Chapter 1
Building a Case for Plant Bioproducts

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Chapter Highlights

- Global carbon emissions associated with fossil fuel dependence are increasing steadily and are a major root cause of climate change.
- In order to reduce our reliance on fossil fuels, there is an imminent need to find sustainable alternatives to petrochemicals.
- Bioproducts are produced from renewable biomass and include biochemicals, bioenergy, biofuels and biomaterials.
- Increased use of bioproducts will assist in curtailing our dependence on fossil fuels and reduce greenhouse gas emissions.
- Ultimately, our goal should be for all carbon dioxide produced to be recaptured into renewable biomass, thus closing the carbon cycle.

1.1 Introduction

Until about 200 years ago, humans relied almost exclusively on bioproducts to fulfil their material and energy needs (Primer on Bioproducts 2004). Since the Industrial Revolution, however, the global community has become increasingly dependent on energy derived from petroleum for heat, generation of electricity, transportation fuel and the manufacture of industrial products and consumer goods (Fig. 1.1). Indeed,

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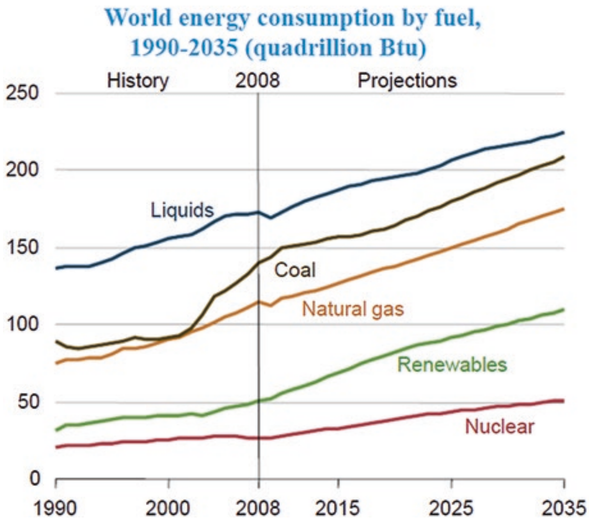

Fig. 1.1 World energy consumption by energy source, 1990–2040 (quadrillion Btu). (From: International Energy Outlook (2017))

today's petroleum provides about 85% of the world's energy requirements. Although there is currently a glut of oil on the market, fossil fuels are still a finite resource. Experts debate on when fossil fuels will run out; however, a supply crisis is sure to eventually occur given our insatiable appetite for fossil fuel-derived energy. Furthermore, political instability and war in some oil-producing areas can also impact supply. In March 2002, a white paper prepared by the Colorado River Commission of Nevada (2002) indicated world petroleum, natural gas and coal reserves were estimated to last 98, 166 and 230 years, respectively. The recent identification of new fossil fuel deposits, along with improved extraction procedures, however, will likely increase the amount of time we have left before reserves run out (Kerr 2010, 2011).

Carbon emissions associated with fossil fuel dependence are a main driver of global **climate change** and are thus a major concern, especially given the rate at which their production has been escalating in the past few decades. These emissions contain **greenhouse gases** (GHGs), which are gases that absorb and emit radiation within the thermal infrared range and result in atmospheric warming. Indeed, escalating fossil fuel emissions have been linked to rising global temperatures, increasing sea level and reduced snow cover and glacial thickness (Intergovernment Panel on Climate Change [IPCC] 2007). As an example of this, in early August 2016, arctic conditions allowed the 280-metre-long cruise ship, Crystal Serenity, to travel through the Northwest Passage and stop at the hamlet of Cambridge Bay, Nunavut (Canadian Broadcasting Corporation [CBC] News 2016). Climate change has also been implicated in an increase in severe weather and flooding (Smith and Katz 2013; Estrada et al. 2015), with other well-known environmental costs including the destruction of wildlife habitat and accidental exposure to chemicals. The BP oil spill in the Gulf of Mexico, which commenced on April 20, 2010, and continued until July 15, 2010, spilling an estimated 650 million litres of oil (CBC News 2015) is one example of this. This was one of the largest oil spills in history, affecting up to 400 animal species.

Table 1.1 Greenhouse gas emissions based on type of gas from 2010

Type of gas	Global contribution (%)
Carbon dioxide from fossil fuel and industrial processes	65
Methane	16
Carbon dioxide from forestry and land use	11
Nitrous oxide	6
Fluorinated gases	2

Source: IPCC (2014)

Table 1.2 Contributions of various countries to carbon dioxide emissions from fossil fuel consumption and some industrial processes

Country	Global contribution for carbon dioxide emission (%)
China	30
USA	15
India	7
Russian Federation	5
Japan	4
Other countries	39

Source: Data of 2014, from Boden et al. (2015)

GHG emissions come in many forms having different contributions (Table 1.1). Interestingly, while water is actually the most abundant GHG, it is not as sensitive to the impact of human activities as other gases and, as such, does not have much of an effect on the environment. Conversely, carbon dioxide is the worst offender in terms of GHGs, followed by methane and nitrous oxide (IPCC 2014). Global contributors to carbon dioxide emissions stemming from fossil fuel combustion and some industrial processes are shown in Table 1.2 (Boden et al. 2015), with China and the USA being the leading contributors.

GHG emissions come from various sources (IPCC 2014; Table 1.3), with fossil fuels and industrial processes being the greatest contributors to carbon dioxide emissions. GHG emissions from agricultural activity account for about 24–26% of total global **anthropogenic emissions** (Sejian et al. 2011; Natural Environment Research Council [NERC] 2016), which refers to pollutants originating from human activity. Similarly, livestock account for about 18% of the world's anthropogenic GHG emissions, which includes the effect of deforestation to generate grazing land along with methane gas emissions (Gill et al. 2010; NERC 2016). Since plants actively take up carbon dioxide during photosynthesis, deforestation removes critical "carbon sinks" from the environment, which causes changes in the amount of solar radiation reflected back into the atmosphere and is referred to as **albedo**.

Furthermore, the "concrete jungles" of the world are dependent on enormous amounts of cement, which also contributes to GHG emissions. Cement production

Table 1.3 Global greenhouse gas (GHG) emissions by economic sector

Economic sector	Contribution to GHG emissions (%)
Electricity and heat production	25
Agriculture, forestry and other land uses	24
Industry	21
Transportation	14
Buildings	6.4
Other energy	9.6

Source: IPCC (2014)
GHG greenhouse gas

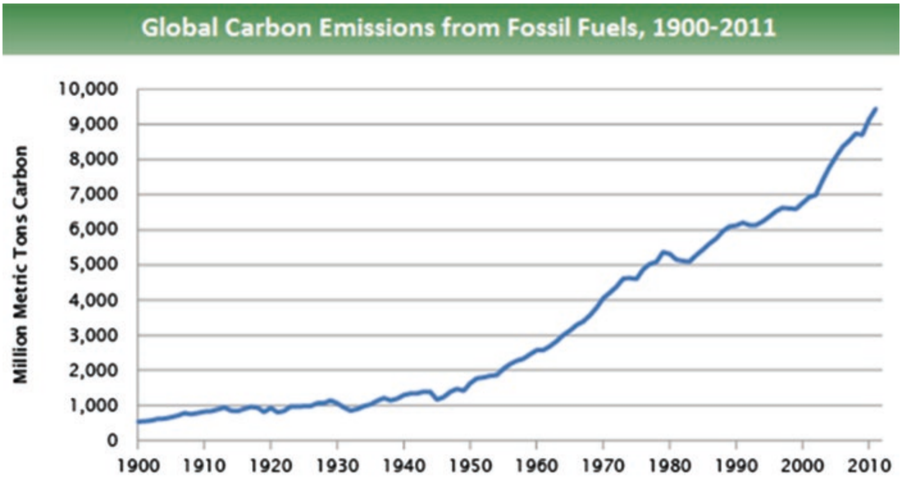

Fig. 1.2 Carbon emissions over time. (From: Boden et al. (2015))

accounts for about 5% of anthropogenic carbon dioxide emissions (Hendricks et al. 2004; NERC 2016), with about half arising from the chemical process itself since cement is mostly made of calcium carbonate. Another 40% of carbon dioxide emissions related to cement production come from burning fuel associated with the process. Indeed, approximately 900 kg of carbon dioxide is emitted for every 1000 kg of cement produced.

Between 1950 and 2010, our global carbon emissions have increased by about sixfold (Boden et al. 2015; Fig. 1.2). If this rate of GHG emissions continues, it has been estimated that we could exceed the 2 °C global warming threshold set by the IPCC as early as 2036 (Mann 2014). Global warming above this threshold value has been predicted to have serious, and potentially irreversible, consequences to both the environment and human livelihood. In order to limit global warming to 2 °C or less between now and the year 2100, we will need to reduce our GHG emissions by 40–70% by 2050 and reach a point of zero GHG emissions by the end of the century (IPCC 2014). Given that our global demand for energy, fuel and industrial chemicals is projected to grow at a very fast rate over the next few decades, it is essential that we reduce our reliance on fossil fuels and switch to cleaner and more sustainable forms of energy.

1.2 Towards Closing the Carbon Cycle

In order to reduce our reliance on fossil fuels and reduce GHG emissions, there is a need to use them more efficiently and to diversify our energy usage to include hydroelectric, hydrogen fuel cell, nuclear, wave action, wind, solar, geothermal and **biofuel**-derived power. Currently, the burning of fossil fuels results in the production of more carbon than can be offset by **biomass** (Fig. 1.3a), which can be generally defined as biological material from living or recently living organisms and most often refers to plants or plant-based materials that are not used for food or feed (https://en.wikipedia.org/wiki/Biomass). If our fossil fuel dependence is eliminated, however, we will then have a situation where the carbon dioxide produced from burning biomass is recaptured into renewable biomass, thus closing the carbon cycle (Fig. 1.3b).

In 2005, 192 countries signed the Kyoto Protocol, which was aimed at “stabilizing GHG concentrations in the atmosphere to a level that would prevent dangerous anthropogenic interference in the climate system” (United Nations Framework Convention on Climate Change). This document established legally binding commitments to reduce major GHGs. The USA, however, did not end up ratifying and Canada withdrew in 2011 (CBC News 2011). That being said, Canada remains a member of the Copenhagen Accord (2009), which represents a nonbinding agree-

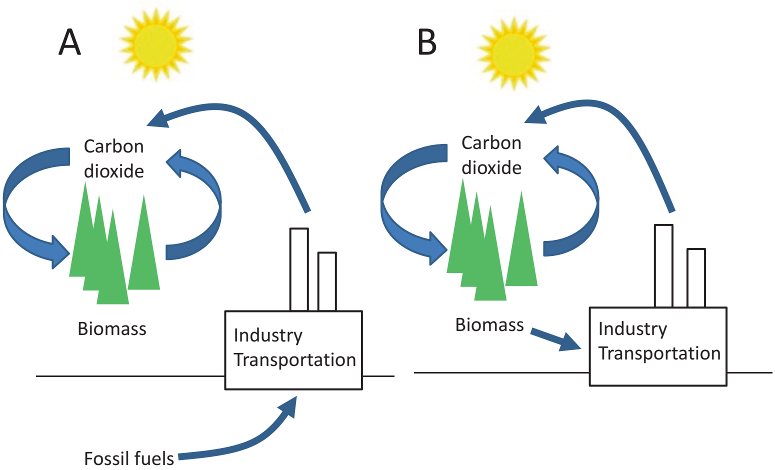

Fig. 1.3 Using biomass for energy can close the carbon cycle. (**a**) Burning fossil fuels results in the release of more carbon than can be utilized. (**b**) Using only biomass for energy closes the cycle. (Adapted from Primer on Bioproducts (2004))

ment involving a subset of Kyoto signatories. As such, Canada is still committed to reducing emission levels, but the target is more realistic, with updated commitments reflected in the Paris Agreement (World Economic Forum 2016).

There is a lot that we can do as citizens of the globe to reduce our own carbon footprint. Strategies to conserve energy include the use of energy-efficient appliances and vehicles, improved building practices, increased use of public transport and carpooling and purchasing carbon offsets. In this regard, it can be an interesting exercise to calculate one's own carbon footprint (see www.carbonfootprint.com/calculator.aspx).

There has also been recent interest in generating large-scale carbon sinks for capturing carbon dioxide from the atmosphere. For example, in the case of **carbon capture and storage**, carbon dioxide is captured, compressed into a liquid and injected into deep reservoirs for permanent storage (Haszeldine 2009; Alberta Energy 2016). Intriguingly, Mayumi et al. (2013) have shown that captured and stored carbon dioxide can lead to methane production via the action of microbial methanogens. These investigators suggested that this represented a new opportunity for the production of energy from methane derived from the stored carbon dioxide. Unfortunately, carbon capture and storage also has some potential disadvantages. This includes the fact that the separation of carbon dioxide from other gases is energy intensive and there are technical challenges associated with large-scale capture that still need to be overcome.

The potential use of microalgae to capture carbon dioxide derived from industrial processes is also under extensive investigation (Sayre 2010). Some types of microalgae produce very high levels of vegetable oil, which accounts for as much as 60% of its dry weight. Since carbon makes up about 75% of this oil, it can be extracted from the microalgae and injected into geological formations to store the carbon. Alternatively, microalgae can be converted into **biochar** by **pyrolysis** under oxygen-free conditions in the presence of catalysts (Hielmann et al. 2010). Biochar contains more than 90% carbon and can remain unaltered in the soil for millions of years.

1.3 Why Plant Bioproducts?

Another way in which we can reduce GHG emissions is through increased usage of sustainable, bio-based alternatives to petrochemicals. **Bioproducts** are industrial and consumer goods manufactured wholly or in part from renewable biomass and may be derived from crops, trees, marine plants, microorganisms and some animals (Spellman 2014). In terms of plant bioproducts, the major plant components used for their production include storage lipids, complex carbohydrates and proteins.

In the strictest sense, bioproducts have more to do with industrial applications than representing a source of human food or animal feed and may include biochemicals, bioenergy, biofuels and biomaterials. For example, many fatty acids produced by certain plants are highly valued for their use in the generation of various industrial products that are currently derived mainly from petroleum, such as lubricants and solvents. In addition, various other biochemical components of plants have also been found to be useful in the development of a plethora of bioproducts such as natural rubber and bioplastics.

The use of bioproducts as renewable replacements for petrochemical-based materials has far-reaching benefits. This includes not only a decreased dependence on fossil fuels, along with an associated reduction in GHG emissions and enhancement in environmental safety, but also the generation of additional markets for commodities and by-products that were considered waste materials in the past for growers and food processors.

1.4 Closing Comments

Increased use of plant bioproducts, combined with the use of energy derived from hydroelectric, hydrogen fuel cell, nuclear, wave action, wind, solar and geothermal sources, can collectively contribute to decreasing our reliance on petroleum and subsequently lead to environmental benefits such as reduced GHG emissions. Interestingly, **biodiesel**, which can be produced from seed oil, is often considered to be carbon neutral because burned biodiesel ends up as carbon dioxide that plants can take up from the atmosphere and reconvert into new biomass. Unfortunately, this is not entirely true, since growing certain oilseeds, such as canola (mainly *Brassica napus*), requires the application of nitrogen fertilizer, which represents a substantial cost input in crop production (Karmakar et al. 2010). In addition, the production of nitrogen fertilizer generates nitrous oxide, which we have already identified as powerful GHG. In contrast, soybean (*Glycine max*) can be produced with little or no nitrogen, which highlights the fact that crop choice can be extremely important in terms of achieving carbon neutrality.

Although the use of plant-derived products as feedstocks for the generation of biodiesel and biofuel has garnered the majority of interest in terms of non-food applications for crops, a host of additional uses also exist. Indeed, plant bioproducts have the potential to provide a sustainable, renewable, environmentally friendly alternative to many fossil fuel-derived chemicals. Therefore, while the actual closing of the carbon cycle may be considered somewhat of a fantasy by some, it is of the utmost importance that we work towards trying to achieve it, and plant-derived bioproducts will certainly play a role in this endeavour.

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