Perspective

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Thinking clearly about biofuels: ending the irrelevant 'net energy' debate and developing better performance metrics for alternative fuels

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Abstract: As the world shifts away from a dependency on petroleum resources it is imperative that clear and accurate perceptions of the value of alternative fuel sources are recognized. The silly 'net energy' argument revolving around fuel ethanol offers a textbook example of how not to think about alternative fuels. For over 25 years a small but vocal group of critics has argued that ethanol from corn has a negative net energy. This viewpoint has been widely disseminated and is a major perceived drawback to ethanol. Net energy analysis is simple and has great intuitive appeal. It is also dead wrong and dangerously misleading. If we are to make wise decisions as we embark on this brave new world of alternative fuels, we will need to carefully choose our metrics of comparison. Two complementary metrics suggest themselves. First, alternative fuels (e.g. ethanol) can be rated on their ability to displace petroleum; and second, ethanol could be rated on the total greenhouse gases produced per km driven. These are appropriate metrics, though there is still room for more discussion. Useless, misleading and dangerous metrics such as net energy must be eliminated from our discourse.

Key words: net energy, megajoule (MJ), ethanol, fossil fuels, metrics

Introduction

The age of petroleum is ending. If we are to make sound choices about our energy future, we will have to think clearly and carefully. We will also need to make appropriate comparisons between real energy alternatives. The first step in clear thinking about energy is to realize that we do not value energy *per se*. Instead we value energy for the **services** it can provide. These services include heat, light and mobility. Heat is provided by many sources including

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Table 1. Comparison of energy carriers (US$ per million Btu)

Energy carrier	Energy content* (Btu/X)	Typical market value ($/X)	Market value ($/million Btu)
Coal	20.4 MM• Btu/short ton	$40.30/short ton	$2.00
Natural Gas	1,030 Btu/cubic foot	$7.30 per 1000 cubic foot	$7.10
Petroleum	5.8 MM Btu/barrel	$60 per barrel	$10.40
Electricity	3413 Btu/kw h	$0.082/kw h	$24.00

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*US Energy Information Agency, 2004, pp. 357–386.

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coal, natural gas, wood and so forth. Light (electrical power) also has many sources: hydro, nuclear, coal, etc.

However, modern society is almost completely dependent on petroleum for the liquid transportation fuels required to meet our mobility needs, although electricity is increasingly a future option to provide mobility. Our overwhelming current dependence on petroleum for mobility increasingly puts industrial society at risk geopolitically, environmentally and economically. Biofuels offer one of very few options for mobility needs that simultaneously can provide geopolitical, environmental and economic benefits. If we are to properly evaluate the potential role of biofuels in our energy future, we will need proper metrics to compare biofuels with our alternatives.

'Net energy': an irrelevant metric

The net energy argument revolving around fuel ethanol offers a textbook example of how **not** to think about biofuels and other alternative transportation fuels. For over 25 years a small but vocal group of critics has argued that ethanol from corn has a negative net energy. Simply stated, they argue that more fossil energy (petroleum, coal and natural gas) is used to produce ethanol than is delivered when ethanol is burned. Their viewpoint has been widely disseminated and is a major perceived drawback to ethanol. Net energy analysis is simple and has great intuitive appeal. It is also irrelevant and misleading. Here is why.

The critics' most recent paper[1] concludes that corn ethanol has a –29% net energy. Net energy is defined as ethanol's heating value (a fixed, known quantity) minus the fossil energy inputs required to produce the ethanol. For convenience, the ethanol critics add up all fossil energy inputs as equivalent: one megajoule (MJ) of coal equals one MJ of petroleum equals one MJ of natural gas. This is the fundamental premise of net energy and it is completely wrong. All MJ are not created equal and **cannot** be added in this way. If all MJ were equal, then energy markets would reflect that fact. But the energy markets do no such thing. At current prices, a MJ (or Btu) of natural gas is worth about 3.5 times a MJ of coal, and a MJ of petroleum is worth more than five times a MJ of coal. A MJ of electricity is worth about 12 times a MJ of the coal raw material from which electricity is frequently generated. Clearly, all MJ are not created equal. Table 1 summarizes these data for various energy carriers.

These market realities summarized in Table 1 reflect another underlying, fundamental reality. As discussed above, we do not value energy *per se* but rather the services or 'qualities' that the energy provides. For example, the energy in coal cannot directly light our homes. Coal must be converted to electricity in a power plant in order to provide many desired energy services. About 1 MJ of electricity is produced for every 3 MJ of coal burned. Using the definition of 'net energy' as given above, the net energy of electricity is electrical energy out minus the coal energy used, approximately –200%, much worse than the corresponding figure for ethanol. Are we going to turn off the lights because electricity has a terribly negative net energy? The logic of the 'net energy' argument would say 'Yes, turn them off!'.

'Net energy' is fundamentally wrong

The details of the net energy calculations of the ethanol critics have been criticized on numerous grounds, including: (1) byproducts of corn ethanol were not appropriately accounted for; (2) some data used are obsolete or inappropriate; (3) system boundaries were not appropriately drawn, etc. All of these criticisms are correct. But they miss the fundamental problem with net energy. The underlying premise of the net energy argument is wrong. The 'net energy' metric is mistaken at the very core – not at its margins. Different energy carriers cannot be compared on a straight energy basis because all MJ are not created equal. In the real world, the different 'qualities' of different energy carriers must be considered. Apples are good for making apple juice; apples are not good for making orange juice. Petroleum is uniquely suited for making liquid fuels; neither coal nor natural gas are nearly so well-suited to make liquid fuels. The net energy calculation includes coal, petroleum and natural gas. Thus it is misleading and irrelevant as a public policy guide to use net energy to compare liquid fuel alternatives.

Making comparisons between ethanol and gasoline

Comparisons of alternatives are central to science and sound policy decisions, but unfortunately the net energy advocates have never published a single comparison of ethanol with other liquid fuels. It is not difficult to do such calculations. First the appropriate liquid fuel to which ethanol must be compared is determined. Ethanol and gasoline are both good fuels for the internal combustion engine. Therefore it is appropriate to compare ethanol and gasoline as alternatives. Figure 2 from the Farrell article[2] (27 January 2006) is very helpful in making these comparisons.

Using these data from Farrell, we see that 1 MJ of gasoline requires 1.1 MJ of petroleum plus 0.03 MJ of natural gas plus 0.05 MJ of coal, for a total fossil fuel input of 1.18 MJ per MJ of gasoline. The net energy is therefore 1.0 MJ –1.18 MJ equals –18% net energy. The net energy for ethanol (again, see Figure 2, the 'ethanol today' scenario) is 1.0 MJ of ethanol requires 0.05 MJ petroleum plus 0.3 MJ of natural gas plus 0.4 MJ of coal equals a total fossil fuel input of 0.75 MJ per MJ of ethanol. Thus the net energy for ethanol is 1.0– 0.75 MJ equals +25% net energy. Using precisely the same net energy methodology and assumptions of the ethanol critics, one quickly finds that gasoline has a net energy that is poorer than ethanol's. Thus ethanol is actually superior to gasoline in its net energy metric. In doing this calculation, we are not advocating net energy as a metric, but simply demonstrating the power of making comparisons. Had such comparisons been done years ago on corn ethanol's net energy, we might not be in the muddled state in which we now find ourselves on the net energy issue.

Developing better metrics for biofuels

We have now come full circle. We started this article by stating that clear thinking and sound comparisons are required if we are to make wise decisions as a society about our energy future. Clear thinking shows us that we do not value energy *per se*. Rather we value the services that various energy carriers provide: heat, light and mobility. Petroleum has a unique role in meeting the mobility needs of modern society. At a minimum, therefore, liquid biofuels should be compared with petroleum. Can better metrics than net energy be developed to compare alternative fuels with petroleum and with each other? There is much room for discussion on this issue, but several complementary metrics suggest themselves.

First, alternative fuels (e.g. ethanol) could be rated on their ability to displace petroleum, our most pressing *energy security* policy issue. To produce 1.0 MJ of ethanol requires about 0.05 MJ of petroleum, while it takes 1.1 MJ of petroleum to produce 1.0 MJ of gasoline (data from Farrell *et al.*[2]). Thus ethanol displaces 1.1/0.05 equals 22 MJ of petroleum for every MJ of ethanol produced. *We greatly extend our supplies of petroleum and thereby reduce its importance by producing corn ethanol.* Cellulosic ethanol has similar petroleum displacement numbers relative to gasoline. Cellulosic ethanol is not currently in large-scale production, although construction of large-scale cellulosic ethanol plants based on various technologies is currently underway. Given the past history of technological improvement, it is likely that the petroleum displacement metric will improve as cellulosic ethanol technology improves.

Second, ethanol could be rated on the total greenhouse gases produced per km driven, our most pressing *climate security* policy issue. The Farrell *et al.*[2] piece also provides the data for making these comparisons. From Figure 2 we see that corn ethanol provides an 18% reduction in greenhouse gases compared with gasoline while cellulosic ethanol gives an 88% reduction in greenhouse gases compared with gasoline. Similar values for greenhouse gas reduction have been published by Dr Michael Wang of Argonne National Laboratory. Thus corn ethanol currently achieves modest greenhouse gas reductions, but new technologies in agriculture and in biorefinery operations are reducing greenhouse gas emissions. Cellulosic ethanol will reduce the life cycle greenhouse gas emissions per km driven by almost ninefold compared to gasoline – a huge improvement.

We note here that the Farrell article assumes a single set of conditions for the agricultural phase of ethanol production. The reality is considerably more complex, and the opportunities for further greenhouse gas reduction greater, than this simple assumption would suggest. We will provide more information on the environmental impacts of the agricultural phase of biofuel production in a later issue of this journal.

Third, there are many potential biofuels including at least ethanol from sugar, corn and cellulosics as well as biodiesel from oilseeds and animal fats. Thus biofuels should be compared with each other as well as with petroleum and non-petroleum alternative transportation fuels. In addition to the two metrics outlined above, and given the importance of using land efficiently, it would be well to compare biofuels with each other based on their net liquid fuel production per hectare of land used.

Summary

So what have we learned? If we are to make wise decisions as we embark on this brave new world of alternative fuels, including biofuels, we will need to carefully compare energy sources based on the serviced they provide. We must not simply make comparisons of different fuels on their gross energy inputs, as the net energy metric does. Instead, we must wisely choose our metrics of comparison. We want attractively priced alternative fuels that will reduce total petroleum use and also provide environmental improvements versus gasoline and diesel. For comparisons among biofuels we should also compare the efficiency of land use. These are appropriate metrics for biofuels and other alternatives. Useless, misleading and irrelevant metrics such as net energy must be eliminated from our discourse on fuel alternatives.

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