

Why Not Liquid Biofuels For Transportation as Part of a 100% Wind-Water-Solar (WWS) and Storage Solution to Global Warming, Air Pollution, and Energy Security

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3.5. Why Not Liquid Biofuels For Transportation?

Liquid biofuels are generally used for transportation as a substitute for gasoline or diesel. The most common transportation biofuels are ethanol, used in passenger cars and other light-duty vehicles, and biodiesel, used in many heavy-duty vehicles. Liquid biofuels should not be used as part of a 100 percent WWS infrastructure due to their high air pollution mortality and morbidity, climate, land, and water supply impacts. This section discusses these issues.

Ethanol (C_2H_5OH) is produced in a factory, generally from corn, sugarcane, wheat, sugar beet, or molasses. The most common among these sources are corn and sugarcane, resulting in the production of **corn ethanol** and **sugarcane ethanol**, respectively. Microorganisms and enzyme ferment sugars or starches in these crops to produce ethanol.

Fermentation of cellulose originating from switchgrass, wood waste, wheat, stalks, corn stalks, or *Miscanthus*, also produces ethanol. However, the process is more energy intensive because breakdown of cellulose (e.g., as occurs in the digestive tracts of cattle) by natural enzymes is slow. Faster breakdown of cellulose requires genetic engineering of enzymes. The ethanol resulting from these sources is referred to as **cellulosic ethanol**.

Ethanol may be used on its own, as it is frequently in Brazil, or blended with gasoline. A blend of 6 percent ethanol and 94 percent gasoline is referred to as **E6**. Other typical blends are **E10**, **E15**, **E30**, **E60**, **E70**, **E85**, and **E100**. In many countries, including the United States, E100 is required to contain 5 percent gasoline as a **denaturant**, which is a poisonous or foul-tasting chemical added to a fuel to prevent people from drinking it. As such, E85, for example, contains about 81 percent ethanol and 19 percent gasoline.

A proposed alternative to ethanol for transportation fuel is **butanol** (C_4H_9OH). It can be produced by fermenting the same crops used to produce ethanol but with a different bacterium, *Clostridium acetobutylicum*. Butanol contains more energy per unit volume of fuel than does ethanol. However, unburned butanol also reacts more quickly in the atmosphere with the OH radical than does unburned ethanol, speeding up ground-level ozone formation relative to ethanol. On average, ethanol used in internal combustion engine vehicles produces more ground-level ozone than does gasoline used in such vehicles in most regions of the United States (Jacobson, 2007; Ginnebaugh et al., 2010; Ginnebaugh and Jacobson, 2012).

Biodiesel is a liquid diesel-like fuel derived from vegetable oil or animal fat. Major edible vegetable oil sources of biodiesel include soybean, rapeseed, mustard, false flax, sunflower, palm, peanut, coconut, castor, corn, cottonseed, and hemp oils. Inedible vegetable oil sources include jatropha, algae, and jojoba oils. Animal fat sources include lard, tallow, yellow grease, fish oil, and chicken fat. Soybean oil accounts for about 90 percent of biodiesel production in the United States. Biodiesel derived from soybean oil is referred to as **soy biodiesel**.

Biodiesel consists primarily of long-chain methyl, propyl, or ethyl esters that are produced by the chemical reaction of a vegetable oil or animal fat (both lipids) with an alcohol. It is a standardized fuel designed to replace diesel in standard diesel engines. It can be used as pure biodiesel or blended with regular diesel. Blends range from 2 percent biodiesel and 98 percent diesel (**B2**) to 100 percent biodiesel (**B100**). Generally, only blends B20 and lower can be used in a diesel engine without engine modification. The use of vegetable oil or animal fat directly (without conversion to biodiesel) in diesel engines is also possible; however, it results in more incomplete combustion, and thus more air pollution byproducts, as well as a greater buildup of carbon residue in, and damage to, the engine than biodiesel.

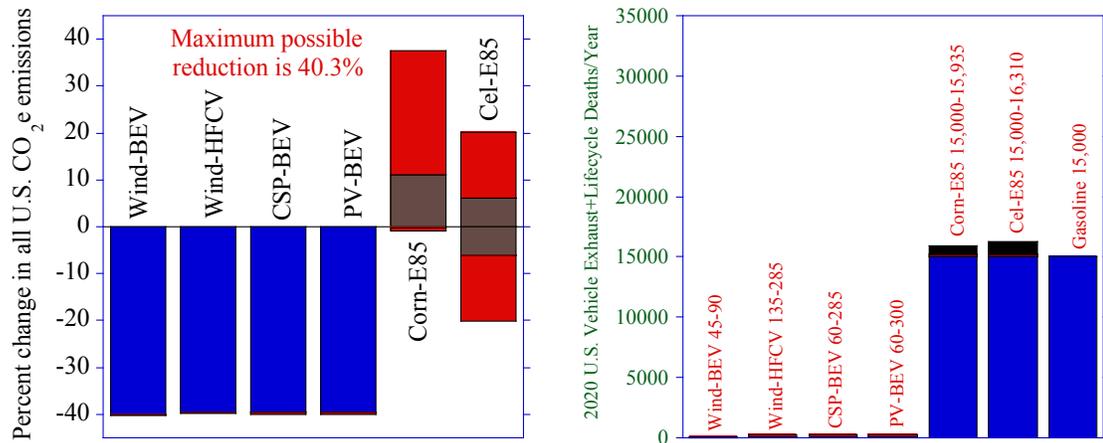
A significant effort has been made to produce **algae biodiesel**, which is biodiesel from algae grown from waste material, such as sewage. However, efforts have been hampered by the fact that algae can be grown efficiently only when exposed to the sun. As such, they cannot be grown efficiently when densely layered, with one on top of the other. Instead, they require a significant surface area exposed to the sun. Each volume of oil produced from algae also requires about 100 times that volume of water. Both factors have limited the growth of the algae biodiesel industry.

Liquid biofuels (e.g., corn ethanol, cellulosic ethanol, butanol, or biodiesel) are not recommended as part of a 100 percent WWS energy infrastructure. The main reasons are that (1) nearly all biofuels are combusted to generate energy, resulting in air pollution similar to that from fossil fuels; (2) liquid biofuels do not reduce CO_{2e} emissions nearly to the extent that WWS-powered battery-electric or hydrogen fuel cell vehicles do; (3) some liquid biofuels increase CO_{2e} emissions relative to fossil fuels; (4) many biofuels require rapacious amounts of land; (5) many biofuels require excessive quantities of water; and (6) many biofuels are derived from food sources, increasing food shortages, food prices, and starvation (Searchinger et al., 2008; Jacobson, 2009; Delucchi, 2010). Because liquid biofuels cause greater climate, pollution, land, and water problems than do WWS technologies, biofuels represent opportunity costs.

The main issues with liquid biofuels are illustrated by comparing the impacts of using ethanol to provide energy for internal combustion engines with the impacts of using wind or solar to provide electricity for battery-electric (BE) vehicles or hydrogen fuel cell (HFC) vehicles. Figure 3.2 (a), for example, compares the net change in CO_{2e} emissions and air pollution premature mortalities if all light- and heavy-duty on-road vehicles in the United States were converted from those powered by liquid fossil fuels to those powered by battery electricity, hydrogen fuel cells, or E85.

Figure 3.2. (a) Percent changes in 2017 U.S. CO_{2e} emissions upon replacing 100 percent of on-road (light- and heavy-duty) fossil-fuel vehicles with battery-electric vehicles (BEVs) powered by wind, CSP, or solar PV electricity; with hydrogen fuel cell vehicles (HFCVs) powered by wind; or with E85 vehicles powered by corn or cellulosic ethanol. The maximum possible percent reduction in CO_{2e} due to such a conversion is 40.3 percent because 30.2 percent of U.S. CO_{2e} originates from vehicle exhaust and 10.1 percent originates from upstream fuel production. Low and high estimates are given. In all cases, except the E85 cases, blue represents the low estimate and blue plus red, the high estimate. For E85, the full bars represent the range at 100 percent penetration, and the brown bars represent the range at 30 percent penetration. For both ethanol sources, the high estimate occurs when emissions associated with price changes of fuel crops are accounted for. Such emissions occur when the price of corn increases due to corn's use as a fuel instead of food, and this triggers a conversion of forested or densely vegetated grassland to agricultural land, increasing carbon emissions (Searchinger et al., 2008). (b) Estimates of 2020 U.S. premature deaths per year due to

upstream and exhaust emissions from vehicles for the scenario in the left panel. Low (blue) and high (blue plus red) estimates are given. In the case of corn E85 and cellulosic E85, the red bar is the additional number of deaths due to tailpipe emissions of E85 over gasoline for the United States and the black bar is the additional number of U.S. deaths per year due to upstream emissions from producing and distributing E85 fuel minus those from producing and distributing gasoline. The estimated number of deaths for gasoline vehicles in 2020 is also shown. Updated from Jacobson (2009).



In the United States, about 30.2 percent of all CO₂e emissions in 2017 were from vehicle exhaust and 10.1 percent were from the upstream production of fuel. As such, converting to BE vehicles, HFC vehicles, or E85 vehicles could reduce U.S. CO₂e emissions by a maximum of 40.3 percent. Figure 3.2(a) shows that converting to wind-powered BE vehicles reduces U.S. CO₂e emissions by 40 to 40.2 percent, which represents a 99.3 to 99.8 percent reduction compared with the maximum possible reduction.

Using wind electricity to produce hydrogen for HFC vehicles results in about three times more emission than using wind-electricity to power BE vehicles directly because using hydrogen for a fuel cell vehicle requires about 3 times the number of wind turbines than using electricity from a battery for a BE vehicle. The reason for this is that a battery-electric vehicle converts 64 to 89 percent of the electricity from a plug outlet to motion in the car, whereas an HFC vehicle converts about 23 to 37 percent (Table 7.2).

HFC losses are due to three main factors: losses in the **electrolyzer** (used to produce hydrogen from electricity), **compressor** (used to compress hydrogen), and **fuel cell** (used to convert hydrogen to energy and water) (Table 7.2). Nevertheless, an HFC vehicle is still more efficient than is an internal combustion gasoline engine, which converts about 17 to 20 percent of the fuel in its tank to mechanical motion.

Regardless, wind-powered HFC vehicles still reduce 98 to 99 percent of the maximum possible CO₂e reduction. Figure 3.2(a) indicates that, in comparison, corn E85 and cellulosic E85 vehicles either increase CO₂e or cause much less CO₂e reduction than do the WWS options.

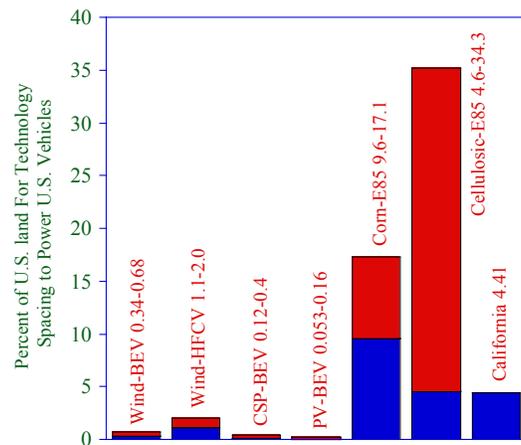
Figure 3.2(b) shows that the air pollution mortality associated with either corn or cellulosic ethanol vehicles significantly exceeds that associated with WWS-powered BE and HFC vehicles. The reason is that BE vehicles have zero tailpipe emissions of pollutants, and HFC vehicles have tailpipe emissions of water vapor only. Thus, the only pollutant emissions from BE and HFC vehicles are from the upstream production of wind turbines or solar panels. Such upstream emissions are the only cause of the mortalities for BE and HFC vehicles in Figure 3.2(b). Production of the vehicles themselves also results in emissions, but such emissions are excluded for all vehicles in Figure 3.2. E85 vehicles, on the other hand have similar tailpipe emissions as gasoline vehicles during their operation and have upstream emissions from fuel production. Whereas the tailpipe emissions of E85 vehicles differ in composition from those of gasoline or

diesel vehicles, the air pollution impacts of the E85 vehicles are often greater than those of fossil fuel vehicles (Jacobson, 2007; Ginnebaugh and Jacobson, 2012), especially for at low temperature (Ginnebaugh et al., 2010).

Another problem with ethanol is water consumption. Irrigating only 13.2 percent (the U.S. average irrigation rate for corn) of the U.S. corn supply needed to power a U.S. on-road vehicle fleet with corn ethanol would require about 10 percent of the U.S. water supply (Jacobson, 2009).

Finally, because of the significant land required for either corn or cellulosic ethanol (Figure 3.3), corn or cellulosic E85 could never provide enough energy for any more than a few percent of the U.S. vehicle fleet, even ignoring the climate, air pollution, and water supply issues associated with E85. Analyses for other types of liquid biofuels result in similar results.

Figure 3.3. Spacing area required for a given technology to provide energy for all U.S. vehicles in 2017 as either battery-electric vehicles (BEVs), hydrogen fuel cell vehicles (HFCVs), or E85 vehicles run on corn or cellulosic ethanol. The blue is the low estimate and the blue plus the red is the high estimate. The percentages are relative to the combined land area of all fifty U.S. states. The land area of California is shown for comparison. Updated from Jacobson (2009).



In sum, liquid biofuels are not recommended as part of a 100 percent WWS energy infrastructure because of the climate, health, water supply, and land opportunity costs they incur.

References

- Ginnebaugh, D.L., J. Liang, and M.Z. Jacobson, Examining the temperature dependence of ethanol (E85) versus gasoline emissions on air pollution with a largely-explicit chemical mechanism, *Atmos. Environ.*, 44, 1192-1199, doi:10.1016/j.atmosenv.2009.12.024, 2010.
- Ginnebaugh, D.L., and M.Z. Jacobson, Examining the impacts of ethanol (E85) versus gasoline photochemical production of smog in a fog using near-explicit gas- and aqueous-chemistry mechanisms, *Environmental Research Letters*, 7, 045901, doi:10.1088/1748-9326/7/4/045901, 2012.
- Jacobson, M.Z., Effects of ethanol (E85) versus gasoline vehicles on cancer and mortality in the United States, *Environ. Sci. Technol.*, 41 (11), 4150-4157, doi:10.1021/es062085v, 2007.
- Jacobson, M.Z., Review of solutions to global warming, air pollution, and energy security, *Energy & Environmental Science*, 2, 148-173, doi:10.1039/b809990c, 2009.
- Searchinger, T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, and T.-H. Yu, Use of U.S. cropland for biofuels increases greenhouse gases through emissions from land-use change, *Science*, 319, 1238-1240, 2008.