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Supersize Me! Utilizing Food Waste in Landfills to Reduce Greenhouse Gas Emissions and Power the Renewable Energy Transition

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ABSTRACT

Our biweekly fast food takeout is responsible for causing an increase in greenhouse gasses that is only getting worse as the population increases. The United States is a world leader in the production of food waste, as described by a writer for *The Atlantic*, with much of this waste ending up in landfills. As our population continues to grow exponentially, there needs to be a sustainable fuel supply that meets the demands of our population's fuel usage. We propose an innovative method of food waste recycling that will utilize the oversupply of food waste towards a sustainable fuel resource to effectively reduce greenhouse gas emissions and mitigate fossil fuel consumption. This research paper aims to investigate the creation of biofuels and provide meaningful insights towards the food waste and landfill problem in America. Such biofuels could be used as a more eco-friendly and sustainable replacement for the fossil fuels we use today. By targeting large sectors of plant and animal waste to create biofuels we can build cleaner cars and reduce greenhouse gas emissions.

Food Waste Is (Really) Bad for The Environment

Food waste is a big problem. Here are the numbers. In the United States, it is estimated that 30-40% of the food supply goes to food waste (*Food Waste Faqs | Usda*, n.d.). As of 2010, this was estimated to be 133 billion pounds of food per year, or approximately 220 lbs of food waste for each of the 309 million people in the US at that time (*Food Waste Faqs | Usda*, n.d.). Today, the US population is estimated at 346 million people (*United States Population 2024 (Live)*, n.d.). This increase of 37 million citizens is nearly as large as the population of California, the country's most populous state. Due to this expanding population, the amount of food waste produced has only grown. Compared to 2010 we generate an extra California's worth of food waste each year! That amounts to over 8 billion pounds of extra food waste each year.

In addition, compared to other countries, the United States is unfortunately a leader in food waste production [see figure 1]. The effects of this waste on society is multi-fold.Over time, the amount of food waste going directly into landfills is growing far more rapidly than the amount being converted into energy via combustion (*Food Waste in America in 2024*, n.d.). Not only does waste that is being burned or placed in landfills cause massive land and energy resource depletion, but transporting waste puts more vehicles on the road, consumes even more energy and puts additional strain on our roads and existing infrastructure. These avoidable events concurrently increase GHG emissions as a byproduct of motor vehicles and food waste disposal.

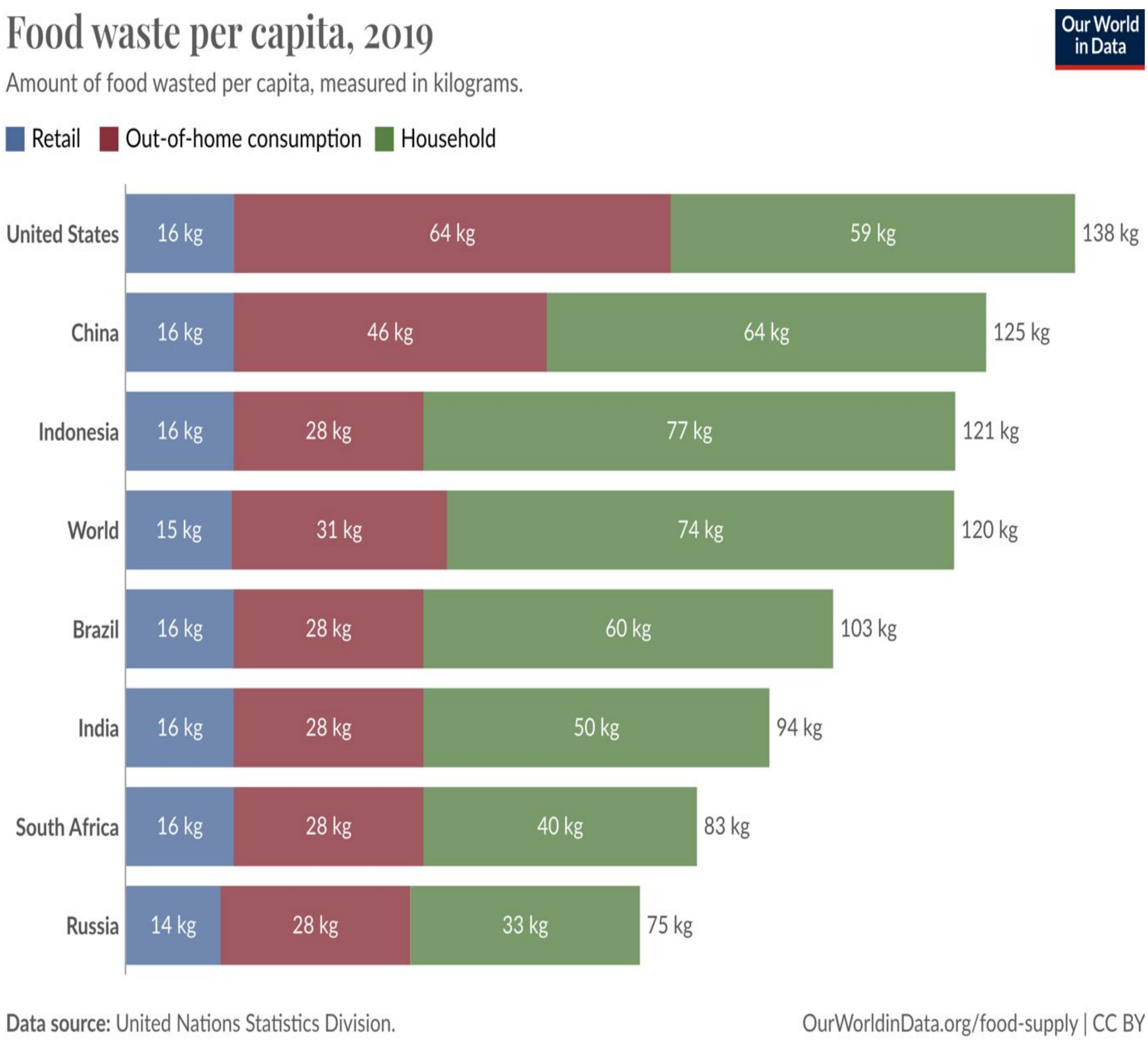

Figure 1. Food waste per capita in kilograms according to the United Nations Statistics Division.

Much of our food waste ends up in landfills. The average landfill size is 600 acres and there are over 3000 active landfill sites in the United states, so landfills occupy more than 1,800,000 acres in the US. (*The Hidden Damage of Landfills | Environmental Center | University of Colorado Boulder*, n.d.) This means that the number of landfills in the US take up the same amount of space as over 9 New York Cities.

Locally, landfills create many environmental problems. Landfills destroy the natural habitats for wildlife and contaminate nearby ecosystems. Though landfills are required by federal law to have clay or plastic liners to contain them, these liners are difficult to rely on and often leak (*The Hidden Damage of Landfills | Environmental Center | University of Colorado Boulder*, n.d.). This allows fluid created from decomposing material and percolating rainfall, called leachate, to contaminate nearby water sources. This leachate contains high levels of ammonia that is converted into nitrate. This nitrate causes eutrophication, the excessive growth of microorganisms in a body of water. When eutrophication occurs, the oxygen in the water depletes creating a “dead zone.” Dead zones are places where animals can’t survive due to lack of oxygen (*The Hidden Damage of Landfills | Environmental Center | University of Colorado*

Boulder, n.d.). The leachate also often contains dangerous toxins heavy metals such as mercury, further contaminating ecosystems.

Landfills can also cause lifelong damage to families nearby. In addition to the odor, noise, insects and pests that come along with landfills, they cause an increased risk of birth defects. Newborns have a 12% increased risk of congenital malformations if the family lives within a mile of a landfill. Landfills also have a negative effect on property values, so their effects are disproportionately borne by those with low incomes (*The Hidden Damage of Landfills | Environmental Center | University of Colorado Boulder*, n.d.).

The most globally detrimental effect of landfills is the creation of landfill gas which contributes to global warming. The predominant gasses in landfills are carbon dioxide and methane [see figure 2]. The composition of gas in landfills changes as its components degrade over time [see figure 3]. Initially, it is composed primarily of carbon dioxide produced from aerobic decomposition. Typically within a year, the oxygen is consumed, and anaerobic bacteria take over, breaking down the waste, resulting in the production of methane. As a greenhouse gas, methane has over 28 times the warming power of carbon dioxide (US EPA, 2016). The amount of methane produced in landfills is surprising. The waste sector produces an estimated 20% of global human-caused methane emissions (*Nasa Sensors to Help Detect Methane Emitted by Landfills - Nasa*, 2022) and municipal landfills were estimated to be responsible for 14% of US methane emissions in 2022 (US EPA, 2016). Material in landfills are at different stages of decomposition at the same time. Gas generation usually starts in the first year or two after waste disposal and can continue for 15-25 years (Scheutz & Kjeldsen, 2019)(Thomasen et al., 2019), with peak gas production occurring within the first 10 years (*Atsdr - Landfill Gas Primer - Chapter 2*, n.d.). This means that the trash we discard today will continue to produce GHG emissions for decades to come.

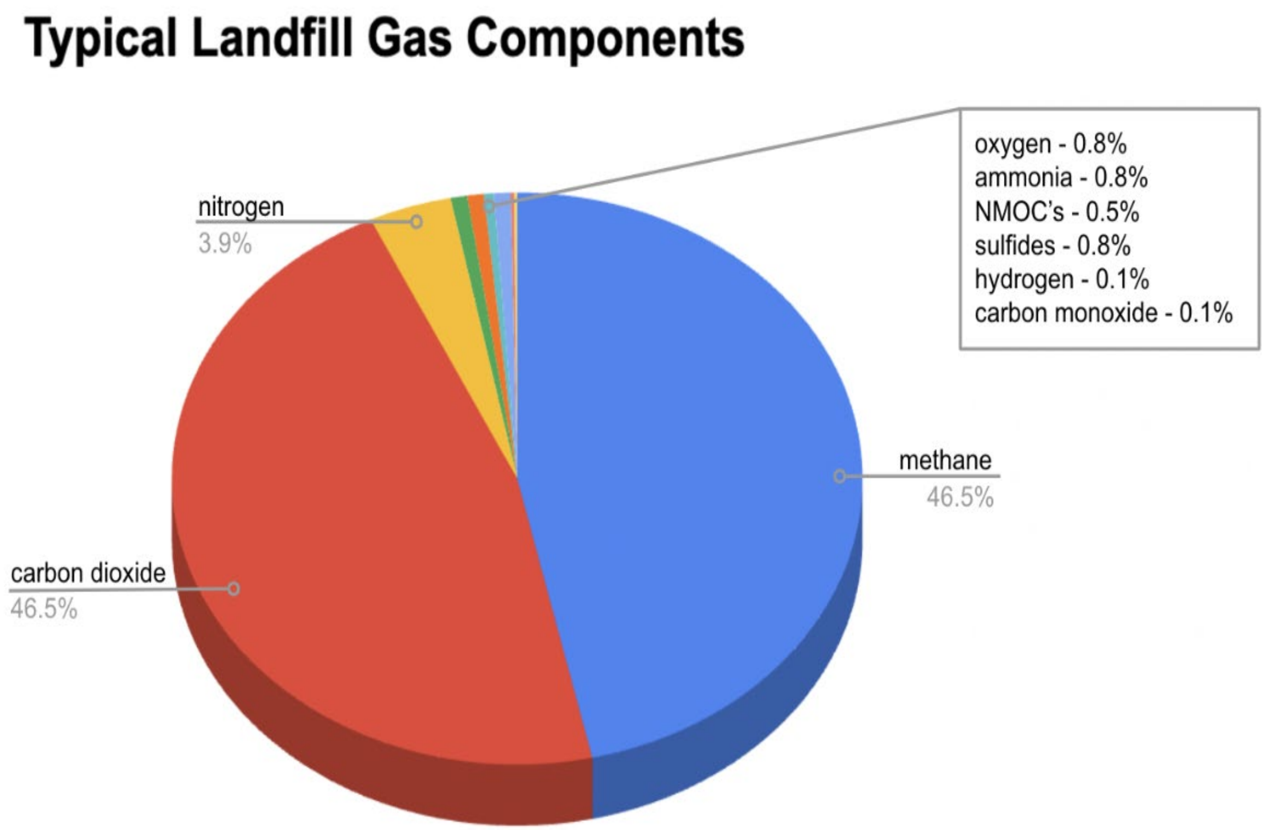

Figure 2. Gasses found in landfills with percentages of each type of gas. Adapted from (Atsdr - Landfill Gas Primer - Chapter 2, n.d.).

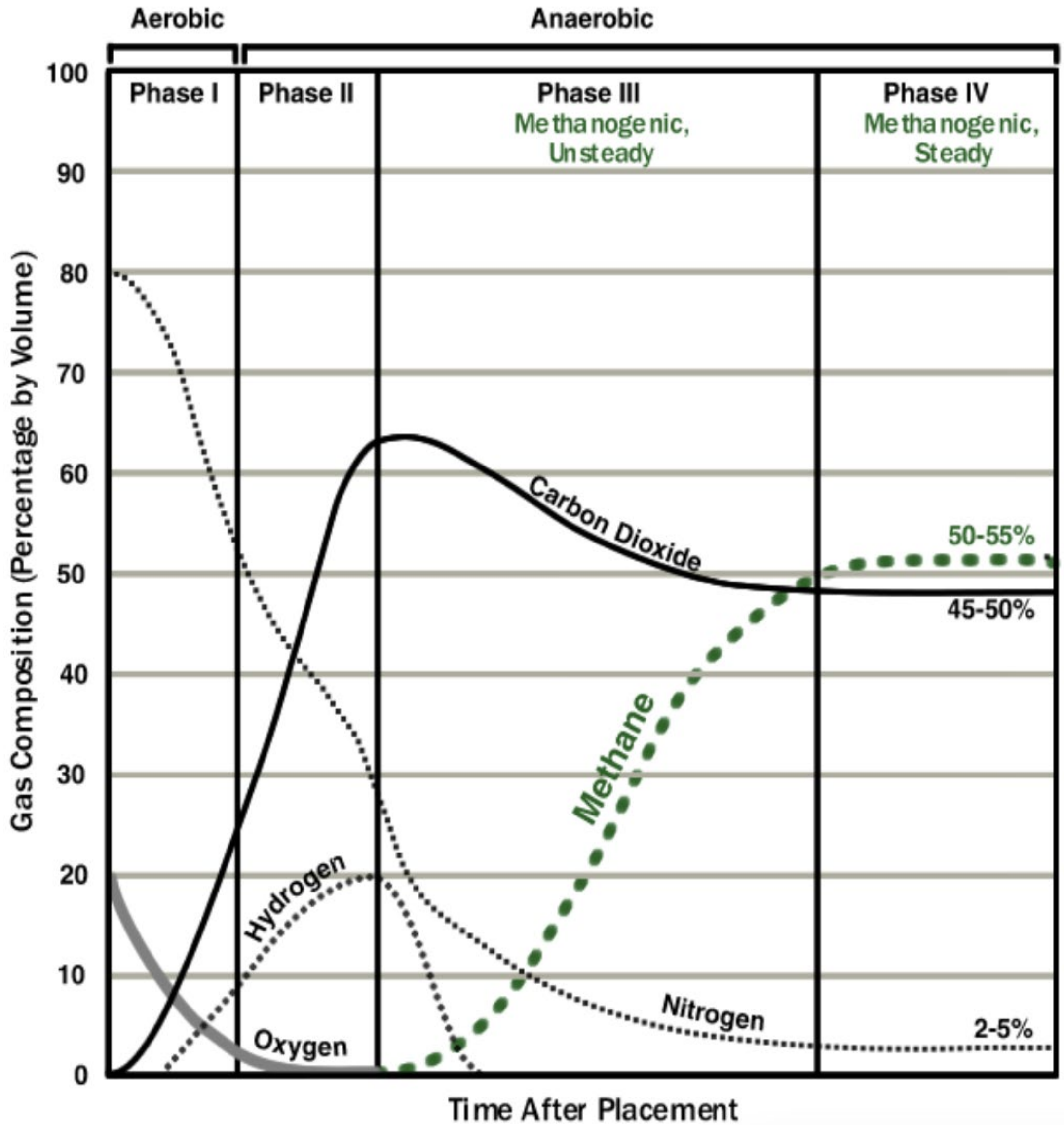

Figure 3. Production phases of typical landfill gasses. From (*Atsdr - Landfill Gas Primer - Chapter 2*, n.d.)

Landfills are responsible for 17% of methane emissions across all economic sectors (US EPA, 2016). Hypothetically, if landfills were a country, it would be the third leading country in greenhouse gas emissions (Franco, 2023). Food waste takes up 24% of landfills (makes up 432,000 acres of land) and is a large contributor to overall methane emissions (*Food Waste for Thought | the National Environmental Education Foundation(Neef)*, n.d.). This build up of food thrown out and sent to landfills leads to many pounds of methane to be released into the atmosphere. Methane is a greenhouse gas- *over* 28 times more potent than carbon dioxide (US EPA, 2016). Not only was the energy to make all that food in those landfills wasted, but the food in landfills produces methane over time (US EPA, 2023). There is an excessive amount of wasted food that according to the United States Environmental Protection Agency, the total wasted food in the U.S. produces the same amount of GHG emissions as over 50 million gas-powered cars (US EPA, 2023). This means that the methane emissions from food in US landfills produce the equivalent of 30 million gas-powered cars in methane. If we can reduce the amount of food waste in landfills, it would prevent millions of tons of methane from being released into the atmosphere (Nickolas J. Themelis & A.C. (Thanos) Bourtsalas, 2021).

In the United States, there is often little to no waste treatment of trash once it reaches a landfill. The current strategy for reducing greenhouse gas emissions from landfills focuses on drilling wells in municipal landfills and collecting landfill gas (LFG). This gas is subsequently treated to remove moisture and impurities before being used in a variety of landfill energy projects (US EPA, 2016). Such projects include the production of electricity, heat, or renewable natural gas. Heat generated from landfill gas has even been used to evaporate leachate to make it more concentrated and manageable to dispose. These strategies are important for addressing the trash that already exists in landfills. However, they do little to reduce the vast amounts of additional space that will be taken up by food in landfills in the future or to prevent the leachate and gas from being produced in the first place. It is estimated that current efforts capture only up to 40% of landfill gas, leaving much room for improvement if we are to reduce methane emissions (*WMW | GHG Emissions*, n.d.).

Singapore As an Alternative

In contrast to the United States [Figure 5], other countries such as Singapore, the world's most sustainable country, have different procedures for landfills, and we can follow in their footsteps [Figure 4] Singapore gathers all the waste and transports it to Semakau Landfill, an island 8 kilometers off the coast. Their procedure starts before anything reaches the landfill with heavily promoting the reuse of resources, recycling items, waste treatment, and only then putting waste into landfills. Singapore incinerates their waste and uses the heat for energy which in result also reduces the amount of land needed by 90% (*National Environment Agency*, n.d.). Similar strategies to those Singapore use could be very beneficial for the sustainability for the US.

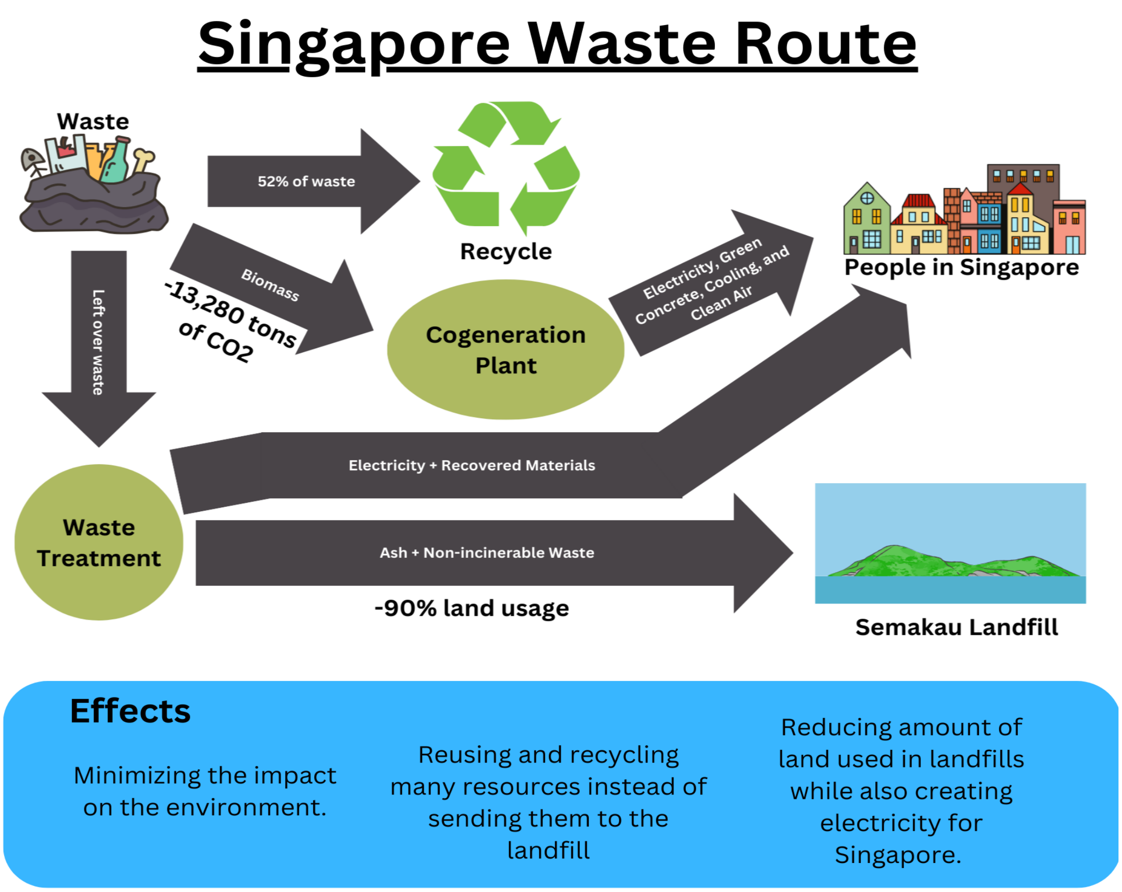

Figure 4. The method of how Singapore handles trash. Source: https://www.nea.gov.sg/our-services/waste-management/overview

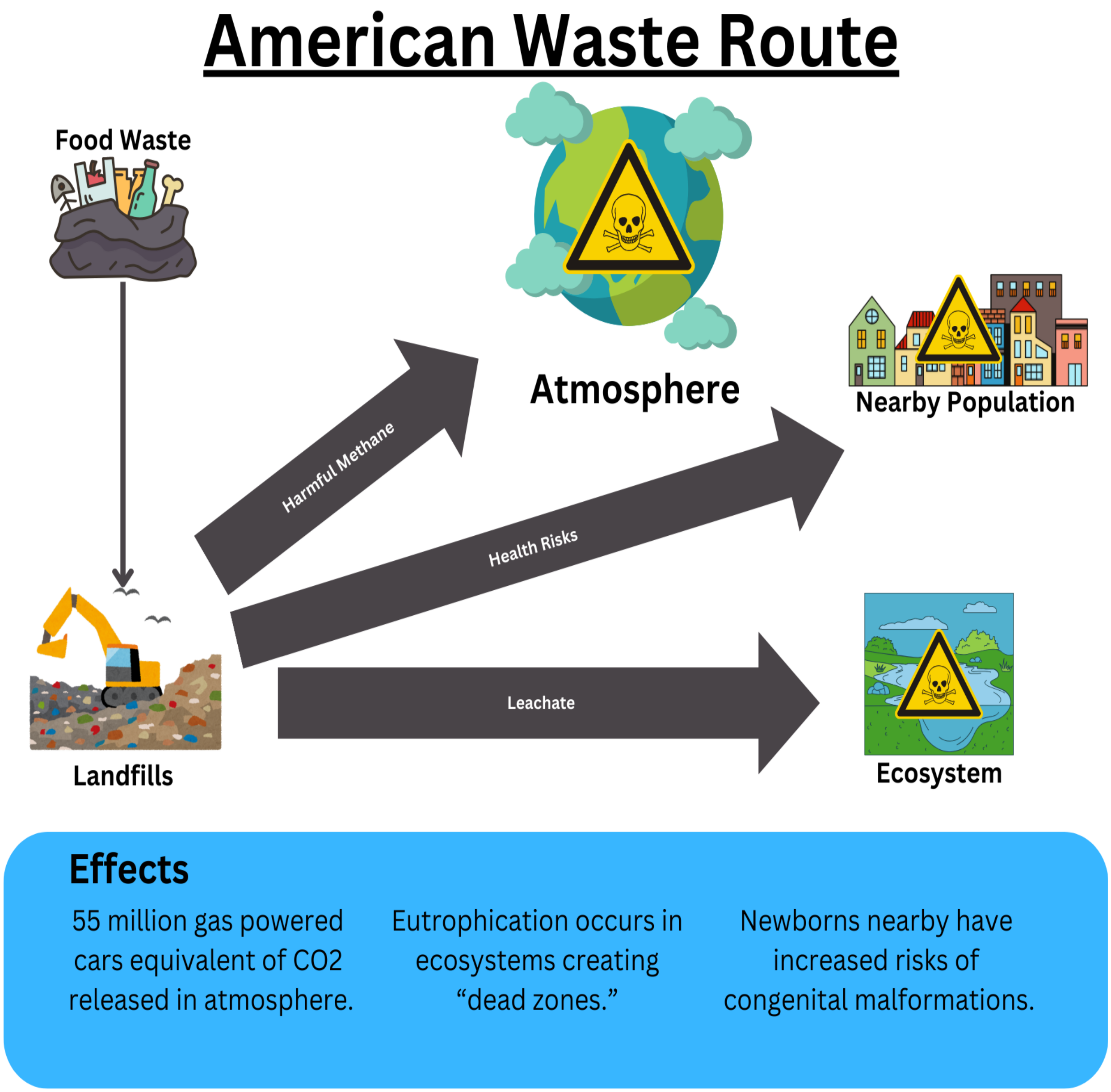

Figure 5. The method of how America handles trash. Source: https://www.colorado.edu/ecenter/2021/04/15/hidden-damage-landfills

Already, there are many initiatives from innovative companies to statewide legislations that counteract the amount of food waste going into landfills, but it is still not enough to address the rise in greenhouse gasses affecting our health and our environment (*Food Waste in America in 2024*, n.d.). The United States has been proactive with recycling and reusing resources. However, the United States throws away 52.6% of municipal solid waste into landfills leaving a lot of waste to reuse (Vaverková, 2019). We already recycle paper, metals, and plastics. Food waste can be another resource to start recycling to biofuels in the near future. Some communities already separate organic wastes for municipal composting. In 2019, 3.3 million tons of wasted food was composted from retail, food service, and household sources. While it seems massive in quantity, this accounts for only 5% of food wasted from these sources (US EPA, 2019). The recycling of food waste therefore represents a huge opportunity for helping our environment. If we were to remove all the food waste from landfills, not only would it reduce emissions of greenhouse gasses, we would have 432,000 acres of less land causing detriment to the ecosystem, environment and families nearby. This could save countless babies from getting congenital malformations and save many ecosystems in the US.

In addition, other countries, such as Japan are trying to increase recycling and biofuel use. Japan wants to use biofuels with four main goals: reduction of greenhouse gas emissions, energy security, rural development, and the realization of a recycled-based society. They are using strategies and plans to promote biofuels: The Biomass Nippon Strategy, Kyoto Protocol Achievement Plan, and New National Energy Strategy. The Biomass Nippon Strategy has four main objectives: mitigation of global warming, development of a recycled based society, incubation of a new industry, and revitalization of a recycled-based society. The Kyoto Target Achievement Plan has the objectives of a reduction of emissions 6% from 2008-2012 and reduce Japan emissions by 60%-80% by 2050. Finally, the New National Energy Strategy establishes numerical targets to improve Japan's energy security such as a 30% improvement in energy efficiency by 2030 and to reduce the dependency of the transport sector of petroleum from 100% to around 80% (Matsumoto et al., 2009).

Biofuel Is a Proven Way to Lessen Our Dependence on Non-Renewable Fossil Fuels

As our population continues to grow exponentially with a predicted peak of 10.4 billion by the year 2086, sustainable fuel demand is higher than ever (Ritchie et al., 2024). Other than the detrimental environmental impact of fossil fuels, our planet does not have enough of these finite resources to sustain energy production for the planet. Our increasing population is depleting our natural resources, including fossil fuels. The lack of action towards finding replacements for fossil fuels, will lead to an energy crisis in the near future. It is predicted that we will run out of fossil fuels to use by the year 2090 if we aren't finding new sources of fossil fuels ("When Fossil Fuels Run out, What Then?," 2019).

A direct change that we can implement for a cleaner future is to apply biofuels to existing diesel applications like vehicle engines. In 2022, biofuels accounted for 6% of the total energy sources in the US transportation sector (*Use of Energy for Transportation - u. S. Energy Information Administration(Eia)*, n.d.). However, there are many current sources of fuel that could be replaced with biofuels, including diesel fuels and jet fuel [see figure 6] (19.8% and 12% of total transportation energy sources) (*Transportation - Energy Kids: U. S. Energy Information Administration(Eia)*, n.d.). By replacing these fuels with a sustainable alternative, we could potentially save 36.6% of total greenhouse gas emissions from the US transportation sector (28.1% diesel and 8.5% jet fuels) [see figure 7] (US EPA, 2024). By convention, biofuels are net-zero to carbon emissions. This makes empiric sense, as the plants used for the biofuel first capture the carbon from the atmosphere that is subsequently released when burned as a fuel. By itself, this makes biofuels an attractive alternative to fossil fuels. One major advantage of biofuels is the ability to use them with existing equipment and infrastructure.

One particular type of biofuel that is widely used in the transportation industry is biodiesel due to its compatibility with existing diesel engines. On an energy content basis, diesel fuel accounts for around 23% of total energy consumption in the U.S. transportation sector, even though diesel vehicles account for only 7 million (about 2.5%) of the over 283 million vehicles on the road today, making diesel vehicles an attractive target for reducing emissions (*Use of Diesel - u. S. Energy Information Administration(Eia)*, n.d.). B20, a mix of 20% biodiesel and 80% petroleum diesel, is already a common blend sold at the pump. B20 reduces 15% of emissions compared to petroleum diesel and is appealing to consumers, as it costs 13 cents less per gallon and also produces nearly 99% of the energy usage per gallon than the conventional diesel equivalent. Significantly more emissions savings can be had with B100, or 100% biodiesel. B100 reduces more than 75% of emissions than petroleum diesel (*Biodiesel Basics*, 2011). B100 also has

93% of the energy of the diesel gallon equivalent (*Alternative Fuels Data Center*, n.d.). Though at a slightly increased cost. The United States Department of Energy reports that B100 gas is 50 cents more per gallon than conventional diesel (*Alternative Fuels Data Center*, n.d.).

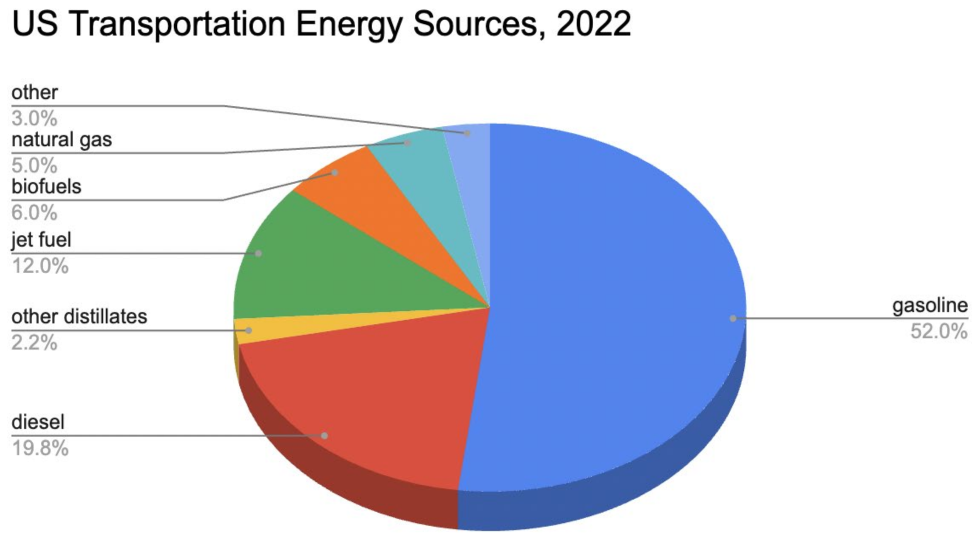

Figure 6. The energy sources from the transportation sector in the US. Adapted from U.S. Energy Information Administration (Oct 2008).

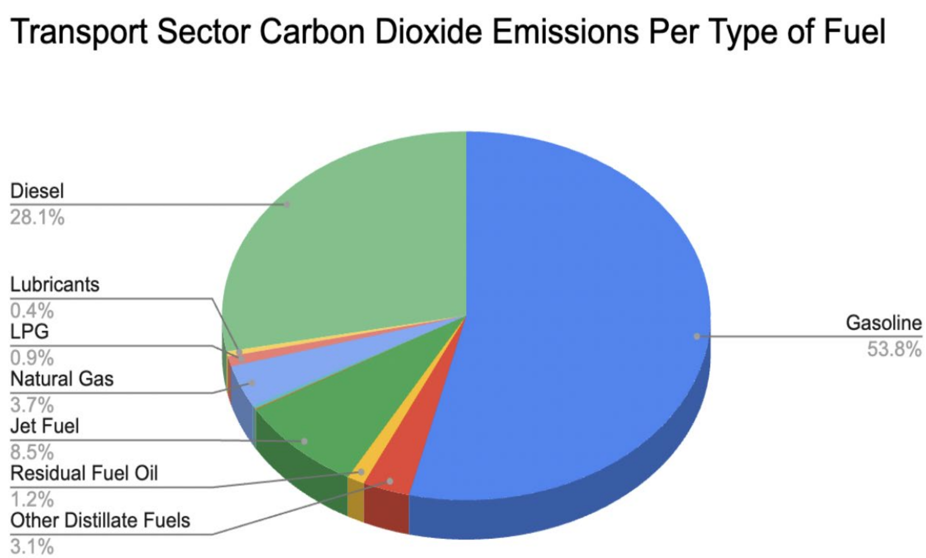

Figure 7. The energy sources from the transportation sector in US. Adapted from (US EPA, 2024)

Much attention has been paid to the transition to electric vehicles. And while we are in the process of transitioning to electric vehicles in passenger cars, that transition is taking longer than expected, with the possible transition to electrified commercial vehicles being even further away. (*Diesel Technology Forum: 57% of All Commercial Diesel Trucks on the Roads in US Are near-Zero Emissions Models*, 2023) The applications of biodiesel in transportation are also more broad. Diesel engines are used in delivery trucks, trains, and large cargo ships which transport nearly everything people consume (*Use of Diesel - u. S. Energy Information Administration(Eia)*, n.d.). Diesel is also used heavily in farming and construction equipment. That being said, diesel and electricity are not necessarily energy competitors, as diesel generators can be used to generate electricity. In this way, biodiesel and EVs can be complimentary technologies helping us transition to a cleaner future. By applying the simple transition to replace diesel gas in existing diesel-operating car engines with biodiesel, we can diminish our dependence on traditional non-renewable energy sources and meet a greater demand for-renewable energy.

The Problem with Current Biodiesel Production in The United States

Currently, the United States of America produces 2.1 billion gallons of biodiesel per year, with 90% of biodiesel production in America derived from-soybean oil (*Biodiesel*, n.d.). In order to expand the production of biodiesel to replace our current use of diesel in the United States , we would need to expand production to 60.3 billion gallons of diesel as of 2022 (*Where Our Diesel Comes from - u. S. Energy Information Administration(Eia)*, n.d.). The current production of biodiesel requires one bushel or 8 gallons of soybeans to create 1.5 gallons of biodiesel (*Biodiesel*, n.d.). In 2009, 77.4 million acres of land were used to create 33.4 billion bushels of soybeans (*Soybeans for Biodiesel Production – Farm Energy*, n.d.). Following the current state of soybean production in the United States, even if we were to use all the existing soybean to make biodiesel, we could only produce 5.1 billion gallons of biodiesel. If America were to grow enough soybeans to keep up with the demand for biodiesel (assuming they are using B100), it would need ~40.5% of the country's landmass which makes this a non-viable solution for replacement of fossil fuels in the future.. To realistically expand the production of biofuels in the United States on a larger scale, we need to look for other sources for production.

Using Trash to Create Energy: Converting an Environmental Toxin into Biodiesel Feedstock

One step in creating a cleaner future could be to to source food and plant waste in the process of biodiesel production. Instead of relying predominantly on soybean to create biodiesel, we can look to food waste found in our homes, restaurants, and landfills which can become a reliable feedstock for the production of biodiesel. Common current feedstocks for biodiesel production include palm oil mill effluent, waste cooking oil, animal fats, fish oil, grease, and oil crop waste(Stephen & Periyasamy, 2018). Biodiesel can easily be produced from plant waste through a process called transesterification (Puricelli et al., 2021). Transesterification is when oil and alcohol are turned into ester and glycerol (Sajjad et al., 2022). Since the byproduct of making biodiesel is crude glycerol, the glycerol can be refined into a purer form and be redirected to food, pharmaceuticals, and cosmetic industries (*New Uses for Crude Glycerin from Biodiesel Production – Farm Energy*, n.d.).

According to the United States Environmental Protection Agency, in 2019, 66 million tons of waste came from the food industry (US EPA, 2015). Out of that 66 million tons, about 60% of it were sent directly into landfills (US EPA, 2015). Instead of allowing mountains of waste to be put into landfills to rot and emit methane, the waste can be redirected toward the production of biodiesel. The amount of biofuel that can be produced from a certain amount of food waste depends on the contents of the food waste. For a rough estimate of the total amount of biofuels that could have been made from the food waste from landfills in the United States, we can assume that 1 kilogram of food waste is equivalent to 248.21 grams of biodiesel according to a study from 2019 (Patel et al., 2019). Therefore, if all of the United States food waste in landfills was turned into biodiesel, we would produce around 3 billion gallons of biodiesel [see table 1].

If the United States turned all the landfill food waste into biodiesel including its current soybean biodiesel production, it would produce around 5 billion gallons of biodiesel. Furthermore, this 5 billion gallons of biodiesel can be turned into 25 billion gallons of B20. Even though this isn't enough biodiesel to replace America's consumption of 60.3 billion gallons of diesel annually, it is a large improvement to what we have now. In addition, if you take into account the the potential methane emissions from food waste in landfills, it is also the equivalent of getting an additonal 50 million cars off the road-(US EPA, 2023). Therefore, even though this may be a relatively small amount of total biofuel replacement, the concurrent depletion of both food waste in landfills and vehicles burning diesel fuel creates a disproportionately large reduction in greenhouse gas emissions.

Table 1. Amount of biodiesel that can be produced from different feedstocks.

	B20	B100
1kg Food Waste	1241.05g	248.21g
Theoretical U.S. production per year	25,241,150,315 gal	5,048,230,063 gal
Current Soybean Biodiesel Production	10,500,000,000 gal	2,100,000,000 gal
Theoretical (non-viable) Soybean Biodiesel Production	25,500,000,000 gal	5,100,000,000 gal
Theoretical US Landfill Food Waste Production	14,741,150,315 gal	2,948,230,063 gal

Not all foods can be used to create biodiesel. To create biodiesel you need the fats and oil in the food, and some foods, such as starchy foods cannot be converted into biodiesel. However, starchy foods can still be composted into fertilizer to help grow more crops. Second,-starchy foods can be used to create lightweight concrete (Glenn et al., 1999). Making starch into lightweight concrete can also be effective in lowering greenhouse gas emissions as concrete is one of the biggest industries that contributes to greenhouse gas emissions. The production of concrete produces around 8% of the world's greenhouse gasses (IRENA, 2017). Finally, starchy foods can also be used to create bioethanol [see figure 8].

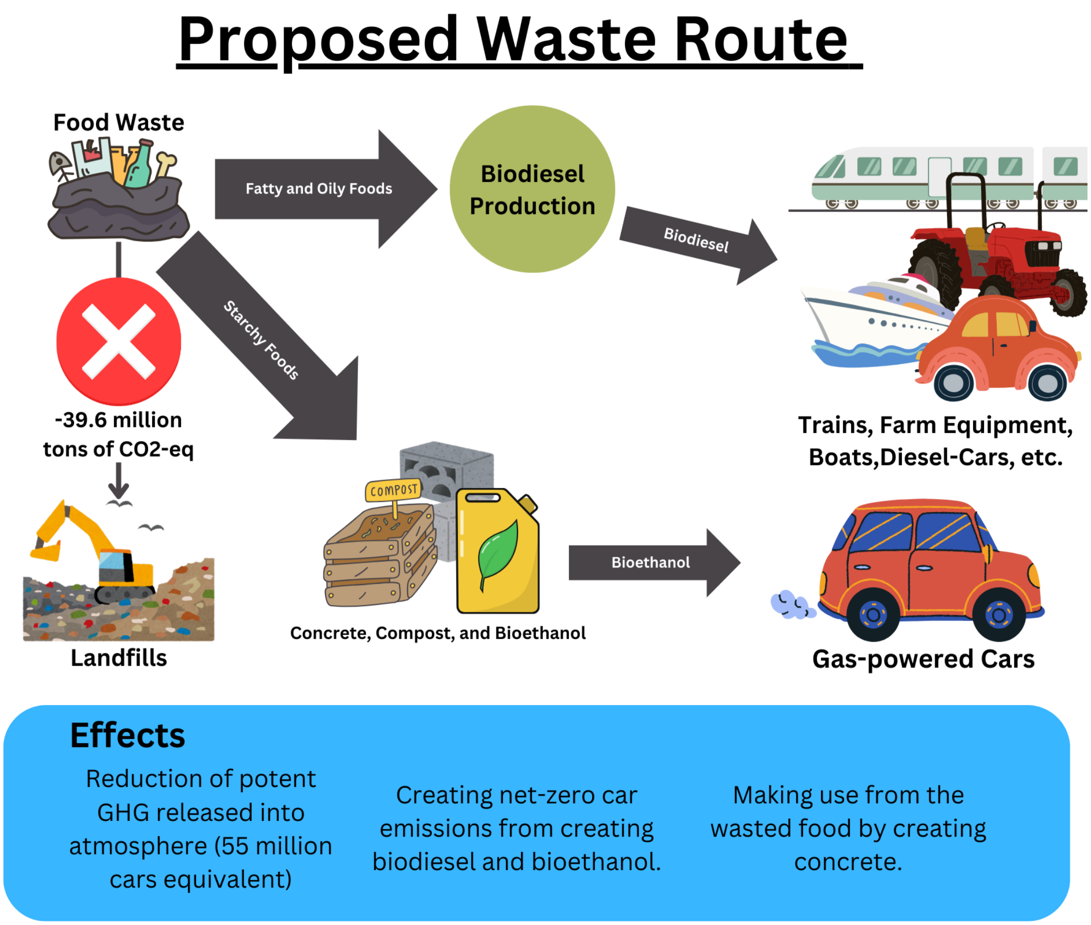

Figure 8. Our proposed method we should direct food waste to.

Conclusion

The continued rising population trend poses a challenge with the increasing greenhouse emissions, so solutions must be found as quickly as possible. There is every reason to believe that biodiesel will provide a sustainable approach to the transport industry as an alternative to the use of conventional fuels. Biodiesel can limit the impact on the environment because it implements waste material such as food waste while being net zero in emissions. The transition from fossil fuel to clean energy taking place worldwide will be greatly aided by this. Finally, biodiesel is a crucial part of the solution for climate change, and sustainable energy provision serves as a stepping stone towards a more environmentally friendly planet. If any country is fit for using food waste as a fuel source it would be the United States, who is a global leader in this. To utilize food waste to create biodiesel will not only provide a substrate for this production, but would simultaneously reduce landfills which are toxic to the environment, humans and the ecosystem. Even if the US could replace only 5% of its annual diesel use, this would save 67,140,000,000 pounds of CO2 a year. By applying this simple transition to replace diesel gas in existing diesel-operating car engines with biodiesel, we can diminish our dependence on traditional non-renewable energy sources. This early transition to a cleaner future before the estimated population peak in the year 2086 will allow us to ease our dependence on traditional fuel sources -and to meet a greater demand for-renewable energy.

Ever since humans started creating massive amounts of emissions in the industrial revolution (1760-1840), the average global surface temperature has increased by 1°C. Although it does not seem like a big difference in temperature, this "small" difference makes us lose 13% of our arctic sea ice each year. Arctic sea ice is important for the ecosystem for two main reasons: it reflects heat back into space, and it prevents coastal cities from being submerged. Since the arctic ice reflects heat back into space, the less we have the faster our earth's heat rises which can create many heat waves down the line. Furthermore, if all the arctic sea ice melted, it is predicted that the sea levels would rise by approximately 230 feet (70 meters). This would certainly flood and submerge every coastal city in the world. It is in response to threats like this that the recent Paris climate agreement set a goal of limiting the global temperature rise to below 2°C above pre-industrial levels by the end of the century (*Key Aspects of the Paris Agreement*, n.d.).

Future Work

Since the UN expects humanity's peak population to come within a century, we don't have that much time to apply this solution. There are also many other factors to consider such as the logistics and cost of such an operation. The first objective to think about is to find where massive quantities of food waste can be converted to biodiesel. However, sections of food waste could be redirected to already existing facilities by this time. This would immediately start the production of biofuels while simultaneously increasing production. Another large objective to think about is the process of separating normal waste from food waste and separating starchy waste (what can be converted into Bioethanol, concrete and compost) from fatty and oily waste (which can be converted to Biodiesel). Other facilities are also going to have to be created or redirected to existing facilities to produce bioethanol, concrete, compost, and pharmaceuticals. Overall, the main goal of this theoretical operation would be to reduce as many emissions as possible and create usable fuel. By immediately starting to create biodiesel from food waste, the amount of emissions over time from existing facilities can lead to millions of tons of greenhouse gasses being reduced from the atmosphere.

Both biodiesel blends have their advantages and disadvantages. B100 is significantly better in terms of greenhouse gas emissions, but B20 is more economically attractive and has nearly the same energy usage as conventional diesel while reducing more emissions than petroleum diesel. This is why the transition to B20 is one that is clearly easier and already occurring at the gas pump. However, we should be working towards transition to biodiesels which are better for the environment. If production of B100 increases, the cost of producing B100 may decline as the scale of production increases, making this a more palatable option. This current method of biodiesel production has some existing drawbacks degradation of rubber hoses found in older vehicles. (Stephen & Periyasamy, 2018). Therefore, a future challenge is making sure modern cars can adapt to using this biodiesel; this may require modification of older engines and ensuring that new car production is compatible with biodiesel use.

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