THE LAND CONUNDRUM

Luis Razon[1]

[1] Chemical Engineering Department, De La Salle University,
Manila, Philippines, Tel: 63-2-536426,
e-mail: luis.razon@dlsu.edu.ph

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Petroleum has a Problem

Fossil fuels, particularly petroleum, have been the primary source of energy of the world for a very long time. Under its aegis, the world has been changed, for better or for worse. Can we imagine the world without vehicles powered by oil, gas or coal, the road networks meant to accommodate them and the buildings that could not have been built or operated without fossil fuels? The very production of our food depends greatly on the energy available for cultivation, irrigation, harvest and processing.

In the 19th century, fossil fuels and the engines that burned them were considered one of the greatest inventions of mankind. Compared to other fuels like wood and crude vegetable oils, fossil fuels delivered more energy per volume and burned more cleanly. Compared to animal and wind power, the engines were reliable and required little maintenance. The speeds achievable with fossil fuels very soon became much faster than any that could be achieved even if an unlimited number of animals were attached to a vehicle. With the energy-dense fuels being so readily available, sometimes just seeping out of the ground or being easily extracted with picks and shovels, it was also inexpensive. Fossil fuels never really spoil, so distributing the fuel was never a problem. The advantages were so clear that once the early bugs were ironed out, fossil fuel engines completely displaced all other modes of propulsion.

As populations increased and economies prospered, the demand for transport also increased. The initial satisfaction with having a cheap source of energy started to wane. First identified were the concerns with the more obvious emissions like smoke and soot (unburned hydrocarbons). The health effects of carbon monoxide were then the next concern. Smoke and carbon monoxide were associated with direct effects on the human body. That is, other than the ugly sight of dark smoke, if inhalation could be avoided then the effects were minimal. Beyond a few hundred meters, there were no expected harmful effects as the pollutants are dispersed and so the impact was very localized. Unburned hydrocarbons and carbon monoxide could also be easily eliminated by improving combustion efficiency or by using catalytic converters. It would not end there, however.

The concerns arising from the incomplete combustion of fuel were soon replaced by concerns about the byproducts of the complete combustion of carbon fuels: sulfur oxides and nitrogen oxides. Sulfur and nitrogen oxides could lead to acid rain and smog and thus the impact was felt over a larger distance. Rather than impacting only the immediate vicinity, nitrogen and sulfur oxides could be transported long distances and the resulting acid rain could be deposited elsewhere. Nonetheless, means were also found to control these with more stringent fuel composition regulations and end-of-pipe controls.

However, in the late 20th century, it was then realized that carbon dioxide could enhance the greenhouse effect of earth's atmosphere. By enhancing global warming, carbon dioxide emissions would now have the potential to affect the entire planet, even those regions like the South Pacific which are as far as can possibly be from the largest sources. This problem was not as easily solvable as the other problems. It is the global warming potential of fossil fuels, combined with their impending depletion, that has now provided the chief impetus for the search for alternatives to fossil fuels.

Biofuels also have a Problem

Among the alternatives proposed for the replacement of fossil fuels are biofuels. Biofuels have plenty of advantages over fossil fuels. Biofuels are renewable and emit significantly less of the local emissions like particulate matter and sulfur oxides. When compared to other energy alternatives like nuclear and solar power, they have other advantages. They can be used in internal combustion engines. They have a similar energy density and, with some minor modifications, could be used in existing engines. While great strides have been made with electric land transport, there is still no viable electric alternative for air and water transport. Unlike hydrogen which requires a completely different distribution system, some minor adjustments will allow bioethanol to use the same distribution system while biodiesel merely requires some additional provisions for blending.

While biofuels have some unquestionable advantages, they also cost more. Most of the current feedstocks: corn, palm, soy and rapeseed are also food crops. While these issues can eventually be resolved through improved technology and developing non-food feedstocks there are some very important questions that have arisen with respect to their global impact.

It is important to realize that the production of biofuels is essentially an agricultural operation and agriculture requires land. While agriculture seems to be capable of enormous amounts of food for the world population, the scale of the demand for fossil fuels dwarfs the scale of food production. Some simple calculations showed that even if all of the vegetable oils in the world were converted to biodiesel, only 18% of the world demand for diesel fuel would be filled [1]. Schenk [2] also computed the amount of land required for the complete replacement of global petroleum demand with biodiesel from oil palm (currently the highest yielding oil feedstock) and arrived at the figure of 819,000,000 hectares. This amount of land is equivalent to 41% of the land on Earth suitable for agriculture. This amount of land is too large to dedicate to energy needs, not to mention the fact that not all of it is suitable for growing oil palm. Biofuels cannot be a replacement for fossil fuels. Not unless demand is greatly reduced or agricultural yields are greatly intensified.

The combination of the enormous demand for fuels and the finite amount of land result in a difficult dilemma. To grow the biomass feedstock for biofuels requires that arable land currently being used for some other purpose will need to be rededicated to the culture of biomass feedstock. For example, to fulfill increased demand for biodiesel, large amounts of tropical rainforest are being cleared to make way for oil palm plantations. Fargione et al. [3] have calculated that this results in a “carbon debt” which is incurred because of fires used to clear the land or the decomposition of trees and leaves after the initial growth is cut down. This is called direct land use change (DLUC). But there are further effects that need to be considered. If farmers convert their food crops to biofuel crops, will this result in clearing more land for the displaced food crops? This is the so-called dilemma of indirect land use change (ILUC) for which there are still no clear rules [4]. Gawel and

Ludwig [5] have a thoughtful and extensive discussion of the problems that arise from trying to account for indirect land use change. The primary problem that arises is that of causality. If the primary use of a parcel of land is changed, will the change be attributed to the expansion in biofuels or is there some other cause like population or government policies.

Accounting for carbon emissions from indirect land use change is extremely complex as can be seen from the previous discussion. It is not difficult to imagine how much more complex the accounting for effects that interact with each other like those of nitrogen and carbon would be. What should be done with other environmental impacts? In what ways do we also weigh the other environmental benefits and impacts that may arise from biofuels? Some are direct and short-range like the reduced emissions from particulate matter. Others are global and may have many contributions from indirect impacts.

The dilemma of accounting for land use change also illustrates one of the chief advantages of using petroleum in the past. Pumping petroleum from the ground really required very little land when compared to trying to growing the biomass feedstocks. As it also turned out, much of the richest oil deposits in the world come from locations which are not very useful for agriculture like the Middle East, the American Southwest, Alaska and the Russian tundra. Land use change was never an issue for petroleum.

The obvious solution would be to use degraded land or land that would not normally be used for agriculture for biofuels. This was one of the most frequently cited advantages of Jatropha curcas. Subsequent studies showed however that the promised yields would not be achieved if jatropha was grown on poor or unfertilized land. Microalgae (microscopic aquatic or marine plants) have been proposed as alternative feedstock for biofuels since these do not have to be grown on arable land but the technological challenges are immense. There remains to be an issue as to whether more energy can be extracted from microalgae than is expended to produce fuel from it [6]. Microalgal culture would also need more water than the culture of terrestrial plants. Would we eventually have to worry about indirect water use change?

Perhaps the answer would be to tap the ocean. Aside from the known challenges of working in the ocean, with the exposure to the elements and the corrosivity of salt water, shifting to the marine environment just shifts the location of the displaced activities. Already, there are some initial proposal for how to account for the environmental footprint when part of the ocean is occupied. For example, it was found by Taelman et al. [7] that on-shore petroleum production in Saudi Arabia has a smaller environmental footprint than off-shore petroleum production in the Norwegian continental shelf.

Is there a Solution?

This editorial has illustrated some of the difficulties in replacing the chief energy source of the world-petroleum and other fossil fuels. It has to be replaced but how really are we to replace an energy source that really can just be pumped out of the ground; can rapidly produce large amounts of propulsive energy; can provide so much energy in a small volume; can be easily stored and transported and to which so much installed infrastructure is already dedicated?

In the past, it was acceptable to just find energy sources; anything that made the vehicle move was fine. Now the fuels must be efficient, be compatible with the existing vehicles and not produce smoke, carbon monoxide, sulfur oxides and nitrogen oxides.

Lastly, its overall production, not just its use, must contribute only a small amount to the greenhouse effect and not compete for resources that may be used for other human activities.

This is the challenge for engineers and policy makers of all kinds. It is insufficient for one discipline to work in just its own corner of the technology world. We must endeavor to work with all kinds of engineers, natural scientists and social scientists if we are to find a solution to his intractable problem.

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