The Role of Biofuels Within the Context of Climate Change Mitigation

CRE-401

Biofuels

School of The Environment: University of Toronto Professional Development

December 4, 2017

Instructor: Lucy Sportza

Adam Johnston

Word Count: 3,200

Introduction

As a renewable energy resource, biofuels can mitigate or neutralize greenhouse gas (GHG) emissions, thanks to their ability to capture carbon in living matter (plants, trees, crops), while releasing it as energy (National Geographic, 2017). Biofuels provides opportunity to both limit carbon (CO_2) emissions and develop economic growth.

Human-induced climate change is a significant concern among millennials (World Economic Forum [WEF] 2017), with fossil fuel extraction the leading cause (Wuebbles et al., 2017). Scientists suggest keeping carbon emissions below 350 parts per million (ppm) would mitigate the worst effects of climate change (Hansen et al., 2008). Increased extreme weather events (intense rainfall, heatwaves, & wildfires), from climate change, is causing infrastructure breakdowns (Government of Canada, 2015). Meanwhile, financial costs are also increasing at $240 USD billion yearly in the US alone, rising to $360 USD billion in ten years, from climate change (Watson, McCarthy & Hisas, 2017). Global population will reach 9.8 billion by 2050, adding more stress on limited natural resources (United Nations [UN], 2017). The need for sustainable biofuel development is critical in reducing climate change risks.

This paper will analyze the role of biofuels in climate change mitigation. I will examine wood feedstocks and wood waste on their GHG reduction potential within the overall biofuel ecosystem. I will investigate and compare other biofuel feedstocks compared to wood biomass. Using economic incentives, eradicating trade barriers, and developing a global environmental biofuel certification strategy will support biofuels as a climate change mitigation strategy.

Biofuels within the Climate Change Context

Biofuels are defined as a gas or liquid fuel borrowed from biological matter (Eisentraut, Brown, & Fulton, 2011). Biofuels are combustible within the carbon dioxide cycle, sustainable, and biodegradable (Demirbas, 2017). Biofuels are utilized for all sectors (heating, electricity, and transportation) as a clean energy source in reducing carbon emissions, while avoiding intermittency concerns of wind and solar energy (Center for Climate & Energy Solution [C2ES], 2017a)

Transportation makes up 15% of all emitted carbon emissions (C2ES, 2017b). Fossil fuels make up 95% of all transportation fuels (Environmental Protection Agency [EPA], 2017). Electricity & heat (31%), manufacturing & construction (12%) agriculture (11%) & forestry (6%), fugitive emissions (5%) and other (8%) make up the remaining the industry percentage of carbon emissions (C2ES, 2017b).

These statistics highlight the need for a sustainable biofuels strategy, even with the acceleration of global electric vehicle (EV) markets reaching between 40 million to 70 million by 2025, as falling lithium battery prices push costs down (International Energy Agency [IEA], 2017a). Long-haul transportation and aviation sectors need sustainable fuels today also, as the commercial scalability of E-trucks and E-planes are limited until midcentury (Eisentraut, 2010) (International Renewable Energy Agency [IRENA], 2017). Bioenergy production will need to accelerate as transportation demand is expected to triple by 2030 (IEA, 2017b). With carbon emissions now past 400 parts per million (ppm) (Co2.Earth, 2017), and the earth human population reaching 9.8 billion by 2050 (United Nations [UN], 2017), biofuels are needed more than ever to meet the Paris climate agreement of no more than 2C above pre-industrial levels, while aiming for 1.5C (United Nations Framework Convention on Climate Change [UNFCC], 2017). Wood biofuels are one feedstock which can play a prominent role in mitigating GHG emissions.

Wood Biomass & Wood Waste

Wood-based biofuels come from woody biomass and consist of four groups (Johnson et al., 2010). Direct fuels involve immediately extracted wood products, forests, and woodlands which can provide energy (Johnson et al., 2010). Wood-derived fuels require wood feedstock conversion to fuel and can come in gas or liquid form (Johnson et al., 2010). Indirect wood-based fuels & recovered wood fuels are two other groups which are discussed in depth later within wood wastes. These feedstocks can include wood pellets substituting coal for electricity at power plants (Canadian Council of Forest Ministers,

[CCFM], 2017), or residues used for aviation jet fuel (International Air Transport Association [IATA], 2015).

Adequately harvested wood feedstock provides a promising clean energy source to mitigate carbon emissions. Wood biomass (forests) mitigates carbon emission through trees as they act as a sink while changing biomass into energy, releases GHG & CO_2 emissions, making wood fuels carbon neutral. (NRCAN, 2010). The timeframe of wood energy wood bioenergy depends on forest expansion rates; types of fossil fuels switched; modification technologies used; contrasting different uses for wood vs. fuel; and understanding life cycle analysis (LCA) (NRCAN, 2010).

Therefore, based on the analysis of Johnson et al. (2010), and NRCAN (2010) wood fuels provide a carbon neutral alternative to fossil fuels currently being used in various economic sectors.

One example of how wood energy can be used to reduce GHG emissions is through Cogeneration. (*Combined Heat and Power or CHP*). Cogeneration is the coetaneous generation of heat and power, which are both consumed at the same time (COGEN Europe, 2017). Meanwhile, cogeneration can cut two-thirds of GHG compared to coal plants (NSW, 2017). Renewables (biogas, biomass, biofuels) provide 60% of total gross electricity generation of fuels from European Union cogeneration power plants (COGEN Europe, 2017).

Eriksson & Kjellström, (2010) analyzed excess wood ethanol from potential sources including electricity district heat. Eriksson & Kjellström, (2010) looked for possibilities where electricity comes from residues, solid fuel, and heat. The results found a combined cycle power plant with wood fuel reduced CO_2 emissions 25% per litre of created ethanol compared to other options, while not requiring a large base load, making it more accessible in finding a suitable ethanol plant (Eriksson & Kjellström, 2010).

Meanwhile, Bright, Stroman, & Hawkins (2010), investigated the possibilities of wood biomass as a solution towards GHG mitigation within Norway. Bright et al., (2010), showcased two scenarios where wood biofuels can displace fossil fuels in the transportation sector: A passive projection (50% wood biofuels use by 2050) and ambitious projection (50% wood biofuels by 2035, from the declining pulp & paper industry). Considerable CO_2 emission reductions were found in road transportation in both the passive (6.1 megatonnes of carbon emissions [Mt-CO_2 yearly]) and the ambitious (7.8 Mt-CO_2 yearly) scenarios, decreasing emissions by 39% and 51% respectively (Bright et al., 2010)

Based on Bright et al.'s (2010) analysis suggest wood biofuels can reduce CO_2 emissions globally ranging from 58 Mt-CO_2-eq under the passive scenario, and 83 Mt-CO_2-eq with the ambitious scenario. Pulp and paper imports reduced GHG emission mitigation by 23 Mt-CO_2-eq due to pulp and paper imports (Bright et al., 2010).

Some challenges are facing the development of wood bioenergy. Improper land management can lead to root and soil losses, (Johnson et al., 2010) and impact total GHG emissions. Johnson et al. (2010) relate to McKechnie, Colombo, Chen, Mabee, & MacLean's (2010) concerns, with the relationship between harvested biomass and complexity of forest carbon stocks. A better approach to mixing forest carbon modeling and LCA is needed, considering standing forest trees only show a limited GHG reduction in wood fuel use (McKechnie et al., 2010). The Government of Quebec (2012) in a report said standing forest trees have the most extended carbon payback of over 20 years compared to wood waste from residues (under ten years) and deadwood from pine beetle invasions and wildfires (10-20 years).

Zhang, Johnson, & Wang (2015) analyzed LCA impacts regarding wood bioenergy production in Michigan. Factors included in the use of emissions for harvesting, biomass along with transportation. Zhang et al.'s., (2015) case study of the Gaylord biofuel facility in Michigan, was in a significant biomass resource-rich area. Research from Zhang et al., (2015) found with the plant running on wood biofuels created 60% less GHG emissions. However, Zhang et al., (2015) found harvesting machines using fossil fuels, along with longer distances in transportation, offset potential decreases in carbon emissions from woodfuel use.

Both Sweden (with cogeneration use) and Norway show the potential wood fuels has as a clean energy source which mitigates GHG emission. However, accounting for land mismanagement, and LCA factors, including transportation, is required for sustainable development.

Residual Wood Waste

Residual wood waste comes from byproducts of either indirectly from primary and secondary industries (saw scrap, shavings, sawdust, black liquor) or recovered wood fuels from non-forest sector activities (wood chips, pellets, briquettes, powder) (Johnson et al., 2010). Most Canadian wood feedstocks came from forest residues and categorized as indirect wood fuels. (NRCAN, 2010).

Carriquiry, Du, & Timilsina (2011) said forest residues (from harvested operations, forest land extracted, wood fuel) and wood processing residues from primary and secondary sources provide abundant amounts of residue from extensively used sources, creating surplus wood material and supporting a healthy forest. Wood residues have the quickest carbon debt payback (10 years) then damaged wood (10-20 years) and then standing forest wood (20 years) (Government of Quebec, 2012)

One industrial source which can leverage wood waste residues is aviation biofuels. Residues provide high levels of sequestering carbon emissions (95%) only behind algae (IATA, 2015). Airlines are trying to reduce their carbon emissions by 50% baseline to 2005 levels by 2050 (IATA, 2015). Fernando Preto, a researcher at NRCAN told *The Globe and Mail* millions of tonnes of excess bark, branches, and wood scraps from cutting could help meet Canadian jet fuel industry requirements (Marowits, 2017). WestJet's Fuel & Environmental Director Geoffrey Tauvette also told the *Globe & Mail* (Marowits, 2017) biofuels are the best way to cut emissions while researching improving aircraft efficiency. Wood waste can also provide a clean alternative to coal in electrical power plants. Ontario Power Generation switched an Atikokan electricity plant from coal to now running on wood pellets (CCFM, 2017).

However, there are concerns with forest residues within the context of climate change mitigation. Repo, Tuovinen, & Liski, (2015) said forest residue collecting methods don't necessarily ensure wood-based bioenergy is carbon neutral. Wiens, Fargione & Hill (2011) suggest soils & plants have 2.7 times greater carbon than in the atmosphere, causing a concern if forest residues from improper land management. Limited access to residues can also raise transportation costs of residue collecting activities (Carriquiry et al., 2011). Increased use of transportation will likely cause more fossil fuel use, impacting the LCA on GHG emissions mitigation, based on analysis from Zang et al., (2015). Caution is needed when using wood residues to ensure the carbon payback is within a short period and no indirect GHG emissions are released.

DeadWood

Pine beetle or wild firewood (deadwood) provide another form of wood waste. Increasing seasonal temperatures are accelerating pine beetle populations, causing considerable damage to Western Canada's forest (Warren & Lemmen, 2014). Freezing temperatures (-35C) had kept the pine beetle contained. However, declining cold temperatures have helped advanced the mountain pine beetle population. By 2012, 18.1 million hectares have been affected in Western Canada from the pine beetle explosion, affecting the forest supply, while reducing carbon sinks (Warren & Lemmen, 2014). Pine beetle infestations will alone discharge 270 megatons of atmospheric carbon dioxide into the atmosphere by 2020 (Kurz et al., 2008).

Climate change is also expected to increase extreme weather events, including wildfires and intense heatwaves (National Oceanic and Atmospheric Association [NOAA], 2016). Higher temperatures from human-induced climate change have increased Canadian wildfires in the past forty years (Flannigan et al., 2013). More wildfires are expected in northern regions of Canada, Russia, and Alaska due to a warming world thanks to three reasons: hotter temperatures evaporating water quickly, which holds more water vapor, creating lower water table positions, and cutting fuel moisture (Flannigan et al., 2013). Either more intense rainfalls or droughts will occur from this. The second reason is rising temperatures will create more lightning strikes (Flannigan et al., 2013). The third reason is wildfire season will likely increase from warmer temperatures lasting longer (Flannigan et al., 2013).

Its estimated about 2.1 million hectares on average yearly from over 8,000 fires from lightning strikes cause 85% of hectares burn while only half the fires (Canadian Wildland Fire Information System, 2017).

As discussed both the rise of pine beetle and wildfires reduce carbon sequestration (Hofstetter & Wagner, 2011). However, pine beetle and wildfire-damaged wood can provide new opportunities, cutting discharged carbon, while trimming biofeedback’s from future wildfires (Hofstetter & Wagner 2011). Kumar (2009) echoes Hofstetter & Wagner's (2011) sentiments, suggesting developing a bio-economy based on damaged wood from pine beetles and wildfires, can help reach climate goals, and create jobs. Deadwood also provides a low to modest carbon debt payback of 10-20 years (Government of Quebec, 2012).

Deadwood can be used as aviation fuel. Nonfood based feedstocks, including storm wood waste, provide an environmentally sustainable alternative to first generation (1G) feedstocks (Hari, Yaakob, & Binitha 2015). With air travel to expand, partially thanks to an increasing appetite from the middle class in emerging markets (Boeing, 2016), wood waste from deadwood will play in in an important role for more environmentally friendly aviation fuel sources.

Deadwood’s biggest challenge is it creates more intermediate term GHG emissions, while in the long term these increases are offset from forests used as carbon sinks (NRCAN, 2010). Detailed attention must be taken in the processes of developing fuels from deadwood

Discussion

With 112GW in capacity, generating 504 TWh of electricity, and 135 billion litres of ethanol in 2016 (REN21, 2017) biofuels will have a crucial role in GHG mitigation, including wood-based fuels, and can provide a competitive feedstock amongst other options.

First generation (1G) biofuels come from starch sugar, animal fats and oil crops, which are used for feed or food (Eisentraut, 2010). Examples include Brazilian sugar cane or corn ethanol from the United States. Depending on the feedstock, biofuels (sugarcane) can offer as high as 90% GHG reduction (Koçar & Civas, 2013). However, competition with food-based crops, indirect carbon emissions from land mismanagement (Eisentraut, 2010) and high use of fertilizers limits most 1G biofuel feedstocks GHG reduction potential. Corn-based ethanol uses fertilizers and fossil fuels for transportation, which dramatically lower corn ethanol GHG reduction (Doornsbosch & Steinblik, 2008). Wiens, Fargione, & Hill (2011) note GHG mitigation only occurs when proper land management and containing carbon reposition is higher than if there was no biofuel production. Therefore, the food vs. fuel debate makes 1G biofuels as an unsustainable energy source, compared to wood feedstock, as it does not have to compete for food over biofuel development.

Second generation (2G) biofuels come from lignin, cellulose or hemicellulose (Eisentraut, 2010). Examples of second-generation feedstocks include forage crops (switchgrass, miscanthus), agricultural residues which are used for ethanol, & jatropha, which is used for biodiesel (Carriquiry et al., 2011). Like wood-based feedstocks, other 2G biofuels don't have with food vs. fuel concerns as first-generation biofuels do. Some cellulosic feedstocks can reduce GHG emissions by 80% from lignin combustion for electricity & heat processing (Scown, Gokhale, Willems, Horvath, & Mcone, 2014). However, second-generation biofuels face some concerns, including adverse environmental impacts if soils are not adequately managed for certain feedstocks (Carriquiry et al., 2011). Wood feedstocks while having the same benefits of 2G biofuels also have similar challenges with regards to proper soil and harvesting management techniques to ensure wood and wood waste feedstocks are environmentally sustainable. Regional differences, where non-food based crops (switchgrass, miscanthus) are plentiful compared to wood biomass in some areas, would make 2G biofuels a more logical local choice (Canadian Prairies & American Midwest vs. Northern Canada and Pacific regions) when offered.

Microalgae biofuels possibly provide an optimal biofuel solution for mitigating GHG emissions. Algae consume considerable allocations of carbon while sequestering it (Singh, Olsen, & Nigam, 2011). Algae-based biofuels can grow in areas (lakes, oceans, desert lands) which conventional 1G and 2G fuels can't, providing algae a comparative advantage (Miller, 2010). Algae biofuels do not have to compete for food which makes algae more environmentally friendly than 1G biofuels and has more significant conversion rates than 2G fuels (Milano et al., 2010). Algae-based biofuels can provide a diverse set of energy types including bioethanol, biohydrogen, biodiesel, and biogas (Jones & Mayfield, 2012).

However, energy inefficiency from half of the energy used and half of the GHG emissions coming from fertilizers, (Lam & Lee, 2012), along with high capital cost from harvesting (Milano et al., 2010) create some environmental and economic concerns for algae biofuels. In comparison, wood fuels are readily available, provide ample supplies of bioenergy, with using forests as a carbon sink to also mitigate carbon.

Fourth generation (4G) biofuels may offer future promise including solar biofuels because of their ability to change instantly to fuels, creating plenty of clean energy through synthetic dialogical development (Aro, 2016). However, further development and research is needed to find scientific breakthroughs to make 4G biofuels commercially scalable in the future (Aro, 2016), which limits their near-term use.

Solutions

Biofuels, when correctly used, can provide a reliable tool for mitigating climate change. Wood and wood waste (residues and deadwood) are an opportunity to use an underutilized renewable energy resource while respecting sound economically and environmentally sound principles.

Tax credits, to support sustainable wood-based fuel industries, like the US solar investment tax credit of 30% (SEIA, 2017) in forest resource-rich areas including Northern Canada would help to encourage communities to produce energy from wood or wood waste. Subsidies in wood ethanol plant projects including the Colorado Department of Energy providing $30 million USD for developing cellulosic ethanol from pine beetle wood to fuel (Hofstetter & Wagner, 2011) would also help support those communities in climate change strategies, and those hampered from declining pulp and paper mill industries. Eliminating regulations and restrictions on low carbon energy development can help speed up deployment while having long-term policy frameworks over a specific time frame (10-15 years) ranging from country transport targets, phasing out fossil fuels and fossil fuel subsidies would help support further biofuel use (IEA, 2017b). Improving trade barriers by lifting tariffs on biofuels can help countries meet sustainability goals (IEA, 2017b).

Developing global certification of biofuels must be incorporated to ensure developing bioenergy in an environmentally friendly manner, can reduce critical concerns of unsustainable production (clear cutting from deforestation, low LCA's, high fertilizer use) (Doornbosch & Steenblik, 2008).

Conclusion

With growing concerns on climate change, and population increase, sustainable biofuels can provide a sustainable alternative for electricity, heat, and transportation fuels instead of fossil fuels, Wood-based fuels (either harvested standing wood or through wood waste) provide opportunities for developing a GHG mitigation energy strategy where it's applicable.

Wood can be used as both a carbon sink and for energy use. Through proper management, Wood fuels through cogeneration can reduce carbon emissions, and help cut carbon emissions drastically. However, improper land management and usage of fossil fuels for transportation of fuel can decrease GHG mitigation benefits. Wood waste (residues from industrial production) along with damaged provide lower carbon debt payback rates then harvested wood and can be used for many uses including eco-friendly jet fuel. Wood waste faces challenges of higher transportation costs, likely correlated to higher fossil fuel use, and the potential indirect increase of carbon emissions from improper land use. Wood-based fuels offer a competitive alternative to 1G biofuels as they don't compete with food, while are more commercially accessible now than algae fuels.

Overall, improving economic incentives in relevant forest resource areas (tax credits, direct investments), elimination to trade barriers for biofuels with countries, along with developing a biofuel certification system would help ensure a globally environmentally sustainable bioenergy strategy into the future.

References

Aro, E. M. (2016). From first generation biofuels to advanced solar biofuels. *Ambio*, *45*(1), 24-31.

Boeing (2016). Long Term market: Current Market Outlook 2016-2035. Boeing. Retrieved September 24, 2017. http://www.boeing.com/commercial/market/long-term-market/traffic-and-market-outlook/.

Bright, R. M., Strømman, A. H., & Hawkins, T. R. (2010). Environmental Assessment of Wood-Based Biofuel Production and Consumption Scenarios in Norway. *Journal of Industrial Ecology*, *14*(3), 422-439.

Canadian Council of Forest Ministers [CCFM] (2017). Fact Sheet: Bioenergy from Canadian Forests. *CCFM*. Retrieved December 3, 2017. https://www.sfmcanada.org/images/Publications/EN/Bioenergy_EN.pdf.

Canadian Wildland Fire Information System (2017). Canadian Wildland Fire Information System: Canadian National Fire Database. *Canadian Wildland Fire Information System*. Retrieved November 24, 2017. http://cwfis.cfs.nrcan.gc.ca/ha/nfdb.

Carriquiry, M. A., Du, X., & Timilsina, G. R. (2011). Second generation biofuels: Economics and policies. *Energy Policy*, *39*(7), 4222-4234.

Center for Climate & Energy Solutions [C2ES] (2017a). Renewable Energy. *Center for Climate & Energy Solutions*. Retrieved December 3, 2017. https://www.c2es.org/content/renewable-energy/.

Center for Climate & Energy Solutions [C2ES] (2017b). Carbon Emissions. *Center for Climate & Energy Solutions*. Retrieved November 26, 2017. https://www.c2es.org/content/international-emissions/.

CO_2.Earth (2017). Carbon Emissions. *CO_2.Earth.* Retrieved December 1, 2017. https://www.co2.earth/.

COGEN Europe (2017). What Is Cogeneration? *CONGEN Europe*. Retrieved December 3, 2017. http://www.cogeneurope.eu/what-is-cogeneration_19.html.

Doornbosch, R., & Steenblik, R. (2008). Biofuels: is the cure worse than the disease?. *Organization for Economic Cooperation & Development OECD.* Retrieved Nov 27, 2017.

Demirbas, A. (2017). Tomorrow's biofuels: Goals and hopes. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *39*(7), 673-679.

Eisentraut, A. (2010). Sustainable production of second-generation biofuels. *International Energy Association (IEA).*

Eisentraut, A., Brown, A., & Fulton, L. (2011). Technology roadmap: biofuels for transport. Parix Cedex: International Energy Agency.

Environmental Protection Agency [EPA] (2017). Global Greenhouse Gas Emissions Data. https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data *EPA.* Retrieved November 26, 2017.

Eriksson, G., & Kjellström, B. (2010). Assessment of combined heat and power (CHP) integrated with wood-based ethanol production. *Applied Energy*, *87*(12), 3632-3641.

Flannigan, M., Cantin, A. S., De Groot, W. J., Wotton, M., Newbery, A., & Gowman, L. M. (2013). Global wildland fire season severity in the 21st century. *Forest Ecology and Management*, *294*, 54-61.

Government of Canada. (2015, November 23). The Science of Climate Change. *Government of Canada.* Retrieved November 5, 2017. http://publications.gc.ca/collections/collection_2017/eccc/En4-303-2015-eng.pdf.

Government of Quebec (2012). Scientific advisory report The Use of Forest Biomass to Reduce Greenhouse Gas Emissions in Quebec. Government of Quebec. Retrieved Nov 26, 2017. https://mffp.gouv.qc.ca/english/publications/forest/forest-biomass.pdf

Hansen, J., Sato, M., Kharecha, P., Beerling, D., Berner, R., Masson-Delmotte, V., ... & Zachos, J. C. (2008). Target atmospheric CO_2: Where should humanity aim? The Open Atmospheric Science Journal, 2008, 2, 217-231.

Hari, T. K., Yaakob, Z., & Binitha, N. N. (2015). Aviation biofuel from renewable resources: routes, opportunities and challenges. *Renewable and Sustainable Energy Reviews*, *42*, 1234-1244.

Hofstetter, R. W., & Wagner, M. R. (2011). Carbon, bark beetles, and biofuels. *Journal of Forestry*, *109*(4), 245-246.

International Air Transport Association [IATA] (2015). IATA Sustainable Aviation Roadmap: 1st Edition. *IATA*. Retrieved November 26, 2017. https://www.iata.org/whatwedo/environment/Documents/safr-1-2015.pdf.

International Energy Agency (IEA) (2017a). Global EV Outlook 2017. *IEA.* https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf. Retrieved November 26, 2017.

International Energy Agency (IEA) (2017b). Technology Roadmap: Developing Sustainable Bioenergy. *IEA.* Retrieved December 2, 2017. http://www.iea.org/publications/freepublications/publication/Technology_Roadmap_Delivering_Sustainable_Bioenergy.pdf.

International Renewable Energy Agency [IRENA] (2017). Biofuels for Aviation: A Technology Brief. *IRENA*. Retrieved November 26, 2017. http://www.irena.org/documentdownloads/publications/irena_biofuels_for_aviation_2017.pdf

Johnson, F. X., Tella, P. V., Israilava, A., Takama, T., Diaz-Chavez, R., & Rosillo-Calle, F. (2010). What woodfuels can do to mitigate climate change. Food and Agricultural Organization of the United Nations (FAO).

Jones, C. S., & Mayfield, S. P. (2012). Algae biofuels: versatility for the future of bioenergy. *Current opinion in biotechnology*, *23*(3), 346-351.

Koçar, G. and N. Civas (2013). An overview of biofuels from energy crops: Current status and future prospects. Renewable and Sustainable Energy Reviews. 28(2013): 900-916

Kumar, A. (2009). A conceptual comparison of bioenergy options for using mountain pine beetle infested wood in Western Canada. *Bioresource technology*, *100*(1), 387-399.

Kurz, W. A., Dymond, C. C., Stinson, G., Rampley, G. J., Neilson, E. T., Carroll, A. L., ... & Safranyik, L. (2008). Mountain pine beetle and forest carbon feedback to climate change. *Nature, 452*(7190), 987-990.

Lam, M. K., & Lee, K. T. (2012). Microalgae biofuels: a critical review of issues, problems and the way forward. Biotechnology advances, 30(3), 673-690.

McKechnie, J., Colombo, S., Chen, J., Mabee, W., & MacLean, H. L. (2010). Forest bioenergy or forest carbon? Assessing trade-offs in greenhouse gas mitigation with wood-based fuels. *Environmental science & technology*, *45*(2), 789-795.

Marowits, R. (2017, July 25). Canadian Airlines Aim to Become Biofuel Superpower, Reduce Carbon Emissions. *Globe and Mail.* Retrieved November 26, 2017. https://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/canadian-airlines-aim-to-become-biofuel-superpower-reduce-carbon-footprint/article35793305/.

Miller, S. A. (2010). Minimizing land use and nitrogen intensity of bioenergy. Environmental science & technology, 44(10), 3932-3939.

National Geographic. (2017). Reference: Biofuels. *National Geographic.* Retrieved December 4, 2017. https://www.nationalgeographic.com/environment/global-warming/biofuel/.

National Oceanic and Atmospheric Association [NOAA] (2016, December 15). Scientists: Strong Evidence That Human-Caused Climate Change Intensified 2015 heatwaves. *NOAA*. Retrieved December 4, 2017. http://www.noaa.gov/media-release/scientists-strong-evidence-human-caused-climate-change-intensified-2015-heat-waves.

Natural Resources of Canada [NRCAN] (2010). Is Forest Bioenergy Good For the Environment?: Canadian Forest Service Science- Policy Notes. *NRCAN.* Retrieved November 16, 2017. http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/31936.pdf.

NSW (2017). Cogeneration. *NSW*. Retrieved December 3, 2017. https://www.resourcesandenergy.nsw.gov.au/energy-consumers/sustainable-energy/cogeneration.

Renewable Energy Policy Network For The 21st Century. (REN21) (2017). *Renewables 2017: Global Status Report. Renewable Energy Policy Network For The 21st Century*.

Repo, A., Tuovinen, J. P., & Liski, J. (2015). Can we produce carbon and climate neutral forest bioenergy?. *Gcb Bioenergy*, *7*(2), 253-262.

Scown, C. D., Gokhale, A. A., Willems, P. A., Horvath, A., & McKone, T. E. (2014). Role of lignin in reducing life-cycle carbon emissions, water use, and cost for United States cellulosic biofuels. *Environmental science & technology*, *48*(15), 8446-8455.

Singh, A., Olsen, S. I., & Nigam, P. S. (2011). A viable technology to generate third-generation biofuel. *Journal of Chemical Technology and Biotechnology*, *86*(11), 1349-1353.

United Nations [UN] (2017, June 21). World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100. *UN*. Retrieved November 5, 2017. https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html

United Nations Framework Convention on Climate Change [UNFCC] (2017). The Paris Agreement. *UNFCC.* Retrieved December 3, 2017. http://unfccc.int/paris_agreement/items/9485.php

Warren, F.J. and Lemmen, D.S. (2014): Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation; Government of Canada, Ottawa, ON, 286p. Retrieved Nov 23, 2017 at http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2014/pdf/Full-Report_Eng.pdf.

Watson, R, McCarthy J., Hisas, L. (2017, September). *The Economic Case For Climate Action in the United States*. Alexandria Virginia. Universal Ecological Fund.

Wiens, J., Fargione, J., & Hill, J. (2011). Biofuels and biodiversity. *Ecological Applications*, *21*(4), 1085-1095.

World Economic Forum [WEF] (2017a). Shapers Survey. *WEF*. Retrieved October 29, 2017. http://shaperssurvey.org/static/data/WEF_GSC_Annual_Survey_2017.pdf.

Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (2017). Climate Science Special Report: Fourth National Climate Assessment, Volume I *U.S. Global Change Research Program*, Washington, DC, USA. Retrieved November 3, 2017. https://science2017.globalchange.gov/downloads/CSSR2017_FullReport.pdf.

Zhang, F., Johnson, D. M., & Wang, J. (2015). Life-cycle energy and GHG emissions of forest biomass harvest and transport for biofuel production in Michigan. *Energies*, *8*(4), 3258-3271.