A Revolution in Transportation Powered by Second-Generation Biofuels

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1. Abstract

Our dependence on petroleum-based fossil fuels for our transportation needs has come at high environmental, financial, and political costs. The emergence of biofuels as a viable alternative to fossil fuels would eliminate many of these costs. However, while there are renewable and environmentally safe methods of biofuel production, the costs of production cannot yet compete with that of fossil fuels.

There are two types of biofuels, first and second generation. First generation comprises of biofuels produced from simple fermentation reactions. A current example of this is corn-based ethanol. Second-generation biofuels are produced from more advanced means, such as enzymatic biochemical reactions, and utilize such products as algae and plant waste. Currently, Second generation biofuels are more expensive to produce than first generation, which is the main reason that they are not as prevalent. One main advantage of second generation versus first generation is that it bypasses the whole “food versus fuel” debate, as second generation biofuels as produced from non-food products, while first generation uses food products such as corn or sugar cane. The ongoing research presented in this paper will show how we may one day be able to utilize second generation biofuels to satisfy 100% of our transportation needs.

In this paper, the following plan is proposed to eventually wean ourselves off of fossil fuels. In the present day, incorporate a blend of first generation biofuels with petroleum. This is already occurring, as evidenced by the availability of such blends as E85 (15% ethanol blended with petroleum). In the near term (2-3 years in the future), incorporate second generation

biofuels as a blend with petroleum. And in the future (5+ years in the future), have all our transportation needs met by 100 % full renewable second generation biofuels. While these are ambitious goals, the ongoing research will show that once production of second generation matures, these fuels will be able to be produced at a competitive cost as current petroleum-based fossil fuels.

2. Introduction

One of the necessities for biofuels is the environmental impact of fossil fuels. The usage of fossil fuels for transportation has a well-documented environmental impact. Production and usage of fossil fuels has been shown to increase global warming, lead to destruction of natural environments, and pollute the environment.

Burning fossil fuels causes the release of Carbon Dioxide (CO_2), which gets trapped in and heats up the atmosphere, which causes global warming. The phenomena of global warming and its causes is one that is often debated. Recently, Richard Muller, a scientist at UC Berkeley, produced data that show that humans are responsible for the rise in the Earth's temperature, and that it is not simply a natural phenomenon.

Global warming is real and humans are the cause: "Our results show that the average temperature of the earth's land has risen by two and a half degrees Fahrenheit over the past 250 years, including an increase of one and a half degrees over the most recent 50 years. Moreover, it appears likely that essentially all of this increase results from the human emission of greenhouse gases."

Humans are the cause: "chart of temperature from 1753 to the present, with its clear fingerprint of volcanoes and carbon dioxide, but containing no component that matches solar activity. Four of our papers have undergone extensive scrutiny by the scientific community, and the newest, a paper with the analysis of the human component, is now posted, along with the data and computer programs used. Such transparency is the heart of the scientific method." [1] The graph shown below (Figure 1) illustrates the correlation of CO_2 increase and temperature increase:

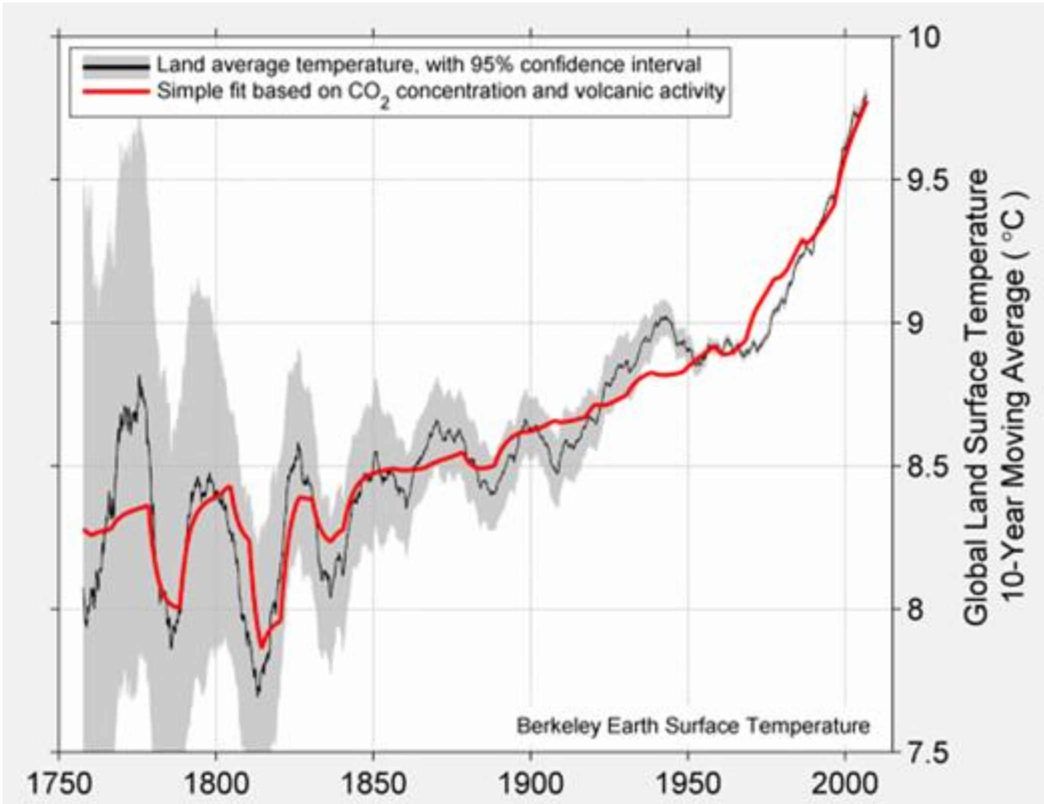
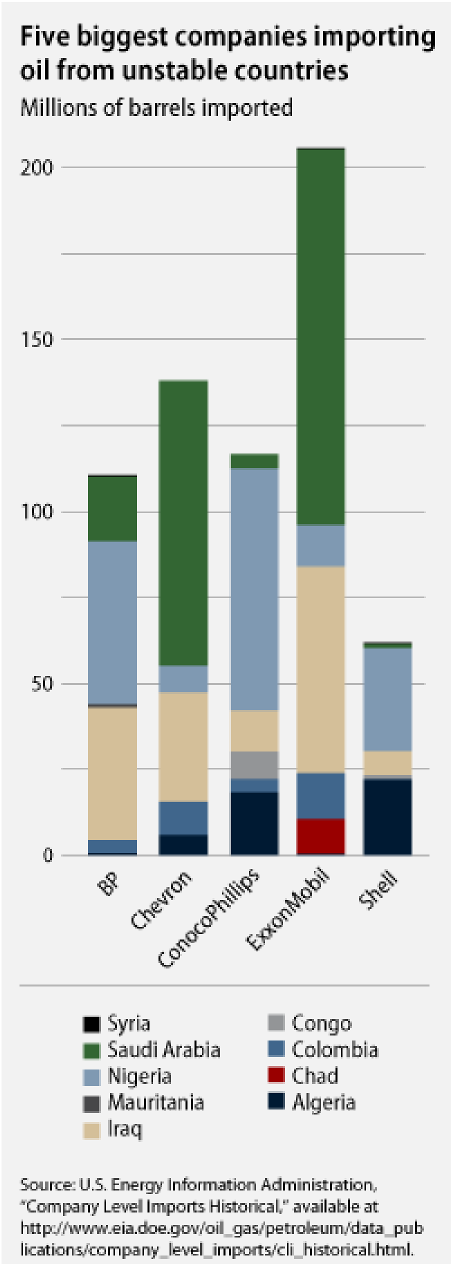


Figure 1: Global land surface temperature and CO_2 levels over the past 250 years



"Muller notes this doesn't prove that carbon dioxide is responsible for warming, but adds:

"To be considered seriously, any alternative explanation must match the data at least as well as does carbon dioxide."" [2]

While oil production in the US has steadily increased, the amount of money spent on foreign oil is still staggering. As Figure 2 shows, a lot of this money is going to countries deemed "unstable", or even having "hostile relations to the United States". [3]

Figure 2: International sources of oil from some of the world's largest oil companies

3. Potential Benefits of Switching From Fossil Fuels to Biofuels

"*Biofuels* are transportation fuels like ethanol and biodiesel that are made from biomass materials. These fuels are usually blended with the petroleum fuels — gasoline and diesel fuel, but they can also be used on their own. Using ethanol or biodiesel means we don't burn quite as much fossil fuel. Ethanol and biodiesel are usually more expensive than the fossil fuels that they replace, but they are also cleaner-burning fuels, producing fewer air pollutants." [4]

There are two potential benefits from switching from fossil fuels to biofuels: environmental and fiscal. The environmental impact could lead to reduced emissions and reduced pollution. The fiscal impact could lead to the creation of new jobs. Both are explained below.

Environmental Impact

Biofuels from plants and trees have been shown to produce fewer emissions compared to gasoline[5]. This effect is illustrated on Figure 3.

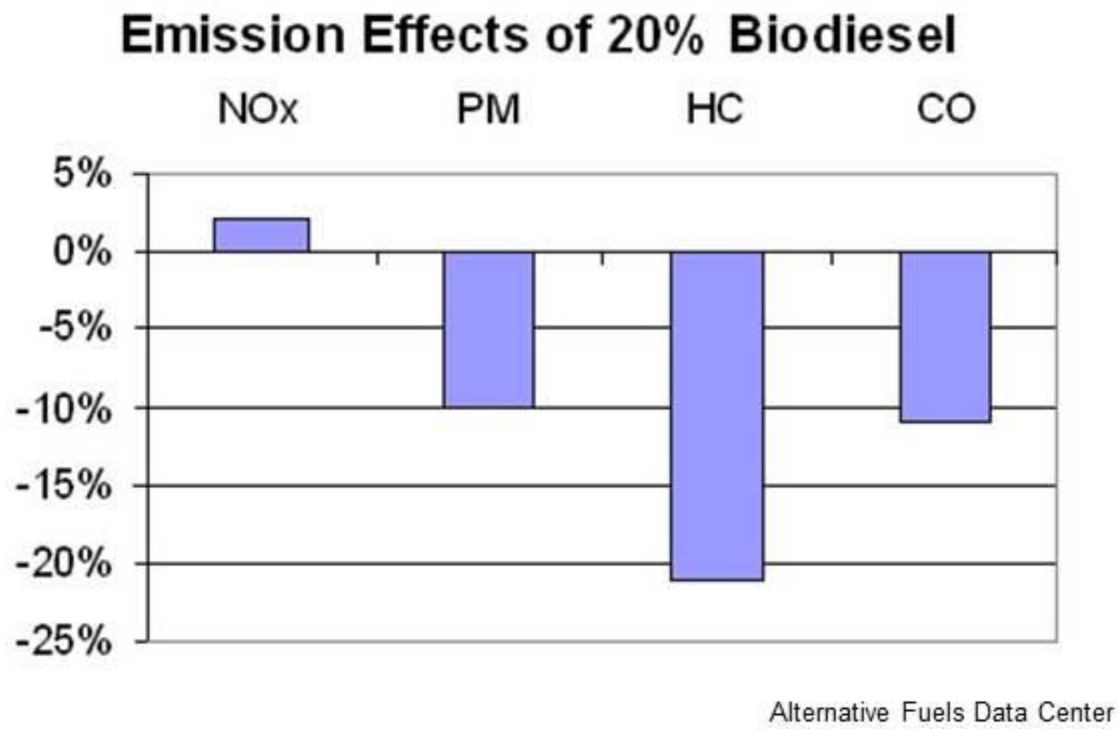


Figure 3: Emission Effects of Biodiesel

This graph compares the release of nitrous oxide (NO_x) particulate patter (PM), hydrocarbons (HC), and carbon monoxide (CO) from B20 (20% biofuels in conventional diesel) biodiesel to conventional diesel fuel emissions. It shows that while a slightly more amount of NO_x is released from biodiesel, the amounts of PM, HC, and CO released from biodiesel are lower than conventional diesel[5].

In addition to the reduction of PM, HC, and CO emissions, "sulfur oxides and sulfates, which are major components of acid rain, are not present in biodiesel."[5] This reduction in emissions will help to slow the erosion of the ozone layer and reduce air pollution. Another benefit to plant-derived biofuels is that while they release CO_2 into the atmosphere, the net amount of CO_2 released is less than the levels released from conventional fuels. The reason for this is that plants need CO_2 from the atmosphere to grow, and the CO_2 that is released back into the atmosphere is CO_2 that was already present from the atmosphere. The CO_2 released from conventional fuel is CO_2 that was stored underground, and thus not readily available, so when released into the atmosphere is a net gain in CO_2. CO_2 is also the main source of Greenhouse Gases (GHGs). The release of GHGs from fossil fuels causes climate change, which can lead to natural disasters and even water and crop shortages.

Another potential environmental benefit of using biofuels is the ability to use lignocellulosic biomass, such as plant waste, wood chips, grasses, and plant products that are both abundant and have no other agricultural or industrial use. However, the presence of lignin, which is present in plant cell walls to strengthen and stabilize the plant, provides a hindrance to mass biofuel production. To extract the plant sugars needed for biofuel production, lignin need to be broken up. The process of breaking up lignin to extract the plant sugars used to make biofuels is currently time-consuming and expensive[6]. However, there is some early-stage research that may one day make mass production of biofuels from lignocellulosic biomass a reality. Some of these research ideas include: making plant lignin weaker by removing a protein necessary for the lignin production,[6] understanding how anaerobic fungi from horse digestive tract break down plants,[7] and using a chemical liquid to dissolve plant lignin.[8]

Fiscal Impact

While switching to biofuels certainly has positive environmental benefits, there are also economic benefits. One such benefit is job creation directly related by increased biofuels production.

Biofuels Impact	13.9 billion gallons	36 billion (RFS, 2022)
Direct Jobs	90,200	233,612
Total jobs	401,600	1,040,115
US GDP contribution	42.4	109.8
Oil import reduction	49.7	128.7

Figure 4: Job Creation Associated with Increased Biofuel Production

Figure 4 shows how new jobs will be directly created with increased biofuels production. Also of note is the decrease in oil imports, which has both economic and political implications.[9] The added benefit of domestic biofuel production means that less money is being spent on foreign oil.

4. Challenges/Incentives Facing Biofuels

Biofuels are produced from different raw materials and methods. Based on this, they are characterized as first and second Generation Biofuels.

First generation biofuels are produced by fermentation to get ethanol. Corn-based ethanol is a common first generation biofuel. The technology to produce these is simple (fermentation), but there are potential issues such as the "food versus fuel debate" (i.e., utilizing valuable farmland to produce fuel, driving up the price of the food or fuel, and whether to use the crop for food or fuel, and the opportunity cost of not being able to use the farmland to produce other crops). Therefore, since there are a number of controversial issues with the production of first generation biofuels, this may not be the best option for mass production of transportation-based biofuels.

Second generation biofuels are produced by other more complex technology. This can utilize starting materials such as algae, plant-waste (cellulosic), wood chips, and other bio products that either grow on land that can't be used to grow other crops, or have no other use, or can be easily and cheaply grown (do not require a large land area to produce a large amount of biofuel), or are simply a waste product that may otherwise end up in a landfill. The main drawback to using second generation biofuels is that the cost to produce is very high, due in part to the complex technology currently required to produce the biofuel. This leads to a much higher cost of a unit (of energy output) of second generation biofuel relative to the cost of the same unit (of energy output) a first generation biofuel or even a conventional fuel (such as fossil fuel). However, as the technology to produce second generation biofuels advances and matures, the cost to produce will inevitably come down. This in turn will lead to greater utilization of second generation biofuels, and a reduction in the usage of fossil fuels. We are already seeing some of the early potential of biofuels in the form of biodiesel, which has been shown to power jets at a similar efficiency as conventional diesel fuel[10].

In addition to being a cleaner-burning fuel than conventional biofuels, second generation biofuels hold some distinct advantages over first generation biofuels. The first of these is an avoidance of the whole "food versus fuel" debate. Second generation biofuels are typically produced using plant waste, algae, and other non-food items. Also, many of these biological products grow in areas where nothing else can grow, so the whole argument on utilization of valuable farmland is avoided. Some biofuels, such as algae, can be massively grown in a bioreactor to potentially produce a large amount of biofuel in a small area. In some cases, potentially harmful chemical products, such as CO_2 can be used to produce biofuels[11]. In cases such as these, biofuel production and utilization could not only reduce pollution, but potentially reverse some of the environmental damage that the heavy usage of fossil fuels has caused. A potential drawback to using plants, however, is that some plants, like switchgrass, have important environmental functions like preventing soil erosion and providing homes for animals.[5]

Another benefit of the ease of production of biofuels is the potential to bring this energy source to parts of the world which may not have easy access to conventional fossil fuels. An example of this is the jojoba bean, which produces oil that is very easy to extract from the bean and can be subsequently used as fuel. This plant is native to the SW USA/Mexico, but could conceivably be grown in other parts of the world, especially in a similar climate as the SW USA/Mexico.

In the next few years, algae/petroleum blends provide the best way to meet the RFS quota. Advantages are that it is easy to produce; it avoids the food versus fuel debate common to first generation, fermented biofuels, and can be produced using a relatively small land area. However, one drawback is that it is not yet a 100% drop-in fuel for current engines. That being said, algae/petroleum blends are already being utilized in diesel engines, and increased use in privately-owned vehicles is not far off.

In the present term, first generation, fermented fuels based on such crops as corn and ethanol are the way to meet the RFS. These are very easy to produce, and can already be used in current engines as an 85% blend. The obvious drawback is that these crops require substantial farmland to produce, at the expense of other crops. This brings up the other obvious drawback of the "food versus fuel" debate. The usage of food crops for biofuel will eventually be phased out, as second generation biofuels such as algal ethanol will become a more viable option as production technology becomes more efficient.

While corn is very commonly used today to produce biofuels, it may not be the best option. "Corn is not considered to be a major oil crop—it produces around 18 gallons of oil per acre per year, which is less than half as much as soybeans. The yield of oil from algae still needs to be demonstrated on a large scale, but assuming an optimistic but not unrealistic annual yield of 4,000 gallons of oil per acre, it is clear that algae could be a couple hundred times more productive than corn. Comparing algal oil to corn ethanol, algae would be around ten times more productive in terms of fuel energy."[12] Another current method of energy is solar/wind power, however, this alone may not be enough to satisfy all our energy needs. "Algal photosynthesis is essentially a type of solar energy, because the cells are converting the energy of sunlight and carbon dioxide into stored energy in the form of oil. Assuming 4,000 gallons of algal oil per acre per year, the overall efficiency of algal oil production (energy in the oil divided by the total energy in the incident sunlight) would be around two percent on a full solar spectrum basis. This is lower than the efficiency of electricity production by typical photovoltaic solar cells, so photovoltaics would generate more energy per land area. However, algae are producing a liquid fuel, whereas photovoltaics (or wind turbines) are producing electricity. I think that we will continue to need both types of energy in the future. Even if all cars ran on electricity, we would still need an energy-dense liquid transportation fuel for trucks, trains, and airplanes."[12]

5. Biofuels in Transportation

Cars that run on biofuels such as algae and used vegetable oil are in use now, especially in diesel engines. These can use a blend of up to 20% biofuel/petroleum blend[13]. Some benefits of algae are that it is easy to grow[14], will not take up valuable farmland, and does not cause pollution[15].

Current and future mandates are specifying for the inclusion of biofuels in transportation fuels. The Group of 8 (G8) is requesting a 50% global reduction of CO_2 by 2050. According to the International Energy Agency (IEA), "by 2050, biofuels could provide 27% of total transport fuel and contribute in particular to the replacement of diesel, kerosene and jet fuel. The projected use of biofuels could avoid around 2.1 gigatonnes (Gt) of CO_2 emissions per year when produced sustainably"[17].

In addition, federal mandates require increasing levels of renewable fuels into current transportation fuels. "The U.S. Renewable Fuel Standard (RFS) for transportation fuels sets minimum levels of renewable fuels that must be blended into gasoline and other transportation fuels from 2006 to 2022. Specific requirements for blending advanced biofuels, including cellulosic biofuels and biomass-based biodiesel, begin at 0.6 billion gallons per year in 2009 and rise to 21 billion gallons in 2022."[18]

Widespread use of biofuels as a petroleum replacement is a future possibility. There are some instances of cars fueled by algae or used vegetable oil, and even more widespread, biodiesel in diesel engines. One of the reasons that biodiesel has gained more of a foothold compared to non-diesel vehicles is that biodiesel is a drop-in replacement for diesel fuel. This means that any diesel engine can run either petroleum-based diesel fuel (such as a 20% blend with conventional diesel) or biodiesel without any modification to the engine. While this certainly is a positive step to wean ourselves off of petroleum, diesel engines are a small percentage of the total vehicles on the road.

To produce cars that can run on 100% algae or used vegetable oil (as opposed to a biofuel/petroleum blend), significant engine modifications need to be made. One possible way to achieve this in the next few years, assuming the cost and scale of production become reasonable, is to use a biofuel/petroleum blend that can work in current automobile engines without any further modification. By doing this, not only are GHG emissions reduced, biofuel production is potentially more profitable. Another reason for using a biofuel/petroleum blend before going to 100% biofuel is that it will provide oil-producing companies (which may already have the intellectual and even technical capacity to produce biofuels) sufficient time to change their business models. This will help ensure that jobs are not lost, and that those individuals currently working to produce petroleum can be re-trained to produce biofuels.

Another benefit of the shift to biofuel/petroleum blend is the potential advancement of vehicle engine technology. By having to modify an engine, it could potentially be re-designed to not only run 100% biofuels, but to be more efficient with fuel consumption. A potential side-effect is the creation of new companies and new jobs, but as with petroleum-producing companies, current vehicle engine-producing companies could already have the capacity to design engines powered by 100% biofuels.

Vehicle usage is projected to go up, especially in developing countries (Figure 5), which means that there is an even greater need for fuels that release little or no GHGs. "Transport accounts for 19% of global energy use and 23% of energy-related Carbon Dioxide (CO_2) emissions and these shares will likely rise in the future. Given current trends, transport energy use and CO_2 emissions are projected to increase by nearly 50% by 2030 and more than 80% by 2050."[19]

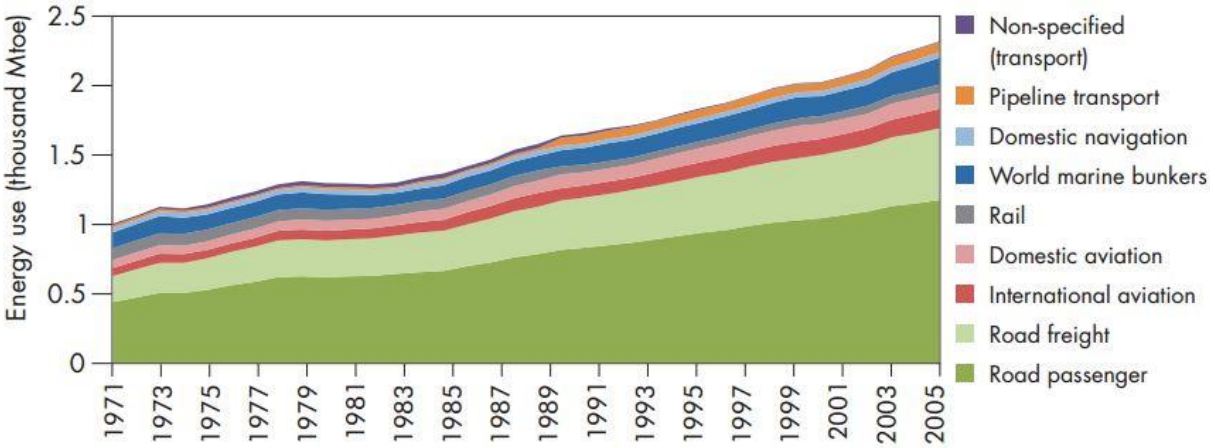


Figure 5: World transport energy use has more than doubled in 40 years.[19]

While production of biofuels has increased, there is still a very long way to meet the world's transportation needs. Biofuels will become cheaper as production technology advances, and consequently easier to scale-up to a level that is practical for widespread use.

"World biofuel production has increased sevenfold since 2000, but still meets only 2.3% of final liquid fuel demand. Production of biofuels globally grew from 16 billion liters in 2000, to an estimated 110 billion liters in 2012[20] (Figure 6). Biofuels accounted for around 2.3% of total transport fuel demand in 2011. Brazil, the United States and the European Union have considerably higher shares, at 20.1%, 4.4%, and 4.2% respectively in 2010."

This is an encouraging start, but to make a real impact more needs to be done: “Production must more than double from today’s levels to meet 2DS goals (Note: 2DS is 2-degree Celsius scenario, which is the rate of progress required to achieve a 2-degree Celsius limit in global temperature rise)[20]. Global biofuel production is set to increase by 25% by 2017, to around 140 billion liters. Despite this growth, a considerable gap of 100 billion liters remains between projected 2017 production volumes and volumes required in the 2DS[20].”

One way to ensure that the biofuel production goals are met is to improve on current technologies for production: “Advanced biofuel production capacity[24] continues to expand, reaching 4.5 billion liters in 2012, up 1.3 billion liters from 2011, and 2.9 billion liters from 2010 (Figure 6). This progress, while significant, must be accelerated. Commercial deployment of advanced biofuel conversion technologies will be required to reach 2DS objectives, while improving conversion efficiency, cost and sustainability of conventional biofuels. The 2DS assumes less than 30 billion liters of advanced biofuel capacity in 2020. The advanced biofuel sector is projected to see solid capacity additions out to 2017, with installed production capacity forecast at 10 billion liters in 2017. This is only one-third of the capacity required to meet the 2DS, however, so significantly more investment in commercial production units is required[20]”.

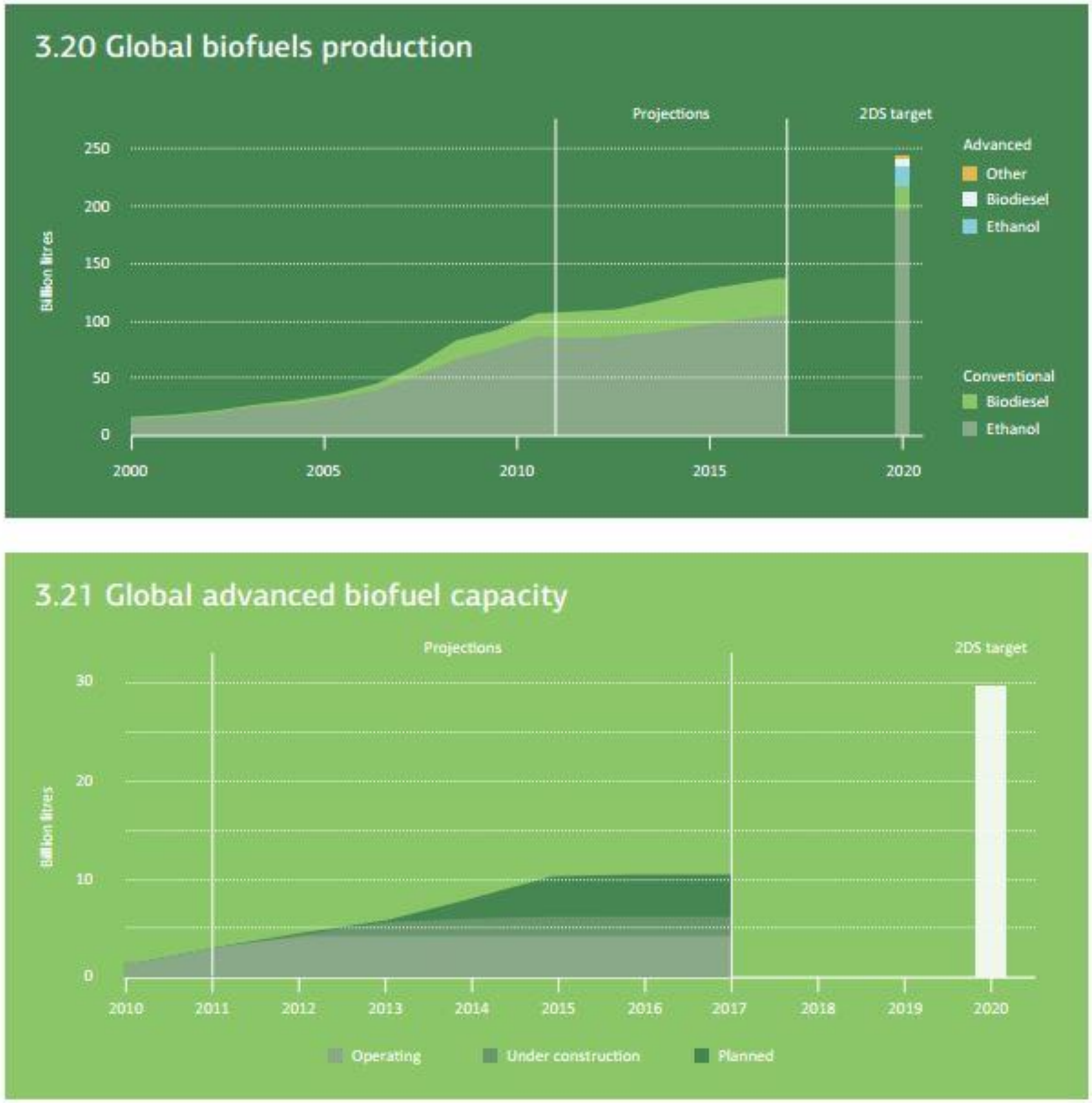


Figure 6: current production and capacity levels needed to reach the 2DS target in 2020.

6. Biomass Energy Pros and Cons[21]

As with many technologies, there are benefits and drawbacks. The production of biomass-based biofuels is no exception. Some of the pros to producing biomass-based biofuels are: biomass-based biofuels are truly renewable, widely available, and in abundant supply. These attributes are satisfied since biomass-based biofuels are made from a wide variety of plant-based material. In addition, the input costs are generally low, due to the fact that plant waste can be used. The use of plant waste can not only relieve the need to use plant-based crops, but can also help relieve the waste disposal issue. On a political note, biomass-based biofuels can be produced domestically to promote energy independence from foreign nations. From an environmental standpoint, there is a low carbon byproduct from the production of biomass-based biofuels, thus making them cleaner to produce than fossil fuels.

Although the pro arguments show that the use of biomass-based biofuels can be beneficial, there are con arguments that need to be considered. Some of these considerations are economical, in that the overall costs of production can be very high, sometimes with little or no net gain from the production process. Water is also required, which is another added cost, as well as the food versus fuel argument for those fuels derived from food crops, such as corn and sugar cane. From an environmental standpoint, deforestation could result in order to grow crops specifically for biofuels production. Also, some biofuels are not totally clean when burned as fuel, as NO_x, soot, ash, CO, and CO_2 are harmful byproducts, with methane and CO_2 emitted during biofuels production.

7. Algae-based Biofuels Pros and Cons

While the drawbacks of algae-based biofuels are significant now, these could potentially be resolved in the future with advances in production technology. However, the benefits to using algae-based biofuels are massive. The fuel is essentially carbon neutral when used, and is inherently renewable. In addition, it can be grown on land unsuitable for other types of agriculture, and waste CO_2 and waste water can be used as nutrients to grow the algae. This eliminates the whole food versus fuel issue. From an economic standpoint, algae-based biofuels give a higher energy per-acre than other biofuels, and that 17 % of U.S. oil imports could be met with algae[22]. Algae-based biofuels can also be used as a drop-in replacement for petroleum-based liquid tech fuels, and research to improve the production, costs, and quality of algae-based biofuels has been going on for more than 50 years.

With all the pros of algae-based biofuels, there are some cons, primarily economic in nature. The upfront capital costs can be high, as a controlled temperature environment and a considerable amount of both land and water are needed. Also, it's not yet clear what the ultimate cost per gallon will be, although it is presently too high for algae-based biofuels to be utilized for mass consumption[23].

8. Natural Gas Pros and Cons

Natural gas is the cleanest fossil fuel available, but as detailed below, is nowhere near as clean and environmentally-friendly as biofuels. There are, however, some benefits to using natural gas. Natural gas is widely used, with the delivery infrastructure and end use appliances already in place. It also emits 45% less CO_2 than coal and 30% less CO_2 than oil, making it the cleanest of all the fossil fuels. There is an abundant supply in the U.S, with the DOE estimating 1.8 trillion barrels[24].

The cons of natural gas are abundant, with both environmental and overall safety concerns. Natural gas is a non-renewable fuel source, and the supply cannot be replaced for millennia. It contains 87-97% methane[25], which is a potent GHG. It is also stored and transported under high pressure, and is explosive[26]. To transport natural gas, extensive pipelines that can disrupt the environment need to be built[27]. The liquefied form that is typically transported by tanker ships over water is also very dangerous[26].

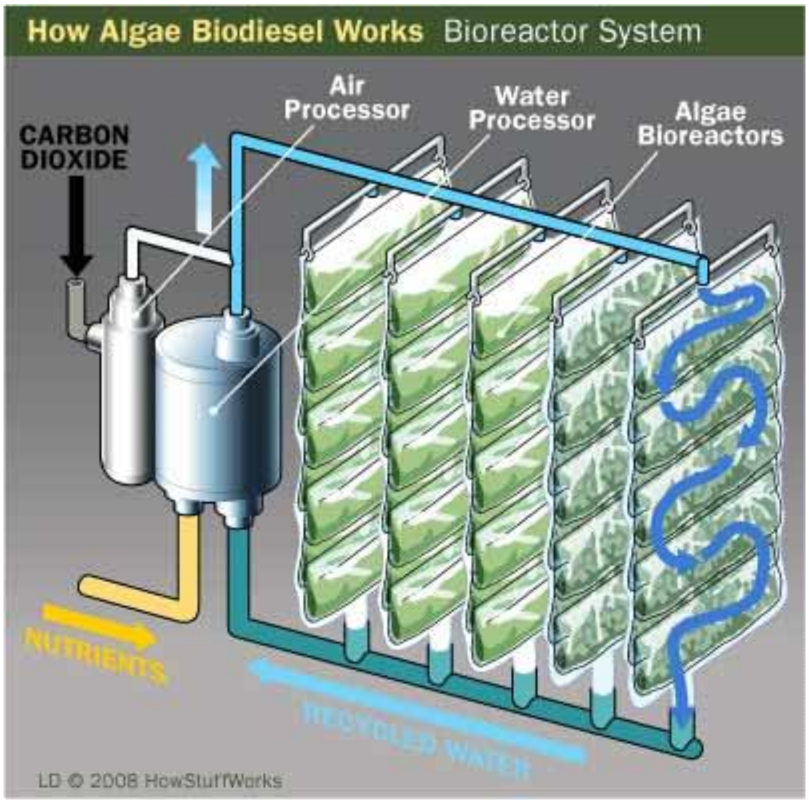
There are also a lot environmental risks associated with fracking, which is the process used to extract natural gas from beneath the Earth's surface. Fracking requires a large amount of water, which can also cause water pollution due to chemical runoff[28]. Fracking can also bring up adsorbed underground toxins such as arsenic[29].

9. Current Modes of Algal Biofuel Production

There are many ways that algal biofuels are currently being produced. Some methods used by larger companies are more established and can currently produce biofuels at relatively high scale and with lower costs. Smaller companies and research labs are also working on methods that could potentially lead to a breakthrough in high-scale, low cost production. Currently, however, the scale and cost at which algal biofuels are being produced is not enough to satisfy the world's needs, or the RFS standard.

Some of the different techniques used are detailed below[30]:

- Open system (ponds): This is the technique used by one local algal biofuel-producing company, Sapphire Energy[31]. One of the advantages is that an algal pond can be located anywhere with sufficient sunlight, and the process is non-invasive. However, there are concerns with contamination and temperature regulation, which can get expensive.
- Bioreactor (vertical growth/closed loop system, Figure 7)[30]: To eliminate the disadvantages of the open system method, a closed-loop system has been utilized. Algae are placed in clear plastic bags, and exposed to sunlight so the algae can grow. Nutrients, carbon dioxide, and water are pumped in, with the water cycling through and getting recycled. This minimizes the use of water in growing algae. After sufficient growth, the algae are then harvested, and the oil can be extracted to produce biofuel. The resulting biomass can then be recycled back into the system to repeat the process.



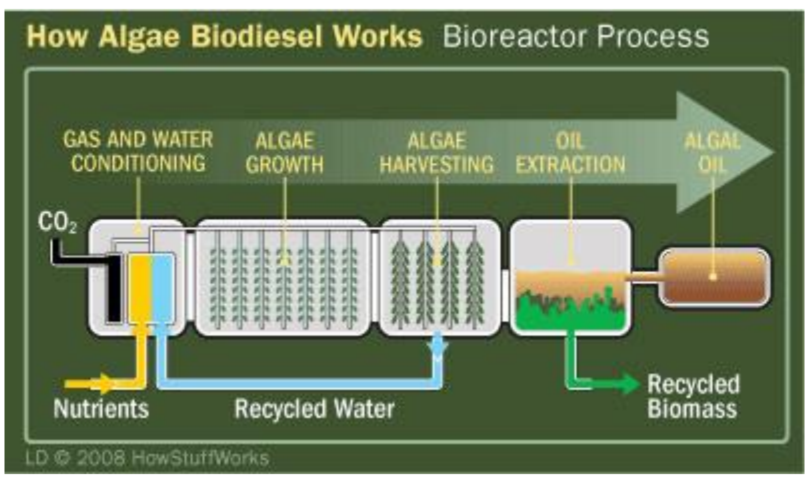


Figure 7: The bioreactor system (top) and process (bottom) used for the production of algae biofuels

One challenge for growing algae is the use of water and other nutrients needed to sustain cultures. However, "Similarly, by using wastewater from agricultural or municipal sources to grow and feed the algae, one could address both the water and the nutrient issue, and lower the energy demands in the process as well"[32]. Also, in a closed system this water is recycled, so that would only need to be an initial input of water, as opposed to continually supplying the system with water.

Another company, Algenol, is currently able to produce algal-based ethanol at a production cost of $1.18/gallon with a total production of 10,400 gallons/acre/year[33]. This is a much greater output than either corn (400 gallons/acre/year) or sugar cane (800 gallons/acre/year).[34]Another advantage to Algenol's process is that the production process starts with salt water, then produces 1.4 gallons of clean water for every gallon of algal biofuel produced. The further plan is to market the fuel at 75 cents less than the current market price for algal-based ethanol fuels, thus making it more competitive with petroleum-based fuels.

Some examples of ongoing research to improve algal biofuel production are described below:

- As an experimental algae production, NASA's OMEGA (Offshore Membrane Enclosure for Growing Algae) project shows promise (Figure 8)[35]. This system uses large, clear plastic tubes called photo bioreactors that contain algae and float in the ocean. To provide nutrients to the algae, wastewater is pumped into the photo bioreactors. The tubes are on the ocean surface and have exposure to sunlight. After utilizing the nutrients and sunlight, the algae then release clean water and oxygen, which also serves to clean the wastewater. Once the algae have sufficiently grown, it can be harvested to make biofuels, and the process can be repeated.

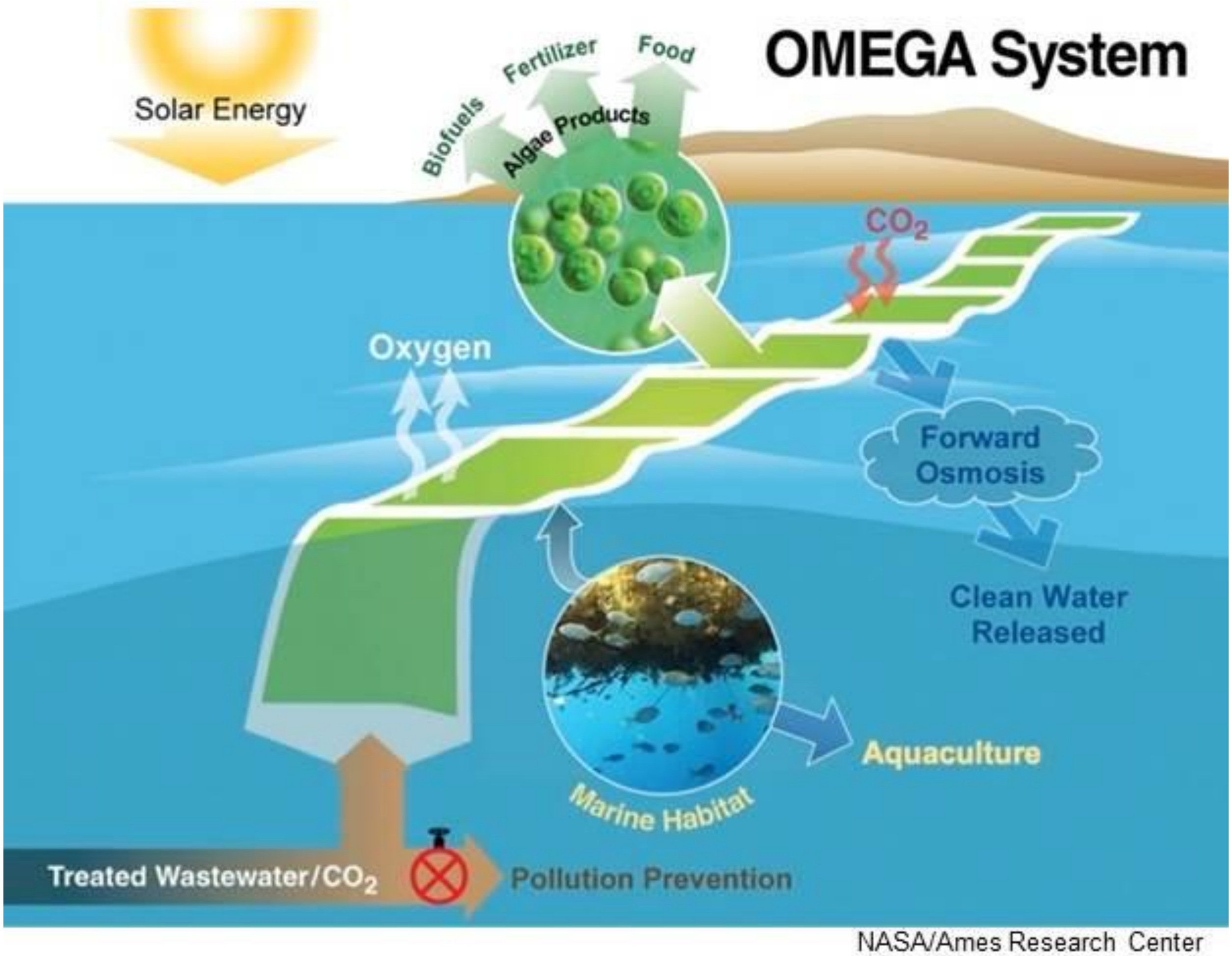


Figure 8: Overview of the OMEGA system for algae biofuels production

- Using algae found in harsh environments to engineer tougher biofuel-producing algae[36]. A research team recently sequenced the genome of Galdieria sulphuraria, which is red algae that is found in such harsh climates as volcanoes and sulfur in hot springs. By studying the genetic factors that allow for the algae to survive in these harsh climates, biofuel-producing algae can be engineered to tolerate high-heat and metal contamination. This would in turn allow for biofuel-producing algae to be more robust and less prone to breaking down, no matter which type of method is used for algal-based biofuel production.

- Ferredoxins are proteins that can transfer electrons in a redox reaction. According to a research group from the Energy Department's National Renewable Energy Laboratory, 2 of the 6 ferredoxins (FDX1 and FDX2) found in Chlamydomonas reinhardtii algae could potentially result in increased hydrogen production, which could lead to hydrogen as a biofuel. If the bacteria can be modified so that more electron transport goes through FDX1 (or less preferentially FDX2), then hydrogen can be produced at an increased rate by the bacteria. This hydrogen could then be used as a biofuel[37].

10. Production of Biofuels from Biomass

In addition to algal biofuels, biomass can provide biofuels that can potentially satisfy the world's transportation needs.

Meeting the challenge of producing cellulosic ethanol (i.e. from switchgrass or "plant waste") to reach the 36 billion gallons by 2022 challenge will be difficult. However, it is theoretically not impossible. As quoted by the Worldwatch Institute, "Using biochemical methods (hydrolysis and fermentation), each dry ton of switchgrass can in theory yield 111 gallons of ethanol. Using thermochemical processes (gasification, pyrolysis, and depolymerization), the theoretical maximum is 198 gallons. In practice, researchers today estimate getting 100 gallons per dry ton of switchgrass**;** roughly double the 50 gallons a ton produced in pilot projects just a few years ago. According to a 2005 government study of the total available biomass in the United States—known as the "billion ton study"—roughly 1.3 billion tons of cellulosic biomass could be harvested sustainably nationwide each year by mid-century. If these 1.3 billion tons were converted to fuel at 50 to 100 gallons a ton, the United States would produce between 65 billion and 130 billion gallons of cellulosic ethanol[38]". While this would easily surpass the goal of 36 billion gallons produced by 2022, there is still the issue of land utilization to get to this goal. To answer this, the Worldwatch Institute has determined the following: "Most of the switchgrass grown intentionally in the United States today is in the Conservation Reserve Program (CRP), which encompasses about 34 million acres, a tiny fraction of the country's total agricultural land. If the average switchgrass yield is 3 tons per acre (as one study suggests, assuming that marginal land is used and that some biomass is left on the fields), and the ethanol is converted at 100 gallons a ton, then *120 million acres* will be needed to produce 36 billion gallons of fuel. This is a large amount of land, though, for comparison, it represents only 15 percent of the total U.S. land currently used for grazing livestock. But if the average feedstock yield is 10 tons an acre, rather than just 3, which could be realistic using a different grass variety or better-managed switchgrass, then only *36 million acres* would be needed to meet the RFS. This is still more area than is currently enrolled in the CRP, but it represents only about 5 percent of the land used today for grazing, or 8 percent of the current cropland[38]". With the relatively small amount of land required to meet the production goal, the environmental impact could be minimal.

In addition to switchgrass, there are other potential methods of producing biofuels. Some examples of ongoing research to improve cellulosic biofuel production are described below:

- Hydrogen from plant sugar xylose as a fuel source: Found in any plant, so plenty of options and bypasses the food versus fuel debate. Also emits very low GHGs, unlike current hydrogen source of natural gases. This process of extracting hydrogen from plant xylose is known as Synthetic Pathway Biotransformation (SyPaB). It involves a series of enzymes that act as catalysts to produce hydrogen from xylose and a polyphosphate. The energy that is produced from SyPaB is more that the energy that went into the reaction, which results in a net energy gain. This is in contrast to ethanol and butanol produced from sugars, which require a higher energy input than the output of the reaction, or an energy penalty. While SyPaB is far from perfect, it has the potential to use one of the most abundant plant sugars and use it to make hydrogen-based biofuels in an energy-efficient and renewable process.[39, 40, 41]
- Breakdown of lignin[42]: One of the barriers to producing biofuels from biomass is lignin, which forms a protective wall in plant cells. In biofuel production, this wall must be broken down to get to the cellulose used to make ethanol. A research group

in North Carolina has found a way to genetically modify a plant cell with reduced lignin. The result is that the plant cell is weaker and less energy-intensive to break down. Discoveries such as this could to breakthroughs in more energy-efficient and thus cost-effective biofuel production.

11. Other Speculative Research

- A research team from the United Kingdom has created hydrocarbons that are chemically the same as hydrocarbons found in petroleum using *E. Coli* bacterial cells grown in a laboratory. In theory, this could replace petroleum in engines without needing to modify existing engines,[43, 44] To do this, the researchers created a new metabolic pathway in genetically modified *E. Coli* cells that could produce the same types of carbon chains found in petroleum. The main drawback is that only a very tiny amount of the hydrocarbons were produced. However, the potential to produce a 100% renewable drop-in fuel into existing engines is very promising.
- Another group is converting ionic liquids into biofuels[45]. Ionic liquids are waste products from biofuel production, such as lignin and cellulose. A research team was able to turn them back into biofuels using sugars from biomass. This "closed-loop system" cuts down on waste and the cost of producing biofuels from raw materials. At present, this method uses expensive chemicals to generate the production, but this cost could come down by substituting cheaper chemicals. This, in turn, would help minimize waste products from biofuel production.
- Enhanced *E. Coli* cells used to produce bio-gasoline (isopentenol).[46] A research group has found a possible method to scale-up the production of isopentenol, which can be used as a bio-gasoline. The problem that the group encountered was that the *E. Coli* bacteria used to produce the bio-gasoline would be killed by the same product. This toxicity made is near-impossible to scale-up production. To fix this, the group identified and included the genes responsible for isopentenol resistance, thus enhancing the *E. Coli* bacterium's ability to survive and continue producing bio-

gasoline. The genetic modifications allow for isopentenol to be forced out of the *E. Coli* cell, and allowing the bio-gasoline to float to the surface, as an oil-water mix. This makes the valuable biofuel easy to obtain, and allows the bacteria to survive and produce more biofuel.

12. Conclusion

While current technologies are an improvement over older production methods, there is still more technological advancement that needs to be accomplished to increase the use of biofuels. ”Without costly and time-consuming infrastructure and engine remodeling, the maximum blend ratio of biofuel to petroleum distillate (the blend wall) is between 10% and 20%[4]. Consequently, without a dramatic change in vehicle technology and fuel supply infrastructure, 80–90% of transport fuel demand cannot be met through replacing petroleum-derived fuels with the biofuels currently available[47].”

Another challenge is the overall cost needed to produce second generation biofuels is currently higher than the cost to produce a similar amount (in terms of energy units) of fossil fuels[48].

How to address this challenge: The above statement is currently true, however, this will not be the case in the future as technology develops and reduces the cost of production. As dependence on fossil fuels is reduced, resources (such as land, water, labor, and technology) previously used to produce fossil fuels can subsequently be diverted to the production of second generation biofuels. In the short term, there should be two main focuses: 1) developing transportation that is powered by biofuels, and phasing out transportation that is powered by fossil fuels; 2) reducing the cost of second generation biofuels production through technological advances. Due to the high cost of production and resulting purchase, this would have to be done on a very small scale at first. However, it has been shown that modifications to existing engines would not be excessive, so the changes could happen sooner rather than later. In fact, blended biofuels (such as E85) are already used in many diesel engines. Another article describes how existing jet engines perform better with algal biofuels: “Test flights have shown aviation biofuels have a higher energy density that imparts **better fuel mileage**. Engines running on biofuels also encounter lower burn temperatures, which means less fatigue on parts and longer engine life[49]."

In the present term, a petroleum/biofuel blend is the way to go to at least reduce our fossil fuel dependence and slow environmental destruction. This is currently taking place with biodiesel. A biodiesel engine can run on an up to 20% blend (or B20), without any additional modification to the engine [13]. Since most current vehicle engines run on petroleum, technology needs to be further developed for either these engines or completely new engines to efficiently run biofuels. In the long term, a complete switch to 100% biofuels may be possible with advancement of production technology, reduction of production costs, and modifications to vehicle engines. Algae biofuels alone may not be enough to meet the current goal of 5% (39 billion gallons) of US transportation needs[50], so other biofuels, such as those made from plant waste, may be needed to wean our dependence from fossil fuels. Weaning ourselves off of petroleum is especially important as the number of cars in the world will increase, especially with the rapid economic growth in countries such as Brazil, India, and China, which will all have huge demands for fuel. Let's make sure that the fuel is something that is clean-burning and does not release any more GHGs into the atmosphere.

In the next few years, algae/petroleum blends provide the best way to meet the RFS quota. Advantages are that it is easy to produce; it avoids the food versus fuel debate common to first generation, fermented biofuels, and can be produced using a relatively small land area. However, one drawback is that it is not yet a 100% drop-in fuel for current engines. That being said, algae/petroleum blends are already being utilized in diesel engines, and increased use in privately-owned vehicles is not far off.

With all of the ongoing research and improvements to existing technologies, second-generation biofuels, such as algal-based fuels, will soon become commonplace for drop-in fuels in many modes of transportation. Weaning ourselves off of conventional fuels such as petroleum has many benefits for all people and the planet for many generations to come.

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