The Ecological Footprint of Biofuels.
Jørgen Vos, Planet Metrics

Selecting a sustainable biofuel for your operations

Introduction

There is growing interest in the potential of biofuels to feed the world's energy appetite, reduce carbon emissions and replace the use of fossil fuels. However, many of the conversations today around biofuels are providing decision makers with incomplete information. This is misdirecting their ability to decide what mobility technologies and biofuels to choose and which ones to avoid.

Biofuels discussions today tend to focus on the energy balance or on the emissions balance of an approach. The focus of these discussions has for a long time been on whether more or less energy is used and more or less greenhouse gases are emitted in the production of a biofuel than will be saved compared to the current use of fossil fuels in the vehicle fleet. Increasingly discussions are focusing on whether growing fuel is competing with growing food and whether enough land area is available for doing both.

All of these discussions are relevant, but by their piecemeal nature they do not make it easy for fleet managers or consumers to make their decisions on what fuels and vehicles to choose. This article describes a method of analyzing biofuels along multiple dimensions and provides some resulting rules of thumb that can help you assess their sustainability.

The biofuels market

Biofuels are fuels made from made from renewable materials. Today they are typically based on oils or sugars derived from plants. In coming years, they will also be derived from algae and possibly other sources such as tree trimmings. The common denominator for these fuels is that the CO_2 that gets released when burning the fuel is essentially the same CO_2 that got absorbed by the growing plant. Using the fuel therefore is part of a closed loop that under ideal circumstances does not contribute to global climate change. Unfortunately, in most cases these ideal circumstances do not exist since the production of crops and the conversion of crops to fuel as well as their transport typically make use of fossil fuels and fossil fuel-based fertilizers.

The main biofuels market segments consist of biodiesel and ethanol, both of which markets have been experiencing and are expected to keep experiencing double-digit growth rates throughout the coming decade. Biodiesel can be used to replace fossil diesel or can be blended with it. Ethanol replaces gasoline or can be blended with it. Ethanol is the dominant fuel in volume, accounting for roughly 80% of global biofuels supply (EIA).

Europe has been the main market for biodiesel, both in production and use. The main market drivers in Europe include aggressive renewable fuels policies by individual countries such as Germany, as well as renewable fuel mandates set by the European Union. The preference for biodiesel stems from the popularity of diesel powered vehicles in Europe with over 50% of new passenger vehicles sold being diesel powered, as well as the ready availability of rapeseed (a.k.a. canola) oil crops. In the U.S., soy is the main crop used for biodiesel production.

Brazil and the U.S. have been the main market drivers for ethanol production and use. Brazil has a large and mature sugar cane market that provides the raw material for ethanol production. It also has a mandate for blending 25% ethanol into all gasoline used nation-wide. The U.S. has a large supply of corn as a raw material for ethanol production and is moving toward a 5% - 10% blending mandate in several states, partly driven by the need to replace MTBE that is being phased out.

Addressing all dimensions of sustainability

Business leaders have become increasingly aware of the link between climate change and humanity's role in causing this change and are actively joined in the effort to address it. Organizations that employ vehicle fleets have started looking at those fleets as a source of emissions and are investigating options to reduce those. UPS has started deploying Hybrid-Electric technology in the power trains of their new trucks (UPS). McDonald's Corporation has started to recycle some of their waste cooking oil into biodiesel for their transportation vehicles (McDonald's).

With these efforts, making the right choice of technologies and fuels is becoming a primary concern for several reasons including:

- Any vehicle technology choice is by definition a choice in a long-term investment in a visible aspect of your company's operation,
- Not all biofuels are sustainable. An uninformed choice may expose your company to negative publicity,
- The biofuels field is still evolving. Your platforms need to be able to make use of future generations of these fuels as they become available.

The European Union issued an energy policy mandate in 2007, calling for "a 10% binding minimum target to be achieved by all member states for the share of biofuels in overall EU transport petrol and diesel consumption by 2020, *to be introduced in a cost-efficient way* (emphasis added)" (Council of the European Union). While well intentioned, the mandate was lacking a sustainability directive. As a direct result of this lacking, large areas of Indonesian rainforest were clear-cut to make way for palm oil plantations for biodiesel production – releasing more greenhouse gases in the process than will be recovered from the use of the biofuel over the life time of the plantations (Fargione et al). At the same time, the price of palm oil – a basic food staple and the primary coking oil for millions of Asians – has reached record prices. The European Commission is as a result of these and similar developments forced to re-evaluate their biofuels mandate, introducing proposals for minimum sustainability standards.

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With large and sophisticated organizations such as the European Union making mistakes like these, opening itself up to widespread criticism, how can a corporation be expected to make the right choice, especially when operating in countries or regions that do not have biofuels sustainability standards the corporation can trust or depend on? How can the corporation make choices that minimize the risk it exposes its reputation to?

As demonstrated by the previous, looking at a single dimension such as expected emissions reduction is not sufficient to minimize this risk. There are other dimensions that need to be taken into account:

- Will the planet be able to support a large-scale use of a given biofuel?
- Where does the fuel come from? Did it have, or is it expected to have a negative impact on the biodiversity or the social circumstances in its region of origin?

In the absence of broadly recognized and internationally trusted eco-labels for biofuels, the onus is on the fleet managers and the sustainability manager of organizations to do the research and ask the hard questions surrounding the source of their biofuels. Whether a fuel is sustainable when becoming used on a large scale is something that can be calculated – and even estimated based on some rules of thumb. Using the Ecological Footprint as a metric is an elegant approach to bringing the three dimensions of energy-balance, food vs. fuel, and climate change together into a single expression, helping to provide insight into the long-term sustainability of a biofuel.

Introduction to the Ecological Footprint

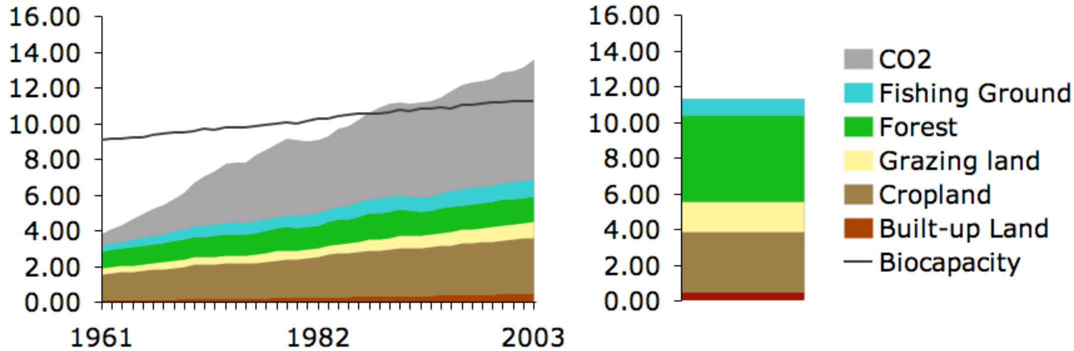
The Ecological Footprint is a resource accounting method that tells us how many renewable resources the Earth makes available each year, and how much of that humanity uses. Every year trees, crops and fish grow, and carbon dioxide gets sequestered. Every year, humanity uses trees, fish, crops, and many other raw materials, while generating carbon dioxide that needs to be absorbed by the biosphere. Each of these resource cycles requires biologically productive land for growing crops or trees, ocean area for growing fish, and land and ocean area for carbon sequestration.

The Ecological Footprint of Biofuels.

Jørgen Vos, Planet Metrics

Humanity's Ecological Footprint has been steadily increasing over the past 4 decades. The Ecological Footprint measures the amount of cropland, grazing land, forest area, and fishing grounds that are needed to satisfy humanity's need for food, clothing, shelter, and products and services. In addition to that, it measures the amount of land required to sequester our emissions after subtraction of the oceans' absorptive capacity. When this total amount of land needed exceeds the amount available to us, we are in said to be in overshoot, as we have been since the mid-1980's. Over the years, we have been able to increase biocapacity, mainly through increased crop yields and expanding area under cultivation. This increase has, however, not been able to keep up with the increase of the world population and with our increased rates of consumption.

Ecological Footprint 1961 - 2003 **Biocapacity, 2003**



Humanity's Ecological Footprint 1961 – 2003 and Biocapacity 2003 in Billions of 2003 Global Hectares.
Source: Global Footprint Network 2006

The Ecological Footprint expresses all the land areas that the earth has available for generating renewable resources in a single unified metric, the global hectare (or global acre). A Global Hectare is a mathematical representation of the productivity of real land, established by Wackernagel and Rees (Wackernagel). It is calculated in a way that allows us to compare the productivity of different land types around the world. It also helps us to calculate the resource use of people everywhere. All products and services humanity uses came from raw materials that came from a land area or out of the earth and may result in emissions that need to be absorbed somewhere.

According to the Living Planet Report 2006 (WWF), humanity as a whole uses nearly 25% more resources than the planet can make available annually. Or in other words, humanity today would need 1¼ planet to sustain us. Some people use more, and some people use less. If everybody lived like the average American, we would need more than 5 planets. Italians live la dolce Vita on about 2 1/3 planets, while the Thai in their land of smiles use only ¾ of a planet.

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How is it possible to use more than the planet provides? It's easy. Similar to living on a credit card, we can spend more than we earn. We can draw more water from underground aquifers than gets replenished each year. We can cut more forest area than the amount that will grow back. But, while living on a credit card can be done in the short run, when you do so for too long there are consequences. Global climate change is one result we are seeing. So is the worldwide collapse of fish populations.

The good news is that we already have many technologies available that can help us become more efficient in our use of the limited amount of resources available to us. But we need to start using and promoting them much more aggressively then we are today in order bring things back into balance while simultaneously accommodating for a growing population. The world population is projected to reach 9 billion by mid-century, up from 6.6 billion today. Meanwhile, the planet is not projected to grow.

Biofuels production and use in the context of the Ecological Footprint

When analyzing the sustainability of biofuels using the Ecological Footprint, we need to look at the total use of renewable resources and express those in land area required to provide those resources. There are two benchmarks we can then compare the Footprint of a biofuel against:

- The Footprint of current gasoline or diesel production and use, and
- A sustainability target

With the Ecological Footprint of humanity exceeding the generative capacity of the planet today, it should be clear that any decision made that increases this Footprint will defeat the purpose, even if it satisfies a subset of requirements. In the case of biofuels, the carbon Footprint is a subset of their total Ecological Footprint. Even if a biofuel looks good from a global warming perspective by reducing the carbon Footprint of its users, it may increase their Ecological Footprint on other dimensions, such as land use for growing the feedstock. If this is the case, the biofuel will be unsustainable from a whole systems perspective and needs to be avoided.

When a biofuel passes the first test of reducing the Ecological Footprint compared to current gasoline or diesel use, it may be a reasonable product for use today. But in order to be sustainable over the long run there are more strict criteria that need to be taken into account. The Ecological Footprint of humanity is projected to grow by a factor of two under a business as usual scenario [6]. This indicates that any sustainable transportation solution must at least contribute to halving the transportation Footprint compared to today, and will likely be required to target an even higher reduction in order to compensate for growth in vehicle use in developing countries.

The Ecological Footprint of Biofuels.
Jørgen Vos, Planet Metrics

Ecological Footprint method for assessing the sustainability of biofuels

Virtually any product or service we use has an Ecological Footprint associated with it that includes all of the land use types described before; cropland, grazing land, fishing grounds, forests, built-up land, and CO_2 sequestration land. In the case of transportation fuels, the majority of their Ecological Footprint consists of cropland and CO_2 land. The other land types are mostly present in the form of small indirect contributions from road and building infrastructures, and consumption patterns of the staff that support the production and supply of fuels. It is therefore reasonable to focus a comparative analysis of these fuels on the magnitude of the Footprint contributions of these two land types unless the fuel feedstock is not a crop or a fossil raw material.

CO_2 land

The CO_2 land component of the Ecological Footprint is calculated by multiplying CO_2 emissions by 0.27, the number of global hectares required to sequester a ton of CO_2 (Global Footprint Network). The emissions associated with gasoline, diesel, and various biofuels are publicly available from several web sites. In our calculations we have made use of a model created by the UC Berkeley Renewable and Appropriate Energy Laboratory (RAEL). RAEL has analyzed a series of past studies and has used those to create a model of the U.S. corn ethanol production and use cycle. According to this EBAMM model, corn ethanol has a slightly positive energy balance (it can generate more energy than it takes to produce it). It also generates less greenhouse gases over its entire production and use cycle than gasoline does (ERG).

Since we are looking at the Footprint of actual fuel use, we convert the emissions intensities derived using the EBAMM model into units of global hectares of CO_2 land needed for emissions sequestration per gallon of fuel, rather than a more scientific approach of using Mega Joules as our units of calculation. Using gallons enables us to compare different real-life vehicle scenarios.

The calculations in this paper are mostly U.S. centric and will sometimes be expressed using American units. They are however valid for any global situation and can be made applicable anywhere through a metric conversion.

The advantage of using the EBAMM model is that it is detailed and includes all steps of the Ethanol production and distribution processes. This makes it possible to translate the model to other biofuels and thus derive reliable and comparable estimates of their carbon Footprint. Note that the objective is not to achieve the best possible scientific estimate of these carbon Footprints. There are and will be disagreement about the results of scientific studies that between them show different estimates of the carbon Footprint of corn Ethanol, for example. The objective is to find biofuels that show a significant improvement in the Ecological Footprint over fossil fuels, an improvement that transcends margins of calculation or interpretation error.

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The EBAMM model shows us that there are a number of practices that have a negative impact on the emissions associated with the production of biofuels. Among the largest contributors in current methods of ethanol production are the use of fossil energy during the distillation phase, and the use of fossil fertilizers for growing the feedstock.

Cropland
Calculating the cropland component of the Ecological Footprint of a biofuel is a multi-step process, some of which require access to licensed data (ERG). We will describe the calculation method here, and later in this article extract some rules of thumb that can help you with making estimates when you do not have access to this data.

The calculation of the cropland Footprint of a biofuel uses four input factors:

- Cropland intensity (in global hectares per ton of global average yield)
- National or local crop yield (in tons per hectare)
- A Footprint Allocation Factor (in economic share of end products)
- Fuel yield (in liters per hectare or gallons per acre)

By multiplying the first three factors and dividing the outcome by the fuel yield factor we calculate the amount of cropland used per gallon of fuel. Adding this to the previously calculated amount of CO_2 land per gallon of fuel gives us the total Ecological Footprint of a gallon of a fuel, enabling us to compare real-life vehicle use scenarios.

Before doing so, we need to take a look at the factors listed above and a few others to gain a qualitative understanding of their meaning:

- The cropland intensity factor is a measure of land use intensity associated with growing a ton of a crop, when looked at from a global perspective.
- Crop yield is a local productivity factor for a crop. When multiplied with the cropland intensity factor it yields a multiplier (global hectares per hectare) that indicates the relative amount of global productivity associated with growing that crop in that place. Cropland in developed countries tends to be associated with higher than average productivity when compared on a global scale.
- The Footprint Allocation Factor is used to calculate the share of land use that actually goes into producing a fuel. Soy-based biodiesel for example is not the only product coming from an acre of soybeans. Other products are soy meal and glycerol, each of which has a market of its own. The Footprint Allocation Factor of soy biodiesel represents the economic share derived from selling biodiesel as a fraction of all product sales generated by an acre of land.
- Fuel yield is the estimated amount of fuel that can be derived from a certain crop growing an acre of land in a given region.

- The energy content per gallon differs per type of fuel. This has a direct impact on the fuel mileage that can be achieved with comparable vehicles and thus needs to be taken into account in our real-life vehicle use scenarios.
- The technology platform used enables you to get the most out of a given fuel. When minimizing the mobility Footprint associated with your fleet.

Special cases and exceptions
The method described here is not directly conducive to comparing local and global scenarios. This method focuses mostly on large-scale scenarios. Small-scale fuel production solutions that may make use of marginal land or uses crops that work extremely well under specific circumstances that only occur in specific regions of the world do not translate into large-scale production applications. These solutions may not fit this model. That does not imply that they are less valuable than large-scale production since millions of highly specialized local solutions could add up to a very sustainable world.

The model is clear in showing that having a high yield of a crop in a certain region does not imply that this region is best suited for generating a biofuel from that crop. It means that this region is a relatively large supplier to the global crop needs. If crops get diverted away from the food chain in a highly productive area, a larger area needs to replaced it in a region with lower productivity.

Waste-based fuels, such as biodiesel made from recycled cooking oil constitute a special case. Since they are a second-use product and the original production objective of the oils did not include their use as fuels, they have a Footprint Allocation Factor of zero. Being a biofuel, their combustion emissions are by definition netted out against the sequestration that occurs during the growing of the feedstock. All other emissions associated with growing the feedstock are attributed to the original cooking oil. There will be emissions and some other resource use occurring during the collection, transport, and refining of the fuel, but these will be small. As a result, waste vegetable oil biodiesel has a near zero Ecological Footprint and is an excellent choice if it is available where you need it. This fuel is one example of a specialized local solution since its supply is limited by the throughput of vegetable oil through restaurants. This implies that the moment demand starts to have an influence on this throughput rate, the Footprint Allocation Factor cannot be assumed to be zero anymore and the Ecological Footprint of this fuel will start creeping up.

Finally, the Ecological Footprint model does not directly take into account the unintended consequences of scale. Diesel for example has a lower Footprint than gasoline and may seem to be a more desirable fuel. But the scale of use (over 50% of new vehicles sold) in Europe has led to significant air quality problems. When making a choice for a technology or a fuel, the possibility of such unintended consequences occurring will need to be taken into account and designed out of the system.

The Ecological Footprint of some current and near-future biofuels

Using the previously described method we are able to calculate the Ecological Footprint for some current and near-future biofuels as they are available on the U.S. market. We can then apply those Footprints to calculate a typical scenario.

CO_2 land

Table 1 shows the CO2 land required to sequester the emissions resulting from the production, distribution, and for fossil fuels combustion of a number of generally available fuels. Most data sources provide these emissions in units of grams of CO2-equivalent per Mega Joule of embedded energy, which we then translate into global hectares per gallon.

Fuel	Crop	Country of origin	Grams of CO_2 emissions per MJ	Global hectares per gallon
Gasoline			94 *	0.0031
Ethanol	Corn	USA	77 *	0.0017
Ethanol	Sugar cane	Brazil	30 *	0.0006
Ethanol	Sugar beet	France	65.8 **	0.0014
Cellulosic ethanol	Switchgrass (current crop yield)	USA	11 *	0.0002
E85	Corn	USA	(blended)	0.0019
E85	Sugar cane	Brazil	(blended)	0.0012
E85	Switchgrass	USA	(blended)	0.0007
Diesel			91 *	0.0034
B100 Biodiesel	Soybeans	USA	49 ***	0.0018
B100 Biodiesel	Rape seed	USA	43.7 **	0.0016
B100 Biodiesel	Palm oil, produced on existing cropland or plantation	Malaysia	27.3 ****	0.0010

Table 1: CO_2 land per fuel type.
Sources:
*: (ERG)
**: (Concawe)
***: (Hill et al.)
****: Computed from (Carbon Capital)

This table shows one aspect of biofuels a fleet manager needs to be aware of. While the emissions associated with for example corn ethanol compared to gasoline are less than 20% lower per unit of embedded energy, they are 45% lower per gallon. Ethanol is less dense than gasoline and has as a result a 35%

lower energy content per gallon. This will result in a lower fuel mileage for your vehicles. Diesel is a denser fuel and gives a higher fuel mileage. In addition, these fuel mileages are influenced by engine technologies and design.

Cropland

Table 2 shows the amount of cropland required to grow the same fuels as listed in table 1.

Fuel	Crop	Country of origin	Footprint Allocation Factor	Yield in gallons per acre	Global hectares per gallon
Gasoline			n/a	n/a	n/a
Ethanol	Corn	USA	0.86	370 *	0.0041
Ethanol	Sugar cane	Brazil	1	650 *	0.0016
Ethanol	Sugar beet	France	1	715 **	0.0023
Cellulosic ethanol	Switchgrass (current crop yield)	USA	1	550 *	0.0016
E85	Corn	USA	(blended)		0.0035
E85	Sugar cane	Brazil	(blended)		0.0013
E85	Switchgrass	USA	(blended)		0.0014
Diesel			n/a		n/a
B100 Biodiesel	Soybeans	USA	0.28	58 ***	0.0058
B100 Biodiesel	Rape seed	USA	0.71	127 ****	0.0053
B100 Biodiesel	Palm oil, produced on existing cropland or plantation	Malaysia	0.99	635 ****	0.0028

Table 2: Cropland per fuel type.

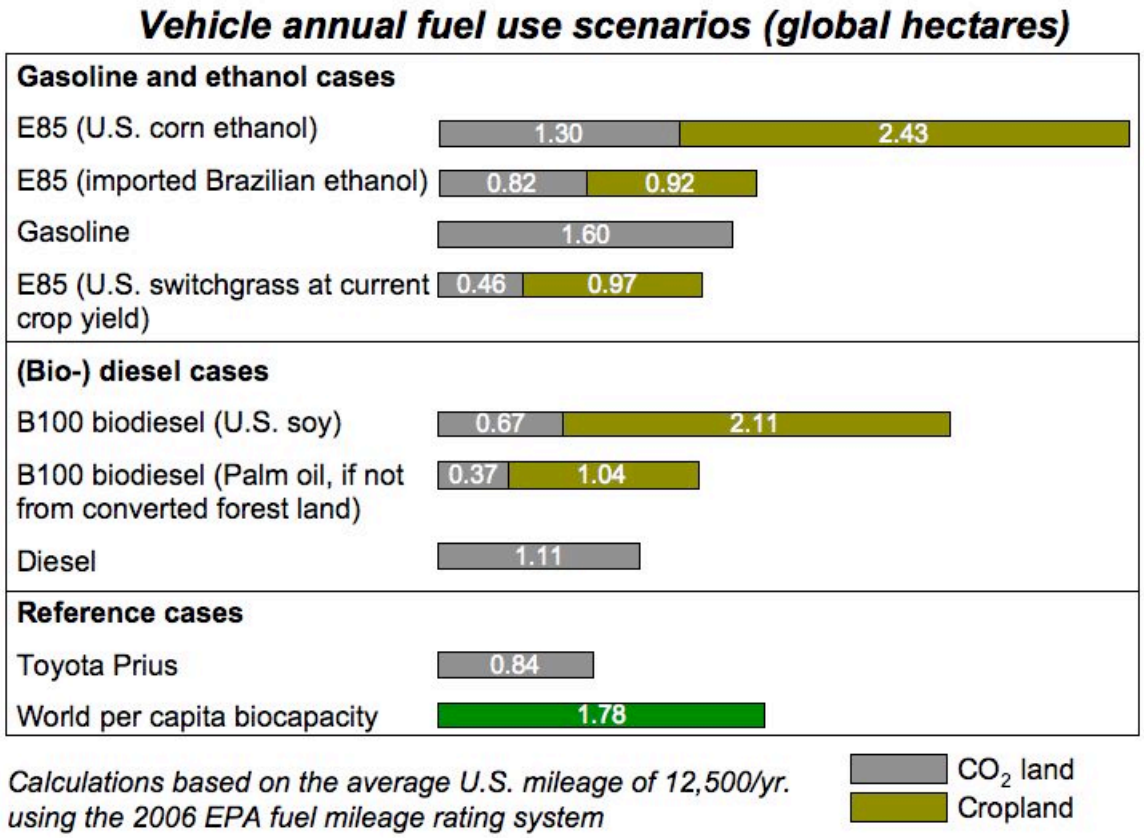
Sources:
*: (ERG)
**: (Concawe)
***: (Hill et al.)
****: (Journey to Forever)

This table shows several noteworthy things. First among them is that the current fuelcrops prevalent in the U.S., corn and soybeans, yield much less fuel than other crops. Producing biofuels may be a good hedge for a farmer who wants to spread his risks and find additional markets, but these are the least desirable crops to use on a large scale for biofuels production.

Cellulosic ethanol made from switchgrass is said to hold a lot of promise, and it may. But the technology of creating this type of ethanol is still early in its life cycle. At the same time, the current crop yields as shown in the table are less than half of what is expected to be possible. Finally, farmers need some market certainty before they will be willing to switch over to growing this new crop. Fleet managers should not take it into their short-term considerations when deciding on a fuel strategy.

A real-life scenario

As we have seen, the fuel you use while driving has an Ecological Footprint. Emissions from burning fossil fuels and emissions related to the growing of crops need to be sequestered by plants, trees and other organisms. Fuel crops need land mass for their production. To make it easier to understand this Ecological Footprint of fuels we can compare them using realistic day-to-day scenarios. To do this we look at an average driver in a typical vehicle, like the one used by the author's wife. The average American drives 12,500 miles per year. Driving this distance in a Volkswagen Jetta requires approximately 520 gallons of gasoline, the burning of which will result in a fuel footprint of 1.6 Global Hectares. If the same car were to use E85 (85% ethanol blended with 15% gasoline, not available for this vehicle today) made out of U.S. grown corn, its fuel footprint would increase to 3.7 Global Hectares. E85 made from Brazilian sugarcane shows to be fairly comparable to gasoline in its Footprint, showing the difference that the choice of appropriate crops can make when selecting to grow them for a specific purpose. The graph below shows some more examples of different fuels that can be used for different models of this vehicle and their respective Ecological Footprints. We see for example that diesel has a lower Footprint, which is due to the higher gas mileage that can be achieved with a diesel engine. A Toyota Prius running on gasoline has been added for comparison purposes, as has the per capita biocapacity (our individual fair share of the planet, not including the needs of other species) that is available to each person on the planet (1.8 Global Hectares).



The comparison between an average vehicle and a hybrid vehicle shown here shows the importance of vehicle technology innovations in addressing the Ecological Footprint of a vehicle fleet. It shows that besides of looking at alternative fuels, implementing fuel efficiency measures should be a keystone element of any Footprint reduction strategy.

Conclusions and rules of thumb to assist your decisions making

Sustainability strategies will have to be dynamic as we learn more and make mistakes while the field matures. Organizations that already are using biofuels may need to take the information presented here into account and look at their messaging around the use of biofuels in order to minimize the risks of being exposed to criticism around their past choice. Organizations considering the best course of action for their fleet strategy should take the following into account in their deliberations:

- With the exception of biodiesel made from waste vegetable oil, 1st generation biodiesel and ethanol are not sustainable solutions. Only companies that have a regional or a specific supply chain reason for using them should use these fuels.
- Most 1st and 2nd generation biofuels can make a positive contribution to addressing global climate change, but may not be a desirable part of a long-term industry growth solution. Decision makers need to look at the

total Ecological Footprint of a fuel as well as inquiring about more details about the source and production methods of the fuels. Certification of the sustainability aspects of fuels may need to be demanded given the potentially complicated and murky nature of their supply chains.

- Efficiency has a high net positive impact. Due to the land use needs of biofuels their sustainability potential is limited until very high yield fuels become available. Improving the fuel mileage of the vehicle fleet needs to be a primary consideration.
- Migrating from gasoline-powered vehicles to new, high-efficiency diesels may be a good solution. Diesel engines are more efficient than gasoline engines, diesel is rapidly becoming a clean fuel, and there currently is a clearer pathway to very high yielding biodiesel made from algae. Cellulosic ethanol is promising but is not expected to reach the same yield, and research into the production of ethanol from algae is currently in its infancy. None of these solutions however should be expected to be available on a large scale for several years to come.

More and more people will own cars as economies around the world continue to develop. A sustainable economy needs ultra-efficient vehicle technologies, combined with an intense focus on research into very high-yield and low-footprint alternative fuels – such as algae-derived biofuels that have the potential of more than a five-fold increased yield over 2nd generation fuels. Governments, business, and consumers all have a big role to play in moving the world toward the best technologies through the investments they make and the technologies and the policies they promote and advocate for.

References

(Carbon Capital), Carbon Capital, *The CO2 and Energy Balance of Malaysian Palm Oil,* 2007, www.malaysiapalmoil.org/pdf/20070606_CarbonCapital1.ppt

(Concawe), Concawe, *Energy and greenhouse gas balance of biofuels for europe - an update,* Brussels, April 2002, http://www.concawe.org/DocShareNoFrame/Common/GetFile.asp?PortalSource=156&DocID=340&mfd=off&pdoc=1

(Council of the European Union), Council of the European Union, *Energy for Europe*, Press Release 6271/07, Brussels, February 15, 2007, http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/trans/92802.pdf

(EIA), Energy Information Agency, *IEA Energy Technology Essentials 2 – Biofuel Production*, January 2007, available at http://www.iea.org/Textbase/techno/essentials.htm

(ERG), UC Berkeley Energy and Resources Group, *ERG Biofuel Analysis Meta-Model,* 2006, http://rael.berkeley.edu/ebamm/

(Fargione et al), Fargione, J, Hill, J, Tilman, D, Polasky, S, Hawthorne, P. 2008, *Land Clearing and the Biofuel Carbon Debt,* Science 29 February 2008: Vol. 319. no. 5867, pp. 1235 – 1238, http://www.sciencemag.org/cgi/content/abstract/1152747

(Global Footprint Network), Global Footprint Network, *National Footprint Accounts,* 2007 edition, Oakland: Global Footprint Network, http://footprintnetwork.org/

(Hill et al.) Hill, J, Nelson, E, Tilman, D, Polasky, S, Tiffany, D, *Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels,* 2006, PNAS, July 25, Vol. 103, No. 30, pp. 11206-11210. http://www.ddgs.umn.edu/articles-industry/2006-PNAS%20Vol%20103%20No%2030%20p11206-11210%20ethanol.pdf

(Journey to Forever), Journey to Forever, *Oil yields and characteristics,* http://journeytoforever.org/biodiesel_yield.html

(McDonald's), McDonald's Corporate Values: *Recycling and Reusing*, McDonald's corporate web site, http://www.mcdonalds.com/corp/values/place/enviroment/recycling.html

(UPS) UPS, *UPS "Green Fleet" Expands with 50 Hybrid Electric Vehicles*, UPS Press Release, ATLANTA, May 22, 2007, http://www.ups.com/pressroom/us/press_releases/press_release/0,1088,4894,00.html

(Wackernagel), Wackernagel, M. and Rees, W. 1996. *Our Ecological Footprint*. Gabriola Island: New Society Publishers.

(WWF) World Wildlife Fund, *Living planet report 2006,* available at www.panda.org/livingplanet/