthy City goals." About 56% of all GHG emissions in Vancouver come from buildings – more than from transportation and waste together.

The goal of the BC government is to have carbon neutrality of government operations; projects include upgrading government and municipal buildings, reducing emissions in vehicles, reducing energy in buildings and industries, using solar and wind power, and biomass combustion to offset natural gas consumption. According to a David Suzuki’s *Newsletter*, the implementation of the carbon tax in 2008 led to a “drop in petroleum-fuel use by 17.4 percent.” According to Simon Fraser University Professor Merran Smith since the carbon tax was implemented BC “fossil fuel use was reduced by 16 percent”. We need to use the revenues generated from the carbon tax to expand on renewables that would create new jobs but instead the BC government uses that money for reducing personal income taxes. *Clean Energy Canada* and “Missing the Bigger Picture” document at [https://cleanenergycanada.org](https://cleanenergycanada.org) have an encouraging message for reducing emissions with projects across Canada from its Director Merran Smith. Smith says that the clean energy sector isn’t just about fighting climate change—it’s also about using Canadian innovation to create better and cheaper solutions for everyday life. “Despite being home to four leading electric bus manufacturers, Canadian cities have not adopted the technology as quickly as a number of jurisdictions in California, Europe, and China. Drive to Zero is a deliberate effort to speed up the adoption of cleaner, less wasteful commercial vehicles. They’re
electric and clean, they’re far more efficient than passenger cars, and many are built by Canadians working at Canadian companies.”

The following are some examples of major projects that are win-win initiatives in British Columbia and cited from “The Business of Climate Change” by The Pembina Institute. First, the Selkirk Waterfront Building complex in Victoria is owned by Jawl Properties comprising 800,000 square feet of space for tenants. Jawl identifies effective ways to reduce energy in consultation with BC Hydro that includes efficiency in heating and air conditioning, and changing tenant behaviour through greener education. The saving of 23% in Hydro bills was realized and those savings were passed on to the tenants after initial costs and with 300 tonnes less of GGE being added into the atmosphere. West Coast Air flies back and forth from Vancouver to Vancouver Island and the Sunshine Coast and has a fleet of 17 planes in service, at the time of writing; it has reduced its emissions by 12% through its maintenance program. Azure Dynamics in Burnaby, BC, with companies across North America and Europe, designs and manufactures hybrid electric components for commercial vehicles that have reduced maintenance costs by 30% and fuel efficiency by 40%; FedEx, Purolator and school buses are some of the vehicles now using those components. Fourth, Quantum Lighting in Coquitlam, BC, specializes in designing, modernizing and servicing energy efficient lighting systems and controls in schools, hospitals, shopping malls, and at the Vancouver Convention Centre with a saving of 30% on electrical bills. The above are but a few examples of many across BC and Canada operating in changing the way business is being done to save on energy while reducing GGE.

Ballard’s Mission of “power to change the world” states: “Use our extensive fuel cell and systems know-how to profitably deliver innovative clean energy solutions to our customers, create rewarding opportunities for our team, and provide extraordinary value to our shareholders.” You can access the Ballard Power Systems and learn more about its products on “Putting Fuel Cells to Work” at www.ballard.com. Ballard has partnered with many of the world's leading automotive manufacturers including Volkswagen AG, Audi, Daimler AG, Toyota, Ford Motor Company and Honda Motor Company, delivering to the automotive industry’s exceptionally high standards. Zero-emission transit bus fleets powered by Ballard's fuel cell modules are an effective means to address air quality and climate change challenges. More information on
vehicles and fuel cell-hydrogen technology is provided later in this chapter. The hydrogen and fuel cell markets are expanding rapidly. The demand for fuel cell products is growing across a range of geographies and applications, including those for different types of buses, medium and heavy-duty trucks, and even rail. Vehicle operators will benefit from a much lower total life cycle cost. The new Ballard’s ‘FCmove’ fuel cell “enables commercially competitive deployments of fuel cell electric buses at scale in our cities, as in the H2Bus Europe project. Passengers will enjoy a clean, quiet and comfortable vehicle. Drivers won’t need to worry about range limitations” according to Ballard.

A Climate Leadership Plan (https://www2.gov.bc.ca) in 2016 was put together by a team of experts from many sectors to guide the BC government on its environmental and economic plan. The Team forwarded many recommendations to the government to enact upon on meeting GGE targets, to mitigate negative impacts, to increase the carbon tax, requiring new vehicles to be zero-emission by 2050, to cut methane emissions from industry by 40% and to commit to 100% clean electricity by 2025. According to the Pembina Institute, the BC Climate Leadership Plan does not meet the future clean economy as emissions keep on rising. The province is focusing on liquefied natural gas exploration for export and has approved the $8.3 billion Site C Dam for generating electricity - a massive hydroelectric project that would flood a large area of the Peace River Valley in northeastern B.C. There has been controversy on the flooding of prime agricultural land for the dam site but with future power to supply more than 450,000 homes and electric vehicles. The BC government has given the green light to continue work on Site C Dam. Mark Jaccard at Simon Fraser University calculates that Site C Dam is “key to hitting climate targets” and is needed for British Columbia.

On a personal level, what are we doing to save on your daily energy (and food) diet and to lower your carbon footprint? You may start by listing some of the ways you could change behaviour for a greener household. People make decisions by not smoking for personal health reasons and to set an example to others in the family or community or school. Decisions have to be made in the same way for energy efficiency to save on natural gas, gasoline and electricity. Here are some suggested
resources to get you started on a greener path. You may check out the following: [www.pembina.org/bc](http://www.pembina.org/bc) in “Walking the Green Talk”, *National Geographic* (March 2009) on “It Starts at Home”, a “Green Guide” [www.nationalgeographic.com](http://www.nationalgeographic.com), and David Suzuki’s “Nature Challenge” at [www.davidsuzuki.org](http://www.davidsuzuki.org). Another Canadian website you may like for solutions to reduce our carbon footprint, go to [www.cleangrowthcentury.org/](http://www.cleangrowthcentury.org/) emphasizing, “Together, let’s be part of a #CleanGrowthCentury for Canada.”

*The Grantham Institute – Climate Change and the Environment* at the Imperial College in London is a highly recommended site that provides achievable plans to reduce GHG emissions (GGE) and to lower our carbon footprint. The website is: [https://www.imperial.ac.uk/grantham](https://www.imperial.ac.uk/grantham) accompanied with research papers for students, the public, professionals and most of all, politicians, to read. You could access for example “9 things you could do about climate change” of the most desirable ways you could personally make a difference. Under “Health and Green Space” from the above website, “green space can play an important role in the mental health of individuals – those living closer to green space in urban areas have been found to experience lower rates of anxiety or mood disorder treatment while a number of studies have shown the link between access to green space and reduced levels of stress. One particular study looked at the experience of members of the public in the UK and Italy who used green spaces during periods of high temperatures and found that longer and more frequent visits to green spaces led to improvements in wellbeing and helped to alleviate the perception of thermal discomfort during periods of heat stress.” An article entitled “Nature and mental health: An Ecosystem service perspective” in *Science Advances*, 24 July, 2019 presents a number of scenarios of human well-being linked to the natural environment in number of ways.

Citing another piece of research, under Health and Food, the *Grantham Institute* reported on the health benefits of a diet that is lower in GHG emissions and largely derived from a reduction in red meat consumption. “Diets with relatively high amounts of beef, lamb and pork are associated with higher risks of cardiovascular disease, stroke and certain types of cancer. Beef and lamb in particular are responsible for a disproportionate amount of GHG emissions from the food sector because, unlike pigs and chickens, cows and sheep ruminate (their food ferments in their multi-
chambered stomach), which leads to the production of relatively large amounts of the potent greenhouse gas methane.” The following graph outlines the average yearly dietary greenhouse gas emissions for animal protein consumption versus other diets. Worldwide, the livestock sector is responsible for approximately 14.5% of all GHG emissions and approximately half of these emissions come from beef and lamb. In Canada and elsewhere, plant-based foods sold as ‘meat burgers’ are becoming popular. “Beyond Meat” or “Beyond Burger” are products sold that satisfy the craving for a burger and to reduce a meat intake. You may wish to make your decision on food selection the next time you go to the grocery. Reports of high fat and sodium content of “Beyond Burger” have been reported so do check on the contents of the food you purchase, namely by reading the labels. Incidentally raising a beef cattle for three years takes over 2.4 million litres of water to sustain that animal. Water consumption for that animal is generally used for pasture (irrigation), for grain and hay production, drinking, cleaning stables and farmyards, adding greatly to the cost and energy needed.

![Graph showing dietary greenhouse gas emissions](image)

**Figure 4.1.** Various consumption of meat, fish/seafood and vegetarian diets and GHG production. Credit Grantham Institute and Imperial College, London

Walking to work, walking to neighbourhood shopping malls and walking to school is a good way to start lowering your daily carbon footprint and is a good form of exercise. Biking is the next best way to get around and more people are commuting
to work in urban areas on bicycles. Roads in many communities have defined lanes for bikes. Bike routes are increasing in a number of cities and municipalities across Canada, the US, and widespread in Europe. Because of the mild winters and local government initiatives in Greater Vancouver more bike lanes are commonplace in regional municipalities. The City of Vancouver has added additional bike lanes in the downtown area. Vancouverites cycle the most in Canada with over 100,000 cycling trips made every day, followed by Torontonians with around 96,000 daily trips. Calgary has 578 kilometres of multi-use trails, the most of the five cities studied. Montreal has the most separated cycling lanes – 72 kilometres of separated cycling facilities across the island. Over 4% of all trips in the City of Vancouver are by bicycle. In some cities and municipalities, buses and trains carry bicycles to ease the travel time over long distances.

Streets could be made much safer for bikes and are widespread in the Netherlands and Denmark – ‘green streets’ are where vehicles are not allowed but friendly to cyclists; a number of cities in Europe already have them in place. Copenhagen and Amsterdam are two of the world’s most bike-friendly cities. Bike paths have actually become congested in Amsterdam and as a tourist one has to use caution when walking and not step into bike lanes; also watch for bike lane light-signals.

![Figure 4.1 A. Bicycle rush hour traffic in Copenhagen, Denmark. Photo credit: Mikael Colville-Andersen/Copenhagenize Design Co./Copenhagen at Climate Outreach](www.climateoutreach.org)
that operate in major cities like Amsterdam much like safety signal lights for vehicles. Bike paths are being widened by 4 metres to allow for less bike congestion and to be used by city buses. A city to suburban 15 km highway for bikes opened in 2011 in Denmark. In addition, a bike ride is another way of maintaining good health and provides a good form of exercise. H.G. Wells once remarked “every time I see an adult on a bicycle, I no longer despair for the future of the human race.”

Developing economies and developed countries will continue to depend on fossil fuels for the next 50 years to power vehicles, machinery and aircrafts. On my visit to Japan some years ago I experienced a public transportation system that works very efficiently. Throughout Japan and in the city of Tokyo several modes of public transport are available. The under
ground system in Tokyo is extensive; transit trains travel in and out of the city while the rapid trains move to and from suburban areas, while the famous shinkansen or bullet trains (Figure 4.2) carry passengers across Japan, all running on electricity to and from Tokyo Station.

Figure 4.2 Bullet train or Shinkansen at Tokyo Station. File photo.

Tokyo Central Station can be a confusing place with so many destinations and different routes but signs are posted in English as well. I have been to Tokyo
station on at least four occasions and have got ‘lost’ each time! The annual underground passenger trip in Tokyo adds up to over 3.5 billion followed by Moscow, Seoul, New York City, Mexico City, Paris and London. Beijing’s subway system is projected to be the largest in the world. Commuters in Japan often ride their bicycles and motorbikes and leave them unattended adjacent to train stations (Figure 4.2 A – bike park); the average Japanese carbon footprint happens to be much lower than the average Canadian.

The French also have their own bullet trains travelling at speeds of over 300 kph. The \textit{Train a Grande Vitesse} (TGV) in France holds the record at speed of up to 515 kph and authorities plan to extend this rail system. Throughout the European Union and Britain trains are a major, cheaper and convenient form of transport. A maglev or magnetic levitation train in Germany was tested and travels at speeds of up to 580 kph. The Chinese completed a high-speed rail train from Beijing to Shanghai at a cost of $32 billion travelling with a top speed of 350 kph and a distance of over 1,300 kilometres. A similar high-speed line is being planned between San Francisco and Los Angeles. Europeans more frequently used public transport of rail and bus than North Americans; Europeans generally have shorter distances for commuting to work than North Americans experience and with greater access to public transport and as expected their carbon footprint is much lower than ours. Car trips into the City of Vancouver declined by over 40,000 per day with improved public transport from suburban areas. The \textit{Canada Line} gets you to the airport with transfers to and from Surrey, Coquitlam, Burnaby, Richmond, New Westminster and with connections to North Vancouver by the SeaBus from downtown Vancouver. Buses with Transit Metro Vancouver connect with many \textit{SkyTrain} stations to routes in Metro or Greater Vancouver. The \textit{Westcoast Express} train connects from Mission with many stops along to Vancouver on mornings and late afternoons.

One downside to using personal vehicles as reported by Statistics Canada is that 32\% of the 44,192 accidental deaths in Canada between 2000 and 2004 were due to motor vehicles, and 70\% of them arising from age 15 to 24 years. Most major cities in Canada have good public transport systems using electricity, natural gas and less gasoline or diesel to power transportation. Western Europeans averaged
far less gasoline consumption of about 450 litres per person per year than Canadians. An average size city bus takes 40 vehicles off the road, saving 70,000 litres of fuel and keeping about 175 tonnes of CO₂ out of the atmosphere each year. It is encouraging to see more people changing their lifestyle by using public transport for work, school and everyday shopping. Some universities have linked their tuition fees with the public transit system to discourage cars from campuses with limited parking and hefty parking fees.

Figure 4.2 A. A bike park near Chiba City Station. Many like these in Japan. Photo by the author

Turning onto a grand scale of reducing GGE, scientists Robert Socolow and Stephen Pacala of Princeton University writing in Science journal suggested a number of strategies to reduce annual carbon emissions starting at one billion tonnes a year and with increments for the next 50 years. These two researchers noted that each of the options they suggest has already been implemented on an industrial scale but must be further advanced for decades to come. They developed a chart with fifteen “wedges” or actions to be implemented. A few of these strategies (wedges) include fuel efficient and hydrogen vehicles, efficient buildings (to save on electricity and conserve heat), replace coal as a fuel with natural gas and/or nuclear power, improve and increase carbon capture and storage at power generating plants. All of the fifteen wedges they suggest are supposed to get rid of 200 billion tonnes of carbon in the next 50 years. The scientists also advocate
doubling nuclear power use with full disclosures and inspections by all countries, increase wind power up to 25 times the current capacity, increase solar power up to 700 times the present capacity, reduce deforestation, increase reforestation and new plantings or afforestation. In other words, to aggressively pursue the mission advocated by the *IPBES Report, One Earth, and The Global Deal for Nature* to conserve and expand on Nature and Biodiversity for carbon sinks and 100% renewables as detailed in Chapter One.

Figure 4.2 A. Canada Line connects to Vancouver International Airport. File photo.

Burning coal still accounts for 40% of the world’s GHG pollution. Emissions from coal plants must be sequestered as an immediate priority; coal consumption is high in China, India, South Africa, Australia, Poland, Israel, but reducing in the US, Germany, in the provinces of Alberta and Saskatchewan. Socolow and Pacala are not dreamers but if the world implements just a handful of “their 15 wedges”, it would be a giant step to cut GGE. For starters and taking a few positive steps from the Socolow and Pacala plan, a reduction in the use of personal vehicles, purchasing smaller vehicles and hybrids, efficient driving style and greater access to public transport would reduce fuel consumption. Electric and hydrogen vehicles are still above price for many consumers but becoming less expensive and fast developing in China, Europe and in the US.
A ‘Solar Grand Plan’ described in *Scientific American* could have in place 3,000 gigawatts (billions of watts) of solar power by the year 2050, enough to supply 70% of the US electrical grid system and 35% of its total energy. This project envisages thousands of square kilometres of solar systems erected in the southwest USA. Europe also wants clean power and the *North African Sun* project provides lots of it. Huge solar farms in the Sahara can be built to transmit electricity through subsea cables across the Mediterranean Sea to Europe. The project named *Desertec* is being discussed by scientists, industry and the government of Morocco; the anticipated megaproject is to start by producing two gigawatts of electricity and expanding to hundreds of gigawatts across Europe, North Africa and the Middle East as a multinational venture. Since American technology is expanding with plans to send humans to Mars or a return to the Moon, so too is the grand plan for embarking upon solar and wind power as a reality but not until there is a united political will.

The former federal government of Canada had proposed to cut its emissions by 20% from the 2006 level by 2020, not from the year 1990 that the Kyoto Protocol agreement had called for. Canada has since revised its “action plan” to reduce greenhouse gas emissions by 17% from 2005 level by 2020 to follow what the US had proposed and as mentioned earlier it would not meet its planned reduction target. Obviously, those plans are mere pledges without concrete actions as none of them would be fulfilled. Canada is the only country to have accepted the Kyoto target and then decided to abandon it. In an address to the *World Business Summit on Climate Change* in 2009, a former Environment Minister Jim Prentice spoke positively about “the success in Copenhagen” and the technologies to reduce emissions. There was no “success” in terms of reducing GGE in Copenhagen by Canada or other nations; instead, Canada received the *Fossil of the Year Award* as being “least constructive” at the talks. European countries said that they will work diligently on a 20% reduction of GGE from the 1990 Kyoto baseline by 2020 and by 80% by 2050.

A document produced by *Natural Resources Canada* entitled “Canada in a Changing Climate: Sector Perspective on Impacts and Adaptation” provides details of adaptation activities for Canada. With recent extreme weather patterns around
the world - frequent storms, sea level rise, hurricanes, droughts, forest fires, coral bleaching, heat waves, abnormal snowfall and lack of, *adaptation* is viewed as an essential strategy in preventing only a few of these impacts of climate destabilization. The events of El Nino and La Nina are unavoidable that trigger some extreme weather conditions as discussed in an earlier chapter. The IPCC Fourth & Fifth Assessment Reports on *Impacts, Adaptation and Vulnerability* is extensive that politicians ought to read and digest. The *Stern Review on the Economics of Climate Change* advocates *adaptation* as a contingency and explains that it is crucial in dealing with the unavoidable impacts of climate change. The construction of dykes or levies from floods, tsunamis or hurricanes is a necessary adaptive measure to any impending disaster. Climate change as discussed in Chapter Two is now linked to many extreme weather conditions together with natural variability as cited in the scientific literature.

On the night of January 31, 1953, a combination of storm-force winds and the spring tide created a storm surge that ravaged the low-lying coastal regions in the Netherlands. *Wikipedia* reported “The islands of Goeree-Overflakkee, Schouwen-Duiveland, Tholen, Noord-Beveland, and Zuid-Beveland—which all have an average elevation below sea level—suffered extensive flooding. High water lasted for more than 24 hours and took the lives of thousands of people, tens of thousands of livestock, and severely damaged infrastructure and farmland over an area of 1500 square kilometers, about half the size of Rhode Island.” The Dutch today have a well-planned system for allowing certain regions in Holland to be flooded from the Rhine River and North Sea while sparing other populated regions. They plan to spend billions of dollars on building more dykes. One-fifth of the total area of the Netherlands is below sea level and is reclaimed by pumping water out; these reclaimed lands or polders still have to be drained by windmills and pumps in the old-fashioned way. **Delta Works** is a massive Dutch project to construct dams, storm surge barriers, and dikes. The final barriers were completed in 1997. Without these adaptive measures Holland will be regularly flooded causing severe economic hardships and loss of lives. The City of Richmond where I live in British Columbia is under sea level and surrounded by dykes and pumping stations to rid of excess storm water.
The 160-page document from the *National Round Table on the Environment and the Economy* in Canada focuses on adaptation in the Canadian North and by updating infrastructure to combat the impact of climate change in the Arctic. Countries are anticipating measures necessary for adaptation from climate change such as sea level rise. The need for adaptation is expected to increase with climate change that impact developing countries, low-lying states and coastal cities. Germany is spending close to one billion dollars in constructing a sea wall along the Elbe channel near Hamburg. The Thames Barrier system in London protects against storm surges from the North Sea. The city of Venice is working on preventing flooding from a rising sea in what is known as the ‘Moses Project’. In November 2012 the city of Venice was hit hard with flooding and continues today. Hurricane Katrina disaster and human suffering could have been alleviated or prevented if fortified and higher levies were in place coastal Louisiana. Adaptive measures are expensive projects and should be undertaken in Bangladesh, the Philippines and small island states from sea-level rise, storm surges and periodic cyclones. Bangladesh has had major floods in 1987, 1988, 1995, 2005, 2007 and in recent years with great loss of lives and property. Storm surges from the sea, periodic monsoons and snowmelt from the Himalayas regularly impact on low-lying regions in India, Pakistan and Bangladesh. In 2010 the plains along the Indus River in eastern Pakistan devastated that region with great loss of life and property. In October 2012, superstorm Sandy caused extensive damage to New York and New Jersey. There are ongoing environmental and human catastrophes in regions impacted by the ocean and flood plains. Funds for small island states are in place from the agreement at COP21 in Paris to prevent disaster from a rising sea. Sea level rise is projected to be at least one metre by 2100.

Adaptation must also include rainwater harvesting, storage, conservation and irrigation efficiency. In agriculture, crop variety and rotation, improved land management such as erosion control and protection are some recommended adaptation strategies. China is diverting water in a multi-billion dollar project from the Yangtze River to the water-starved north by constructing a tunnel crossing below the Yellow River; the latter river is known to be heavily polluted with industrial waste, unfit for drinking and with reduced outflow. One-third of that river is unfit for agriculture; 4,000 petrochemical plants are built on its banks.
according to the *Economist* magazine that add to the pollution. As mentioned, many rivers in China’s and India are so polluted that they have become a national health hazard.

Climate economist Nicholas Stern said that those who damage others by emitting greenhouse gases generally do not pay and to allow global warming to escalate is the greatest market failure that the world has seen. Indirectly, the consumer pays and if a commercial industry needs to sequester its carbon albeit an expensive project, it is the consumer who will eventually pay. The reality is that the Kyoto Protocol, while it was an ambitious and a sensible plan, has been “unworkable” for some countries including Canada. Will the Paris COP21 Agreement become the real change for GHG emissions or with nations just promising emission reductions with no achievable plan? Time will tell but projections show that with the Intended Nationally Determined Contributions from the Paris Agreement countries will miss the 2°C projection and very likely have the world’s temperature exceeding 2.7°C by 2100 (Figure 3.18). As mentioned, Canada has initiated a plan, the Pan-Canadian Framework on Clean Growth and Climate Change in 2016 to reduce GHG emissions but we need to do more to achieve our intended goals.

Since 2009, the $30 billion fund passed at COP15 for adaptation to poorer countries is still to be adequately distributed. Developed nations need to find ways to enable poorer countries to achieve economic success with technologies to mitigate GGE and adaptation plans for potential disaster. Canada is committed to deliver $2.65 billion by 2020 to help the poorest countries mitigate and adapt to the adverse effects of climate change as agreed upon in the Paris and Bonn UN Conference of Parties (COP). Long-term polluters of GGE have an obligation to assist those nations; they also need to aggressively work on advancing renewable and alternative sources of energy. It is in the interest of wealthier nations and for their own economic advantage to pursue the agreements made at UN COP meetings. The COP 23 UN meeting in Bonn, Germany was meant to implement the rules made at the 2015 Paris COP 21 Accord. At the time of writing, the next COP 25 will be in Chile in December 2019 with a theme of “Time for Action is Now.”
Canada ranks third as a developed nation in GGE per capita at about 20 tonnes/person/year of CO$_2$ following the USA and Australia. Oil and gas producing countries such as Qatar, Kuwait, Saudi Arabia and even small island states like Trinidad & Tobago and Aruba have higher per capita GGE than Canada. Qatar is a petrostate with the Emir as its petrodicator and it has no plans to reduce its GGE of 61 tonnes per capita; it’s the wealthiest country in earnings per capita for the Qataris. Fact - Workers from North Africa and Asian countries contribute to the wealth and infrastructure to Qatar, Saudi Arabia, Kuwait and the Emirates and are paid very low wages in less than desirable working and living conditions; massive projects such building of stadiums for the 2022 Soccer World Cup event is on example where working conditions are being violated - temperatures reaching over 50°C with no reprieve for workers. It was reported that some FIFA officials have been bribed to host the soccer event in Qatar.

Back to Canada, no new coal plants will be built in Alberta and (former) Premier Notley is expected to phase out coal in a few years. Ontario has taken a leadership role by stopping construction of any new coal plants. All four former Federal Environmental Ministers in the previous Conservative government had not put out a single legislation to curb GGE at satisfactory levels. The present Liberal federal government expects all provinces and territories to implement a carbon tax or a cap and trade scheme as outlined in the document, *Pan-Canadian Framework on Clean Growth and Climate Change*. On page 49 of the latter document, the pricing of carbon tax or cap and trade is noted under “Federal Carbon Pricing Benchmark.” Credit to the Prime Minister and the Minister of the Environment and Climate Change in working with the provinces and territories in a major step to advance cleaner energy. At the time of writing Alberta Saskatchewan and Ontario may not implement any of the federal government’s plans in the above document.

*The National Round Table on the Environment and the Economy* has put out a document to reduce greenhouse gas in Canada, entitled “*Achieving 2050: A Carbon Pricing Policy for Canada.*” This document investigates and recommends unifying carbon prices across all jurisdictions to reduce greenhouse gas and to minimize the adverse impacts on regions, energy sectors and consumers. The above cited document is a serious attempt to reduce GGE in Canada. Coal plants
used in generating electricity should be levied a carbon tax for each tonne of CO$_2$ pumped into the atmosphere unless they implement a carbon capture and storage (CCS) underground; Saskatchewan has a functioning CCS system at its Boundary Dam plant. Funds collected by jurisdictions for carbon taxes must be cycled back into advancing renewable energy and in expanding public transportation. The carbon tax collected since 2008 in BC has not returned that revenue of over one billion dollars a year to renewables but is used to reduce personal and business income tax.

EnCana Corporation in Canada has developed a carbon capture and storage facility in a conventional oil field that is also being used by the Great Plains Synfuels coal plant in North Dakota with a pipeline all the way to Weyburn, Saskatchewan. At present 10 million tonnes of CO$_2$ are being injected underground according to the Canadian Association of Petroleum Producers (CAPP). SaskPower International in Saskatchewan plans to cut emissions of CO$_2$ by one million tonnes annually at the Boundary Dam Power Plant. The US Environmental Protection Agency (EPA) has the authority under the Clean Air Act to regulate GGE. The cap-and-trade programs have already been implemented with some success in the USA to reduce emissions of sulfur dioxide from scrubbing coal. All Canadian provinces need to take a hard look at a carbon tax and don’t get carried away on the cap-and-trade system (Figure 4.2 B) that is already in place in Ontario and Quebec. For more information you can Google “Cap-and-Trade” for Quebec and Ontario on how they implement the system along with California’s cap-and-trade; Ontario may likely opt out of the cap and trade agreement with the elected Conservative government. NASAs former top climate scientist, Dr. James Hansen, says that he already has made up his mind about “the uselessness of cap-and-trade.” Instead, he advises on a carbon and dividend fee to polluters of fossil fuels (oil, gas and coal companies) with dividends to be returned to all legal residents in that state or province.

The cap-and-trade system would set mandatory national or international limits or caps on CO$_2$ emissions. Under that system, suppliers of fossils fuels would hold the rights for each tonne of CO$_2$ emission they produce. Once the allowances are distributed they could be traded or sold. Companies that exceed their emissions’
limit must purchase credits on the market. If, for example as illustrated in Figure 4.2 B, Emitter A is producing more CO\textsubscript{2} than Emitter B, Emitter A could purchase from Emitter B any unused permits or carbon emissions credit. The *Kyoto Protocol’s Clean Development Program* allows companies of wealthier nations to earn emission-reduction credits by investing in energy-efficient projects in poorer countries. For example, company X can invest in a carbon reduction program established by company Y in a developing country. Company X has invested in a solar energy system in company Y and company X gets the credits it needs to offset its GGE; that developing country now uses a new technology and emits less or no GGE than if it were using coal, oil or from deforestation practices. The Cap & Trade system is the primary tool the Québec government has chosen to achieve its ambitious GHG emission reduction targets of 20% below 1990 levels by 2020 and 37.5% below 1990 levels by 2030. Ontario seems likely to abandon its C&T system under the elected Conservative government.

Figure 4.2 B. Cap and Trade system that Ontario and Quebec initiated in 2015. Follow Emitters A & B and how the system works. Credit Government of Quebec website.

For further information on how the cap-and-trade system works, visit *The Pembina Institute* ([www.pembina.org](http://www.pembina.org)) and *Google* “cap-and-trade” for Quebec or California. “Research commissioned by *The Pembina Institute* and the *David
Suzuki Foundation advocates that Canada needs a carbon price starting at $50 per tonne and reaching $200 per tonne by 2020 to cut national emissions to 25 percent below the 1990 level by 2020.” The current carbon tax in BC was set at $30 per tonne of CO\textsubscript{2} equivalent (tCO\textsubscript{2}e) in 2012. On April 1, 2019, BC carbon tax rate rose from $35 to $40 per tCO\textsubscript{2}e. The carbon price for gasoline is presently 8.89 cents per litre while other taxes amount to an additional 40 cents per litre. The tax rate will increase each year by $5 per tonne until it reaches $50 per tonne by 2021. The Federal Government proposed a modest carbon tax across Canada (except in BC and Quebec) of $10 per tonne by 2018 and expected to increase each year by $10 to $50 per tonne by 2022. **What does it cost individuals and family with a carbon tax of $50 per tonne of CO\textsubscript{2} equivalent?** Professor Trevor Tombe at the University of Calgary figured that “a carbon tax will increase the price of gasoline, fuel for home heating, and (in some provinces) electricity. The effect of this is fairly easy to quantify using data on gasoline spending, gasoline prices, electricity emissions intensity, and average household energy use. The average household uses about 2,000 litres of gasoline per year. A $50 per tonne tax adds 11.2 cents per litre to that, for a total cost of $224. To heat the average home, Canadians use just over 90 gigajoules of natural gas and that carbon tax adds about $230 per year to those costs.” The total cost per average household is then $454 per year as a projected carbon tax. **One big question:** Will people change their behaviour in the face of rising fuel prices when the product is essential for their economic success and convenience?

**Carbon Capture and Sequestration (CCS)**

Energy producers must seek ways to sequester carbon dioxide emissions especially from the burning of coal to produce electricity; coal is the cheapest and dirtiest fossil fuel that should be targeted for CCS. CCS can be safely transported to deep underground sites in the Earth’s crust. Injection of CO\textsubscript{2} into suitable geological reservoirs could lead to permanent storage. There are some serious concerns about storage including rapid release of CO\textsubscript{2} from seismic activity and from the impact of poorly sealed well bores. Scientists believe that CO\textsubscript{2} under one kilometre or more beneath the earth will remain in a quasi-liquid state and can be safely stored. The process of carbon capture to storage is divided into four major steps and simplified
as follows: First, capture of CO₂ produces a concentrated stream of the gas at high pressure that is transported for storage. The second step is transportation by pipelines. Compressor stations are located along the pipeline system that provides additional flow for the injection system. The third step is an injection system at the end of the pipeline. The last process is the downstream systems boundary to the storage reservoir deep in the Earth’s crust. Under the ocean is a likely repository for CCS in some marine oil drilling projects. CCS is expensive and it is unlikely that big consumers of coal like China and India would ever sequester any of their coal plants.

In Weyburn, Saskatchewan where a CCS facility has been in place, farmer Cameron Kerr allegedly reported in a *Globe and Mail* newspaper of his dead animals – “a cat, an African goat, a rabbit, a duck, and half a dozen black birds” - and observed gas or foam similar to soda pop coming out of the earth near the CCS site on his property. To date no scientific findings were reported from the farmer’s story in the *Globe and Mail* newspaper (Jan. 12, 2011). Remember that CO₂ concentration in the atmosphere measures 415 ppm by volume today or 0.0415% of the atmosphere containing 99% O₂ and N₂, and this CO₂ concentration of 415 ppm has no direct threat to human health but of importance to plants and the greenhouse effect. However, any release of CO₂ poses immediate danger to human and animal life if exposed to a volume greater than 7% CO₂ in air. An estimated 30% of the CO₂ released by humans into the atmosphere dissolves into oceans, rivers and lakes, which contributes to ocean acidification and reactions with calcium to form calcium carbonate. Since the industrial revolution, the average pH of the ocean is known to have fallen from 8.2 to 8.1, which may seem small but corresponds to an increase in acidity.

The Weyburn-Midale CCS facility in Saskatchewan has been a success story with over 25 million tonnes of CO₂ stored underground to date. A coal gasification plant in Great Plains, North Dakota, uses steam to dismantle lignite coal that is converted into methane and hydrogen. Since the year 2000, the Great Plains Synfuels station has been pumping its CO₂ along 330 kilometres of pipeline to the Weyburn-Midale operations in Saskatchewan for storage. This is one of the world’s largest capture and storage sites for carbon dioxide; the CO₂ is pumped
into porous bedrock about 1,500 metres deep and about 2.8 million tonnes per year are being stored. Cenovus Energy purchased that project; CO₂ is injected into wells to retrieve oil deep underground. Cenovus enhances its oil recovery at Weyburn where it acts like a solvent and helps push more oil towards the producing wells. Cenovus expects this technique will extend the life of the field by 30 or 40 years, and could lead to an estimated 200 million barrels of incremental oil production.

**Saskatchewan’s SaskPower** built a $1.4 billion “clean-coal plant” located near Estevan. It plans to capture about one million tonnes of CO₂ annually from its **Boundary Dam Power Station** and inject the gas to enhance oil recovery and in the process to leave it permanently underground. In July 2016, *SaskPower* announced that the CO₂ capture unit at Boundary Dam had surpassed the capture of one million tonnes of CO₂ since operations began in October 2014 and that the facility was on track to capture 800,000 tonnes of CO₂ by 2016. To date the Boundary Dam coal fired plant has stored over 1.5 million tonnes of carbon dioxide and other pollutants. Saskatchewan uses coal to produce 50% of its electricity but its CCS compensates for less greenhouse gas emissions. The **Quest CCS** facility captures and stores about one third of the CO₂ emissions from the **Shell-operated Scotford Upgrader** near Fort Saskatchewan, Alberta, which turns oil sands bitumen into synthetic crude that can be refined into fuel and other products. The CO₂ is transported through a 65-kilometre pipeline and injected more than two kilometres underground below multiple layers of impermeable rock formations. Since its start up in late 2015 the facility exceeded its target of capturing one million tonnes of CO₂ per year. One million tonnes of CO₂ is equal to the annual emissions from about 250,000 vehicles.

An Algerian gas-extraction facility in the Sahara Desert has been separating CO₂ from natural gas; CO₂ is pumped down two kilometres in the Salah gas field and over 1.2 million tonnes per year are being stored. Statoil-Hydro buries one million tonnes of CO₂ annually under the Sleipner gas field in the North Sea and another project in the Snohvit gas field in the Barents Sea stores a further 700,000 tonnes annually. The latter two Norwegian projects involve injecting CO₂ into deep saline aquifers. The CO₂ that Statoil is injecting at Sleiper is an impurity from natural gas. The CO₂ is injected into a brine saturated sandstone about 700 metres below the seabed. The provinces of Alberta and Saskatchewan still produce much of its
electricity from coal compared to 15% use from the rest of Canada. The good news is that Alberta will phase out coal, plans to expand its wind power in the southern region of the province that is ideal for wind turbines as well as for solar power, thus reducing the highest greenhouse gas emissions in Canada from that province. Of course politics play a part in decision-making in that province. Alberta’s carbon levy is to be included in the price of all fuels that emit greenhouse gases when combusted, including transportation and heating fuels such as diesel, gasoline, natural gas and propane. The levy applied at a rate of $20/tonne from January 1, 2017 and will increase to $30/tonne one year later in line with BCs present rate.

Here is an interesting story I should tell and it is of a personal nature as well. On August 21, 1986, an eruption at Lake Nyos in northwestern Cameroon killed 1,746 people and 3,500 livestock; deaths were caused by CO₂ asphyxiation. That eruption triggered the sudden release of about 100,000–300,000 tonnes of carbon dioxide. Most geologists suspect a landslide, but others believe that a small volcanic eruption may have occurred on the bed of the lake (Figure 4.3). The normally blue waters of the lake turned a deep red after the outgassing, due to iron-rich water deep within the bottom of the and rising to the surface. I am including this story on Lake Nyos for two reasons - the sudden escape of high concentrations

![Figure 4.3. Lake Nyos in northwest Cameroon one week after the eruption. Credit Wikipedia.](image)
of CO$_2$ poses danger to humans and animals, and secondly, my knowledge of that region of West Cameroon before that explosion occurred.

Figure 4.3 A. The author’s daughter (Nila) on the left with Fulani children in the Bamenda grassland in northwest Cameroon. Lakes in the region may still be in danger of CO$_2$ release. Lake Nyos is located several kilometres northeast where this photo location near Bambili, West Cameroon. Photo by author.

I was on an assignment as a Teacher Trainer at the Cameroon College of Arts, Science and Technology in a village of Bambili near the major town of Bamenda with the Canadian International Development Agency (CIDA). Several years before the Lake Nyos natural disaster, we often rode horses that we had purchased from the friendly Fulani people, many of whom had perished in that grassland region with their herds of cattle from the explosion. We had encountered several small lakes along the valleys covering an extensive area in the northwest Bamenda grassland region where Lake Nyos is located. The Fulani are cattle herders and their villages are scattered throughout the north and northwest of Cameroon. The Lake Nyos region is now an abandoned site for good reason and authorities need to monitor other lakes in the region on carbon dioxide concentrations. The Lake Nyos explosion in the Cameroon serves as perhaps the only example of the danger to
humans and animal life from the release of high concentrations and volumes of carbon dioxide. Carbon dioxide is heavier than oxygen and the gas had spread at ground level some 25 kilometres away from Lake Nyos asphyxiating every living organism on its path.

A Carbon Engineering company in Squamish, British Columbia captures carbon dioxide directly from the air to produce products such as diesel, gas and jet fuel. The CO₂ is added to the H₂ to produce the carbon free fuel. (H₂ is best produced from hydro, wind and solar, but not from fossil fuel). Carbon dioxide captured is mixed with calcium to form calcium pellets then CO₂ is recaptured from the pellets to be used in fuel production with hydrogen. “As we move to commercialization, we envision industrial-scale Direct Air Carbon (DAC) facilities, built outside of cities and on non-agricultural land. Individual DAC plants can be placed in any country and in multiple climates, and can be built to capture one million tons of CO₂ per year” a message from Steve Oldham the CEO of Carbon Engineering. For more information on this process with videos to give us a better understanding of the technology and the ongoing operations in Squamish, British Columbia, please visit: www.carbonengineering.com. Climeworks in Switzerland extracts CO₂ from the air and sells it to companies such as Coca Cola for its fizz and greenhouses for enhancing vegetable growth. Another project known as Global Thermostat also captures CO2 in a small way.

Getting nature to sequester carbon is a natural way of keeping CO₂ concentration from rising in the atmosphere. Land plants and the ocean sequester about 55% of GHG in the carbon cycle. A Global Deal for Nature (GDN), One Earth and IPBES, discussed in Chapter One, in conjunction with the Paris Agreement, could ensure that climate targets or projections of temperature are kept under 2°C and to be met while preventing species extinctions and the rapid erosion of biodiversity, and ecosystem services in the terrestrial, freshwater, and marine realms. A growing body of research documenting the inherent interconnection between carbon sequestration and biodiversity lends further support for a proposal to pair GDN, the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES), One Earth (Leonardo di Caprio Foundation), Living Planet Report 2018 – Aiming Higher (WWF), and RESOLVE with the Paris Agreement; refer to Chapter
One for more details. Carbon-rich ecosystems absorb or acts as sinks of carbon from the atmosphere.

This carbon sequestration service is key to climate stabilization and to climate change mitigation. It is no coincidence that some of the most carbon-rich ecosystems on land—natural forests—also harbor high concentration of biodiversity. “It is the very pests, pathogens, pollinators, decomposers, and predators that comprise a tropical forest that generated the carbon-rich growth forms (in both wood and soil) that take the carbon out of the atmosphere. Even in the world’s widespread savannas, carbon sequestration is enhanced by biodiversity. Herbivores are key to plant growth as well as soil carbon sequestration. Predators are key to maintaining herbivore balance with primary production. In the ocean realm, from coral reef to blue water, biodiversity is part and parcel to the flux of atmospheric carbon to stored carbonates and deep ocean sediments. Without biodiversity, this system shuts down as well” as advocated by 20 climate scientists including the lead author Eric Dinerstein in (Science Advances 19 Apr 2019: Vol. 5, No. 4) A Global Deal for Nature: Guiding principles, milestones, and targets.

**Hybrid Vehicles - Hydrogen, Electric & Combustion**

By the time you have finished reading this section many new models of hybrid vehicles – electric, hydrogen and combination with combustion - would have come off the assembly line; this technology is fast evolving with a greener approach to transportation. For readers interested in hybrids - electric, fuel-cell hybrids and plug-in hybrid electric vehicles go to the Canadian Automobile Association (CAA) website at https://www.caa.ca/electric-vehicles. The CAA website is all you may need for cars sold in Canada and also provides specifications of vehicle-type. Questions (FAQ) are asked and answered by CAA. For example: “What are the main differences between a BEV (battery electric vehicle) and HEVs/PHEVs (hybrids and plug-in hybrids)? Answer: “Whereas BEVs operate on electricity alone, HEVs and PHEVs combine electrical and internal combustion engines, which require fuel.” The transition from fossil fuel vehicles to electric is slow; the number of electric and hybrid vehicles in BC grew by 10,500 in 2018
according to the Insurance Corporation of BC. Legislation passed in BC for passenger vehicles must increase to 30% zero-emission by 2030 and 100% by 2040.

Four major types of hybrid vehicles are being manufactured mainly in the US, Japan, Germany & the EU, China and Korea. These include the Plug-in Hybrid Electric Vehicles (PHEV - battery & combustion engine using gasoline), Battery Electric Vehicles with no tailpipes (BEV - battery only power- no combustion engine), Hybrid Electric Vehicles (HEV – battery controls cannot be recharged from power grid & with a combustion engine) and Fuel-cell Electric Vehicles (FCEV – hydrogen fuel uses H2 to produce electricity). The latter process is explained below, and in my opinion, is probably the vehicle of the future when hydro, wind and solar are used to produce hydrogen!

**The following section is taken from the Canadian Automobile Association (CAA) Website:**

**“Battery Electric Vehicle (BEV):** A BEV runs entirely on a battery and electric drive train, without an internal combustion engine. Electricity is stored in onboard batteries that are charged by plugging into the electricity grid. The batteries, in turn, provide power to one or more electric motors. **What you should know about BEVs:**

- The initial purchase price is higher than similar gas-powered vehicles.
- You can save a lot of money on fuel and maintenance costs.
- BEVs have driving ranges upwards of 500 km on a full charge, with most models capable of 200 - 250 km on a full charge.
- Batteries can recharge overnight plugged into a regular household outlet (110 volts), or even faster using a residential electric vehicle charging station (240 volts).
- Residential charging stations cost anywhere between $700 - $2,000 to buy with most falling in the $700-$1,000 range.
- Residential charging stations have similar electrical requirements to a clothes dryer or stove and cost $500-$1,000 to install.
• Fast charging stations, commonly referred to as DC Quick charging stations (400 Volts), will recharge a BEV from empty to 80% in 30-45 minutes. DC Quick charging stations enable inter-city travelling for BEVs and can be found along major highways and travel routes throughout Canada.

**Plug-in Hybrid Electric Vehicle (PHEV):** A PHEV runs on battery and gasoline. PHEVS have rechargeable battery packs that provide 20-80km (depending on model) of all-electric driving before a gasoline engine or generator turns on for longer trips.  
**What you should know about PHEVs:**

• The MSRP of a PHEV is slightly higher than similar vehicles operating on internal combustion engines alone.

• PHEVs have longer overall driving distances than BEVs and because they can operate using a gasoline engine or generator and can take advantage of the existing gas station infrastructure.

• Because PHEVs deliver 20-80 km (depending on model) of all-electric driving, they are often cheaper to operate and maintain than traditional gasoline/diesel hybrids.

**Hybrid Electric Vehicle (HEV):** A HEV has two complementary drive systems - a gasoline engine and fuel tank and an electric motor and battery. The gasoline engine and electric motor simultaneously turn the transmission, which powers the wheels. Where the HEV differs from the above two types of electric vehicles (BEV and PHEV) is that HEVs cannot be recharged from the power grid. Their electric energy comes entirely from regenerative braking and most of their driving is spent using gasoline.  
**What you should know about HEVs:**

• Because HEVs cycle in and out of electric mode, they are cheaper to operate than internal combustion engines.

• HEVs are more similar to gas cars than to EVs as they do not require access to charging

**Fuel-cell Electric Vehicle (FCEV):** A FCEV creates electricity from hydrogen and oxygen, instead of storing and releasing energy like a battery. Because of these vehicles’ efficiency and water-only emissions, some experts consider these cars to be the best electric vehicles, even though they are still in development phases and provide many challenges.  
**What you should know about FCEVs:**
• Purchase price is high because the cost of a fuel cell is several times more expensive than the cost of an internal combustion engine.

• Extracting hydrogen from a water molecule is an energy-intensive process that generates greenhouse gas emissions if renewable energies are not used.

• FCEVs are expected to be widespread on the market in the next few years.

• Since February 12, 2015, the fuel-cell Tucson has been for sale in the Vancouver area, making Hyundai the first original equipment manufacturer to market a fuel-cell vehicle.

• The Toyota Mirai was slated to follow suit, but was stalled due to lack of infrastructure.

• The transportation and infrastructure required to bring this fuel to stations is a challenge. There are only two hydrogen fuel stations in Canada. The Shell Station at the time of writing at 8686 Granville Street in Vancouver opened it hydrogen facility in June 2018.”

**Fuel cell electric vehicles (FCEV) run on hydrogen that create electricity.** A FCEV creates electricity from hydrogen instead of storing and releasing energy like a battery. Because of these vehicles’ efficiency and with water-only as emissions, some experts consider these cars to be the best electric vehicles; busses are now running on hydrogen and trails with trains in China under the Ballard Power Systems. The fuel cell is used as a generator and not as a primary power supply. When hydrogen (H$_2$) gas is fed into a fuel stack it generates electricity when mixed with air to produce water and heat as the only by-products and no carbon dioxide emissions. In short distances, the hydrogen unit does not have to be activated. The Hy-Series Ford Edge hybrid/electric plug-in car can take you over 350 kilometres on 4.5 kilograms of hydrogen. The SUV Chevrolet Equinox hydrogen fuel cell gets about 71 km per kilogram of compressed hydrogen. The new BMW Hydrogen 7 is modified to run on both hydrogen and gasoline and can run on the supply of hydrogen for about 200 kilometres. Plug-in electric can run on hydrogen as well – Mercedes GLCH with 4.4 kg of H$_2$ and a battery is being developed. There are many models and manufacturers of hydrogen powered vehicles on the market today – US, Japanese, Germans, Chinese, Koreans all have their hydrogen vehicles on the road. The big problem is that hydrogen fuel stations are mostly in California and cost almost $2 million to build.
At the 10th Clean Energy Ministerial (CEM) meeting in Vancouver on May 2019, a new international hydrogen partnership with Canada, the United States, Japan, the Netherlands and the European Commission with participation of several other Clean Energy Ministerial (https://www.cleanenergyministerial.org) member countries. The International Energy Agency (IEA) will be coordinating efforts under this initiative. This effort will put the spotlight on the role that hydrogen and fuel cell technologies can play in the global clean energy transition. The Honourable Amarjeet Sohi, Canada's Minister of Natural Resources (seated in vehicle) stated, "Canada is proud to be a founding member of this initiative which demonstrates our commitment to growing economies and workforces. Hydrogen is playing an important role in building the clean energy future." Go to the above CEM website for more information and excellent video clips: “Did you know that two wind turbines are installed in China every hour and 500,000 solar panels are installed globally every day?” as a couple of examples from the video clips. Japan is expected to have 40,000 fuel cell vehicles on the road by 2020. China is a leader in fuel cell buses that can travel 500 km on a full tank of hydrogen and plans to advance fuel cell vehicles that travel longer distances than battery operated vehicles. By 2025 China is expected to have 20% of passenger electric vehicles on the road. Six major cities including Beijing and Shanghai account for 35% of electric vehicles sold in 2018.
Producing hydrogen from water using renewable sources of energy such as wind and solar thermal is one way to proceed for one hundred percent clean fuel. Hydrogen fueling stations and electrical outlets are increasing on California highways and in other locations in cities. Presently there are 34 hydrogen filling stations in California with more hydrogen-powered vehicles on the road; thousands of power outlets are now available across Canada and the US for plug-in electric vehicles. Hybrid cars are being manufactured with greater fuel efficiency as well and with a lower purchase tax as one incentive to customers in some jurisdictions. **Hydrogen Technology & Energy Corporation (HTEC)** opened Canada’s first retail hydrogen refuelling station in partnership with Shell at 8686 Granville Street in Vancouver in June 2018 —it is the first in a six-station network HTEC is building in Greater Vancouver and Victoria. This network will enable the deployment of the first 1,000 zero-emission hydrogen fuel cell electric vehicles in British Columbia and HTEC will partner with Shell on three of the six stations. The **Canadian Hydrogen and Fuel Cell Association (CHFCA)** is a national, non-profit association that supports Canadian corporations, governments and educational institutions that are developing, demonstrating and deploying hydrogen and fuel cell products and services in Canada. “CHFCA works on hydrogen and fuel cell technologies, components, systems supply and integration, fuelling systems, fuel storage, and engineering and financial services.”

**How does a hydrogen fuel cell vehicle generate electricity?** In a simple overview of how the system works, the fuel cell consists of an anode (- end) and a cathode (+ end), with platinum catalysts and a polymer membrane acting as an electrolyte or proton (H⁺) exchange. Hydrogen gas (H₂) is pumped into the anode side of the cell through the catalyst that strips the gas into hydrogen ions (H⁺) or protons and electrons. Electrons (negative charge) pass along an external circuit to the cathode. The protons (H⁺) then combine with the electrons and oxygen (air) on the cathode side to produce H₂O as emission. The electrons generate electricity then flow to supply the power to run the electric motor (Figure 4.4). Using fossil fuels to generate hydrogen is a non-starter as it takes fossil fuel energy to create hydrogen fuel then returning greenhouse gases right back into the atmosphere. Electricity produced from hydro, wind, solar thermal or nuclear to dissociate water
molecules (H₂O) into hydrogen (H₂) and oxygen (O₂), a process known as electrolysis that high school students carry out in chemistry classes; we then would have zero GGE in producing hydrogen gas from renewable power. Ballard Power Systems have developed technologies for fuel cell and hybrid vehicles at their ongoing research at facilities in British Columbia. As mentioned earlier, Ballard’s goal is to change the world and “use of our extensive fuel cell and systems know-how to profitably deliver innovative clean energy solutions to our customers, create rewarding opportunities for our team, and provide extraordinary value to our shareholders.” The company has its facilities in China, USA, Europe (Denmark) and in Burnaby, British Columbia. You can access the Ballard Power Systems and learn more about its products on “Putting Fuel Cells to Work” at www.ballard.com.
China has over 40 million electric scooters and riders only have to charge the battery at night. With improvements in lithium ion battery technology electric bikes have come a long way in a short time. With an increasing affluent society in China and India, more people are purchasing cars with growing congestion and pollution in major cities like Beijing, Shanghai, Hong Kong, Bangkok, Delhi, Bombay and Kolkata; traffic congestion on roads in many Asian cities are worse than in Los Angeles, London or Toronto. Indians are now buying cheap cars that will greatly increase the demand for fuel and overburden greenhouse gas output where air pollution indices are out of control. Tata Motors in India is reportedly selling its new cars for $2,500 (US). In New Delhi alone, more than 200,000 vehicles are being added to the already congested streets every year and with high air pollution indices. Traffic injuries are the leading cause of deaths worldwide for people between the ages of 10 and 24. Cited in Wikipedia on “List of Countries by Traffic Related Death Rates,” according to the World Health Organization, “road traffic injuries caused an estimated 1.25 million deaths worldwide in the year 2010. That is, one person is killed every 25 seconds. Only 28 countries,
representing 449 million people (seven percent of the world's population), have adequate laws that address all five risk factors (speed, drunk driving, no helmets, seat-belts and child restraints). Over a third of road traffic deaths in low- and middle-income countries are among pedestrians and cyclists. However, less than 35 percent of low- and middle-income countries have policies in place to protect these road users. Low-income countries now have the highest annual road traffic fatality rates, at 24.1 per 100,000, while the rate in high-income countries is lowest at 9.2 per 100,000.” When I visited Beijing in 2016 traffic jams were everywhere, an order of the day! Our guide informed us that there are over 7,000 fender benders in Beijing each day! China’s road fatalities were listed as 18.8 per 100,000 inhabitants while in Canada that statistic was listed as 6.0 fatalities per 100,000 inhabitants.

Figure 4.4 B. The International Energy Agency posted its New Policy Scenarios on its website with projections for electric car fleet to 2040 by selected countries. The International Energy Agency (www.iea.org) projects a global electric car fleet approaching 900 million by 2040 with China having over 100 million electric vehicles. Credit IEA.

Most hybrids today have fuel efficiency of greater than 25 percent. In a study by the Imperial College in London, England, it reported that for every 10% increase in fuel prices, traffic was reduced by 3% and with more careful driving fuel
consumption dropped by another 7 percent. The carbon tax levied in BC reduced the use of motor vehicles and fuel consumption. According to Simon Fraser University Professor Merran Smith since the carbon tax was implemented BC “fossil fuel use was reduced by 16 percent.” With higher prices at the pump in BC in 2019 do we know how much less driving and fuel use that BC residents experience. Transit by buses and trains reduce fuel use but most people may have routes that prohibit transit use and highways are more crowded during rush hours. Part of the transportation solution calls for cheaper electric vehicles that would fill that need. China seems to be on the forefront in this regard.

**Alternative and Renewable Sources of Energy**

Fossil fuels today continue to provide at least 80% of the world's energy needs and reserves are expected to peak after 2040 as cited in Chapters One and Two. The historical energy shift was from wood to coal then to oil and gas. Edwin Drake drilled the first oil well in the US in 1858. Whale oil for lamps switched to kerosene as the next fuel; Americans went out of the whaling business for its new energy source - oil. Coal became king as the industrial revolution unfolded in Britain and around the world. Coal still plays an important energy role in developing and developed countries in generating electricity as discussed earlier and with data cited in Figures 1.3 E & 1.3 F. As the world considers the real threat of rising temperatures the plan is for a planet of less than 2°C rise from pre-industrial time in this century. Coal must be left underground and countries such as China, India, South Africa and Australia, to name four large coal polluters in generating electricity, should be phasing out their plants now; but that is not the case anytime soon. The USA with the Trump administration is falsely clinging on to coal as a declining industry in the US with a rise in natural gas and oil, and renewables. Canada and the US export coal to Asia every day through Roberts Bank Terminal in British Columbia.

Energy alternatives of wind power, geothermal power, solar thermal power and solar photovoltaics, hydro power, and methane from landfills are being developed and increasing in use; the technology is available and many countries are making progress in advancing those renewables. **Solar thermal** energy works when heat is
generated by solar collectors to generate high temperatures to run the turbines and generate electricity; mirrors (parabolic trough collectors) are used to collect the Sun’s energy and superheated steam generated that spins the turbines. Hundreds of megawatts of electricity are generated by such systems worldwide. **Photovoltaic** energy uses solar cells or photovoltaic; these are semi-conductor devices usually made of silicon to convert sunlight into electricity. Photovoltaic production is increasing by 25% every year. Some cells use thin-film silicon and in laboratory tests crystalline cells were found to be more efficient; the latter is comprised of a more structured lattice framework and the Japanese plans to produce enough cells in a planned project to generate 1,000 megawatts of electricity supplying more than 350,000 homes. Photovoltaic modules generate direct current similar to batteries but an *inverter* system is used that converts direct current into alternating current to power appliances. **Global Solar Energy** in Tucson, Arizona, uses a technology known as ‘copper-iridium-gallium-selenide’ to make thin-film solar cells and plans to produce enough solar cells to generate 100 megawatts (MW) of electricity.

You may be surprised to learn that Kenya is a global leader in solar power systems as a developing country and a reported 30,000 small solar panels are sold every year in that country. The small solar panels are more affordable and with 1.3 billion people or almost 18% in the world without access to electricity, solar power can become more affordable and available. At the COP 21 in Paris developed countries have pledged $100 billion to states that are vulnerable to climate change impacts and that funding could also be used to advance renewables. Solar panels like those in Kenya will improve the quality of lives in poorer countries. **Vestas**, a large wind turbine company in Denmark, has committed to investments in Kenya and around the world. The goal is to supply 15% of the electrical needs for Kenya, a country that is plagued by expensive and unreliable energy sources.

An 80-megawatt solar thermal plant built in the California desert in 1989 provides one-third less energy than an average nuclear power plant; the level of safety and maintenance makes solar thermal more attractive than nuclear power but the advanced technology with today’s nuclear power plants make them much safer and cleaner than from coal combustion that kills millions of people on health-related matters. Companies in California are constructing solar plants in the Mojave
Desert and the Imperial Valley that would generate additional electricity to the state. The facility in the Mojave Desert south of Las Vegas uses 20,000 curved dish mirrors and provides electricity to 140,000 homes that went into operation in 2014. The Crescent Dunes Solar Plant in Tonopah, Nevada, northwest of Las Vegas, uses more than 10,000 mirrors and generates 110 megawatts. Mirrors track the sunlight onto a ceramic plate to a tower about 100 metres high to produce a temperature of up to 1,000°C that generates the steam needed to drive the turbines. The Topaz Solar Farm in central California produces 550 MW to supply 160,000 homes. The 160 hectares with 760 parabolic concentrators (182,000 mirrors) west of Boulder City, known as *Nevada Solar One* (Figure 4.4), presently supplies 14,000 homes. The average number of homes powered by one MW of solar varies from about 200 - 600 and of course depends on each household usage.

![Figure 4.4 B. The Nevada One Solar field near Boulder City covers about 180 hectares of parabolic concentrators and mirrors that supply electricity to 14,000 homes. Photo on left by the author.](image)

The predominant linear concentrating solar power collectors in operation in the US are parabolic trough collectors. The sun’s rays are concentrated onto receiver tubes of oil piped down rows of reflectors that heats to over 400°C and taken to a water heat exchanger to generate steam that drives conventional turbines connected to a generator to produce electricity. Near Daggert and Kramer Junction in California about a million mirrors at a facility produce 354 MW of power. The Ausra Company in California is building a solar-thermal system that created 4,000 new construction jobs, 1,000 operational jobs and clean power to supply 300,000 homes. Many more solar projects are being assembled in Arizona, New Mexico,
Texas and in other states as well as in Canada, China, Australia, Europe, South American countries and India to name a few.

![Image of floating solar panels](image_url)

Figure 4.4 C. World's largest floating solar panels in Huainan City, China, generating 40 MW electricity. Credit Sungrow Power Supply.

General Motors built the world’s largest rooftop solar power station in Spain with a capacity of 12 megawatts of power. Near Granada, Spain, and in Arizona, the Sona Generating Station use molten salt to heat water to steam and even as the salt cools at night power will still be on. In Britain, solar power is a $1.5 billion business and expanding; in about 10 years it is expected to grow to an industry of $25 billion. Germany has one of the world’s biggest markets of solar and wind products and by 2014 it boosted its renewables of solar, wind, hydro and others to 27 percent for its electricity; the goal is to produce 80% renewables by 2050 for electricity and abandon coal and nuclear. Germany is pioneering an energy transformation it refers to as *energiewende* – an energy revolution that all nations should model if we are to keep our planet from getting over 2°C before 2100. As mentioned, by 2014 Germany was generating electricity from 27% of renewables but 40% still comes from coal. By 2022 German Chancellor, Angela Merkel, plans to shut down the remaining 17 nuclear reactors; some criticisms emerge to decommission those nuclear plants until coal becomes zero use for generating electricity. Emission cuts in GGE are aggressive and Germany expects to reduce emissions by 40% from 1990 levels by 2020 and 80% by 2050.
China holds the world’s largest market for glazed domestic solar hot-water systems. Suntech Power Holdings is China’s largest photovoltaic manufacturer exports over 90% of its product; Suntech overtook Sharp as the world’s biggest producer of solar panels. In the city of Rizhao in China, 99 percent of homes use solar water heaters; traffic and street lights are also powered by photovoltaic solar cells. As of 2014 China was using 21% of its energy on renewables including hydro for electrical generation. China is expected to increase its renewable energy output from 7% to 16% by 2020. At the Queen Victoria Market and shopping complex in Melbourne, 1,300 solar panels were installed as the largest solar unit in Australia. One of NASAs major space project is to launch solar panels into space and then beam the trapped energy down as microwaves to generate electricity. The Japanese Space Agency announced a similar plan to launch a satellite that would unfurl a large solar array and beam 100 kilowatts of microwave or laser power to a receiving station as an experiment.

The Pan-Canadian Framework on Clean Growth and Climate Change document cites a number of wind and solar projects across Canada. In Prince Edward Island, for example, 4 wind farms generate 25% of the province’s electricity. Turbine blades spin a shaft that is surrounded by coils and magnets that generate electricity and transmitted into an electrical grid system. Wind capacity turbines in Canada grew 20 times from 2005 to 2015. British Columbia (BC) needs to be more aggressive and to implement regulations for installing solar panels for new buildings. One project in BC is a “Kimberley solar farm” that powers over 200 homes. Small and innovative projects such as the one at Princess Margaret Secondary School in Surrey, BC, where students and instructors installed solar panels to generate a small amount of electricity for the school are encouraging news. Northern British Columbia, southern Alberta and all coastal regions in Canada are good sites for wind farms. In BC, four wind projects in the Peace Region (Tumbler Ridge and Chetwynd) developed by Finavera Renewables are expected to supply up to 75,000 homes and infuse millions of dollars into the local economy. The Bear Mountain Wind Park near Dawson Creek in BC developed by AltaGas Income Trust generates over 100 megawatts (MW) of power annually. The Dokie Wind Project in Chetwynd, BC, with 48 Vestas towers generating 144 megawatts of electricity annually, enough to supply 32,000 homes. The Meikle
Wind energy project north of Tumbler Ridge is expected to cost $400 million and meet the needs of 54,000 homes. Small but significant solar and wind projects are showing up in all provinces across Canada. By 2014 BC generated about 675 MW of power from almost 220 wind turbines. An off-shore project is being planned in Hecate Strait off Haida Gwaii. Renewables create jobs, contribute to taxes and the well-being of rural communities. For more information on wind power in Canada you may Google Wikipedia.

In Ontario, extensive wind turbines have been installed in Huron and Pickering that now service 4,000 homes; Ontario has the highest output potential of electricity from wind power in Canada generating over 4,300 MW from about 2,200 turbines. Ontario gets more of its electricity from wind than from coal; coal will be phased out in that province. Quebec has been advancing wind turbines in the Gaspe region off the St. Lawrence River and plans to harness hundreds of megawatts more of electricity. Quebec has the second largest wind source of energy in Canada with about 3,300 MW and from about 1,600 turbines. Southern Alberta has one of the best wind and solar sites in Canada and that province expects to abandon its dependency on dirty coal for generating electricity and embark on an aggressive wind power dependency. In Pincher Creek, Alberta, wind farms generate more than a quarter of the municipal district’s annual revenue and it is a big employer in the region. Only 2% of Alberta’s electricity comes from wind power while 40% comes from coal combustion. Alberta’s wind potential could generate more than 64,000 MW of electricity; today Alberta is generating over 1,450 MW from over 1,000 turbines. The government of Alberta is committed to removing coal by 2030 in generating electricity and increase solar and wind power. Acciona Wind Power Turbines builds wind turbines for Canadian and US projects. The Chin Chute Wind Power project in Taber, Alberta, supplies 11,000 homes through the grid system. In south of Lethbridge, Alberta, the Magrath Wind Power project also supplies about 11,000 homes with electricity. At a Council of Federation meeting with Canadian Premiers they were committed to producing 25,000 megawatts of renewable energy by 2020 from hydro, wind, solar and oceanic tides.

One success story comes from the city of Malmo in Sweden that generates 100 percent of its energy from local renewable sources of wind and methane recapture.
from garbage and sewage. Wind turbine supplemented by a photovoltaic system provides the western harbour in Malmo with all of its electricity. The worldwide generating capacity of wind turbines has increased by more than 28% in one year. European nations increased their wind power by almost 60,000 megawatts in the past 10 years. Germany, Denmark, Netherlands, Sweden, Norway, Italy, Portugal, Spain, the UK, the US, China and India are some of the countries in the forefront in installing wind turbines. Germany has generated 22,250 megawatts of electricity from wind power since it started in 2007. Wind turbines are commonly seen along the North Sea off the coasts of Germany and Denmark (Figure 4.5).

A two-megawatt wind tower is about the biggest wind tower you will have bumped into in your daily life. If you’re cycling through Holland or in Denmark, you will typically see two-megawatt wind towers like the ones in Figure 4.5. That’s the size of the Statue of Liberty. The real monster turbine is coming and General Electric (GE) actually offered for delivery in 2022 as a 12-megawatt wind tower. On its upswing, the blade would be nearly as high as the Eiffel Tower. You can access the GE and Renewable Energy site (www.ge.com) on wind turbines and video clips on how turbines work. The GE “Heliade – X” offshore wind turbine platform generates 12 MW capacity from its 220-metre rotor and 107-metre blade. The Eiffel Tower is 324 metres high and the Heliade -X turbine is 260 metres high as a comparison. A single 124-metre high wind turbine can supply up to 1,200 homes with electricity. General Electric turbine business has doubled since 2005 and is gearing up its solar energy business. GE Renewable Energy is one of the world's leading wind turbine suppliers, with over 40,000 across the globe and a multi-billion-dollar business. GM promotion: “Our portfolio includes a suite of onshore and offshore turbines, flexible support services ranging from development assistance to operations and maintenance, and cutting-edge technology to upgrade your fleet.”

In Denmark, wind energy accounts for 18.5% of the electricity generated since 2004; it was reported that in 2014, Denmark was generating around 40% of its electricity from wind. The northern state of Schleswig-Holstein in Germany uses 25% of its annual electricity from more than 2,400 wind turbines. Near Hamburg in Germany, giant wind turbines were installed to generate hundreds of megawatts
of electricity. The world’s largest offshore wind farm comprising 87 turbines, each around twice the height of Big Ben (London’s clock), the Walney Extension in the UK covers an area of 145 square kilometers and has a total capacity of 659 megawatts -- the most produced by any single wind farm on the planet (Figure 4.5) that started operations in 2018. “One 1.8 MW wind turbine at a reasonable site would produce over 4,700,000 kWh of electricity each year, enough to meet the annual needs of over 1,000 households” as calculated by wind turbine company Enercon. Keep in mind that other factors such as the efficiency of the turbine and blade size and hours of operation need to be considered in calculating energy. “The average household in the UK, with 2 parents and 2 children used approximately 5,500 kWh of energy per year” according to a Strathclyde University statistic.

Figure 4.5. Off shore wind turbines on the coast of Denmark (left). Photo by author from a cruise ship. Right photo - Largest offshore wind farm in the Irish Sea to power 600,000 homes in the UK. Credit Walney Extension Offshore Wind Farm.

The United States has led the world in the installation of wind turbines and added 8,500 megawatts of wind power. The Tehachapi-Mojave Wind Reserve in the US holds over 3,000 wind turbines to serve over 250,000 homes with electricity. One wind farm in Texas holds 421 turbines and produces 735 megawatts of electricity to service over 150,000 homes. Lester Brown, the president of Earth Policy Institute in Washington, DC, says that a farmer in Iowa who gives up a tenth of a hectare of land to a turbine might earn $10,000 a year from it; planting corn in the same area would yield $300 worth of bioethanol. Vestas Wind Systems in Denmark is one of the biggest suppliers of wind turbines in the world and has
supplied turbines to 63 countries; at the time of writing, there is a waiting list for turbines worldwide. One downside to wind turbines or wind farms concerns migratory birds that fall prey by colliding with rotating blades weighing some 1,200 kilograms; a new radar technology system is being developed to shut down the turbines automatically in any peak migratory pattern. The latter technology is being pioneered in southern Texas and in Spain.

The story of a young boy named **William Kamkwamba**, then 14 years of age, in Malawi dreamed of powering his village with wind. People thought that he was crazy; he could not attend school because his family could not afford to pay his tuition fees. He started to read up on windmills and by collecting various parts from junkyards he built his first windmill. William always dreamt of magic but also of the magic that made radios play music. When famine hit his village, William was forced to drop out of school and only eat one meal a day. Undeterred, he studied science books from the library and learned how to unlock the magic of a windmill, a magic so strong that it will help him feed his people. His technology was a big success in 2002; he built five windmills, the tallest was 10 metres that generates electricity and pumps water in his village of Lilogwe in Malawi. His blog is [williamkamkwamba.typepad.com](http://williamkamkwamba.typepad.com); he has returned to school and plans to build windmills in Africa. In 2014, Kamkwamba received his bachelor’s degree from Dartmouth College in Hanover, New Hampshire. You can Google his full name and learn more about this innovative young engineer, now in his thirties.

In Canada, **hydro power** generates more than 60% of its electricity needs because of the vast water reservoirs, dams and rivers; BC is the second highest consumer of hydro power in Canada, uses no coal and its carbon footprint is one of the lowest in Canada. The building of more dams for hydroelectricity requires careful environmental planning. The **Site C Dam** is an early-stage project of BC Hydro for a large-scale earth fill hydroelectric dam on the Peace River near Fort St. John in northeastern British Columbia, Canada. The site is downstream from the existing W.A.C. Bennett and Peace Canyon dams. The Site C Clean Energy Project will be a third dam and hydroelectric generating station on the Peace River in northeast B.C. Site C will provide 1,100 megawatts (MW) of capacity, and produce about 5,100 gigawatt hours (GWh) of electricity each year – enough energy to power the
equivalent of about 450,000 homes per year in B.C and surplus energy for electric vehicles. The Site C project received environmental approvals from the federal and provincial governments in October 2014, then got the green light from the previous Liberal government of B.C. in December, 2014. After much debate by the elected NDP government in 2017, the projects at the Site C Dam was again given the go-

Figure 4.5 A. Cite C Dam Project hydroelectric generating station on the Peace River in northeast B.C. Artist Conception by BC Hydro.

Figure 4.5 B. Three Gorges Dam on the Yangtze River in Hubei, China. File photo
ahead approval in 2018 by government. Other major hydro dams and projects in Canada are located in James Bay in Quebec, Churchill Falls in New Foundland and Labrador, WAC Bennett Dam in BC, Ontario Power at Niagara Falls and Manitoba Hydro.

![Figure 4.6 A. Hoover Dam with Lake Mead showing a severe drop in water level. Photo by author in 2017.](image)

The Three Gorges Dam (Figure 4.5 B) along China’s Yangtze River is the world’s largest hydroelectric power generator with 26 turbines generating 22,000 megawatts of electricity supplying tens of millions of homes and industries and costing $32 billion US. This dam is so large that it is visible to the naked eye from space. The Hoover Dam (Figures 4.6 A) completed in 1935 is a unique engineering feat that was designed to divert and supply water from the Colorado River to California, Arizona and Nevada. The second objective of the Hoover Dam was to construct 17 turbines to supply over 2,080 megawatts of power to 1.3 million

418
people, most of it to southern California (Figure 4.6 B). Lake Mead (Figure 4.6 A) behind the dam is the largest man-made reservoir in the US but its water level has been dropping in the past decade; its source of water is from the Colorado river (Figure 4.6 C).

Figure 4.6 B. Hoover Dam in Nevada. Hydroelectric turbines (left) and housing system (right) located beyond the dam wall. Photos by the author.

Figure 4.6 C. The Colorado River on the West Rim of the Grand Canyon replenished from Rocky Mountain snowpack which has been declining. Photo by author in 2017.
The use of sea power is also another water source of electricity, by harnessing the tides in regions like the Bay of Fundy in Nova Scotia and New Brunswick. The 1,000-tonne large turbine was lowered onto the floor of the Minas Passage in Fundy. It was quickly connected to land via a subsea cable and started producing electricity almost right away. The turbine generates two megawatts of electricity — enough to power 500 homes. The Bay of Fundy has the highest tides in the world and efforts to harness energy from the tides dates back 100 years. “It is estimated that more than 2,500MW may be extracted from the 8,000MW of kinetic resource of the Bay of Fundy. Fundy Ocean Research Centre for Energy (FORCE) is a not for profit corporation whose members include the Province of Nova Scotia and five tidal energy developers selected by the Province” according to Natural Resources Canada. The deployment is part of a large-scale demonstration project to test the technology in the powerful tides of the Bay of Fundy over the next several years.

Major sources of energy from biomass include forestry, agriculture, food-processing residues, industrial wastes, municipal sewage and household garbage.
Harvesting energy from forest biomass is an economic benefit for industry. Cellulosic materials should not be discarded (i.e., branches, bark, trunks and stumps, insect-infested, fire-damaged, dying and dead trees) that could become valuable energy products. Biofuels produced from grain should be a non-starter with the decline of grain crops and shortage of food in poorer countries. Cellulosic ethanol is still being processed from corn and sugarcane as biofuels. Biofuels such as methanol and ethanol are liquid fuels produced from biomass. Converting one tonne of landfill gas or biogas is the same as preventing some 20 tonnes of CO$_2$ emissions. The Wastech Company has officially commenced operations of a landfill gas-to-energy plant at the Cache Creek Landfill in British Columbia, a disposal site that serves the Metro Vancouver area. Metro Vancouver sends over 400,000 tonnes annually to the landfill, or about 30 percent of the total amount of municipal solid waste in the region. Wastech Landfill Gas Utilization Plant at the Cache Creek Landfill provides enough to power more than 2500 typical households.

Municipalities and cities are tapping their old landfills to generate natural gas for home heating. Another operation in Salmon Arm, BC, hooks up its landfill natural gas with Fortis Gas Company. The city of Ottawa has a facility to supply enough power for 5,000 homes from methane generation from landfill. Plasco Energy is building a 400 tonne-per-day waste conversion facility in Ottawa that would process all residual household waste instead of taking it to a landfill. The facility will recycle all household waste into valuable products including synthetic fuel gas. The Government of British Columbia has arranged to purchase electricity generated from methane at a landfill near Victoria. In Nanaimo, BC, a landfill converts methane gas to provide electricity for about 1,200 homes. In Monterrey, Mexico, the city’s landfill is extensive and it plans to extend its methane production to meet the needs of 80% of the 4 million residents with electricity.

Wood residues from sawmills like one in Williams Lake, BC, converts biomass energy into electricity. Kruger Products in New Westminster, BC located next to the Fraser River and close to sawmills as an access for wood products, uses wood wastes to produce fuel that is converted into steam to dry its paper products while reducing GGE by 50 percent. Wood pellets made from sawmill waste and from
useless pine beetle wood are being produced by several pellet plants in BC generating over $180 million income as biofuel; pellets are now being shipped to Europe. Nexterra Systems in Vancouver has supplied its technology to Kruger paper products in New Westminster, the University of BC and the University of Northern BC (UNBC) aimed at reducing GGE while producing ‘clean’ heat and electricity. At UNBC, the biomass gasification plant would replace 85% of the natural gas burned on the campus. In Abbotsford, BC, Catalyst Power takes animal wastes to produce biomethane and puts it into the natural gas system. “Abbotsford Bakerview EcoDairy consumes 1.6 million litres of manure to produce 170,000 kilowatts of electricity in its biogas generator and supplies surplus electricity to the BC power grid” as reported in the Vancouver Sun. The Cowpower generator is the first in Canada and supported by industry according to dairy farmer Bill Vanderkooi in Abbotsford, BC. ECODAIRY (www.ecodairy.ca) works in partnership with Science World in Vancouver and arranges field trips for students to learn about agriculture, daily operations on a farm and the dairy industry.

Brazil has been producing ethanol from fermented sugarcane and yields of 1,000 to 1,500 litres of ethanol per hectare of sugarcane, more than twice as much as by using corn as a potential source. Sugarcane ethanol produces 56% less GGE than gasoline and is a cheaper fuel but cannot be used exclusively. Refineries now add 10% ethanol mixed with gasoline. The European Union has decided to phase out the use of corn to produce biofuel since grain crops are on the decline worldwide. Experiments with prairie grass like switchgrass and sawgrass grown on land unfit for crops and other agricultural residues as well as algae are good sources of cellulosic ethanol; elephant grass yields over 5,000 litres of biofuels per hectare. Craig Venter who is best known as the founder of Synthetic Genomics is one of the entrepreneurs looking at producing biofuels from algae and bacteria; he says that his microbes can be reused several times as he has engineered them to release fat which is then refined into biodiesel fuel.

About 16% of the world’s total electricity is generated by nuclear power while 40% is still being powered by burning coal; coal as we know is the major culprit in increasing GGE and air pollution. As of 2015, 438 nuclear power plants were in operation in 30 countries and 15 new plants are under construction. Many more
reactors are being planned in China, India, Japan, Russia, South Africa and the USA. In Japan, 55 nuclear reactors provide much of its electricity needs and it plans to add 13 more reactors with 9 of them in operation in 2015. In 2011, the Japanese Fukushima Daiichi in reactor was disabled by the high intensity earthquake and further damaged by the tsunami; fuel rods were partly melted and workers frantically attempted to cool them with water. At the time of writing, that reactor still poses a health hazard. In France, 80% of its electrical energy comes from 59 nuclear power plants. China is currently operating 23 nuclear plants and will be adding several new ones; most of China’s electrical output today comes from coal-fired plants and is working toward replacing coal plants with nuclear and other renewables. India has 7 nuclear plants with 21 reactors. In the USA 99 commercial reactors in 61 plants provide 20% of the nation’s electrical needs and accounts for 70% of the of the country’s emission-free energy.

In Canada, there are 19 commercial reactors in 5 plants in Ontario, Quebec and New Brunswick supplying power to generate 15% of Canada’s electricity. These are the CANDU (Canadian Deuterium-Uranium) type using uranium and heavy water. You can Google to learn about the number of countries that operate nuclear power plants around the world and how the new generation reactors operate for safety. Small modular reactors (SMR) represent the next wave of innovation in nuclear energy technology in Canada and elsewhere. SMRs are designed to be built at a smaller scale than traditional nuclear reactors, with lower up-front capital costs and enhanced safety features. Canada’s Minister of Natural Resources said that “small modular reactors represent a promising area of energy innovation in Canada. The Roadmap includes recommendations that will help inform ongoing collaboration among federal, provincial and territorial governments — as well as other stakeholders and Indigenous communities — to ensure Canada becomes a global leader in the development of this new technology.”

Older nuclear power plants have a lifetime of 40 to 60 years and dismantling some of those units is costly and poses serious environmental and safety concerns. The Three-Mile Island meltdown in 1979 caused no ill-health consequences. The Chernobyl accident in Ukraine in 1986 was cause for concern – many Ukrainian children were born with birth defects following the Chernobyl accident; cows in Europe were reported to have high radiation levels in milk following the disaster.
The destruction of the reactor by steam explosion and fire killed 31 people and had significant health and environmental consequences. The death toll had since increased to about 56 people. The Fukushima in Japan in 2011 where three old reactors were written off after the effects of loss of cooling due to a huge tsunami were inadequately contained. There were no deaths or serious injuries due to radioactivity, though about 19,000 people were killed by that tsunami. Nuclear power reactors remain safe and many more should be built to curb GGE and air pollution reducing global temperature to less than 2°C by 2100 to abandon the deadly coal combustion.

Scientists are developing advance nuclear technologies with added safety features for modern nuclear power plants. Instead of using fuel rods in the next generation of reactors, thousands of fuel pebbles of uranium oxide are used to withstand temperatures over 2,800°C for collecting the heat with helium that turns the generating turbines. Accidents at nuclear power plants have killed only a few people compared to millions from air pollution with fossil fuel like coal worldwide, a rationale to support more nuclear power plants. Under the International Atomic Energy Agency (IAEA) countries have agreed to maintain high safety standards and to make improvements to their nuclear facilities. IAEA is also investigating whether any country may be advancing weapons technology by using nuclear technology that is meant for generating domestic electrical needs.

One of the major concerns with nuclear plants comes from the disposal of spent uranium or plutonium. Sweden is working on ways to store its nuclear wastes in copper canisters that can be entombed for perpetuity. Deep geological repository is one of the most extensively studied options for storage of spent fuel. The Finnish Parliament has agreed to store its spent fuel near the Olkiluoto nuclear power plant. France is planning to construct deep geological storage facilities; the USA plans to use the Nevada Yucca Mountain area as the burial site for its nuclear wastes amidst much controversy. The spent fuel in the US is stored in dry casks above ground near some of its reactors. In the United Kingdom “hardly a year goes by without some new and terrible revelation about the nuclear complex at Sellafield in Cumbria”, writes George Monbiot. In 2003, inspectors discovered a pond at Sellafield containing 1.3 tonnes of plutonium which have been sitting there for 30
years. The decommissioning and clean up of the Sellafield site estimated to be about $60 billion. By using nuclear power it avoids approximately three billion tonnes of CO$_2$ per year if that energy source was used instead of coal. The IPCC stated that “experience of the past three decades has shown that nuclear power can be beneficial if employed carefully but the problems of potential reactor accidents, nuclear waste management and disposal, and nuclear weapon proliferation will still be constraining factors.” **Wind and solar alone cannot meet the energy needs of the future and advanced nuclear power generation is the safest and a better way to reduce dependency on coal and oil.**

**Geothermal energy** provides another lesser utilized source from reservoirs of underground heat. Iceland has been tapping this form of energy for years since the mid-Atlantic Ridge passes through that country generating underground heat. The mid-Atlantic Ridge is also the site of many submarine volcanoes. A major electrical geothermal plant is located near Reykjavik in Iceland. In New Zealand, the main geothermal plant is located in Wairakei that has been generating electricity for many years and producing hundreds of megawatts. Several countries including Japan, Indonesia, the Philippines and the United States are working on expanding geothermal sources of energy for electricity. Geothermal projects are ongoing near Santa Rosa, California, and at the Nevada Geothermal Power in the state of Nevada. Indonesia sits on the ‘Pacific Ring of Fire’ and taps a lot of geothermal energy that supplies 3.9 million homes with the largest reserves in the world.

The City of Richmond in BC retained Kerr Wood Leidal Associates to design the expansion of the **Alexandra District Energy Utility** “which is the largest ambient heating and cooling district energy system in North America. It uses ground heat as an energy source and has an ultimate capacity of 13.4 megawatts of heating and 5.8 megawatts of cooling for 3.1 million square feet of space for residential and commercial buildings…Running at full capacity, it is estimated to offset 1,300 tonnes of carbon equivalents annually. The district energy system derives its heating and cooling energy from three sources: geoxchange fields, natural gas boilers, and cooling towers. Two geoxchange fields exchange heating and cooling with the earth by gathering renewable heat from 25 kilometres of
buried pipe.” The Richmond project was awarded the ‘IDEA System of the Year Award’ is the highest honour that International District Energy Association (IDEA) can confer on a district energy system. It recognizes an exemplary district energy system providing high-level performance and service that further the goals of the district energy industry. IDEA at https://www.districtenergy.org supports projects in Canada and in the US and for more information you could access this website.

![Image of district energy plant](image)

Figure 4.6 E. Richmond, BC, Alexandra District Energy Utility Plant. Credit Kerr, Wood, Leidal Associates, Burnaby, BC.

With the abundance of natural renewable energy resources, some of the world's energy demands would gradually switch from fossil-based fuels to renewable energy sources. Scientists say that unless expansion of renewable energy sources are advanced more rapidly to solve the growing energy conundrum, there will be greater and longer dependency on fossil fuels, higher food prices, higher prices for gasoline at the pump and a planet that could be in peril with over 2°C increase in this century. Canada as a developed nation has the resources to advance renewable energy generated from wind, solar, biomass, tidal and geothermal for domestic use while at the same time improving the economy by creating green jobs and reducing greenhouse gas emissions; advancing nuclear power still remains a safe option for
Canada. Alberta also needs to vigorously pursue environmental sustainability to extract its bitumen in a more responsible way as outlined in the 2010 report of the Royal Society of Canada. New policies and initiatives were advanced with the implementation of the Pan-Canadian Framework on Clean Growth and Climate Change in 2016 and discussions with the Prime Minister of Canada and Provincial Premiers following the COP 21 Paris conference. Progress is being made to reduce GGE with small and large projects across Canada and worldwide.

Planetary Boundaries & Top 10 Emergencies

The planetary boundaries as outlined by climate scientists are identified from nine global priorities that relate to human-induced changes to the environment. Research shows that these nine processes or boundaries regulate the stability and resilience of the Earth System (ES), the interactions of land, ocean, atmosphere and biosphere that together provide conditions upon which human societies depend. There is increasing evidence that human activities have been affecting ES functioning to a degree that threatens the resilience of the ES. For example, this research published in the scientific journal Science (Vol. 347, Feb. 13, 2015) by Will Steffen, Johan Rockstrom and others identified four of the nine planetary boundaries that have now been crossed and threaten all life: climate change, loss of biosphere integrity, land-system change, and altered biogeochemical cycles. Looking at these four boundaries in brief, the evidence on climate change is clear from the evidence presented in preceding chapters; biodiversity (biosphere loss) in our forests, grasslands, wetlands, oceans and coral reefs have been lost; deforestation continues in land system change. Biogeochemical flows have been altered with fertilizers and pesticides runoffs into our lakes and rivers.

The nine planetary boundaries described by Steffen and Rockstrom are: (1). Climate change, (2). Change in biosphere integrity (biodiversity loss and species extinction), (3). Stratospheric ozone depletion, (4). Ocean acidification, (5). Biogeochemical flows (phosphorus and nitrogen cycles), (6). Land-system change (deforestation), (7). Freshwater use, (8). Atmospheric aerosol loading (microscopic particles in the atmosphere that affect climate and living organisms), and (9).
Introduction of novel entities (e.g. organic pollutants, radioactive materials, nanomaterials, and micro-plastics). How many more of these boundaries will be crossed and when, they could not predict. For more information and what each boundary entails access the Stockholm Resilience Centre at www.stockholmresilience.org. Planetary boundaries and the “top 10 emergencies” cited below carry a similar message.

During the Holocene epoch planet Earth has endured in a fairly stable interglacial climatic period which is the only state of the planet we have known for sure that supports the modern world as we know it, until the advent of this post-Industrial Revolution period. As the glaciers retreated after the last glacial maximum the planet warmed and humans ‘invented’ agriculture that began in the Nile Delta some 12,000 years ago that changed hunting habits in producing more food such as the grain crops. Fast advance in the Holocene to about 100 years ago saw our planet evolving into a new epoch – the Anthropocene – anthropo (man) and cene (new), with humans having changed the fairly stable Earth System in the Holocene into an industrial one, driven by human or anthropogenic activities. Coal was discovered as the start of our modernize world; without the discovery of coal as a source of energy we would have removed much of our forests as an energy source and for other uses. The Earth System then changed not from natural variability but by anthropogenic influences creating this modern world. In other words, as a result of human activities we have crossed from a fairly stable Holocene into the present Anthropocene epoch.

On a global scale, the world's top ten most urgent problems to consider for national or international consideration, and not listed in any priority below, need immediate and continuing attention by policy-makers, business leaders, in all communities. Climate scientists are unanimous in their agreement that our planet is getting warmer though human activities. We must attend to this planetary emergency with the evidence amassed from thousands of scientists worldwide, and from reputable organizations such as NASA, IPCC, NOAA, Environment Canada, to name a few. The impacts from both natural and anthropogenic influences on ecosystems from the Arctic to the Antarctic, in our oceans, rivers, forests and land are well
documented. Earth’s population reached 7.7 billion in 2019 and by 2050 it is projected to climb to 9.2 billion, give or take half a billion. Can Earth’s resources feed and house over 6 billion people in developing countries in the coming decades? Earth’s population is projected to reach 11 billion by 2100 and a projected global temperature of greater than 2.7°C if we cannot decarbonize radically before 2050. Poorer countries today cannot adequately provide food, shelter, electricity and water to hundreds of millions of their citizens. As Thomas Friedman wrote in *Hot, Flat and Crowded*: “This is not about whales anymore. It’s about us. We have exactly enough time, starting now, so it’s an emergency that our leaders cannot ignore.” Nature is the foundation of life on Earth and underlies most human economic activity and wealth creation. “It supports healthy individuals and communities…and we need to become wiser stewards of the natural wealth hidden in our forests, oceans, wetlands, lakes and cities, and build a greener, stronger economy,” as noted in a *Canadian Sustainable Prosperity* document and the *IPBES* 2019 report.

I highly recommend you accessing this essay (White Paper) written by Jeremy Grantham and supported by science in *“The Race of Our Lives Revisited”* at [www.gmo.com](http://www.gmo.com). The following are excerpts of Grantham’s 35-page illustrated and compelling essay: “It was always going to be difficult for us – *Homo sapiens* – to deal with the long-term, slow-burning problems that threaten us today: climate change, population growth, increasing environmental toxicity, and the impact of all these three on the future ability to feed the 11 billion people projected for 2100...

Our main disadvantage is that our species has developed over the last few hundred years not to address this kind of long-term, slow-burning issue, but to stay alive and well-fed today and perhaps tomorrow. Beyond that we have a history of responding well only to more immediate and tangible threats like war.”

An international team of scientists published a study in *Proceedings of the National Academy of Sciences* reported that “even if the carbon emission reductions called for in the Paris Agreement are met, there is a risk of Earth entering what scientists call ‘Hothouse Earth’ conditions.” The study suggests that human-induced global warming of 2°C may trigger other Earth system processes, often called ‘feedbacks’, that can drive further warming like a domino
effect that cascades even if we stop emitting greenhouse gases as illustrated in Figure 3.19 A. Recent research predicts that mean air temperature would be abnormally high from the years 2018 to 2022 - higher than figures inferred from anthropogenic global warming alone. In fact, the years 2015-2016 combined have been the warmest in centuries. “The year 2016 was the hottest year in 137 years of record keeping and the third year in a row to take the number one slot, a mark of how much the world has warmed over the last century because of human activities” according to NOAA. Another pronounced signal of anthropogenic global warming is the rapidly increasing near-surface temperatures in the Arctic at a pace two to four times faster than the rest of the globe, we now refer to as Arctic Amplification (AA). AA connects with positive feedbacks and the domino effect for hothouse earth as described in Chapters Two and Three.

Summary of the Top 10 Emergencies

1) **Human Population**

Jeremy Berg writing in *Science* journal (June 29, 2018) on ‘Tomorrow’s Earth’ stated: “Growing human populations are transforming our planet at an increasing rate, leading to climatic changes, diminished resources, and loss of biodiversity. Continuing on the current path is likely to endanger our own well-being and that of other species, but changing course involves tough choices.” Population in the world is currently growing at a rate of around 1.09% per year (down from 1.12% in 2017 and 1.14% in 2016). It is estimated to reach 1.00% by 2023, less than 0.50% by 2052, and 0.25% in 2076. The current average population growth is estimated at **83 million people per year**. By the year **2100, it may likely be 0.09% per year**, or an addition of 10 million people in that year for a total population of 11.2 billion in data from [www.worldometers.info/world-population](http://www.worldometers.info/world-population). The number of births in the world has been slowly declining. By the end of 2019, the world’s population reached 7.7 billion with greater than 80% living in developing and poorer countries, and with 2.76 billion or roughly one-
third of the world’s population living in China and India; over 5 billion people now live in urban centres worldwide. In the past 70 years or in a mere micro-second of Earth’s history, the world’s population jumped from 2 billion to 7.7 billion. Today, people living in developed countries and developing economies are living longer. Life expectancy in India and China rose in 1952 from 38 and 41 years and in 2010 from 64 and 73 years, respectively. Life expectancy in Canada is 81 years average and higher than in the USA or the UK. In industrialized countries the average life expectancy is about 77 years on average. Human population growth in the poorest countries is tied to health care, political instability, food shortage, lack of education, environmental and economic setbacks.

Forty-five percent of Chinese women say that they do not want to give up their careers to get married. The state of Kerala in India has the lowest birth rate in that country mainly from promoting education of girls, a better medical health care system than the rest of India and available contraceptives for women and men. Canada and the developed countries now have a higher population of senior citizens today than fifty years ago. The poverty gap has been steadily widening between the developed and developing countries. Can planet Earth continue to feed 7.7 billion adequately? The answer is unequivocally ‘NO’. Hundreds of millions of humans today are malnourished and with increasing population, declining carrying capacity, availability of clean water, climate change and extreme weather, billions of humans continue to experience adverse conditions especially in poorer tropical countries. The estimated global population by the year 2025 is expected to reach 8.5 billion and may stabilize at about 9.2 by the year 2050, give or take 0.5 billion, according to the World Bank. By the year 2025, 85% of the world’s population will live in poorer and developing countries. Obtaining the basic needs of adequate food, shelter, safe drinking water, and health services in sub-Saharan Africa and in crowded cities in Asia, Africa and South America are the greatest of challenges. The population in all of Africa is expected to double by 2050 from 1.03 billion to 2.08 billion, while a negative population growth expected
in all of Europe, declining from 739 million today to 720 million by 2050. In all of North America, the population would increase from 364 million today to 471 million by 2050, with most of this increase coming from immigration. You may Google “World Population” or “World Population Clock” for population updates.

![Projected World Population](image)

Figure 4.7 United Nations estimate of world population and three projection scenarios – the ‘middle projection’ is a most likely scenario. Credit the UN Data Center.

2) **Food Production**

The projection in food production is for an increase in developed countries in the temperate region such as Canada, USA and Europe but its production and security would decline in regions of Asia, central Africa and the Middle East. Food production has been declining in recent years due to human population pressures, extreme weather conditions such as droughts, desertification, loss of soil fertility, and lack of and overuse of water for irrigation. Serious food shortage is projected for the next 30 years; there is less arable land, less water available for agriculture, plus a higher cost of fuel and fertilizer that add to the crisis. The 2019 IPCC *Climate Change and Land* reported “an estimated 821 million people are currently undernourished, 151 million children under are stunted, 613 million women and girls aged 15 to 49 suffer from
iron deficiency, and 2 billion adults are overweight or obese.” The world today cannot feed the hungry and projections for the 21st century spell a global crisis. Water for agriculture is already in short supply in the southwest US and especially in California, northern China and throughout India, not to mention sub-Saharan Africa; crop yields and livestock are expected to decrease worldwide.

Precipitation rates have decreased from 10°S to 30°N latitude but increased in other regions since the 1970s while desertification impacts on food production. On the use of water for agriculture for example, a meat diet requires 60% more water consumption than a vegetarian diet; by raising a steer or beef cattle for three years it takes over 2.4 million litres of water to sustain that animal. Water consumption for that animal is generally used for pasture (irrigation), for grain and hay production, drinking, cleaning stables and farmyards. Refer to “The Alarm Has Sounded” in Chapter 3 for more information on food prospects. For “Food Security and Climate Change” or “World Food Programme” visit: www.wfp.org/climate-change. The United Nations Food and Agricultural Organization at www.fao.org is a useful website for accessing the work of the UN to curb world hunger and raise global awareness on the impact of extreme weather and climate change on agricultural resources. You may also access “Food Security” with the Wikipedia free encyclopedia for more information and updates.

3) **Soil Depletion and Desertification**

Soil nutrients are being regularly depleted by compaction, runoffs, water logging, salination and desertification; deforestation reduces tropical soils to barren regions that become less productive even for pastures in regions of Amazonia and throughout the tropics unless good soil management is practiced. Global warming and the El Nino events bring droughts to regions in the Sahel, Southeast Asia and Australia while other regions such as western regions of South and North America receive excessive rainfall that increase soil runoff. Agricultural productivity and fisheries are affected by both El Nino and La Nina in countries such as Peru and Chile in South America, and in the western Pacific from Indonesia to Australia. The Sahara Desert is progressively shifting to the north and south bringing more
droughts to equatorial regions in central Africa. Desertification in western China and India is also a growing concern. As cited in previous Chapters the following are some of the references that are worth accessing: Living Planet report 2018; Aiming Higher, IPBES Report that is extensive for Earth’s regions such as the Americas at www.ipbes.net, and a Global Deal for Nature.

4) **Resource Depletion**

The depletion of fossil fuels is inevitable as energy needs keep increasing to supply all growing economies; fossils fuels at the oil sands operation in Alberta may peak by the year 2050. Natural gas reserves are now being extracted by fracturing in the US and Canada. The US, Canada, Venezuela, Nigeria, Russia and the Middle East are still the major producers of oil and gas but with continued production declining reserves are inevitable. Energy sources from solar, wind turbines, safer nuclear power, landfill reuse for methane production and geothermal power would continue to increase for domestic and commercial use. Regulations on hydraulic fracturing should be in place to safeguard groundwater and pollution from the use of chemicals like hydrochloric acid. Mineral depletion such as iron ore, bauxite and copper will impact on industries worldwide. Water is one of the most valuable resources and Canada may likely expect the US to tap on that resource in future. An increasing shortage of water (a very important resource) for agriculture is evident especially in the south-western USA, Central America, most of Sub-Saharan Africa, the Murray-Darling region in Australia, western India and northern China.

Exploration for fossil fuels will continue to impact on sensitive ecosystems such as Amazonia, in the Gulf of Mexico, the Arctic region (Beaufort Sea) including the Mackenzie River Delta that holds vast reserves of natural gas in northwestern Canada. Natural gas accounts for over a quarter of the primary energy consumed in North America. Hydraulic fracturing is being done to release natural gas by injecting water under pressure that breaks apart rocks to release the gas. Such operations are being carried out in Dawson Creek and Fort Nelson in BC. The October 2010 publication of National Geographic carries a special report on the
“Oil Spill” from the Deepwater Horizon well in the Gulf of Mexico; oil companies now engage in deeper sea floor explorations. Pipelines to deliver oil and gas remain the safest option but opposition to build new pipelines appear to originate in some jurisdictions, by concerned environmentalists and with some First Nations. Nuclear and hydro power would continue to expand in developed countries and developing economies. Coal still remains the most economical option for developed and developing economies and is the biggest emitter of greenhouse gases; renewable energy sources create more jobs than the coal industry and remains in the forefront for reducing greenhouse gas emissions.

5) **Deforestation**

The decline of tropical rainforests in the Amazon, Africa and Asia results in increasing loss of biodiversity and impacts on climate change with increased droughts and loss of fluorescence (photosynthesis) in NE Brazil as documented by data from the OCO-2 satellite. The forests absorb a great deal of CO₂ from the atmosphere and acts as a huge carbon sink. About 20% of Amazonia is already deforested, albeit on a slower decline but from 2019 with Brazil’s new President, the Amazon is open for business and deforestation is increasing. The rate of deforestation worldwide is the highest in Southeast Asia. Boreal and temperate old growth forests are also on a rapid decline in the US and Canada and while the rate of reforestation declined there is a greater need to expand on reforestation and afforestation (new planting) worldwide. With global warming and warmer winters, the infestation of the mountain pine beetle has become widespread in the forests of British Columbia, Alberta and in the US. The removal of old growth forests is akin to mining and continues in the Pacific Northwest; old growth should never be removed. Global deforestation contributes to a 25% rise in greenhouse gases, more than in all of transportation. The green climate fund from the UNFCCC would help developing countries preserve forestry and other land use. China has been in the forefront in reforestation and afforestation efforts to reduce desertification and add to the carbon sink. For more information on deforestation and preserving and advancing nature access the IPBES 2018 Report (Chapter One), and Google deforestation in Canada, the Amazonia, Africa and Southeast Asia.
6) **Water Crisis**

Water for human consumption and agriculture will greatly diminish in all continents. Canadians use more water per household than Europeans. For ways to conserve water use, visit [www.bcwwa.org](http://www.bcwwa.org). Precipitation has been increasing in higher northern latitudes while decreases dominated from 10°S to 30°N latitude since the 1970s. Clean water from wastewater treatment plants and from desalination systems is a costly endeavour using much energy. The quality of water in rivers and groundwater has declined in recent decades principally from industrial and agricultural wastes. More than one billion people today do not have access to safe and clean drinking water; millions still live in slums without adequate sanitation, lack of education or access to electricity. The oceans have become the biggest dumping site and final repository for sewage, industrial wastes and garbage that is not biodegradable. With more than 8 million tons of plastic enter the ocean each year, humanity must urgently rethink the way we make and use plastics, so that they do not become waste in the first place. Yet, only 14% of all plastic packaging is collected for recycling after use, and vast quantities escape into the environment. The vast region between California and Hawaii (North Pacific Gyre) is loaded with plastics and other floating debris as discussed in Chapter One. Zooplankton are confused by eating the tiny pieces of plastic or microplastic that resemble plant plankton and pass toxins like bisphenols onto the next line in the food chain. Birds and mammals consume plastic while many get entangled in fishing gear and plastics left in the ocean. The NOAA claims “that more than 100,000 marine mammals could die from trash-related deaths each year… “An estimated 11 million tons (and growing) of floating plastic cover an area of nearly 5 million square miles in the Pacific Ocean, 700 miles northeast of the Hawaiian Island chain and 1000 miles off the coast of California. Humans are responsible for 100% of the plastic pollution in the ocean — and it is entirely preventable. Approximately 80% of this plastic pollution originates on land, and 20% comes from recreational boaters, commercial operations, maritime industries, and the military” according to NOAA. Plastic pollution, overfishing, global warming and increased acidification from burning fossil fuels cause our oceans to be increasingly hostile to all marine life with depleting resources for human consumption. **The June 2018 issue of National Geographic carries three major**
articles on *The Plastic Apocalypse* and is highly recommended reading in over 50 pages!

*The Global Footprint Network* calculates the date each year when humans demand on nature for food, wood, fibre and carbon dioxide absorption exceeds what planet Earth could regenerate in a year. **On the date August 2, 2017 it happened to be ‘Earth Overshoot Day’ when humans use 1.71 of Earth’s worth of resources; back in 1971 Earth’s Overshoot Day was down to 1.03 Earths.** You can learn more by about ‘overshoot day’ by accessing [www.footprintcalculator.org](http://www.footprintcalculator.org). As human activity pushes the earth system beyond planetary boundaries and into zones of increasing risk, marine ecosystems may change dramatically as a result of ocean acidification and eutrophication including toxic algae. Tens of thousands of premature deaths are caused by drinking polluted water in China, India, other regions of Asia, in Africa and Latin America. More than a billion people rely on glacier-fed rivers for their survival. Climate change is rapidly warming lakes around the world and faster than in the ocean, threatening freshwater supplies and ecosystems, according to studies by NASA and *National Science Foundation*. Using more than 25 years of satellite temperature data and ground measurements of 235 lakes on six continents, the latter study found an increase of 0.72°C in lake water per decade at high latitudes. A special issue on *National Geographic* (April 2010) explores the world of water. Maude Barlow’s book, *Blue Covenant – The Global Water Crisis and Coming Battle for the Right of Water* is recommended reading for Canadians. The **World Resources Institute** is an excellent source for global water and availability. You may review the two sections in Chapter One: “Impacts & Awareness: Regional Ecosystems & Ocean Plastic” and “Water: Global Resource, Storage and Hydrologic Cycle” for this precious commodity and its present state.

**7) Loss of Nature & Biodiversity**

Species are becoming extinct every day with the disappearance of rainforests and threats to aquatic and marine ecosystems. Sources say that we are in the sixth global extinction. A wealth of medicinal plants and knowledge thereof are also being lost as extinction continues and more indigenous people become displaced.
Corals continue to bleach from natural climate variability such as El Nino, and from excessive carbon dioxide mixed with sea water increasing the pH concentration of sea water and from a warming ocean. The Great Barrier Reef and many small island reefs and states have experienced significant coral bleaching with algae loss especially after the severe 1998 and during the 2015-2016 El Nino events and from ocean acidification. Rivers in China, India and in the industrialized countries carry chemicals and sewage that pollute over 50% of its fresh water that kill off fish stocks; groundwater in India and China is loaded with toxic chemicals. The Yangtze and Yellow Rivers in China are two of the biggest polluting sources to reach the ocean – for more details refer to the section on ‘China and India’ in Chapter Three. Most major rivers in the world including the Amazon and its tributaries carry heavy metals (from gold mining) that are harmful to humans and animals. Climate change and Arctic regional warming with rapidly and extensive melting of Arctic sea ice jeopardize the future of polar bears and other mammals; penguin population is on a decline in Western Antarctica. The Beaufort polar bear population dropped from 1,500 to 900 in over 10 years. A 2012 publication by the Royal Society of Canada Expert Panel “Sustaining Canada’s Marine Biodiversity: Responding to the Challenges Posed by Climate Change, Fisheries, and Aquaculture” raises many concerns in Canada’s oceans and food production – the RSC website is: www.rsc-src.ca. The latter report is critical of Oceans and Fisheries Canada, and a warning to politicians when it bluntly stated: “we are failing our oceans.”

The US National Research Council in its publication “Sea Change 2015-2025 – Decadal Survey of Ocean Sciences” asks a number of questions about the ocean; here is one question of the many in that publication: “How different will marine food webs be at mid-century? In the next century?” We may not have the answers to the many questions about the future state of our oceans, rivers and lakes but analyses of water quality and quantity and declining biodiversity are assessments that are very likely projections based on present conditions of species population in our oceans. As mentioned, in Chapter One an entire section is devoted to the need to conserve and expand on nature and biodiversity necessary to reduce global warming by increasing the carbon sink. The following reports on conserving nature, preserving biodiversity and enhancing carbon sinks to be found in Living
Planet report 2018 - Aiming Higher, IPBES Report and extensive for Earth’s regions such as the Americas at www.ipbes.net, and a Global Deal for Nature. Chapter One highlights those reports.

8) Depleting Ice and Snow

Increasing global warming from rising greenhouse gas emissions and positive feedback impacts in the Arctic exacerbate the breakup of the ice shelves and loss of billions of tonnes of ice from Greenland and the Canadian islands such as Ellesmere. With warmer winters in Canada’s north with an average 2.3°C increase since 1948 compared to the global average of 1.1°C since pre-industrial time, the Arctic sea ice has been fast disappearing with the Northwest Passage becoming a potential freighter route from Europe to Asia. In 2016, a cruise ship left Alaska with stops in the Canadian Arctic on its way to New York as a tourist sightseeing-adventure. A National Geographic article in January 2016 noted that “the Arctic Ocean will continue to freeze in winter but it could be ice free in the summer by 2040” and it clearly showed the Northwest Passage free of ice in September 2015 from Baffin Bay to the Beaufort Sea. The Antarctic Peninsula has been shedding billions of tonnes of ice from glaciers and ice shelves and will continue to increase. Retreating glaciers in the Himalaya, Patagonia, the Andes, the Alps, the Rockies, the Cascades in western US and mountains in British Columbia and Alberta are evident and will continue to shed more ice in the coming years.

Glaciologist Lonnie Thompson and Chinese scientists say that 95% of Tibetan Plateau glaciers are shedding more ice than adding. Linear trends in Arctic sea ice extent from 1979 to 2019 are negative in every month. Most of the eastern Antarctic ice remains stable and too cold to lose mass and so too is the interior of Greenland. Polar bear population in the Arctic and from Hudson Bay is declining; penguin population in Antarctic is also on the decline. Sea level is rising by centimeters per decade with a projected increase of about one metre by the year 2100 from thermal expansion and melting of ice sheets and glaciers. Over one billion people live in coastal regions and small island states that are already being threatened by a rising sea. “It is a matter of life and death” was heard from leaders
from small island states at the 2015 COP21 in Paris on the continuing threats of sea level rise on their homeland.

9) **Greenhouse Gases**

We need CO$_2$ as a greenhouse gas to stabilize Earth’s temperature but increasing concentrations of carbon dioxide, methane, nitrous oxide and the halocarbons in the atmosphere have altered the chemistry of the atmosphere and brought greenhouse gas concentrations of CO$_2$ to 415 ppm today from 280 ppm in 1850. Water vapour also happens to be the most abundant greenhouse gas and is increasing in the atmosphere from a warming planet. Increasing levels of anthropogenic greenhouse gases trap the heat as long waves and re-radiate it back onto Earth’s surface causing the greenhouse effect. The Keeling curve of CO$_2$ rise (Figure 1.2) correlates with temperature rise (Figures 1.3 A & B) - increase of CO$_2$ concentrations leads to rising surface temperature. From 1970 - 2000 GGE globally averaged 1.3% per year growth and from 2000 – 2014 it increased to 2.2% per year. **Extreme weather is often linked to global warming** occurring more frequently with loss of biodiversity, changes in precipitation, extensive droughts, crop losses, malnutrition, increase poverty, increase respiratory diseases and mortality, deadly heat waves, forest fires, spread of insect-borne diseases, sea level rise, coral bleaching, melting of polar sea-ice and ice sheets, retreating glaciers worldwide and the thawing of the permafrost; the latter process is known to release vast reserves of stored methane and carbon dioxide as positive feedback impacts. The list of climate impacts is not an exaggeration of doom and gloom but a fact based on scientific evidence.

Earth’s temperature increased by at least 0.75°C during the entire 20th century and by 1.10°C from 1880 to 2019. A conservative prediction of 2.0°C increase is expected in the next 75 years only if greenhouse gas emissions could be mitigated and kept lower than 400 ppm of CO$_2$ equivalent – that level seems to be the maximum threshold for keeping global temperature at a **likely** 2°C by the end of this century. “Even if global temperatures rise by 2°C it would mean that 20-30% of species could face extinction” as predicted by the *Met Office Hadley Centre*. The IPCC projects a warming of at least 0.2°C per decade even if greenhouse gases
and aerosols are kept constant at year 2000 level. Some climatologists predict that the IPCC underestimated global warming since positive feedback phenomena are not calculated in their projections. The projection models tell us that the temperature for this century is likely (probability of 66%) to increase between 2°C and 4°C. China and India now exhale more greenhouse gases (35%) into the atmosphere than the US, Canada and Russia combined (25%) but Canada and the US remain two of the biggest polluters of GGE per capita. Emissions reduction starting in 2014 of about 6% per year is needed along with massive reforestation and afforestation and preserving nature in order to return to 350 ppm CO₂ from today’s 415 ppm to restore Earth’s energy balance and to stabilize Earth’s climate by 2100. It is possible to keep global temperature at or below 1.5°C before the end of this century if we make the determination as advocated by the UN and IPCC and from the credible published reports on what we must do. Earlier chapters provide the evidence on how we could prevent a hothouse earth and not exceed 1.5°C before 2100.

10) **Decrease in Air Quality & the Ozone Hole**

Poor air quality is evident in large urban centres worldwide; this condition is linked to greenhouse gases and pollutants such as nitrogen and sulfur oxides. Megacities especially in Asia are experiencing some of the highest air pollution indices. **Air Quality and Particulate Matter** are discussed on pages 278-279 and 306-308. Air pollution is killing about 4,400 people in China every single day, according to a new study; researchers from Berkeley Earth, a California-based climate research organization, calculated that about 1.6 million people in China die every year from health-related issues caused by the country’s notoriously polluted air. Recent newspapers headlines tell of the “apocalypse” as air pollution in China was linked to 1.2 million premature deaths annually. In India, coal burning results in premature deaths annually from cancers to respiratory illnesses. An estimated 6.5 million premature deaths in the world are linked to air pollution every year with more than half of them being reported from China and India together. India alone contributes 1.59 million deaths to this dismal statistic. Environment Canada lists 2% and 0.8% of deaths in Canada are attributable to ozone and particulate matter (PM2.5) respectively. Air pollution results in 7,700 premature deaths in
Canada each year according to a Canadian Broadcasting Corporation (CBC) report. Deaths from respiratory complications are over 100,000 in the US in any given year.

The loss of ozone from the use of halocarbon family of chemicals (chlorofluorocarbons are now banned) poses concerns with the increasing effects of ultraviolet radiation and on human health; skin cancer has become more common and the incidence is growing concern especially in Australia and the southern US with a loss in ozone levels. Ozone losses continue in the stratosphere over the Arctic and Antarctic despite the phasing out of CFCs as per the Montreal Protocol. The ozone hole is not technically a “hole” where no ozone is present, but is actually a region of exceptionally depleted ozone in the stratosphere over the Antarctic and can be accessed from the Earth Observatory website at https://earthobservatory.nasa.gov. The ozone hole or depression over Antarctica and Arctic is variable and surprisingly extensive, and would take decades for ozone to be restored to acceptable and safe levels well after the phasing out of CFCs and other halocarbons.

The above top 10 are summaries are from the evidence provided by reliable sources in this resource. We control our own destiny as we have created a new epoch, the Anthropocene, as we drifted from the stable Holocene. Collective human action is required to steer the Earth System away from a potential threshold of Hothouse Earth and to stabilize it into a habitable condition. Such action entails stewardship of the entire Earth System - biosphere (nature & biodiversity), climate, and societies – to promote decarbonization of the entire global economy, enhancement of biosphere carbon sinks, behavioral changes, technological innovations, new governance arrangements, and transformed social values. Humans are capable of embarking on the next journey for their survival. Our youths are assembling around the world to demand the right course of action for their future and we cannot fail them and the unborn.

**Looking Back & Moving Forward**

**Canadian Severn Cullis-Suzuki** has made her name known and her voice heard over the years but she was very vocal at a younger age. At the age of 12 she
silenced the world for six minutes at the first UN Earth Summit in Rio de Janeiro in 1992: “Do not forget why you are attending these conferences, who you’re doing this for - we are your own children…. My Dad (David Suzuki) always says, ‘You are what you do, not what you say.’ Well, what you do makes me cry at night. You grown-ups say you love us, but I challenge you. Please make your actions reflect your words.” Fast advance some 25 years to report on the progress or damage done to ecosystems in our planet and we have another young voice speaking out. On *Young People’s Burden*, Sophie Kivlehan, grand-daughter of NASAs (former) climate scientist James Hansen, spoke at the UN COP in 2017 in Germany: “I will make my own plea to today’s adults, but I will argue that young people must do more than plea, we must demand our rights… Why has temperature increased almost linearly since 1975? Because Earth is out of energy balance, more energy coming in than going out. Earth stays out of balance because since 1975 we have kept adding gases that increase climate forcing… I am afraid and angry at the problems that greedy and foolish adults have created… I encourage more young people to stand up for their rights.”

Our children and grandchildren should not be left holding the economic and environmental baggage that this generation and past have created over the past 50 or more years. Climate scientist Andrew Weaver (Green Party Leader and MLA in BC) in *Generation Us*, reminds us that “global warming is the most self-empowering issue we will ever face. Every consumer of energy is part of the problem. Every person is therefore part of the solution.”

As discussed earlier in ‘Young People’s Movement’ led by Greta Thunberg, the 15 year-old girl from Sweden, will continue spread worldwide to demand that we adults must leave them in a world with less pollution and with a global temperature of less than 1.5°C before 2100; we are now at 1.1°C in over 100 years as a global mean but with temperatures in northern Canada and the Arctic more than twice the global mean. Thunberg, now 16, catapulted to fame last year for skipping school every Friday to stand outside the Swedish parliament, protesting against political inaction over the climate crisis and sparking an international movement, the school strike for climate, in which millions of other children followed suit. In Greta’s words: “I think this whole movement in which I just sat down in front of the parliament, alone – I think that had a huge impact, because people saw it and were moved, and became emotional.
Millions of children around the world, striking and saying, ‘Why should we study for a future that may not exist anymore?’ This is not only me, but everyone in the movement.”

Thunberg sailed to New York from England in a zero-free emissions yacht to attend a UN summit on zero emissions in September 2019 after refusing to fly there because of the carbon emissions caused by planes. Hopefully she would educate the minds of deniers of climate change and continue to influence young people about this climate crisis. Greta’s continuing message: “It’s insane that a 16-year-old has to cross the Atlantic in order to take a stand, but that’s how it is. It feels like we are at a breaking point. Leaders know that more eyes on them, much more pressure is on them, that they have to do something, they have to come up with some sort of solution. I want a concrete plan, not just nice words. My role is to be one of many, many activists who are pushing for climate action. I don’t see myself as a leader, or icon or the face of a movement.”

Canada’s nice words in Paris as its Intended Nationally Determined Contribution (INDC) in 2015 of 30% reduction of GGE below 2005 levels by 2030 will be missing its pledge by a wide margin.

Canada is not alone in missing its INDC. Canada has made some progress by producing its Pan-Canadian Framework on Clean Growth and Climate Change in 2016 with most of the provinces and territories paying attention to and enacting upon the document in a positive way. No one is insinuating that we do not need oil and gas – we do need this energy for several more decades. With each country submitting their INDC in Paris, Canada needs to revisit its intended contributions within the next five years and re-submit a more robust plan with greater confidence to the UNFCCC; a plan that is workable and not just an ambitious one that we have seen over the years that was not achievable. The world needs concrete plans to expand on renewable sources of energy such as wind, solar, biomass, hydro, geothermal, nuclear, and to abandon coal consumption now. The technology is here for advancing renewables in small and large projects. The Premiers of every province in Canada should study and emulate especially what Sweden, Denmark, Norway, Germany, the US and yes, China, are doing in advancing renewables and adding power to the electrical grid system. China and India should be in the forefront in advancing renewables since they both continue to use over 40% of coal as their energy source.
Canada’s priority is to phase out coal within 10 years for generating electricity. Some provinces are already advancing plans to shut down coal plants and promote renewables but a timeline is needed with planned alternative energy sources. Should shipping of coal from Canada and the US through Port Metro Vancouver to China and India be banned? With one-third of the world population living in China and India as developing economies it would take more than a couple of decades to dismantle and phase out coal plants but it must be done; both countries contribute about one-third of the global GGE. At the time of writing unfortunately many new coal plants are being planned in China and India who are the biggest consumers of coal to generate electricity. The US and the EU have been dismantling many of its coal plants and advancing renewables.

There are several options available to reduce consumption of fossils fuels as discussed in this book. Climate scientists almost all insist that there ought to be a price on fossil fuel consumption such as a carbon tax that was implemented in British Columbia in 2008 and has been workable at $30 per tonne in 2018 of CO₂ equivalent of emissions. The federal government and most provinces have in general agreed to accept a modest carbon tax of $10 per tonne of CO₂ equivalent in 2018 to be increased every year, and by 2022 to $50 per tonne. Some progress is being made in Canada to reduce GGE while growing its economy; unfortunately, we would not meet our Paris COP21 pledge by 2030. Revenues from the carbon tax collected should be targeted for renewables and public transportation and not for lowering personal income tax or expenses on infrastructure or to be put into general revenue.

A pollution free environment contributes to a higher quality of life, improved health for everyone, freedom for further economic growth, greater security and less instability among nations. Canada is well placed to promote good environmental stewardship and having the resources to conduct research and high-quality science free from political interference. The Government of Canada appears to be promoting leadership on climate initiatives and demonstrates a ‘fresh look’ at environmental concerns without compromising the economy; we are not a perfect country on environmental stewardship as the economy still depends on the oil and gas industries for a few more decades. James Hansen, NASAs former top climate
scientist, once told Canadians on his visit to Alberta “to keep the oil sands in the ground if you cannot develop responsibly.” The Pan-Canadian Framework on Clean Growth and Climate Change is one of Canada’s plan to address climate change and grow a clean economy. As Canadians we may not win every battle in the short-term in alleviating global warming but our strategic goal should focus on conserving and restoring Canada’s natural ecosystems for present and future generations that also act as natural carbon sinks. With today’s global population of 7.7 billion people the overall condition of Earth’s ecosystems from the Arctic to the Antarctic on which human life depends must be improved. The UN objective to bring all nations together at Conference of Parties on an annual basis for a healthier planet is encouraging.

The last IPCC Fifth Assessment Report concluded that “cumulative emissions of CO₂ largely determine global mean surface warming by the late 21st century and beyond. Most aspects of climate change will persist for many centuries even if emissions of CO₂ are stopped.” The IPCC projects more severe weather patterns such as droughts, forest fires, floods and extreme heat in most regions of the planet, with a sea level rise impacting on coastal cities and small island states. Food scarcity is linked to droughts, flooding, soil erosion, depletion of oceanic resources, and lack of water for agriculture. Climate change and extreme weather both impact on ecosystems from the Arctic through to the Antarctic. Greenhouse gas in the atmosphere know no geographical boundaries and the traditional high polluters should compensate those who are harmed or threatened by global warming impacts such as sea level rise.

Given the stakes involved, Canadians need answers to some basic questions such as: (1) How will Canada reach its intended GHG emission targets by 2030 and what must we do to improve on our pledge made at COP21? (2) For how much longer will Canada depend on the oil sands as a major economic resource and for export to overseas market? (3) What must Canada do to become more self-sufficient on its food supplies and improve on land use for agriculture? (4) When would Canadians know about the safety and health of its fresh water supply from coast to coast to coast and what is the role of Environment Canada in this regard? (5) What services will it provide in the Arctic to support infrastructure and
education to the Inuit and to minimize environmental risk? This list is short with more questions than answers. The reader could reflect on “A Planetary Emergency: The Top Ten” in this chapter, and add your own questions and concerns and to share in your discussion and continuing studies. Figure 4.8 provides a summary of many changes from global warming and changes that impact the Canadian landscape and worldwide.

We need to redefine green and rediscover Canada from east to west and from north to south, and in doing so rediscover ourselves and what it means to be Canadians. Within the next decade all Canadians must become part of the solution to reduce consumption of fossil fuels and insist on government and industry to embark on more renewable sources of energy and even safe nuclear power. Human health and environmental considerations with economic prosperity must be our central goal. We have the ability and the will to lay the foundation for a stronger, cleaner economy and a better future for our children and grandchildren. It’s unethical to allow our children and grandchildren to fend for themselves when they become adults and to have them pay a greater economic and environmental price for inactions of our present generation to effectively deal with climate change. Developing countries face severe problems and constraints or dangers with depleting resources such as water and energy, air and water pollution, carrying capacities in arable land and increasing population.

In Limits to Growth, the authors conclude that “humanity is dangerously in a state of overshoot.” They pointed out that once overshoot of carrying capacity has occurred it will inevitably lead to collapse unless the process is reversed. Are humans and planet Earth reaching or have reached its limits to growth? That is an important debate for us. Garrett Hardin’s essay in 1968, The Tragedy of the Commons in Science journal stated in part: “A fair defense can be put forward for the view that the world is infinite; or that we do not know that it is not. But, in terms of the practical problems that we must face in the next few generations with the foreseeable technology, it is clear that we will greatly increase human misery if we do not, during the immediate future, assume that the world available to the terrestrial human population is finite. ‘Space’ is no escape. A finite world can
support only a finite population; therefore, population growth must eventually equal zero.” Hardin’s telling message came 50 years ago!

Climate change affects everyone, so everyone should understand why the climate is changing and what it means for them, their children, and generations to follow. We were reminded by Pope Francis that “acting on climate isn’t just the smart thing to do, it’s our moral responsibility—for the sake of the world’s poor and vulnerable, and on behalf of our kids and grandkids.” “The Race of Our Lives Revisited” by Jeremy Grantham reminds us that “It is about our very existence as a viable civilization. We will need all the leadership, all the science and engineering, all the effort, and all the luck we can muster to win this race. It really is the race of our lives.”

Figure 4.8. The many impacts of climate change are unequivocal. Credit IPCC 5th Assessment Report.

It is up to each of us to become a supporter or spokesperson of climate change in your home, neighborhood, schools, religious group, service club, or political organization. It has become a climate crisis today. Carl Sagan once said “each of us is a tiny being, permitted to ride on the outermost skin of one of the smaller planets for a few dozen trips around the local star.” Theoretical physicist and cosmologist Stephen Hawking leaves us with these words of wisdom: “When we
see our planet from space we see ourselves as a whole...one planet, one human race...we must become global citizens.” The renowned biologist Edward Wilson bluntly asks: “Do we want to destroy the creation? That’s the question. That’s what we’re doing at an accelerating rate” while Mahatma Gandhi and ahead of his time pleaded that “we must be the change we wish to see in the world.” Nelson Mandela in his wisdom proclaimed that “education is the most powerful weapon which you can use to change the world, we know what needs to be done - all that is missing is the will to do it.”

Questions

1) Research the highlights of the document Pan-Canadian Framework on Clean Growth and Climate Change (as a class project). What measures were proposed by the government of Canada to reduce greenhouse gas emissions in that document? What suggestions or recommendations would you send to the government of Canada and Minister of the Environment and Climate Change about reducing GGE?
2) Carry out an internet search by logging on to www.davidsuzuki.org and access the “Nature Challenge.” How can we become more effective in helping to conserve nature while improving our quality of life?
3) Log on to http://nationalgeographic.com. How has the “Green Guide” influenced you in promoting environmental awareness?
4) Log on to www.pembina.org and access “Walking the Green Talk.” Cite some ways you could reduce your carbon footprint.
5) What would be your top three priorities from the ‘Top Ten’ list cited above? Why did you select them in that order? A class discussion.
6) Outline the procedure for carbon capture and storage (CCS). What are some better ways to reduce GGE with carbon sinks?
7) Discuss a meat vs a vegetarian diet and GGE globally or in Canada as a class project.
8) Research what Canada or your province is doing to advance renewable sources of energy – from wind, solar, geothermal, biomass. Access Environment Canada website and provincial websites suggested in this chapter.
9) Do a Google or Bing search or from the CAA on one of the following energy saving vehicles: hybrids, plug-in electric, hydrogen and fuel cell. Suggestion: Select the make and model that you would likely purchase to reduce your carbon footprint.

10) Research Ballard Power Systems technologies are developing and have developed for fuel efficient vehicles in BC and globally. Check Ballard’s website (www.ballard.com) on its advancing technology.

11) Investigate public transportation in your community or in your Metro regions(s). What would you recommend to the Provincial and Federal Ministries of Transportation or to Municipalities on ways to improve public transport in your community.

12) Conduct a survey asking how many people in your school use public transport, walk to school, going shopping, etc. You can be imaginative. In the survey ask: (a) how can people reduce the use of personal vehicle; (b) how to save on home heating bills and electricity; and (c) what does it all mean for any individual to reduce her/his carbon footprint.

13) Read Looking Back and Moving Forward as my concluding remarks in this book. What additional comments would like to you add for improving your own standard of living, your health and future sustainable development?

14) What are the biggest environmental concerns in the community in which you live?

15) What message would you send to your local MLA or MP or the Premier of your province to take additional steps to reduce greenhouse gas emissions?

**Chapter 4 References for Updated 7th Edition (2019/2020)**

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Casey, Allan. “Carbon Cemetery.” Canadian Geographic, Jan./Feb., 2008.


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Lindsay, Bethany. “Pilot project will remove CO\textsubscript{2} for resale.” *Vancouver Sun*, April 10, 2014.
National Geographic Special. “Cool it.” September 2015.
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**Glossary**

Adaptation: to prepare or make plans for an event that is occurring or will occur such as building a levee to safeguard against hurricanes or increasing sea levels; an inherited characteristic of an organism that helps it to reproduce and increases its chance of survival in a particular habitat.

Aerosol: particles from volcanic eruptions, dust, soot and micrometeorites in the atmosphere that absorb solar energy and reflect it back to space; may include human activity from industries such as sulfates; some aerosols have negative and some positive forcing.

Albedo: the reflection of light from a surface; low albedo arises from contaminated snow or loss of snow and ice.

Anaerobic: a biological process that does not require oxygen.

Anomaly: a data measured relative to a reference average; for example the temperature over time is measured in changes and not in absolutes.

Anthropogenic: related to human activities on the environment such as the combustion of fossil fuel and deforestation.

Atmosphere: the gaseous envelope around the Earth consisting of about 78% N\(_2\), 21% O\(_2\), and traces of argon, helium, ozone and long-lived greenhouse gases such as CO\(_2\), CH\(_4\), N\(_2\)O. The atmosphere contains vast amounts of water vapour and particles known as aerosols.

Basal sliding: the process by which ice sheets slide from bedrock heating or from water draining down a crevasse or moulin to lubricate the flow of ice.

Biodiversity: the sum total of the number of different organisms in a particular area or in the biosphere.

Biomass: the total amount or weight of living materials within a given area.

Biosphere: The Earth’s land, air, and water comprising of all ecosystems and organisms both living and extinct; it includes dead organic matter in the terrestrial and oceanic beds; it plays a major role in the carbon cycle.
**Boreal**: refers to the coniferous and deciduous forests in most northern and southern regions of earth, below the timberline, with low rainfall and severe winters as distinguished from the temperate rainforests in the western USA and Canada.

**Biosphere**: the regions of the planet, its land, ocean and atmosphere, where life exists or the sum total of all the biomes.

**Cap and trade**: A set of policies in which government sets a cap on total emissions and establishes allowances to emit up to the cap. Emitters are allowed to buy, sell or bank allowances to meet the emission cap. A cap and trade system has an environmental outcome that is certain (based on the cap). However, the cost of emitting depends on the demand for permits relative to the cap (or supply).

**Carbon cycle**: The flow of carbon and carbon dioxide in the biosphere and includes the atmosphere, oceans, land and soil. Fossil fuels and human activities play important roles in adding carbon dioxide and black carbon in all ecosystems. The cycle involves the processes of photosynthesis, respiration, decomposition and combustion as well as volcanic activities.

**Carbon tax**: Is a tax, fee, or levy payable to the government per tonne of emissions. This price can be applied to all emissions or to a portion of them. A carbon tax has the benefit of providing certainty in terms of cost. A set price such as $30/tonne. Companies and consumers have the choice to pay the tax or to avoid emissions.

**Carbon footprint**: is the total set of greenhouse gas emissions caused directly and indirectly by an individual, organization or product.

“**Carrying capacity**: measures what level of use is sustainable; it is complex, particularly when a very wide range of valued products and services must come from the same environment.” (Wikipedia). The carrying capacity of a biological species in an environment is the maximum population size of the species that the environment can sustain indefinitely, given the food, habitat, water, and other necessities available in the environment.

**Catalyst**: an agent or substance that speeds up the rate of a chemical reaction.

**Chlorofluorocarbons**: are synthetic compounds used for refrigeration, and at one time in aerosol spray cans, that destroy the ozone layer in the stratosphere.
Climate: the average of weather conditions such as temperature and precipitation in a particular region over the course of a year and includes a state of conditions of the climate system.

Climate change: caused by natural processes or external radiative forcing or from human activities over an extended period of time and changes in the composition of the atmosphere, oceans or in land use.

Climate system: involves interactions of the atmosphere, stratosphere, hydrosphere, cryosphere, and biosphere, and influenced by the Sun, external forcings, clouds, human activities that promote climate change.

Climatologist: a scientist who studies weather and climate conditions in regions of earth and in space.

Community: a population of different organisms that live together in a defined area.

Compound: a substance consisting of two or more elements in fixed proportions.

Consumer: an organism that obtains its nourishment from plants or other animals.

Continental drift: land masses that move as a result of tectonic activities and magma flow, a slow process that results in mountain building, and with one continent (South America) being separated from another (Africa).

Convection: the transfer of heat in a liquid or air by temperature difference.

Cryosphere: the region of earth of the climate system consisting of snow, ice and permafrost.

Decommissioning: when nuclear power plants are taken out of service when the effects of radiation are no longer operable.

Decomposition: the breakdown of organic matter into nutrients for the survival of other organisms.

Deforestation: the removal of forests for harvesting timber and increasing the greenhouse effect; associated with burning of wood releasing more carbon dioxide and a loss of photosynthesis by reducing carbon dioxide intake.

Desertification: due to droughts, poor farming practices, El Nino occurrences in some regions, overgrazing, runoffs, resulting in productive lands becoming deserts.

Dobson unit: a measurement of the amount of ozone (O₃) at standard temperature and pressure; a Dobson of 350 units (DU) and higher shows higher amounts of ozone but lower than 300 DU (3 mm thick ozone) indicates depletion of ozone in the stratosphere.
**Ecosystem**: refers to a collection of organisms living together and interacting in a particular physical environment.

**Equivalent CO₂**: refers to the concentration of carbon dioxide that brings about the same amount of radiative forcing as mixed greenhouse gases.

**Element**: any substance that contains only one type of atom and cannot be separated into simpler substances.

**El Nino**: a pattern of decline of easterly winds from South America, low air pressure and higher sea surface temperature in the Pacific Ocean off the coast of South America to the mid-Pacific that influence weather and climate in distant regions.

**Exponential**: when the population increases by a given percentage each year, doubling again and again, and characterized by a J-shaped curve on a graph.

**Feedback loop**: the process by which temperatures increase from loss of albedo or from the thawing of the permafrost by releasing carbon dioxide and methane from a warming Earth, adding to the greenhouse effect.

**Fjord**: or fiord is a long and narrow arm of the sea that is situated between steep cliffs and mountains.

**Food chain**: a number of steps in the ecosystem or community that transfers energy when one organism is being consumed from a producer to consumers.

**Food web**: a complex network of nutritional relationships among and between producers and consumers in an ecosystem.

**Fossil fuels**: pertain to coal, oil and gas that had its origins from ancient plant and animal remains and produce carbon dioxide when burned.

**Geothermal**: refers to an energy source that can be harnessed from deep underground for domestic and commercial use.

**Greenhouse effect**: causes global warming due to solar radiation being transmitted to the earth’s atmosphere and surface; some thermal energy emitted from the earth’s surface and solar energy are absorbed by greenhouse gases such as carbon dioxide and methane, clouds or water vapour, and re-radiate this energy into space, as well the atmosphere and onto earth’s surface.

**Greenhouse gases**: carbon dioxide and methane are two important greenhouse gases that act as blanket that absorb some of the thermal radiation emitted from the earth’s surface and warm the atmosphere. The list of greenhouse gases is extensive and contained in this text.
**Ice core**: compact ice in tubes that is collected deep in the cryosphere of the Arctic, Antarctic or from glaciers that can tell the history of the region, similar to tree rings that tell how old a tree is and the past climate.

**Ice sheet**: a mass of ice from several kilometres to hundreds of metres thick overlaying bedrock as in Greenland and Antarctica.

**Ice shelf**: an extension of an ice sheet of considerable thickness that floats in the sea and may be attached to the coast.

**Infrared**: invisible long waves of energy from the Earth’s surface into outer space and acts to cool the surface but will return Earth to warm its surface in the greenhouse effect.

**Isotope**: is a different form of an element with different atomic mass. For example, $^{12}$C has two fewer neutrons than $^{14}$C.

**La Nina**: the opposite phenomenon of El Nino that results in a drop of sea surface temperature of the eastern to mid-equatorial Pacific Ocean, higher air pressure and stronger easterlies.

**Megawatt (MW)**: is a unit of energy equal to 1,000,000 watts, or 1,000 kilowatts. Electricity generation facilities are often described based on their generating capacity, in megawatts. For example, depending on the technology, a single commercial-scale wind turbine has a capacity of 1 to 4 megawatts (1 to 4 million watts), whereas a rooftop solar panel typically has a capacity of about 250 to 300 watts. One MW can supply about 200 average size homes or 1,000 homes for about one hour.

**Metabolism**: a process of biochemical reactions that build up or break down molecules.

**Model**: a pattern, prior and present information and data that are used to predict an event or situation.

**Mitigation**: a human intervention to reduce the origin or sources or sinks of greenhouse gases.

**Molecule**: the smallest unit of compounds; a combination of two or more elements.

**Mutation**: a change in the gene or DNA sequence that may alter the genetic information of the organism.

**Negative forcing**: a change in the energy balance; a negative forcing refers to the natural and human effects that induce cooling the planet.

**Nanometre**: a ‘nano’ prefix is $10^{-9}$ of quantity or a billionth of a metre.
**Ozone Hole**: a large region over Antarctica where during the southern spring months a significant amount of ozone is being depleted.

**Paleoclimate**: refers to climate in the past and detected through ice core studies or tree ring studies.

**Peninsula**: a narrow piece of land extending and surrounded by a body of water.

**Permafrost**: a large area in the tundra of frozen subsoil containing vast reserves of carbon.

**pH scale**: a measurement system to indicate the level of hydrogen ion \( (H^+) \) concentration from a scale of 0 to 14.

**Photosynthesis**: a process that all green plants uses to convert carbon dioxide in the presence of light and water to make sugars and produce oxygen.

**Photovoltaic**: is solar power that uses solar cells to convert light from the sun into electricity.

**Phytoplankton**: refers to any algae or small photosynthetic organisms in the ocean or fresh water; these are also primary producers of energy in the food chain.

**ppb**: a measurement in parts per billion; for example, 300 ppb means 300 molecules exist per billion molecules of dry air.

**ppm**: a measurement in parts per million; for example, 400 ppm means 400 molecules exist per million molecules of dry air.

**Polar Vortex**: Refer to the illustration in this book. A counter clockwise flow of cold Arctic air confined over the Polar region by the jetstream. It may push south and displaces the jetstream to bring severe cold weather to regions of northern Europe, Canada and the US.

**Population**: a group of individuals of the same species (humans) in a given area, country or the world.

**Positive forcing**: is the change of energy from human and natural causes, influences that cause the climate to become warmer.

**Protocol**: an agreement or treaty signed by policy-makers based on diplomatic rules through negotiations and conclusions; the Montreal and Kyoto Protocols.

**Radiative forcing**: is the change that is caused in the global energy balance of the earth relative to pre-industrial times; the influence that a factor has in altering the balance of incoming and outgoing energy.

**Reforestation**: any new planting on forests on lands that have been converted to some other use or what was previously forested lands.
**Satellite**: refers to an object launched into space equipped with instruments aboard and managed by organizations such as NASA and NOAA to monitor and provide data on earth’s ecosystems.

**Scenario**: a future situation and plausible description based on present and past events where assumptions are made on projections for climate change. The IPCC has outlined several families of scenarios or narrative description.

**Solar System**: refers to the sun and its planets with respective moons, all moving in an orderly manner along the Milky Way Galaxy.

**Spacecraft**: an object launched into space from the ground carrying specialized instruments to collect data, make observations of the planets, moons and sun in the solar system.

**Stratosphere**: it is the region above the atmosphere and measures some 12 – 50 kilometres wide; it is important by consisting of ozone gas and is the first barrier of incoming ultraviolet radiation.

**Temperate forest**: generally considered to be high in rainfall and moderate temperatures as in the Pacific Northwest of the USA and Canada; evergreen trees are hundreds of years old.

**Thermohaline circulation**: refers to the vast conveyor belt of circulating warm to cold and salty (dense) water from the tropics and southern hemisphere to the north Atlantic.

**Tonne**: is a unit of mass that is 1,000 kilograms of mass or a metric ton; one megatonne (Mt) is one thousand tonnes and one gigatonne (Gt) is one billion tonnes.

**Weather**: conditions on earth’s atmosphere such as sunshine, clouds, rainfall, temperature, wind velocity and direction, pressure, snowfall, occurring at a particular time and place.
Websites

www.rsc.ca – Royal Society of Canada
www.ec.gc.ca – Oil Sands Advisory Panel
www.oag-bvg.gc.ca – Reports of the Commissioner of the Environment and Sustainable Development
http://earthobservatory.nasa.gov – NASA climate research, images and more
www.giss.nasa.gov – Goddard Space Flight Center, research, satellite images.
http://www.noaa.gov – National Oceanic and Atmospheric Administration, Climate Oceans, Satellites, Fisheries, research and more
https://scripps.ucsd.edu/ - Scripps Institution of Oceanography
http://www.epa.gov/climatechange - US Environmental Protection Agency, climate change and more.
http://nsidec.org - National Snow and Ice Data Center
www.ipcc.ch – Reports from the Intergovernmental Panel on Climate Change
http://www.ec.gc.ca – Environment Canada, climate change and more
www.env.gov.bc – Environment Protection Division
www.pembina.org – The Pembina Institute (Canadian)
http://www.mnh.si.edu/biodiversity/home/htm - Smithsonian Institution
www.davidsuzuki.org – David Suzuki Foundation (Canadian)
www.skepticalscience.com – Distinguishing Science from non-science claims
www.ngm.com/climateconnections - National Geographic
www.sierraclub.org – US Sierra Club
www.resourceworks.com – engaging British Columbians in decision-making…
http://www.sierraclub.ca – Canada’s Sierra Club
ecokids@earthday.ca – Earth Day Canada/EcoKids
www.climateark.org – Climate change information
www.epa.gov/msw/reduce.htm - Reduce, reuse, recycle
http://www.ukace.org – Association for the Conservation of Energy
http://www.cat.org.uk – Centre for Alternative Energy
www.royalsociety.as.uk – The Royal Society (UK)

Note: Additional Websites appear throughout the text.
Acronyms & Abbreviations

AAAS; American Assoc. for the Advancement of Science
AVHRR: Advanced Very High Resolution Radiometer
BC: British Columbia
CAPP : Canadian Association of Petroleum Products
CBC: Canadian Broadcasting Corporation
CFCs: Chlorofluorocarbons
COP: Conference of Parties – UN Climate Conference
EOS: Earth Observing System
EPA: Environmental Protection Agency
ENSO: El Nino Southern Oscillation
ESA: European Space Agency
G8: Group of Eight Developed Countries
GEOS: Geostationary Operational Satellite
GGE: Greenhouse Gas Emission(s)
GHG: Greenhouse gas
GISS: Goddard Institute of Space Studies
GRACE: Gravity Recovery and Climate Experiment
IEA: International Energy Agency
IPCC: Intergovernmental Panel on Climate Change
MODIS: Moderate Resolution Imaging Spectroradiometer
NAFTA: North American Free Trade Agreement
NASA: National Aeronautics and Space Administration
NCDC: National Climate Data Center
NEB: National Energy Board
NOAA: National Oceanic and Atmospheric Administration
SMMR: Scanning Multichannel Microwave Radiometer
TOMS: Total Ozone Mapping Spectrometer
UARS: Upper Atmosphere Research Satellite
UN: United Nations
UNESCO: United Nations Educational, Scientific and Cultural Organization
UNEP: United Nations Environment Program
UNF: United Nations Foundation
UNFCCC: United Nations Framework Convention in Climate Change
USA/US: United States of America/United States
WHO: World Health Organization
WMO: World Meteorological Organization
Credits
The author wishes to acknowledge and thank the many organizations and sources cited for the use of illustrations, graphs and photos while upgrading this resource for educational purpose. This book is annually updated on the physical science of climate change, impacts from natural variabilities and anthropogenic influences as well as ways to reduce global warming or greenhouse gas emissions. It is not for financial gains but solely as the author’s message for students and teachers as classroom resources, learning and discussion. Credit must be given to the authors and citations for the use of any material cited from this book and contents should not be copied for publication and financial gains. Teachers and students are welcome to use any of the contents in this resource citing references for your learning.
Signed Harold Gopaul
This Project is Dedicated to Our Children & Grandchildren

To our grandchildren and youths who should not be left with the environmental and financial burden because of the lack of our willingness to deal with climate change in a more responsible way, and the potential consequences likely to unfold; the urgent need is to decarbonize and advance cleaner energy for an environment free of pollutants. We cannot leave our children, grandchildren and the unborn to fend for themselves. Sustainable development with environmental stewardship should be promoted for the health and prosperity of all Canadians.

The Author’s Grandchildren. Left to Right: Robyn, Rebecca & Rosie. Dated photo.
About the Author
Harold Gopaul taught Biology and Earth Science in School District #43 in Coquitlam, British Columbia. He was on a teacher training assignment with the Canadian International Development Agency in Cameroon, West Africa, and later as a curriculum advisor for Science and Biology with the Ministry of Education in Qatar. After 33 years of high school teaching, he spent five years as a student-teacher Advisor in the Faculty of Education at the University of B.C. and with the University of Victoria.

Harold’s globetrotting took him from the glaciers of the Yukon and Alaska to Tierra del Fuego to the rainforests of Central Africa in the Cameroon, to Kalimantan in Borneo, Java in Indonesia, Malaysia, Sri Lanka, India, and Trinidad & Tobago. With his interest in coral reefs he enjoyed snorkeling in the Great Barrier Reef in Australia, Tobago, Fiji and Fanning Island.

He is the author and co-author of three Biology books. Harold was the recipient of an Outstanding Biology Teacher Award (1985) for Canada by the National Association of Biology Teachers (USA). He also received Distinguished Service Awards (1990 & 1996) presented by the BC Science Teachers’ Association (BCScTA) for his contribution as Editor of the journal Catalyst of the BCScTA and as co-chair to promote professional development at BC Science Teachers conferences held at Simon Fraser University in 1990 & 1993. He completed his education at the University of BC and San Diego State University. Harold presently resides in Richmond, British Columbia and enjoys his grand-kids, the outdoors, golfing, occasional skiing and still globe-trotting.

This photo of the author appears on the front cover of his book Surviving Prostate Cancer.

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