Chemical Relationships between Greenhouse Gases and Air Pollutants in Biomass Energy Production

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Many proposals for alternative sources of energy have been put on the table as solutions to the climate change crisis: wind, solar, nuclear, natural gas, geothermal, hydroelectric, and biomass. However, not all of these sources are as clean and renewable as they claim to be; in particular biomass power plants emit an abundance of greenhouse gases that make them a part of the problem and not part of the solution.[1] Indeed "biomass burning may be an important driver for global change in the atmosphere and climate" (Levine).

The pollutants emitted by biomass power plants that contribute to climate change can be divided into two basic groups: direct greenhouse gases and indirect greenhouse gases. The direct greenhouse gases are carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). The indirect greenhouse gases are non-methane volatile organic compounds (NMVOCs), nitrogen oxides (NOx) comprised of nitrogen monoxide (NO) and nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO). The direct greenhouse gases serve to increase global warming by absorbing infrared radiation radiated from earth's surface and lower atmosphere, trapping it, and radiating it back towards the surface of the planet, therefore warming the earth (U.S. Global Change Research Program 14). The indirect greenhouse gases contribute to global warming by producing direct greenhouse gases through reactions with other chemical compounds, through their own chemical transformations, influencing the atmospheric lifetime of other greenhouse gases, and affecting the absorptive characteristics of the atmosphere such as affecting cloud formation (United States Environmental Protection Agency, "Inventory" ES-2).

Carbon Dioxide

The contribution of carbon dioxide, the flagship greenhouse gas and largest source of U.S. greenhouse gas emissions, emitted from biomass power plants to climate change has been overlooked due to an assumption of carbon neutrality (United States Environmental Protection Agency, "Inventory" ES-7). In the natural carbon cycle, carbon dioxide is stored in sinks such as oceans and forests and is released by sources; naturally CO_2 stays roughly balanced between sources and sinks. Humans have altered this equilibrium primarily by burning fossil fuels, however "important contributions [come] from the clearing of forests" and other changes in forestry and land use practices (United

[1] The predicted emissions from the proposed 18 megawatt Seneca cogeneration biomass power plant in Eugene, Oregon will be referred to throughout this paper to provide an illustration of the amount of emissions released by biomass power plants. The primary focus of this report is woody biomass, however the incineration of waste biomass will be referred when discussing methane.

States Environmental Protection Agency, “Inventory” ES-7; U.S. Global Change Research Program 9). Supporters of biomass power plants say that the CO_2 released from burning biomass is effectively carbon neutral because it would have been released naturally in the decomposition process, in a routine cycle from a sink to a source.

In fact, biomass power plants can be “either CO_2 neutral, positive or negative” (Azar 49). The incineration of woody debris collected off the forest floor that already is beginning the decomposition process, or would have been burned as part of forest management, is considered to be carbon neutral. However burning debris, while effectively carbon neutral, still releases CO_2 into the air much faster than through natural decomposition. It is assuredly not carbon neutral to log and burn mature, standing trees. The removal of these trees eliminates a carbon sink and upon incineration turns them into a carbon source; even if the trees are immediately replanted there is at a minimum 30 to 60 years, the time required for tree growth, in which more carbon has been released into the atmosphere than was previously being stored.

Logging and incinerating trees amplifies the greenhouse effect: “Forests hundreds of years old can continue to actively absorb carbon, holding great quantities in storage. Resprouting clear-cuts, on the other hand, often emit carbon for years, despite the rapid growth rate of young trees” (Levy 2). Deforestation also leads to soil disruption causing a release of the carbon stored in soils (Booth “Letter, 6 July 2008”). Indeed, 20 percent of human-induced CO_2 emissions over the last several decades are from deforestation and associated agricultural practices (U.S. Global Change Research Program 14). Casting off biomass plants that burn fresh trees as carbon neutral ignores this reality. Furthermore, touting biomass power plants as carbon neutral and failing to report the transformation of the logs from carbon sinks to sources violates the Kyoto Protocol’s requirement to report “ ‘net changes in greenhouse gas emissions by sources and removal’s by sinks resulting from direct human-induced land use change and forestry activities’ ” (Johnson 2).

Prior to combustion, the CO_2 contributions from the operations required to run the biomass power plants as well as the forestry practices being used for biomass fuel need to be evaluated: “the carbon impact of bioenergy systems also depends on the input of fossil fuels in the production, transport and conversion of the biomass” (Azar 49). The processes for growing trees used for biomass, such as spraying pesticides and fertilizing the soil, require a huge amount of fossil fuels for their creation and for their distribution and application, which typically requires the use of airplanes, helicopters, or tractors. Harvesting trees requires heavy equipment run on fossil fuels such as bulldozers and saws. Similarly, hauling all the biomass (e.g. slash, tree tops, branches, leaves) from the forests to the energy plants in inefficient trucks powered by fossil fuels is also a major source of CO_2 (Booth “Letter, 6 July 2008”). These practices are unarguably not carbon neutral. Truck transport generates more CO_2 than leaving the biomass on the forest floor and finding other ways to meet our energy needs.

Burning biomass reduces our ability to slow climate change through the sequestration of CO_2, and instead accelerates its progress by transforming sinks to sources and speeding up the release of CO_2 from natural sources such as woody debris: “when compared to coal, per megawatt, this [biomass] burning emits 1.5 times the carbon dioxide" (Ayers et al.). Furthermore, the longer we wait to reduce our emissions of CO_2 the smaller the effect our efforts will have (U.S. Global Change Research Program 9). Therefore, we must begin evaluating the true carbon reality of biomass and looking for new ways to meet our energy needs.

Nitrous Oxide

Nitrous oxide is another direct greenhouse gas that is produced from biomass burning (United States Environmental Protection Agency, "Inventory" 1-4); it is produced as a result of the combustion of nitrogen (Levine). While not as well known as carbon dioxide, "N_2O is approximately 300 times more powerful than CO2 at trapping heat in the atmosphere" because of its long atmospheric lifetime of approximately 120 years (United States Environmental Protection Agency, "Inventory" ES-10; United States Environmental Protection Agency "Nitrous"). Nitrous oxide is also produced through the oxidation of nitrogen monoxide (NO), which is released from biomass power plants ("NOx" 15). The concentration of N_2O in our atmosphere has increased by 18% since 1750 and will continue to increase unless we reduce the sources emitting this gas, such as biomass power plants (United States Environmental Protection Agency, "Inventory" 1-4).

Methane

Methane is another direct greenhouse gas that is produced during biomass burning. Methane is produced during the combustion of woody biomass as a result of incomplete combustion of biomass material (Simon; Levine). Methane is always produced from biomass burning because "complete combustion is not achieved under any conditions" (Levine). This gas is "is more than 20 times as effective as CO_2 at trapping heat in the atmosphere" (United States Environmental Protection Agency, "Inventory" ES 9). Furthermore, the more methane there is in the atmosphere, the longer it stays in the atmosphere. This is because the quantity of the hydroxyl radical (OH) that removes methane from the atmosphere is reduced as the concentration of methane increases, lengthening the lifetime of methane (United States Environmental Protection Agency, "Inventory" 1-3). Methane is eventually converted into CO_2 and remains in the atmosphere as a greenhouse gas although in a less potent form (United States Environmental Protection Agency, "Inventory" 1-4).

Another major source of methane is the anaerobic decomposition of organic materials such as in landfills. The incineration of landfill waste, another form of biomass, has also been put forth as an energy solution. While the combustion of landfill waste is not introducing a new source of methane, as it would have been released during decomposition anyway, describing this practice as a positive, renewable source of energy directs attention away from the harmful climatic affects of excess methane and the root cause of the emissions: our over-consumption and wasteful use of resources. Reducing our emissions of methane would lead to a reduction in global warming "within weeks to decades" and it is crucial that we do not support another source of this potent greenhouse gas (U.S. Global Change Research Program 9).

Global Warming Potentials: Direct Greenhouse Gases

The Intergovernmental Panel on Climate Change (IPCC) created the concept

Global Warming Potential (GWP) to compare the ability of different greenhouse gases to trap heat (United States Environmental Protection Agency, "Inventory" ES-2). CO_2 is used as the base gas, which the other greenhouse gases are compared to; therefore the GWP of CO_2 is 1 (ES-3). The GWP of methane is 21 and the GWP of N_2O is 310 (ES-3). Although there is less methane and nitrous oxide than CO_2 being released into the air, they are both much more powerful greenhouse gases than carbon dioxide.

Non-methane Volatile Organic Compounds and Nitrogen Oxides

Non-methane Volatile Organic Compounds (NMVOCs) and nitrogen monoxide and nitrogen dioxide (collectively known as NOx) released from biomass combustion contribute to global warming by aiding the formation of tropospheric ozone (also known as photochemical smog), which is a greenhouse gas. NMVOCs are also released from the diesel trucks that are used to bring both woody debris and fresh logs to the biomass plants. When NMVOCs combine with NOx in the presence of sunlight they form tropospheric (ground-level) ozone. Ozone in the stratosphere (upper atmosphere) is helpful to humans by protecting us from too much ultraviolet radiation, but ozone in the troposphere is a powerfully destructive force: "Tropospheric ozone…is estimated to provide the third largest increase in direct radiative forcing [warming] since the pre-industrial era, behind CO_2 and CH_4" (United States Environmental Protection Agency, "Inventory" 1-4). Although "our potential for control of Tropospheric ozone lies in reducing the levels of atmospheric pollution arising from man-made sources, such as biomass burning, industry and transportation" newly constructed biomass power plants and their fleets of inefficient trucks will only serve to increase the amount of this potent greenhouse gas (Reay). As is, Lane County is precipitously close to exceeding the ambient ozone standards established by the United States Environmental Protection Agency, and the Seneca power plant's predicted emissions of 7.73 tons per year of NMVOCs and 185.61 tons per year of NOx will only bring the County closer to this point (Bridgewater Group Inc.).

Not only do NMVOCs and NOx contribute to climate change, they also cause severe health problems. Some NMVOCs are Hazardous Air Pollutants (HAPs), which are pollutants that are known or suspected carcinogens or pose a serious threat to human health (United States Environmental Protection Agency, "About"). Exposure to NMVOCs can also cause "eye, nose, and throat irritation; headaches, loss of coordination, nausea; damage to liver, kidney, and central nervous system" (United States Environmental Protection Agency, "An Introduction"). NOx reacts with other atmospheric gases such as ammonia and fine particles to form particles of nitric acid, which can deposit themselves in the lower lungs of human beings and animals causing respiratory problems like emphysema and bronchitis and can worsen heart disease ("NOx" 14; United States Environmental Protection Agency, "Nitrogen Dioxide"). Current scientific evidence has shown even short term exposure, anywhere from 30 minutes to 24 hours, to NO_2 is linked to negative respiratory effects (United States Environmental Protection Agency, "Nitrogen Dioxide"). Furthermore, the end-product of NMVOCs and NOx, ground-level ozone, "when-inhaled, even at very low concentrations,…can cause acute respiratory problems" ("NOx" 14).

Carbon Monoxide

Carbon monoxide (CO) is well known as a human health threat and air pollutant. Carbon monoxide reduces oxygen delivery to the organs and tissues such as the brain and heart and at high levels of exposure CO can cause death (United States Environmental Protection Agency "Carbon"). However, there has not been much public discussion of the role CO plays as an indirect greenhouse gas. CO is classified as an indirect greenhouse gas because it does not absorb infrared radiation itself, but contributes to climate change through its interactions with tropospheric ozone, methane, and carbon dioxide.

Carbon monoxide is formed when carbon-containing fuels are incompletely burned and is released during biomass combustion (United States Environmental Protection Agency, "Inventory" 1-5). Carbon monoxide does not aid in the formation of tropospheric ozone or methane, but elevates concentrations of them in the atmosphere through reactions with other atmospheric chemicals such as the hydroxol radical (OH) that would otherwise be able to help destroy these greenhouse gases (United States Environmental Protection Agency, "Inventory" 1-5). Eventually CO is oxidized to CO_2 and continues contributing to climate change (United States Environmental Protection Agency, "Inventory" 1-5). Biomass burning "when compared to coal, per megawatt,…emits…1.5 times the carbon monoxide" (Ayers et al.). The proposed Seneca biomass power plant is predicted to release 200.89 tons of CO per year (Bridgewater Group Inc.).

Sulfur Dioxide

Sulfur dioxide, coupled with "elemental carbon emissions," contributes to the formation of aerosols, which directly and indirectly affect warming and cooling in the earth's atmosphere. Aerosols are exceptionally small particles or liquid droplets (United States Environmental Protection Agency, "Inventory"1-5). They directly affect the climate by scattering the sun's radiation and sending it back to space, and they indirectly affect the climate by increasing clouds' lifetimes and thickness and decreasing water droplet size, while increasing water droplet concentration in the atmosphere (2-26). Sulfur dioxide produces "sulfate aerosols" and elemental carbon emissions produce "carbonaceous aerosols," which both are created during biomass combustion (2-26, 1-5). It is believed that the net effect of aerosols is negative radiative forcing i.e. a cooling of the earth's atmosphere (1-5). However aerosols' contributions to global warming are difficult to quantify because they "have short atmospheric lifetimes, and have concentrations and compositions that vary regionally, spatially, and temporally" (1-5). Furthermore, aerosols formed from black carbon are believed to have a positive radiative forcing effect (1-5). Therefore the contribution of aerosols to global climate change is not definitive and "comparatively,…the level of scientific understanding of aerosols is still very low" (1-2). Therefore, preventative efforts should be taken to reduce the emissions of both sulfur dioxide and carbon.

Beyond sulfur dioxide's environmental impact, this gas also is detrimental to human health. Long term exposure to sulfur dioxide in both its gaseous and particulate forms can cause breathing difficulties, respiratory illness, and aggravate existing heart disease. Sulfate particles can build up in the lungs and can cause premature death. Lastly, sulfate particles can impair visibility, reducing quality of life and posing a potential safety threat (United States Environmental Protection Agency "Sulfur"). The Seneca power plant will release 38.64 tons per year of sulfur dioxide (Bridgewater Group Inc.).

Global Warming Potentials: Indirect Greenhouse Gases

There is no agreed-upon method for which to determine the exact contribution of these indirect greenhouse gases (NMVOCs, NOx, CO, SO_2) to global warming. This is due to the short lifetime of these gases in the atmosphere, their spatial variability, or their indirect effects that are hard to quantify. Therefore there is not a precise global warming formulaic potential for NMVOCs, NOx, CO, and SO_2.

Wind and Solar Power

Biomass supporters also suggest that while biomass energy may have its flaws, so do other renewable sources of energy such as wind and solar: mainly their required input of fossil fuels and their use of nonrenewable materials for their manufacturing. There is some merit to this claim. These energy sources do require an input of fossil fuels, as well as other nonrenewable materials, for their production and transport, but they do not emit any other pollutants during their lifetime as energy producers (Good Company 9). Biomass on the other hand, also requires fossil fuels for both its production and transport and emits the above cornucopia of greenhouse gases during its lifetime. While wind and solar may also use nonrenewable, energy intensive materials for their production, such as silicon for solar energy and aluminum and steel for wind, there is a high chance that if the production of these energy sources is allowed to be scaled up, technology will advance and a new, more efficient manufacturing process will be discovered. In order for this to happen we must move away from the easy and convenient solutions such as biomass production and put society's resources towards these new energy sources.

Conclusion

Taken together, direct and indirect greenhouse gases work to increase global climate change, and it is crucial that we look for energy solutions that do not further increase their presence in the atmosphere. Putting a positive spin on biomass energy deflects attention from the need for our society to reduce our consumption, the waste it produces, and ultimately reduce our impact on the climate system and the earth as a whole. Biomass power plants are an easy answer that allows the same timber and energy industries to continue to profit, while still releasing a plethora of toxins and pollutants that are harmful to our environment and our health. It is imperative that we act now to reduce our emissions of these greenhouse gases because the faster we act, the greater effect our actions will have. Burning and incineration are old, polluting practices that take us in the wrong direction in the quest for truly "green" and renewable energy. We must find innovative energy solutions that do not increase the presence of greenhouse gases in the atmosphere.

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