# Food Waste Utilization as a Viable, Alternative Energy Generating Feedstock (Review)

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***Abstract*—Energy demands across the globe are significantly increasing *on* a day to day basis. With so many issues regarding technological policies, greenhouse gases, fuel prices, and day to day accessibility to fuel types, we are left with very few solutions to recover energy, and even use it. Practical solutions include the likes of renewable energy and alternate fuel. Renewable energy spans across using solar, wind, and water kinematics majorly for our energy and electrical consumption. Energy generation methods like alternative fueling, suggests the use of biomass to create biodiesel, bioethanol, and electricity as the sustainable substitute to our transportation needs. While these sources of energy and fuel are useful substitutes currently, they are not efficient enough to completely rule out gasoline and generated electricity, especially in financial markets. Ethanol and biodiesel both require land to grow crops, and must go through hurdles within government policy to avoid politics involving limiting food sources in countries. Without a doubt, we are in a competitive race to determine the planet's next generation energy solutions and fueling sources. This paper analyzes the literature currently available on research relevant to food waste's utilization as an energy generating feedstock, along with the environmental and economic impacts it could have as a feasible solution.**

***Index Terms*—Food waste, green alternatives, biofuel, energy generation, sustainable technology.**

## I. Introduction

The ideology behind what renewable energy is stems from its many sources, primarily and popularly: solar, hydro, geothermal, and wind power. These sources produce energy effective solutions to supply the technological demand of modern civilization [1]. However, the substantial growth of energy consumption and demand has increased the focus of environmentally beneficial, economically feasible, cost efficient energy solutions. Renewable energy markets could potentially be the almighty successor to common energy collection practices, but not without novel improvements.

The introduction of biofuels created from biomass, another renewable energy source (i.e. organic matter like wood, grass, vegetables, fruits, and meats), provided a proof of concept that even our transportation fuel sources (gasoline, electricity, diesel) can be imprinted upon with technological improvements. So much so, that countries like Brazil have completely transitioned into using ethanol, created from sugarcane, as its primary transportation fuel. The utilization of biomass for biofuels promotes cleaner air due to lessened Greenhouse Gas (GHG) emissions and toxic particulates like sulfur, cheaper fuel prices due to gasoline blending, improved fuel security should fossil fuel deposits run low, and are biodegradable causing less environmental harm should they spill [2]. However, the utilization of biomass has as much negative impact as it does positive impact, if not more. The usage of biomass requires land usage changes (LUCs), strips away bulk amounts of food destined for starving people and refines it for transportation fueling, increasing the cost of everyday foods, all while still producing GHG emission due to biofuel refinery operations and LUCs.

The influence food has on the everyday evolution of mankind, in both a survival and technological sense, is powerful, and it can be improved. That improvement is turning food from a renewable energy source into an alternative energy source, by utilizing its wastes. Alternative energy is energy generated in ways that do not deplete natural resources or harm the environment significantly. With the utilization of food waste, negative impacts like LUCs, food shortages, GHG emissions, and food cost increases are significantly decreased, if not maintained at its current level. Furthermore, food waste provides the same positives as biomass while improving cleanliness of soil and water, improving ecosystem health, decreasing landfill pollutants, and minimizing municipal solid waste (MSW) stream. This is further supported in studies related to bio-energetic sustainability systems and solutions, stating that soil quality, water quality and quantity, GHG emissions, biodiversity, air quality, productivity, social well-being, energy security, trade, profitability, resource conservation, and social acceptability could potentially all be significantly improved [3]-[6] with an effective, alternative solution.

## II. Environmental Benefits

Environmental benefits of using wasted food deal largely with ecosystem health i.e. landfill pollution, water pollution, resourcefulness, and GHG emissions [7]. Utilizing food waste keeps the water in the surrounding areas clean, as well as the land. Direct GHG emissions mean ranges from -56 to 163 grams (g) of carbon dioxide per mega joule ($C0_2$eq/MJ) of fuel in studies of lignocellulosic ethanol in a statistical analysis responding to cultivation, studying yield and soil carbon factors, among others, beyond the obvious differences between feedstocks. [8], [9]. This is done due to the soil being cleaner and healthier allowing for water streaming throughout the land to have more natural affects. For example, enhanced water and air quality, improved soil conditions, stable jobs, and economic benefits can all accrue if the agricultural system is designed and deployed in a way

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that efficiently meets the demand for food, fiber, and feedstocks [10], [11]. Food waste, after being properly processed (refined and sterilized for additional distribution), can be used as a feed for animals and natural fertilizer for soil, along with being used as a biofuel. This would create healthier soil and reduce the need for synthetic fertilizers, maximizing the overall usage of food in general.

Using food waste from consumers, corporations, and landfills will not only conserve limited landfill space, but decrease the amount of methane ($CH_4$) and carbon dioxide ($CO_2$) entering the atmosphere through the rotting of the organic compounds. According to the Environmental Protection Agency (EPA) between 1990-2010, approximately 34 billion tons of carbon dioxide (primarily from the burning of natural resources and vehicle emissions) and 7 billion tons of methane (primarily from the decomposition of food, plants, and organic matter) were the primary sources of GHG [12] both of which can be reduced with the alternative fuel solution of converting wasted food into biofuel creations. Methane ($CH_4$) enters the atmosphere primarily through the decomposition of wasted extractions primarily in food, plastics, and cardboard or paper products. Methane is a GHG that remains in the atmosphere as long as 15 years and is 20 times more effective at trapping heat than carbon dioxide ($CO_2$) [13]. According to the EPA in 2010, approximately 1 billion metric tons of $CO_2$ gases were produced from waste alone [13]. These numbers can be drastically reduced with the implementation of food waste as an additional source to alternative fueling due to the utilization of landfilled food waste as the source location.

These specifications make food waste to fuel extremely economically competitive. Currently there is no dominant design for advanced biofuel technologies or feedstocks, which mean many different technologies are being perfected that can use a wide variety of feedstocks [14]. Due to the infancy of biofuel technologies, this opens up opportunities for many technical and business innovations in this sector from deploying very large-scale systems to small modular and even on-farm systems [14]. Primary industry beneficiaries would include the transportation industry (cruise ships, train stations, gas stations, airports, etc.), the food industry (restaurants, fast food chains, festivals, etc. selling spoiled and rotten food to biofuel facilities), and the waste removal industry (collecting, organizing, processing, and selling current and future waste to biofuel facilities or producing their own fuel through pyrolysis and sell the remains, etc.). However, without food waste utilization, each of these industries would be responsible for a significant portion in the detriment of ecosystem health, including increased GHG emissions and polluted soil.

Currently, many landfills are only protected by a liner which is placed under the waste to prevent leakage into the soil and water. According to the EPA, " No liner can keep all liquids out of the ground for all time. Eventually the liners will either tear or crack and will allow liquids to migrate out of the unit [15]." Once these wastes leak into our soil and water, it could jeopardize the health of the surrounding rural areas and bodies of water. These leaks contain hazardous chemicals like phenols, benzene, ammonia and many others as illustrated in Fig. 1 below. This would eventually have a negative impact on wildlife, including humans, and could be linked to probable cause of disease and famine [16]. "The extent to which toxic landfill contaminants suppress the immune system has been underestimated." according to Dr. David Carpenter, Director of the Institute for Health and the Environment at the State University of New York and Albany [16]. Creation of food waste technologies could be the defining resolution towards a cleaner environment. Furthermore, deployment of these technologies will lead to an increase in the number of STEM related jobs across the country, which will be difficult to off-shore and will also lead to rural wealth creation.

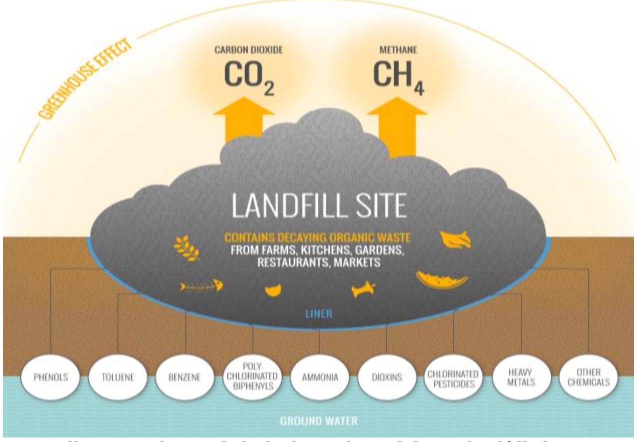

Fig. 1. Illustrates chemicals leaked into the soil due to landfilled organic (food) waste [17].

## III. Economic Impact

Besides gasoline and generated electricity, our energy sources in regard to fuel for vehicles primarily come from ethanol and biodiesel. Ethanol majorly comes from corn in the United States (sugarcane in Brazil), which must be harvested and maintained on an acre by acre scale. Currently the United States uses about 10% ethanol (E10) in its gasoline, and newly approved 15% ethanol (E15) in newer vehicles 2015 and beyond [18]. Along with the production of ethanol, the production of ethanol based co-products have provided economic benefits. According to the Renewable Fuel Association (RFA), " In 2014, ethanol bio-refineries produced approximately 39 million metric tons of feed, making the renewable fuels sector one of the largest animal feed processing segments in the U.S. This amount of feed produced by the ethanol industry last year would be enough to produce nearly 50 billion quarter-pound hamburger patties – or seven patties for every person on the planet. Similarly, this amount of feed would produce enough chicken for every American to eat one normal-sized chicken breast every day for one year [19]." Additionally, RFA states that approximately 1/3 of each 56-pound bushel of grain used in ethanol production goes to animal feed and accounted for about 27% of a typical dry mill's gross revenue [19] from the sale of distiller grains and corn distiller's oil in 2013.

Probable solutions to improve biofuel technologies across the nation can be organized on a regional basis. This could mean more suitable and different feedstocks or processes per region. For example, forestry and poultry are two of the biggest industries in Southeastern United States that can supply feedstocks currently for biofuels with their wastes. In the Midwest, the most prominent feedstock to be used for biofuels would be soybean oil, to produce biodiesel. Currently, the United States is ranked number one in the global soybean production with 32% world production, according to the World Soy Foundation. Most of the United States ethanol production comes from corn starch. According to the Monsanto Company in 2012, 29% of all United States' corn was used for ethanol production, primarily from the Midwest and Central Heartland of the United States. However, while the uses of corn starch and grains have its obvious benefits in the production of ethanol [20], there is a negative financial burden being the increase in both domestic and international food prices. This is in part due to the increased energy costs, higher costs for agricultural inputs, tight global grain supplies, export restrictions, poor grain crops in other countries, and the growing world demand for food [21].

A research study has already been done on finding the effectiveness of alternative fueling through ethanol from corn grain and biodiesel from soybeans, the most common food crops in the development of biofuels. The study findings resulted in ethanol yielding 25% more energy than the energy invested in its production, whereas biodiesel yielded 93% more [22]. Additionally, compared with ethanol, biodiesel releases just 1.0%, 8.3%, and 13% of the agricultural nitrogen, phosphorus, and pesticide pollutants, respectively, per net energy gain [22]. Relative to the fossil fuels they displace, GHG emissions are reduced 12% by the production and combustion of ethanol and 41% by biodiesel. Within this study, the net energy balance was determined by the excess amount of biofuel energy content in comparison to fossil fuel energy inputs. This study represented a proven reference to what we already know being that crops can be utilized as an alternative fuel source. With the induction of more crops and feedstocks being of the likes of vegetables, fruits, and meats, fuel collection through wasted food could prove to be a respectable addition to the alternative fuel development for the transportation and fuel industry.

According to a recent study, lipids extracted from food waste were converted to biodiesel in 95–97% yield [23]. On the other hand, 92–96% bioethanol was obtained by the fermentation of food waste [23]. Other feedstocks across the United States could be different, possibly using grasslands or algae. Algal starches have been shown to be fermentable by yeast [24], but an approach to directly couple ethanol production to photosynthetic carbon fixation in situ may be preferred. Many microalgae have fermentative metabolic pathways to ethanol, but to couple ethanol production to photoautotrophic metabolism will require changes in regulatory pathways or the insertion of new metabolic pathways [25]. With cyanobacteria, the creation of a pathway for ethanol biosynthesis has been demonstrated, with the insertion of pyruvate decarboxylase and alcohol dehydrogenase from the ethanol genic bacterium Z. mobilis. [26], [27]. Essentially, algae could even utilize MSW and waste water as a potential source for low cost lipids in production of biofuels as well [28]. This could make the production of algae an important source for biofuel production under multiple platforms and processes.

A hydrothermal process that converts industrial wastes into fuels was developed by Appel and coworkers at Changing World Technologies, Inc. (CWT) [29], [30]. The first plant located in Carthage, Missouri converts turkey offal waste into diesel oil, fertilizer products, and carbon [31]. The chemical structure of fatty acids is similar to that of the hydrocarbons present in liquid transportation fuels like gasoline and diesel oil. The major difference is the presence of the carboxyl group. Fatty acids in many naturally occurring fats and oils, both vegetables and animals, often have chain lengths similar to those found in gasoline or diesel oil. Thus, if the carboxyl group could be eliminated, a bio-based gasoline or diesel oil would result [32].

More recent work has been done in Ethiopia on the usage of wasted banana peels and radish leaves in the production of biodiesel and bioethanol by transesterification. Results from the fermentation of carbohydrates extracted from banana peels and radish leaves produced 1.37% and 1.23% bioethanol, respectively from 855g and 950g of the powder forms of banana peels and radish leaves [33]. This process in particular was done by soaking the waste powders of the feedstocks in n-hexane to produce an oily content which undergone transesterification to produce biodiesel, and filtration and fermentation to produce bioethanol. Due to the carbon neutrality of the fuels, $CO_2$ emitted in the combustion process is absorbed and recycled as additional heat. This allows for no significant increase in GHG, however if the wasted food could decompose in the landfill, it would have a significant impact on both pollution and the atmosphere, obscuring the ecosystem health further.

## IV. Financial Recovery

The current legislation on food waste treatment prioritizes the prevention of waste generation and least emphasizes disposal [34]-[36]. According to the United States Environmental Protection Agency (EPA), food waste is the second largest category of MSW sent to landfills in the United States, accounting for approximately 18% of the waste stream [37]. That's over 30 million tons of food waste that the U. S. sends to the landfills each year. Less than 3% of that waste is currently being diverted and composted to produce fertilizer and animal feed [37]. That leaves an astounding 97% of food waste in landfills to rot and be unused. According to the Natural Resources Defense Council in 2012, approximately 40% of the U.S food is wasted. This approximates to $165 billion a year in wasted food, amounting to $1,350 to more than $2,275 annually in wasted food per family of four [38]. Calculating in the 97% of food waste going to landfill approximates to an incredible $160 billion dollars lost to landfilled, unutilized food waste annually. Retail waste, including waste in institutional food service, is valued at $64.6 billion, which shows that businesses and organizations also have much to gain by reducing waste [39].

Disposal and recycling initiatives have been developed by the EPA and a multitude of corporations, dating back to the 1960's to reduce, reuse, and recycle consumer goods like tires, soda cans, plastic bottles, paper products, and batteries. According to the EPA in 2013 [40], 34.3% of consumer recyclables have been recovered and reused for industry usage. These numbers include 99% lead-acid batteries, 67% newspaper papers, 55.1% aluminum cans, 40.5% tires, and 31.2% bottles and jars, amongst other categories. This is a major improvement being that only 6.4%, 6.6%, 9.6%, 16.0%, 28.5%, and 34% of consumer recyclables were recovered in 1960, 1970, 1980, 1990, 2000, and 2010, respectively. This proves that with a proper recycling initiative in place, recovery rates will improve annually allowing for increased financial recovery due to the minimization of production and processing.

Due to government policies, land operations, and food usages, the overall benefit of using biofuels has more of a long term economic significance than a short term financial significance. This is where using food waste comes into play. Essentially, using food waste will maintain the current production of crops and usages of land, while benefitting individuals and corporations in terms of financial improvement and recovery. Due to biofuel technology and processes being very young dating back to the early 2000s, investments have not been made on a grand scale to support biofuel creation. This is a clear indication of the infancy of biofuel technology and processes. However, this should make the biofuel industry quite attractive to investors. Stakeholders can help identify ways in which bioenergy investments can reinforce efficient local food production and other services. Stakeholder engagement also supports adaptive decision-making to enhance goal achievement [41]. Recommendations for improving food security are to invest in rural agricultural technology, which are discussed in the SOFI reports and reflected in recent initiatives to provide 'growth' in the food industry [42]-[45]. However, during periods of historically low real prices for food producers, there is limited motivation for investments in technology or yield improvement.

TABLE I: BENEFITS OF FOOD WASTE ENERGY PRACTICES (FWEPS)

| Focus Area | How Can Investments into FWEPs Improve the Respective Focus Area? |
|---|---|
| Soil and Water Quality | • Reduction of Landfilled Waste<br>• Minimizing of Chemicals Absorbed into Soil and Surrounding Area,<br>• Improves Underground Water Spots Accessible to Plants<br>• Improves Aquatic Ecosystem (i.e. Water and Fish) Near Landfilled Areas |
| Greenhouse Gas (GHG) Emissions *Primarily $CH_4$ and $CO_2$ | • Reduction of GHG Emissions Resulting from Organics Directly<br>• Potentially Adds a Directive into Regional Based Emissions from Food and its Effect on that Particular Subsystem<br>• Mature Technology Could Create a Closed System Network that Recycles Emissions, like $CH_4$ and $CO_2$, as Additive Heat Sources |
| Financial Recovery *Including Crop and Market Pricing | • Creates Industry Partnerships with Markets and Corporations<br>• Reduces Food Prices and Gasoline Price (per barrel) in Markets<br>• Supplies Industries with Additional Recycling Techniques for Spoiled/ Rotten and Pre-Distributed Food |
| Land Usage Changes (LUCs) | • Maximizes Utilization of 'Already Produced' Crops [46] from Current LUCs<br>• Minimizes Need for Biofuel Cropping through Deforestation<br>• Reduces Deforestation in Rural Areas Conserving Ecosystem Health |
| Fuel Production | • Emphasizes Usage of Additional Feedstocks Without Creating More Through LUCs<br>• Could Significantly Decrease Gasoline Dependency in Developed Countries<br>• Improves Focus and Demonstrates Importance/Significance of 'In-House' Farming in Underdeveloped Countries |
| Food Security | • Allows Food Meant for Consumption to be just that, not 'Technological Consumption'<br>• Reduces Political Pressures as it Pertains to Starvation, Importation, & Exportation<br>• Provides an Insurance to Governments that Rely on Exportation and Importation of Food Crops and Feedstocks |

Food waste could surely be the next effective, energy generating solution to allow monetary advancements for corporations. Proper food waste energy practices (FWEPs) can be used to not only garner short term funding with fuel production but also long-term funding with food security, as illustrated above in Table I. FWEPs could create closed system biofuel networks for under developed and developed countries, creating enhanced food infrastructure and management. Partnerships addressing land, water, and air quality and usage would provide even further monetary and technological advancements for the energy generation infrastructure. Most processes for biofuel acquisition are deemed energy inefficient due to the energy input equaling or being greater than the energy output of the system. Therefore, the feedstock is not just the issue, but the processes themselves. Similarly, should this be resolved, stock markets for biofuels will see rapid growth, which could happen soon, with current technology. Case studies that document actual conditions before and after project implementation can support more integrated project designs and adaptive management [47], [48] to address strategic investment planning.

## V. NET ENERGY GAIN (NEG)

To be a viable alternative, a biofuel should provide a NEG, have environmental benefits, be economically competitive, and be producible in large quantities without reducing food supplies. With the use of wasted food, all of these requirements are satisfied and exceeded. Food supply chain waste is an abundant resource with significant potential to be used as raw material for fuel production and other industrially viable compounds. Due to the fuel source being from wasted food, the NEG mainly revolves around how much usable oil or heat (to be further converted into electricity if applicable) is produced from the feedstock collections (positive) versus how much facility estimate energy will be used in converting crops to biofuels, building and operating biofuel production facilities while sustaining production facility workers and their households, and transporting these crops to biofuel production facilities (negative). Factors dealing with farming, maintenance, and disbursement play a minor role being that these applications were already performed to originally produce the feedstocks and would technically be assessed prior. Similarly, these input energies, or farming applications would be negated including, but not limited to: energy used for growing the hybrid or varietal seed planted to produce the crop, feed provided to the farm animals, energy to groom and maintain farm animals, powering farm machinery, producing farm machinery and buildings, producing fertilizers and pesticides, sustaining farmers and their households, and transporting goods to the homes and businesses to be sold and utilized. The result, or output energy from the net energy balance, would be the biofuel itself and its co-products, like animal feed and pesticides.

Many different methods and practices have been used to enhance the NEG from feedstocks to biofuel. For instance, the use of lignin, which is prominent in most crops, could be burned and used for heat and power in bio-refineries or useful for enhancing extraction efficiency in biofuels [49]. There is also the enzymatic approach through biochemical refining. Biomass solids can be broken down by enzymes to turn the biomass into liquid sugars, allowing microbes like yeast to ferment the sugars into renewable fuel. Thermochemical refining uses extreme heat, in the absence of oxygen, turns biomass into bio-crude oil that can be refined to make biofuels. A similar process, thermochemical gasification [50], utilizes oxygen to turn biomass solids into a gas (bio-gas) that can be condensed and converted into biofuel. These energy generation processes prove that different biosub-fuels can be created for various energy applications, as illustrated in Fig. 2 below.

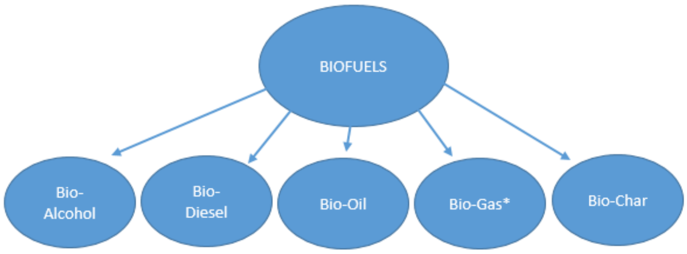


Fig. 2. Energy fuels include: Bio-Alcohols (methanol (wood)[51], ethanol (sugars/wheat), propanol, and butanol), Vegetable Oil & Biodiesel (fuel energy from modified viscous seed oil), Bio-Oil (fuel energy formed from liquid or condensable gas), Bio-Gas (fuel energy formed from the gases of digesters & manure/sewage, including Bio-Hydrogen), and Bio-Char (fuel energy formed from burned feedstocks). *Includes Bio-Hydrogen (hydrogen formed from pyrolysis).

Pyrolysis is thermal decomposition occurring in the absence of oxygen. Slow pyrolysis, or carbonization, is a proven technology using low temperatures and long residence times, with charcoal (bio-char) resulting as the main output. The energy acquisition technique, fast (flash) pyrolysis, is the most economically and environmentally efficient solution for food waste using current technology. Fast pyrolysis is an emerging technology that uses moderate temperatures and short residence times. However, it is currently at pilot stage due to the poor thermal stability and corrosivity of the oils [52]. It produces energy fuels with high fuel-to-feed ratios, making it the most efficient process for biomass conversion, and the method most capable of competing and eventually replacing non-renewable fossil fuel resources.

The conversion of biomass to liquid bio-oil can have an efficiency of up to 70-75% for flash pyrolysis processes [53]. This is further supported by many studies, including a review of fast pyrolysis on biomass, which stated 75%, 35%, and 5% of liquid biofuel was created through fast pyrolysis, carbonization, and gasification, respectively [54]. If carbon is used as an energy source, either through processed heat or slurred with liquid, then efficiency approaches 94% [55], making an efficient fast pyrolysis system ideal for the future of alternative fueling in heat acquisition processes. According to the EPA in 2013, kilograms of carbon dioxide emissions versus kilograms of consumed food were most significant in meats, with lamb and beef having the highest ratio of 39.2 and 27.0 kg $CO_2$ emitted, respectively. Keeping this in mind in regard to using wasted food as an alternative fueling source, spoiled and uneaten meat feedstocks could prove to be very significant in the creation of bio-oil, bio-gas, and bio-char, all of which are major outputs using fast pyrolysis processes being 60-70% bio-oil, 10-15% bio-gas, and 15- 25% bio-char.

With the yearly increase in electric vehicles, food waste could also prove useful. Heat generated from processes like pyrolysis could be converted into electricity through thermal electric generators. Across the planet, studies are being conducted on novel energy storage devices like lithium ion batteries [56] that utilize smaller doses of energy, to improve electrical storage [57], power outputs, and recyclability [58]. In an energy balanced environment, our dumped organic waste facilities could double as energy generation nodes providing both biofuels and electricity for the surrounding areas.

## VI. Food Security

This leads to the most politically important requirement to why food waste is a viable alternative: minimizing the reduction of food supplies while producing potentially large quantities of fuel. Biofuel effects on food security could be determined by a project's influence on physical infrastructure, asset accrual, institutional capacity, training, technologies that enhance food safety or resilience, ecosystem stability, cultural wellbeing, or other drivers and coping mechanisms omitted from food price indices [59]-[62]. To put this into perspective, most poor, under developed countries (94% of the world's hunger reside in Africa and Asia [63]) obtain their food by farming agriculturally within their homeland and importation. An initial step must be to understand relationships between biomass production, food production, and hunger. Food security is recognized as a fundamental human right [64] with modern energy services being an essential component of food production, supply, and preparation [65]. With less emphasis on destroying land and growing crops to be converted directly into biofuels, these maintained lands can be used for the growing of more consumer crops for community use and exportation, increasing the nation's food security. Food waste created in these countries as a result, while small, could be gathered and sold to corporations or individuals who could use those wastes as potential fuel substitutes.

This process will be recycled and repeated so on and so forth. This ultimately will create a reduction in deforestation, a reduction in global pollution, a reduction in landfilled GHG emissions, a reduction in LUC (using farmland to grow crops specifically meant for biofuels), an increase in food usages, an increase in biofuel, hydrocarbon oil, and electricity production, improved food shortage security, and an opportunity for many countries to acquire money quickly through food waste quality and quantity. Additionally, farming lands would increase due to the clearings of food waste dumps and regeneration of soil and water quality in the surrounding dumps. A recent study provides recommended practices to enhance food security and produce sustainable biomass bioenergy; including energy security, local food security, employment and income generation, access to land, water, and markets, community development, and cross-cutting aspects, all while focusing on sustainable systems and policies.

## VII. Conclusion

Alternative energy solutions range from a wide variety of sources namely solar, wind, hydro, and biomass. Since the 1990s, innovations in technology, system integration, and logistics have allowed producers to meet the growing global demands for food without requiring additional land [66], [67]. Utilizing food waste as a primary alternative energy source could have the potential to effectively provide a supplement to common fuels like gasoline and electricity, while extending the uses of food, and not being a detrimental result of LUCs. The goal is to utilize an otherwise untouched energy source that does not necessarily replace gasoline, but could act as a suitable alternative to minimize gasoline's negative impact effectively, while providing fueling capabilities efficiently. Food waste contains carbohydrates, lipids, phosphates, vitamins and amino acids. Carbohydrates, lipids, and carbon containing materials present in food waste can be converted to bioethanol, heat, electricity, biodiesel and bio-oil and become the future of fueling for both electric vehicles and liquid fueling vehicles.

It is understood that each food type will output different yields, however, utilizing the remaining energy from the waste could provide substantial benefits to the environmental and economic health of the source country. Food security will be improved without the need for additional LUCs. The 2015 assessment of progress toward Millennium Development Goals (MDGs) [68] found that several countries with domestic biofuel production policies, such as Brazil, China, Indonesia, Malawi, Malaysia, and Peru, also achieved or exceeded challenging hunger reduction goals [69]. This will ultimately allow access to nationwide financial recovery and growth in research topics relevant to the capabilities of food and NEG of different feedstocks.

## References


[1] Energy Information Administration, *Annual Energy Outlook 2006 with Projections to 2030 Dept. of Energy*, U.S. Department of Energy, Washington, DC, DOE Publ., no. EIA-0383, 2006.

[2] G. K. Sharma, M. S. Khan, and A. Tiwari. "Bio fuels towards a greener and secure energy future (a review)," *International Journal for Research in Applied Science & Engineering Technology*, vol. 4, issue 2, February 2016.

[3] K. L. Kline *et al.*, "Reconciling food security and bioenergy: Priorities for action," *GCB Bioenergy*, 2016.

[4] A. McBride, V. H. Dale, and L. M. *Baskaranetal.*, "Indicators to support environmental sustainability of bioenergy systems," *Ecological Indicators*, vol. 11, no. 5, pp. 1277-1289, 2011.

[5] V. H. Dale and K. L. Kline, "Modeling for integrating science and management," *Land Use and the Carbon Cycle: Advances in Integrated Science, Management, and Policy*, Cambridge University Press, New York, NY, USA, pp. 209-237, 2013.

[6] V. H. Dale, R. A. Efroymson, K. L. Kline *et al*., "Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures," *Ecological Indicators*, vol. 26, pp. 87-102, 2013.

[7] D. G. Tiffany and V. R. Eidman, *Food, Agriculture, and the Environment: Economic Issues*, pp. 325-40, 2005.

[8] M. C. McManus *et al*., "Challenge clusters facing LCA in environmental decision-making — What we can learn from biofuels," *The International Journal of Life Cycle Assessment*, vol. 20, no. 10, pp. 1399-1414, 2015.

[9] F. Menten, B. Chèze, L. Patouillard, and F. Bouvart, "A review of LCA greenhouse gas emissions results for advanced biofuels: The use of meta-regression analysis," *Renew Sust Energ Rev*., vol. 26, pp. 108-134, 2013.

[10] G. Berndes, H. Youngs, M. V. R. Ballester *et al., "*Land and bioenergy. In: Soils andwater," *Bioenergy & Sustainability: Bridging the Gaps*, chapter 18, pp. 618-659, Paris, 2015.

[11] G. M. Souza, R. Victoria, C. Joly, and L. Verdade, *Bioenergy & Sustainability: Bridging the Gaps*, vol. 72, Paris, France, 2015.

[12] *Climate Change Indicators in the United States: Global Greenhouse Gas Emissions*, Global Greenhouse Gas Emissions, Environmental Protection Agency, May 2014.

[13] M. Herndon, "Effect of thermal depolymerization of wasted food extracts onalternate fuel production," in *Proc. ASME 2016 10th International Conference on Energy Sustainability collocated with the ASME 2016 Power Conference and the ASME 2016 14th International Conference on Fuel Cell Science, Engineering and Technology*. American Society of Mechanical Engineers, 2016.

[14] *Creating Jobs and Lower Prices at the Pump: Hearing Beforethe Committee on Agriculture, Nutrition and Forestry, United States Senate, One Hundred Thirteenth Congress, Second Session*, Advanced Biofuels, April 8, 2014.

[15] Carpenter and O. David, "Landfill sites," *Waste-Derived Biofuels*, Gazasia, 2016.

[16] K. D. Hall, J. Guo, M. Dore, and C. C. Chow, "The progressive increase of food waste in America and its environmental impact," *PLoS ONE*, vol. 4, no. 11, p. 7940, 2009.

[17] *Danger of Landfill Sites*, Landfill Sites, South East Asia, Waste-Derived Biofuels, Gazasia, 2016.

[18] G. Truitt, "RF Aanalysis shows uptick in number of automakers who have approved E15 for use in new vehicles," *Renewable Fuels Association*, Dec. 21, 2015.

[19] Co-Products, *Renewable Fuels Association*, July 14, 2015.

[20] A. Aden, M. Ruth, K. Ibsen *et al*., *Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover*, National Renewable Energy Lab., 2002.

[21] *Potential Effects and Challenges of Required Increases in Production and Use: Report to Congressional Requesters*, Biofuels, Washington, D.C.: U.S. Govt. Accountability Office, pp. 43-45, 2009.

[22] J. Hill *et al.*, "Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels," *Proceedings of the National Academy of Sciences*, vol. 103, no. 30, pp. 11206-11210, 2006.

[23] S. K. Karmee, "Liquid biofuels from food waste: Current trends, prospect and limitation," *Renewable and Sustainable Energy Reviews*, vol. 53, pp. 945-953, 2016.

[24] M. T. Nguyen *et al.*, "Hydrothermal acid pretreatment of Chlamydomonasreinhardtii biomass for ethanol production," *Journal of Microbiology and Biotechnology*, vol. 19, no. 2, pp. 161-166, 2009.

[25] R. Radakovits *et al.*, "Genetic engineering of algae for enhanced biofuel production," *Eukaryotic Cell*, vol. 9, no. 4, pp. 486-501, 2010.

[26] M. D. Deng and J. R. Coleman, "Ethanol synthesis by genetic engineering in cyanobacteria," *Applied and Environmental Microbiology*, vol. 65, no. 2, pp. 523-528, 1999.

[27] J. Dexter and P. Fu, "Metabolic engineering of cyanobacteria for ethanol production," *Energy & Environmental Science*, vol. 2, no. 8, pp. 857-864, 2009.

[28] I. Woertz *et al.*, "Algae grown on dairy and municipal wastewater for simultaneous nutrient removal and lipid production for biofuel feedstock," *Journal of Environmental Engineering*, vol. 135, no. 11, pp. 1115-1122, 2009.

[29] B. Lemley, "Anything into oil," *Discover Magazine*, vol. 2, Apr. 2006.

[30] P. Fairley, "Go green this thanksgiving: Turn Turkey guts into oil," *Discover Magazine*, vol. 25, Nov. 2008.

[31] A. A. Peterson *et al.*, "Thermochemical biofuel production in hydrothermal media: A review of sub-and supercritical water technologies," *Energy & Environmental Science*, vol. 1, no. 1, pp. 32-65, 2008.

[32] M. Roberts, J. Williams, P. Halberstadt, D. Sanders, and T. Adams, "Animal waste to marketable products," in *Proc. Natural Gas Technologies Conference*. Phoenix, Arizona, USA, 2004.

[33] A. M. Khan, S. Khaliq, and R. Sadiq, "Investigation of waste banana peels and radish leaves for their biofuels potential," *Bulletin of the Chemical Society of Ethiopia*, vol. 29, no. 2, pp. 239-245, 2015.

[34] *Excise Tax Exemption for Biodiesel Produced by Schools*, Alternative Fuels Data Center, United States Department of Energy, June 4, 2014.

[35] *Alternative Fuel Economic Developmen*t, Alternative Fuels Data Center, United States, Department of Energy, June 4, 2014.

[36] R. Ravindran and A. K. Jaiswal, "Exploitation of food industry waste for high-value products," *Trends in Biotechnology*, vol. 34, no. 1, pp. 58-69, 2016.

[37] *Turning Food Waste into Energy at the East Bay Municipal Utility District (EBMUD)*, Turning Food Waste into Energy (EBMUD), U.S. Environmental Protection Agency, Oct.14, 2015.

[38] D. Gunders, "Wasted: How America is losing up to 40 percent of its food from farm to fork to landfill," *Natural Resources Defense Council*, pp. 1-4, 2012.

[39] K. Venkat, "The climate change and economic impacts of food waste in the United States," *International Journal on Food System Dynamics*, vol. 2, no. 4, pp. 431-446, 2011.

[40] *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2013*, U.S Greenhouse Gas Inventory 2015, Environmental Protection Agency, Feb. 1, 2015.

[41] V. H. Dale, R. A. Efroymson, K. L. Kline, and M. Davitt, "A framework for selecting indicators of bioenergy sustainability," *Biofuels, Bioproducts & Biorefining*, vol. 9, pp. 435–446, 2015.

[42] H. C. J. Godfray, J. R. Beddington, I. R. Crute *et al*., "Food security: The challenge of feeding 9 billion people," *Science*, vol. 5967, pp. 812–818, 2010.

[43] IMF, 2013, "Impact of high food and fuel prices on developing countries — frequently asked questions," International Monetary Fund External Relations Department, Washington DC.

[44] USG, Feed the Future: 2015 Achieving Impact, U.S. Government's Global Hunger and Food Security Initiative, 2015.

[45] World Bank Group, Global Monitoring Report 2014/2015: Ending Poverty and Sharing Prosperity. World Bank, Washington DC, 2015.

[46] Interagency Agricultural Projections Committee, USDA Agricultural Baseline Projections to 2015 (Dept. of Agriculture, Washington DC), DOE Publ. No. OCE-2006-1, 2006.

[47] FAO, "BEFSCI brief: Good socio-economic practices in modern bioenergy production minimizing risks and increasing opportunities for food security," FAO, Rome, 2011.

[48] A. Elbehri, A. Segerstedt, and P. Liu, "Biofuels and the sustainability challenge: A global assessment of sustainability issues, trends and policies for biofuels and related feedstocks," FAO, Rome, 2013.

[49] C. E. Wyman and A. J. Ragauskas, "Lignin bioproducts to enable biofuels," *Biofuels, Bioproducts and Biorefining*, vol. 9, no. 5, pp. 447-449, 2015.

[50] B. J. He *et al.*, "Effects of alternative process gases on the thermochemical conversion process of swine manure," *Carbon (C)*, vol. 45, no. 1, 2001.

[51] D. Mohan, "Pyrolysis of wood/biomass for bio-oil: A critical review," *Energy and Fuels*, vol. 20, pp. 848-889, 2006.

[52] M. Lewan, "Effects of thermal maturation on stable organic carbon isotopes as determined by hydrous pyrolysis of woodford shale," *Geochimica Et Cosmochimica Acta*, vol. 47, no. 8, pp. 1471-1479, 1983.

[53] A. Demirbas, "Biofuels sources, biofuel policy, biofuel economy and global biofuel projections," *Energy Conversion and Management*, vol. 49, no. 8, pp. 2106-2116, 2008.

[54] S. Czernik, *Review of Fast Pyrolysis of Biomass,* National Renewable Energy Laboratory, 2002.

[55] R. Brown and J. Holmgren, *Fast Pyrolysis and Bio-oil Upgrading*, Ames, IA. UOP LLC. PPT.

[56] J. Engel and G. Macht, "Comparison of lithium-ion recycling processes for electric vehicle batteries," 2016.

[57] A. Cordoba-Arenas *et al.*, "Capacity and power fade cycle-life model for plug-in hybrid electric vehicle lithium-ion battery cells containing blended spinel and layered-oxide positive electrodes," *Journal of Power Sources*, vol. 278, pp. 473-483, 2015.

[58] Y. Zou *et al.* "Combined state of charge and state of health estimation over lithium-ion battery cell cycle lifespan for electric vehicles," *Journal of Power Sources*, vol. 273, pp. 793-803, 2015.

[59] D. Rose, "Economic determinants and dietary consequences of food insecurity inthe United States," *Journal of Nutrition,* vol. 129, pp. 5175–5205, 1999.

[60] RTI, 2014, "Current and prospective scope of hunger and food security in America: A review of current research," Research Triangle Institute International Center for Health and Environmental Modeling.

[61] A. Coleman-Jensen, M. P. Rabbitt, C. Gregory, and A. Singh, *Household Food Security in the United States in 2014*, ERR-194, U.S. Department of Agriculture, Economic Research Service, USA,2015.

[62] D. Gustafson, A.Gutman, W. Leet *et al*., "Seven food system metrics of sustainable nutrition security," *Sustainability*, vol. 8, no. 196, 2016.

[63] FAO, IFAD, WFP, 2015a, "The state of food insecurity in the world 2015," presented at Meeting the 2015 International Hunger Targets: Taking Stock of Uneven Progress, FAO, Rome.

[64] United Nations, *Transforming Our World: The 2030 Agenda for Sustainable Development*, United Nations General Assembly Resolution, September 18, 2015.

[65] J. Woods, A. Williams, J. K. Hughes, M. J. Black, and R. J. Murphy, "Energy and the food system. Philosophical transactions of the royal society of London," *Series B, Biological Sciences*, vol. 365, pp. 2991–3006, 2010.

[66] N. Alexandratos and J. Bruinsma, "World agriculture towards 2030/2050: the 2012 revision," *ESA Working Paper*, no. 12-03, Rome, FAO, 2012.

[67] G. Conway and K. Wilson, *One Billion Hungry, Can We Feed the World?* Cornell University Press, Ithica, NY, USA, 2012.

[68] UN Millennium Project about the MDGs. *UN Millennium Project about the MDGs*. Millennium Project-UN Development Group.

[69] FAO, IFAD, WFP, *Achieving Zero Hunger: The Critical Role of Investments in Social Protection and Agriculture*, FAO, Rome, 2015b.


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He has hopes of opening a research and design firm that offers sustainable solutions utilizing his experiences in solar cells, energy generation, and currently, lithium batteries. Ultimately, these solutions will supply communities with energy independent generation and sourcing, at little to no cost.