Biofuels of the Future

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KEYNOTE ADDRESS

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There are good biofuels and bad biofuels. The good ones offer the prospect of transport fuels that have much lower environmental impact than fossil fuels and could before long be less expensive as well. Bad or irresponsibly produced biofuels may at best bring little environmental advantage; at worst they may also cause serious environmental damage, habitat destruction and food shortages. The biofuel industry of the future will make a significant contribution to the greening of the world's vehicle transport systems by producing biofuels that are derived either from plants grown on marginal land where food crops cannot be grown, or from the organic residues from agricultural, industrial or urban processes. The industry is still in its infancy and is likely to spring some big surprises.

Introduction

We are entering a new world for energy. Most of the infrastructure that we have today for transport, for industry, commerce and for everyday living is structured around the tacit assumption that energy is cheap and abundant. Indeed the availability of cheap energy made possible the industrial revolution that began two centuries ago in Europe and spread around the world. But those days are behind us. As this page is being written the oil price is within a whisker of $100/barrel and by the time it is read that line may already have been crossed.

So what has changed? The largest single factor is the relentless increase in the world demand for energy. As people become more prosperous they use more energy; they eat more, they travel more, they heat or cool their houses more, and they use more goods. Two of the largest countries in the world, India and China, accounting for nearly half of the world's population, are rapidly becoming more prosperous and as they do so their energy demand is rising. Simultaneously the total world population continues to increase. In short, the world has more people; on average they are living better and they are using more energy.

This has meant that although world oil production has continued to rise along with demand, the demand and supply curves are now very close and there is the real possibility that demand will outstrip supply. This is one of the main drivers of today's oil prices. For a variety of operational reasons it is unlikely that supply will increase significantly any time soon.

There is a second and quite different concern about oil. It is now beyond reasonable doubt that burning fossil fuels is causing a damaging accumulation of greenhouse gases in the atmosphere. These appear to be responsible for a rise in global temperatures, a steadily rising world sea-level and accelerating climate change. Oil is responsible for around 40% of those gases.

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Although oil is used for a variety of purposes its prime use is as a transport fuel and against this background it is natural that people should look for alternative liquid fuels that are also less damaging to the environment and possibly cheaper as well. Biofuels offer such a possibility.

In this context the price of conventional mineral oil is very significant — the main reason that biofuels have attracted relatively little attention in the past is that they were much more expensive to produce than mineral oil. At oil prices above $70/barrel, however, a succession of different biofuels become price competitive and as time goes on could become the liquid fuel of choice, not only on environmental grounds but on cost grounds as well.

In the discussion that follows I shall concentrate only on the role of biofuels as liquid fuels. They are of course also used for power generation and heating, and locally this can be extremely important.

What is a biofuel?

Biofuels are fuels made from anything that once grew, i.e. biomass derived from plant or animal material. Although biomass can be combusted to generate electricity there are other ways of generating electricity cleanly. Biomass, however, offers the only promising way of making clean liquid fuels for vehicles. High-energy-density liquid fuels will be needed as long as the internal combustion engine is with us, and on present form that looks to be quite a long time.

It is important to recognise, however, that there are good biofuels and less good biofuels. They can be made in different ways and from different starting materials. Some offer little saving of CO_2 emissions; others are based on food crops and have pushed up the price of food. Yet others are being grown on land needed for food production or on newly cleared rain forest. I would go as far as to say that a biofuel industry based on food crops or crops grown on prime agricultural land will never be sufficient to make a noticeable contribution to the world's need for transport fuels — as discussed later, there simply is not enough agricultural land to produce both food and a significant volume of biofuel. No, as discussed below, if the biofuel industry is to make an important contribution to world needs it must draw the greater part of its raw material from elsewhere.

Regardless of the source or nature of the starting material, biofuels can be produced in three main ways. The first is by fermenting material that is rich in sugars and starches and then distilling the liquor to produce ethanol. Sugar cane, corn and other grains may be used in this way. Ethanol mixes readily with petrol and is used today in some countries in petrol/ethanol mixtures up to 85% ethanol (E85). Vehicle manufacturers generally advise, however, that mixtures richer in ethanol than E10 should be used only in flex-fuel engines.

The second main route to biofuel is by refining the crude oil that is produced by crushing oily seeds. The resultant liquid is a biodiesel that mixes readily with mineral diesel. The main seeds currently used are soy, rape (canola) and palm.

The third route is through gasification. Any organic starting material may be heated in a controlled atmosphere to yield gaseous products that include hydrogen and carbon monoxide. These gases may then be used to synthesise liquid fuel to a wide range of specifications including a synthetic petrol and biodiesel. Although the principles of gasification and fuel synthesis are well known there has in the past been little economic incentive to develop the technology for biomass, but this is now changing and commercial development is being undertaken.

It goes without saying that if a biofuel is to have any environmental value it must be produced sustainably and it must contain more energy than was used to produce it. Unfortunately perverse agricultural subsidies allow the production of some biofuel that meets neither of these criteria. This is true of some of the ethanol produced from corn.

Future biofuels

Most of the biofuels available today are produced from food crops and sometimes known as 'first-generation' biofuels. However, in the near future, a group of biofuels produced rather differently will become progressively more widely available and are sometimes known as 'second generation'. The term is not well defined and not very useful.

The most important characteristic of biofuels of the future is that they should not compete with food crops for land or resources. This means that if they are crop-based the crops must be able to grow where food crops are unable to grow or they must use the organic by-products ('wastes') that are generated by other crops or other activities. Both of these approaches are being used.

Crops for biofuel

At present the most promising agricultural crop that meets these criteria is the fruit of the tree known as *Jatropha curcas*. This is often shortened to jatropha but the jatropha plant family is a very large one and most of the members are unable to yield oil in any quantity, and some are even classified as noxious weeds. For this reason it is very important to emphasise that the promising candidate is *J. curcas*.

Jatropha curcas probably originated in central America and is now relatively widely distributed in tropical and sub-tropical regions. This may have been the work of Portuguese Christian missionaries who valued its medicinal properties. The oil produced from the seeds is a strong purgative and presumably for that reason the tree appears not to be grazed by animals. *J. curcas* grows in the wild on marginal land and is now being cultivated by farmers in parts of southern Africa, India and SE Asia in places where it has been difficult to grow other crops. Its water demands are modest. Wild varieties of *J. curcas* appear to yield around 1.7 tonnes of crude oil per hectare at maturity (around five years), but it is likely that selective breeding and better husbandry will allow higher yields. The trees are expected to fruit for 20–30 years. Best estimates at present are that biodiesel produced this way contains around three times as much energy as was used to produce it. It will be available on the world market in increasing quantities from 2008. Growing *J. curcas* in regions that are unsuitable for conventional agriculture has the additional benefit of creating jobs for local people where previously there were none.

Although this seems to be the most promising source of sustainable biodiesel at present there may be competition from other plants in the future. One plant group that is generating interest is the algae. Chief among their attractions is that they do not require agricultural land and different species may live in either salt or fresh water. In principle they could be cultivated in salt-water lagoons or fresh-water lakes or tanks. Algae vary considerably in their bio-productivity and one of the dilemmas is whether to use open lagoons where the stock is liable to be invaded by less productive wild species, or to cultivate them more expensively in large tanks with a controlled environment. In either case the algae form floating mats that can be harvested, dried and then pressed to yield a crude biodiesel liquid and a residual protein mass that might be suitable for animal feed. This approach remains the subject of research and development but seems still to be some way from market.

Residues

The second main source of feedstocks for future biofuels is organic wastes. As the purists will point out, once there is practical use for the residues of other processes, agricultural or industrial, they are no longer wastes but by-products. There are in fact many types of residue that are rich in organic material from which energy can be extracted.

All agricultural residues such as straw, corn cobs, forestry cuttings etc. may be dried and burned either for heating or for power generation. In many cases it will make sense to do this. However, if the need is for fuel liquids a different approach is required and it is necessary to break down the cellulose in the plant structure. One approach is that which was pioneered by a small Canadian enzyme company, Iogen, in partnership with Shell. An enzyme has been developed that can break down wheat straw cellulose into its constituent sugars. Once that step was achieved, traditional fermentation and distillation processes could take over for the production of ethanol. In principle, a similar approach with different enzymes could be used on other agricultural residues. The development of such new enzymes is an area of active research and is attracting the attention of investors.

The other approach for dealing with organic residues, and for that matter any organic material, is gasification as described earlier. In principle this allows recovery of a very high proportion of energy embodied in the residues and has been employed in specific applications (e.g. gasification of coal) for many years. The particular difficulty with mixed organic residues is dealing with the gums and related substances that are produced early in the heating process and foul the equipment.

This is one of those problems that attracted little attention when liquid fuels from biomass were of no interest but which now appears to have been overcome on a commercial scale by the German company Choren.

Although the use of agricultural residues offers the attractive prospect of the co-production of food and fuel, in urban areas there is another substantial and relatively untapped resource, namely urban garbage. Garbage in cities tends to be handled on a local basis and is managed differently in different countries and in different communities within those countries. Until relatively recently, however, it has been regarded as a problem and a cost rather than as a resource. One estimate of the embodied energy in US urban garbage — the waste food, grass cuttings, newspapers, old shoes etc. etc. — is that it is roughly equivalent to the energy content of the fuel used by vehicles in the US. In one sense this is a somewhat meaningless comparison insofar as it would be impracticable and uneconomic to recover more than a small fraction of this energy, but it does draw attention to the magnitude of the resource. It is not unthinkable that communities should have their own gasification plants and, depending on size and local need, either generate electricity or fuel liquids from their urban wastes.

Carbon accounting

One consequence of the interaction of environmental and financial considerations that today characterises energy policy is that for the foreseeable future we shall be involved in double accounting procedures — financial accounting and carbon accounting. The financial accounting is the same as ever — a project has to be able to meet its costs and offer a reasonable rate of return to the on the capital invested by the owners. Carbon accounting is new and different, and is an essential part of evaluating the environmental impact of fuels. If there were a clear and agreed rate of exchange between the currency of carbon and cash currency there would be little need for two systems, but we are a long way from that.

The basic concept of carbon accounting is that when we burn fossil fuels we release into the atmosphere fossil carbon that had been trapped in the Earth by natural processes for many millions of years, and in doing so we disrupt the Earth's carbon balance and precipitate environmental change. In contrast simply burning wood from a tree has no effect on the carbon balance because as the tree grew it extracted CO_2 from the atmosphere and that CO_2 is returned to the atmosphere when the wood is burned. The process of making liquid biofuels normally falls somewhere in between these two extremes, because generally some fossil fuel will have been use in transporting and converting the biomass into a fuel liquid. In the case of the food crops currently being used to make biofuels, energy will have been spent on cultivation, fertiliser and harvesting as well. The energy in/energy out (EI/EO) calculation sounds relatively simple, but often it is not and there is an urgent need for an agreed set of procedures so that proper comparisons can be made. At present biofuel companies tend to use their own methods and the results are not directly comparable with those of others. In the case of energy from agricultural residues — say, corn straw — there is also the question of whether to regard energy expenditure as beginning when the straw is collected from the field. Alternatively the total energy cost of producing the corn might be taken into account and partitioned between the food product and the straw used to make fuel. A case can be made for either convention, but whatever is done it should be the same for all.

Because in a carbon-constrained world it is likely that governments will seek to tax fuels according to the fossil carbon content that they embody, these carbon calculations will have serious business implications and carbon accountancy will become a new specialised profession. As far as can be judged at present there is quite a spread of EI/EO ratios. Among the best are ethanol from Brazilian sugar and from enzyme-treated straw ('cellulosic ethanol') in the region of 0.15–0.25. At the other end of the spectrum is some ethanol from corn where the energy cost of production may be close to or greater than that of the finished product (EI/EO around 1). In the longer term, EI/EO values close to or below 0.3 should be widely attainable.

The size of the future biofuels industry

In a blundering and uninformed way human beings find themselves conducting an experiment on the environment in which they live. An important question is how much energy can be extracted from biological materials in an energy-efficient, environmentally acceptable and cost-effective way, bearing in mind that at the same time people need to eat.

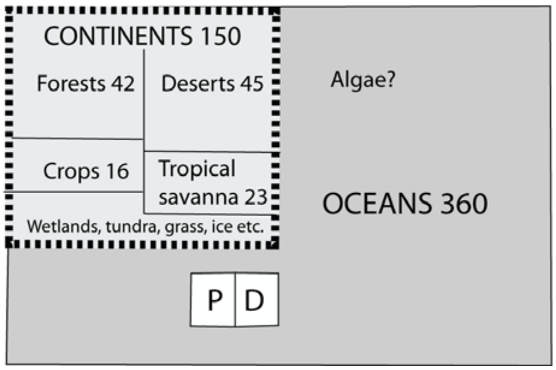

Figure 1. The area of the Earth roughly divided into ocean and land, with the latter showing land use. The numbers indicate areas in millions of square kilometers. See text for explanation of 'P' and 'D'.

Figure 1 depicts the area of the Earth crudely subdivided into its areas of current use. Also shown are the indicative areas that would be needed to satisfy the present world demand for liquid fuels (P: petrol, D: diesel) from biomass crops . It is clear that they amount to around three-quarters of the world's agricultural land. Taking into account the world's increasing demand for food it seems highly likely that if biofuels are grown on normal agricultural land they can never amount to anything more than a minor supplement to other fuels.

The two major areas within which space might be found for biofuel production with relatively low (but not zero) environmental cost are the oceans and part of the tropical savannas.

Coastal areas in the tropics offer the possibility of algal culture; the savannas are regions where only minimal subsistence cultivation is possible at present and but where very hardy plant varieties such as *J. curcas* could be grown.

If half of biofuel production was to be derived from agricultural, industrial and urban waste/residue streams and the other half was derived from non-food crops grown on marginal land, it is not unreasonable to imagine that within 20 years a volume of biofuel amounting to more than half the world's current fuel demand might be available. On a 20-year time scale, however, the picture could have changed profoundly. Biotechnological research that in the past has had little focus on fuels could conceivably lead to the development of microbes that could produce, from simple starting materials, hydrogen or methane or even liquid fuels.

Conclusions

Liquid fuels will be needed as long as we depend on the internal combustion engine; liquids from traditional sources are becoming extremely expensive and in any case are responsible for environmental damage. First supplementing them and then partially replacing them with biofuels could ease the environmental impact of transport. If biofuels are to make a significant contribution to world energy needs, however, they cannot be based on fuel crops grown on normal agricultural land. Organic residues from other processes and specially bred non-food crops grown on land where other crops struggle offer an immediate way forward. Biofuel technology is still immature, however, and there are likely to be both incremental and possibly step-change improvements that may transform the industry still further.