Centre for Global Studies
LOW-CARBON ENERGY PROJECT
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BIOFUELS[i]

Issue: What does current research say about biofuels and the role they might play in a transition to sustainable energy systems for a low carbon society in the medium to long term?

Forest waste products can play a major role in B.C.'s energy future. In many regions, including B.C., dedicated plant crops (e.g. corn) are uneconomic as a source of biofuels, based on a life cycle energy analysis. Of course there is a second best argument in favour of subsidizing some bio fuels, if subsidies to agriculture are deemed unavoidable. There is also a security of supply argument. The real promise lies in applied research – developing lignocellulosic sources for ethanol, new or improved enzymes for decomposing biomass, using micro organisms to create fuels other than ethanol, or to create novel lignin using innovative enzymes, synthetic catalysts and genes.

Background: What is biomass?

Biomass is a fancy name for organic materials—it is what is produced by solar radiation through photosynthesis. Captured solar energy from biological systems has traditionally played a large role in human society through agriculture and small-scale domestic use. Expanding the use of biomass for large-scale energy services could help reduce the greenhouse gas (GHG) intensity of the energy system and hence reduce overall emissions of greenhouse gases. Because photosynthesis captures CO2 from the air, the resulting carbon-based feedstock can be processed and utilized in a similar manner to fossil fuels with lower net emissions of CO2.

To the extent that use of biomass substitutes for fossil fuels, it slows the depletion of hydrocarbon resources and contributes to global security, principally by reducing the dependence of any specific nation on foreign sources of oil and gas.

Biomass energy conversion could take advantage of many existing waste streams, but would also likely involve the cultivation and conversion of dedicated energy crops. The naturally low efficiency conversion of solar energy to biomass leads to large requirements of land, water and nutrients, varying dramatically, of course, by geographic location. Lifecycle cost, energy, and greenhouse gas emission considerations such as fertilizer production, harvesting, and feedstock transportation are all barriers to the widespread use of energy crops. Competition with the resources needed for food production poses further direct barriers.

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Biomass can be used to meet energy needs in electricity production, heating and transport. As previously noted, there are two overarching reasons for current interest in biomass as a fuel source. First, it contributes to energy security by moving away from dependence on coal, oil and natural gas. Second, it may significantly reduce emissions of greenhouse gases in all three areas of use. (In addition, it has been argued that increased production or use of biomass for energy may contribute positively to development prospects in rural or First Nations communities.)

To assess the potential for a net contribution on either of these two dimensions, however, demands a full life cycle analysis (LCA) that takes into account the energy content of all the inputs into the production of the fuel as well as the value of all byproducts. This analysis must also take into account the emissions of pollutants or greenhouse gases through the whole cycle of production and use. Thus, in comments on the potential for use of various biofuels, it is necessary to look both at the energy balance—that is, the relative net contribution of energy (sometimes referred to as the energy return on energy invested, or EROEI)—and also at the comparative scales of pollutants and greenhouse gases emitted. Such system-wide life cycle analyses are inherently difficult and subject to wide differences in empirical estimates. Hence some of the estimates of energy balance and GHG emissions mentioned below remain controversial.

What are biofuels?

For purposes of this briefing, biofuels are understood to be any fuel made from plant material, agricultural waste or vegetation, collectively known as biomass. They are predominantly found in the form of liquid transportation fuels such as ethanol, biodiesel and biogasoline, but in the form of fuels such as wood or switchgrass pellets biomass could be used for home heating, and in the form of wood waste is also widely used for heating and for electricity production. "Combustion of biomass for power generation is a well-proven technology."[1]

In current production of liquid fuels for transportation purposes, the emphasis is on production of ethanol from sugarcane (principally in Brazil), corn or soybeans in the US, and sugarbeets in Europe. The research frontier concerns the development of technologies for producing and converting "cellulosic biomass" or lignin to liquid fuels.

Cellulosic biomass refers to the polymers that comprise the body of plants (e.g. the stalks, leaves, roots). The main polymers are cellulose (a composite polymer of glucose), hemicellulose (a complex polymer of various sugars, notably xylose) and lignin (a very complex polymer). Cellulose and hemicellulose can be hydrolyzed by enzymes or acids to sugars that can be fermented to produce liquid fuels, or thermally converted to volatiles that can be reformed to produce liquid fuels, principally ethanol.

"Today's ethanol production uses predominantly starch or sugar crops, limiting the available feedstock, but new technology could enable the use of lignocellulosic biomass feedstocks as well. This is currently one of the cutting edge areas of energy technology research."[2]

This ethanol can then be mixed with gasoline to create a fuel for internal combustion engines that offers reduced emissions of greenhouse gases. E10 is a mixture of 10% ethanol and 90%

gasoline that can be used in existing internal combustion engines without modification (and within manufacturers' warranties). E85 is a blend of 85% ethanol and 15% gasoline; with limited modification, vehicles can run on both the 85% ethanol mixture and pure gasoline. These cars are called flex fuel cars and it is estimated that there are approximately 4 million of them on the road in North America today.[3] Limitations to the supply of ethanol for transportation purposes are based on land availability, concerns for environmental impacts from accelerated growth of energy crops and competing food demands.

Cellulosic ethanol (produced from switch grass and other plant wastes) can achieve an 80% reduction of CO2 levels compared with regular gas emissions.[4] It has the same genetic makeup as grain-based ethanol but has the ability to produce 3 times the energy.[5] Grain-based ethanol must use fossil fuel to produce the heat in their conversion process, but cellulosic ethanol can utilize lignin, a by-product within the biomass. It is argued that on a net basis, no greenhouse gases are produced through use of cellulosic ethanol because the GHGs released from burning biomass are absorbed as additional biomass grows. Since cellulosic ethanol is produced from switchgrass, willow or other plants that grow on marginal agricultural land and are not used for food, there is not the same competition with food supply as with corn or soy-based ethanol.

Biodiesel is a liquid fuel made from raw vegetable oils such as soybeans, from animal fats or tall oil (a waste product from pulp and paper processing) or from recycled cooking oils known as "yellow grease". It is produced through oils and fats in a chemical process called "transesterification" in which it is blended with alcohol. Compared with conventional diesel, biodiesel combusts better and produces fewer greenhouse gas emissions.[6] It can be blended with conventional diesel in any concentration.

Pellets made from wood, switchgrass or other non-food plants provide fuel for power generation and heating.

Thus, from biomass generally can be produced biofuels for transportation uses such as 'conventional' ethanol from sugar or starch (food crops), cellulosic ethanol from waste or non-food crops and biodiesel from raw vegetable oils, animal fats or recycled cooking oils, as well as various forms of wood or fibre products for heating and power generation. A wide range of valued by-products or joint products may also be produced from the various processes generating these biofuels (and must be taken into account when the merits of various biofuels are being compared).

Potential Contribution

The Earth receives some 6,000 times as much energy from the sun each year as the world uses. The most productive plants capture about 1% of light energy. This translates into 60 times global energy consumption on an annual basis. Thus, in principle, it would be possible to meet all human energy needs, at current levels of demand, by using about 1.7% (1/60) of the Earth's surface (or about 6% of the land surface) to grow highly productive plants for use as energy crops, assuming recovery of the inherent energy at 100% efficiency. If the inherent energy were recovered from the plants at 40% efficiency (i.e., the efficiency of combustion), 15% of the most productive and suitable land surface would be required to meet total current energy needs by use of biofuels.

At a less theoretical level, the International Energy Agency suggests in their 'Accelerated Technology Scenario' that "Savings from liquid fuels would equal more than half of today's global oil consumption, offsetting about 56% of the oil demand foreseen in the Baseline scenario to 2050."[7]

It is estimated that biomass resources in British Columbia could meet about 30% of the energy demand presently met from fossil fuels. A recent BIOCAP study[8] estimates that bioenergy from municipal wastes could provide about 1.6% of the provincial fossil energy demand; animal manure and crop residues another 0.9%; new biomass crops such as switchgrass or hemp could provide about 4.8%; forest residue from existing sustainable forestry operations about 21%, or up to 30% with improved silviculture practices. Accessing 7% of the tree biomass killed in the MPB infestation could provide central B.C. with 300 MW of power for the next 20 years. The report does not discuss specific uses of this energy from biomass, other than to note that use in typical large combustion power generation could maintain about 8000 MW of power generation. (Of course, use of liquid fuels to substitute for gasoline in transport uses may be a preferred alternative not only for biomass from agriculture or waste, but also from forestry if technology for economically viable production of ethanol from lignocellulosic sources is successfully developed.)

Lifecycle assessments

Lifecycle assessment accounts for GHG warming potential of alternative fuels, evaluating the energy expended and the associated GHG emitted both in the steps required to deliver finished fuel into the tank of a vehicle (Well-to-tank, or WTT phase) and the energy expended by the vehicle in use (Tank to wheel, or TTW phase). The International Organization for Standardization has settled on appropriate methods and standards for these evaluations.

There have been a number of lifecycle studies of the various conventional approaches of corn or wheat to ethanol as well as "lignocellulosic" (wood tissue) crops. Estimates of the ratio of output energy to fossil fuel inputs vary with assumptions about the process, the input fuel used, and offsets to prevent soil erosion.

Recent studies have suggested that conventional ethanol can offer net benefits compared to gasoline on energy produced as well as on GHG emissions, though the net energy benefits are small. (Some analysts, such as Pimentel and Patzek[9], continue to argue that on balance, in a full life cycle assessment, the net energy returns are negative for corn or soy-based ethanol, but in any case there is agreement that with current methods the net return, or energy balance, is close to zero, perhaps mildly positive.)

Figure 1, drawn from a presentation by David Hughes of NRCAN [10], illustrates the general situation with the question of energy balance for current biofuels. The results developed by a University of Minnesota research team[11] are illustrated, and these are roughly in agreement with similar results reported in *Science* by a team from the Energy and Resources Group at the University of California at Berkeley.[12]

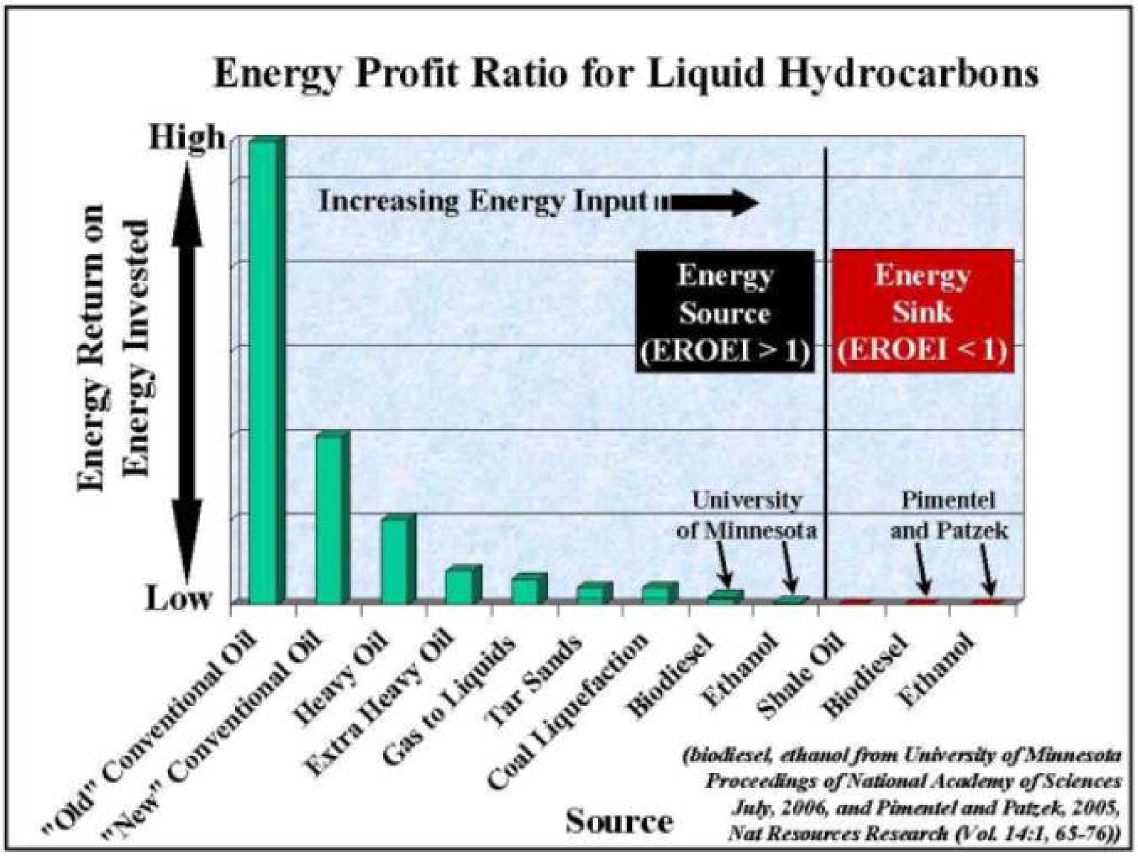

Figure 1. Energy balance for current biofuels.

For lignocellulosic ethanol (not illustrated in the diagram) more promising results were described by Overend who carried out a systematic review of published and peer-reviewed reports and papers comparing renewables and fossil alternatives (see Annex 2) [13]. This review compares the ratio of output energy to all fossil energy inputs in the chain ("R values"), the total energy input, and the Global Warming Potential (GWP) in terms of carbon and CO2 equivalent masses per unit of total energy input. For biomass, the chain includes all the agricultural/ silvicultural inputs, raw material transport, process chemical input, bio fuel output, bio fuel distribution, co-products, and effluent treatment.

The conclusions drawn by Overend are worth noting "... there is a consensus that the ratio of output energy to fossil fuel inputs is about 5 for lignocellulosic crop conversion to ethanol. Unlike the highly controversial history of corn-to-ethanol conversion, there is no argument in the literature that denies the benefits from using lignocellulosic feedstocks."[14]

In addition, the GWP impact of using ethanol produced from corn is about the same as for gasoline when the detailed life cycles of the two products are examined.[15] The case for biodiesel is stronger on both counts, and the potential for cellulosic ethanol is stronger still.[16]

With respect to the global warming potential, for the "Wheel to Tank" stage, biofuel is superior to fossil fuel systems even with carbon sequestration, in part because there are emissions upstream of the fossil processing plant that are not captured (e.g., in exploration, mining).

Advantages and Disadvantages of biofuels

Advantages

Biodiesel and ethanol (indeed any biofuel derived from a sustainable crop) both have essentially closed carbon cycles, meaning the CO2 released when burning the fuel is recaptured by the new growing plant material that may be used to produce additional fuels in the future.[17]

Greenhouse gases (GHGs) can be reduced by 20% by using corn-based ethanol in place of gasoline, and cellulosic ethanol can reduce GHGs by as much as 80% (Newell, 2006).

Use of biofuels can diversify the energy supply and increase security with a lower dependence on energy imports and protection from volatile oil markets.

Widespread use in less developed countries can lead to rural development and new job creation; for example, it is suggested that the Brazilian sugar cane sector is responsible for 700,000 new jobs and 3.5 million indirect jobs associated with production of 350 million tonnes of cane.[18] The job to energy output ratio is much higher than any other energy sector, with a relatively low investment cost. [19] Whether the increase of employment in such labour-intensive farm jobs is desirable in the long run can, as always, be debated.

Disadvantages

Intensive cultivation of energy crops at large scale may introduce all the ecological problems of monocultures elsewhere.

Ethanol has only 70% of the energy content of gasoline (and hence lower miles/gallon); flex fuel vehicles will require larger fuel tanks to achieve the same range as a gasoline-powered vehicle, and competition with gasoline will require that ethanol be priced advantageously unless its use as a transport fuel is mandated through regulation.

Barriers to promotion of biofuels

The major constraint on large scale use of bioenergy remains the lack of cost-effective conversion technology capable of making energy intermediates compatible with machinery optimized for petroleum. Secondary constraints are associated with the environmental impacts associated with large-scale use of biomass.

A further concern is that “aggressive growth in bio fuel production could crowd out production of food crops in some developing countries, creating a tension between the need for energy and the need for food and feed.”[20] Targets set up by countries to achieve fossil fuel reduction through increased use of ethanol or biodiesel have resulted in an increasing world prices for vegetable oil and sugar. Accessing biofuels has not been easy for some smaller and less developed countries which are finding it expensive to import both fossil and biofuels because of the increasing price on the world market.

The push for biofuels has been encouraged by environmental concerns in North America and the EU but can result in environmental degradation and deforestation in other regions, leading to a loss of existing carbon sinks.

Research avenues to reduce barriers

In a 1979 review paper on renewable energy, Harry Swain and his colleagues Overend and Ledwell, then at the Department of Energy, Mines and Resources in the Government of Canada, observed that "part of the challenge will be to shift away from oil, where technically possible, and to reduce oil demand in those markets, like transportation, where there are no ready substitutes".[21] They went on to say that "as with heavy oil and heavy water, development of these [forest biomass] resources cannot await the results of research elsewhere, for no other nation has the opportunity open to Canada", and envisaged in the longer-term, "in the post-petroleum era", a level of exploitation of forest cellulose that could form the basis of a large energy or synthetic chemical industry producing the equivalent of 2 exajoules per year (roughly 1 million barrels per day).[22]

In considering the first of the barriers noted above (already noted in their article), Swain and colleagues observed that the immense potential of biofuels, and the flexibility on the production side, is countered by the need for immense (and very long term) investments—and associated research needs—on the downstream side to make efficient use of the product.

In the September 1986 issue of the Government of Canada's R&D Bulletin, the Bioenergy Development Program was described as "aimed at displacing fossil fuel consumption through the development of technology to convert biomass into thermal, mechanical or electrical energy, with large scale production of transportation fuels or industrial chemicals from biomass as a long-term goal".[23]

So the research challenges have been around for more than a generation.

A recent study published by the US Department of Energy, with substantial input from members of the Global Climate and Energy Program at Stanford University, has summarized the main research objectives associated with decreasing the barriers to the development of a cellulosic biofuel industry[24]. In brief the main research objectives are to maximize the biomass productivity of new energy crops, to develop energy crop production practices that maximize the sustainability of production of all plants that can be used for energy (eg., food crop residues as well as energy crops), to optimize the efficiency with which biomass can be converted to fermentable compounds, to minimize the production of toxic compounds, to maximize the tolerance of industrial organisms for fuels and inhibitors found in biomass hydrolyzates and to maximize the yield of fuels by fermentation of biomass-derived compounds. Each of these broad goals represents a large number of specific problems and research opportunities.[25]

Among the topics identified by the GCEP, the following three are among the most promising:

1. Discover new or improved enzymes for decomposing biomass into sugars.
This is generally considered the main limitation to cost effective production of cellulosic liquid fuels today. There is an opportunity to exploit the large amount of new microbial DNA

sequence information to identify new enzymes that break down lignin or cellulose, in addition to many opportunities to find new enzymes that can hydrolyze the other polysaccharides.

2. Create new fuels.
There are reasons to believe that ethanol will not be the fuel of the future. Microorganisms produce a wide variety of other compounds that would be better, including alkanes. Now that it is possible to engineer major changes in the genes of microorganisms, there is broad interest in developing new microbes that produce other types of compounds at high efficiency.

3. Create novel lignin.
One reason that energetically expensive and chemically harsh treatments are used to preprocess biomass is that the presence of lignin (a phenolic polymer) occludes the polysaccharides, preventing access by enzymes that would otherwise hydrolyze the polysaccharides to sugars. The available evidence suggests that it will not be possible to make plants that lack lignin. However, the idea has emerged that it may be possible to develop a novel type of lignin that is amenable to hydrolysis by enzymes or novel synthetic catalysts. The development of a novel lignin would require finding genes from some organism that produces the relevant molecules and also finding genes for transporters that secrete the molecules into the cell wall and also finding enzymes that hydrolyze the novel lignin. Therefore, the problem requires a multidisciplinary approach and some creative thinking.

Canada has a target of producing 10 million litres of biodiesel by 2020, resulting in the production of 50 million litres of glycerol as a byproduct. Creating a use for glycerol above and beyond soap products could be a huge asset for the development of biodiesel. BIOCAP, a Canadian research network that creates partnerships aiming for a sustainable bioeconomy, has claimed there is strong potential for producing synthesis gas (syngas) from glycerol.[26] Syngas is a mixture of hydrogen and carbon dioxide and can be converted into various products such as methane, ethanol, and gaseous and liquid hydrocarbons, which in turn, can be used in both power generation and transportation fuels.[27]

Policy options

At Gleneagles in July 2005 and in St. Petersburg in July 2006, G8 leaders called on the IEA to advise on alternative energy scenarios and strategies aimed at a clean, clever and competitive energy future.[28] A part of this response is provided by two reports released by the IEA in 2006 – the World Energy Outlook 2006 and Energy Technology Perspectives.[29] Both these reports include significant analysis of the economics and outlook for biofuels. Their key findings are as follows:

- Biofuels could account for 4-7% of road-fuel consumption in 2030, up from 1% today. The lower figure results from an absence of new government action and the higher from the introduction of a range of measures already under consideration.

- Biofuel production costs vary depending on the type of feedstock, the conversion technology, biomass yields and land and labour costs. Sugar-cane ethanol produced in Brazil costs about USD 0.30 per litre of gasoline equivalent. Corn-based ethanol produced in the United States costs around USD 0.60 per litre. Current biodiesel production costs (between USD 0.70 and USD 1.2 per litre) are well above those of petroleum diesel. Biodiesel from waste oil feedstocks is almost competitive with petroleum diesel, but its production potential is limited.

- Similarly, the CO2 emissions profile of biofuels production and use depends heavily on the type of feedstock used and the production process. CO2 emissions can be reduced by as much as 90% with the use of ethanol from sugar cane. Estimates of CO2 emissions emission reduction potential from grain-based ethanol vary widely, 13% is the current "best point estimate" for US production. Conventional biodiesel could reduce CO2 emissions by 40 to 60% over conventional diesel fuel.

- Rising food demand, which competes with biofuels for existing arable and pasture land, will constrain the potential for biofuels production using current technology.

- New biofuels technologies being developed today, notably lignocellulosic ethanol, could allow biofuels to play a much bigger role than that foreseen above. But significant technological challenges still need to be overcome and costs reduced. Lignocellulosic ethanol has the potential to reduce CO2 emissions by 70% and to reduce the potential competition for the use of land.

- Trade and subsidy policies will be critical factors in determining where and with what resources and technologies biofuels will be produced in the coming decades.

Despite the popularity of biofuels, OECD analysis suggests that most biofuel production, with the exception of ethanol production in Brazil, is economically inefficient - production costs exceed the value of fossil fuels replaced. Given the relatively limited net gain in energy availability (i.e. a lot of fossil fuel energy is used to produce biofuels), the economic inefficiency of biofuels makes further policy initiatives, in addition to the significant subsidizations already taking place in several countries, problematic. [30]

To encourage production of biofuels, the first and dominant policy measure obviously ought to be to ensure that fossil fuels are priced in a way that reflects the full social cost of their production and use. This entails introduction of a carbon tax. It should be emphasized that taking greater advantage of market mechanisms by removing existing distortions in the price system through a system of carbon taxes is the appropriate market-based policy. However, the reality is that the prospects for achieving an undistorted price system are not good.

A very complex mesh of subsidies, regulations and other supports has emerged to encourage production of biofuels. The extent of the complexity—and the surprising scale of overall support in aggregate—is emphasized in a recent report from the Global Subsidies Initiative of the International Institute for Sustainable Development (IISD).[31] Given the likely persistence of a political need to maintain agricultural subsidies in some form, it has been argued that efforts should be made at the World Trade Organization and elsewhere to shift from general agricultural subsidies toward subsidies to encourage production of renewable bioenergy products.[32] This argument is contested by those who continue to press the supremacy of the market solution with elimination of market-distorting subsidies altogether.

It does seem clear that there is little argument for subsidy of current ethanol production using existing methods, except as an interim second-best step, but there could well be argument for subsidies to encourage extension of bioenergy crops to marginal lands and for infrastructure to promote commercialization, as well as for public expenditures to support research and development aimed at new technologies for production of ethanol, biodiesel and wood or switchgrass pellets along with more efficient use of wood waste and trees killed by mountain pine beetle.

The Energy Policy Act of 2005 in the US, and new measures announced since, ensure commercial cellulosic ethanol will be produced in the United States.[33] Two billion dollars in spending has been allocated to cellulosic biofuels in the United States over the next 10 years-- 1.1 billion for spending on research, development, and demonstration and $800 million to set up biorefineries.[34] It is predicted that with proper development cellulosic ethanol can leave the production plant at a price between $0.59- $0.91 / gallon by 2015, enabling pricing competitive with oil.[35] (Currently, government subsidies of 51 cents per gallon make corn-based ethanol competitive in the United States with gas.[36] The downsides of such subsidy and other support for biofuels production are extensively documented in the report of the Global Studies Initiative just mentioned; the lesson is starkly outlined in summary form in a March 14, 2007 Globe and Mail editorial by David Runnalls, President of IISD[37], or in an earlier similar commentary by economist Robert Samuelson in a January 24, 2007 Washington Post article, "Blindness on Biofuels"[38]—though it has to be emphasized that the conclusions from either article apply only to the situation in the United States, and not to the case of cellulosic ethanol, which is treated as still an unproved technology.

Brazil's experience is viewed more favourably, and offers some relevant policy lessons - most important were its requirement that the auto industry produce cars using neat or blended biofuels. There were subsidies for biofuels during initial market development; the opening of the electricity market to renewable energy–based independent power producers; support for private ownership of sugar mills, which helps guarantee efficient operations; and stimulation of rural activities based on biomass energy to increase employment in rural areas.[39]

Timeline

Reductions in fossil fuels are necessary to decrease greenhouse gas emissions and maintain a sustainable fuel supply. To replace oil there are generally two paths that can be taken, one being liquid biofuels such as ethanol and biodiesel as discussed, and secondly hydrogen and fuel cells.[40] In the short term it will be the liquid biofuels that can readily replace petroleum because they can be used in conventional internal combustion engines. Cellulosic biofuels have the greatest energy output and are most advantageous to the environment. Presently cellulosic biofuels are still in the development stage and expensive to produce. Until further research and marketing is successfully pursued, ethanol blends (E10, E85) and biodiesel will likely take the lead. Hydrogen fuel cells and electricity may provide a valid route for future alternatives but they both require development of new vehicle technologies that will take time for the public to accept and purchase, as well as extensive infrastructure.[41]

In order for biofuels to succeed in timely fashion there must be increased attention to research and development on technological advances in both conversion and processing.

Funding of demonstration projects and investment to spur commercialization are also necessary. The government must play a leading role and offer support especially during the start-up process by providing subsidies and incentives to both producers and consumers.

The relative benefit of biofuels in comparison to fossil fuels can be challenging to determine at this point because the cost paid at the pump for fossil fuels is not the "real' cost and does not take into consideration externalities such as environmental and health costs. The removal of long standing subsidies on fossil fuels, and removal of existing distortions in the price system through introduction of a carbon tax, will make biofuels competitive in most fields.

From a large scale investment perspective getting biofuels integrated into mass transportation fuels appears to be the most appropriate place to start expansion. This offers the most dramatic benefits with large reductions in vehicle pollution and the vast amount of oil which could be replaced.

Implications for British Columbia

The 2007 BC Energy Plan envisages a bioenergy strategy that will establish British Columbia as a world leader in bioenergy development. It points out that "currently, British Columbia is leading Canada in the use of biomass for energy. The province has 50 per cent of Canada's biomass electricity generating capacity. In 2005, British Columbia's forest industry self-generated the equivalent of $150 million in electricity and roughly $1.5 billion in the form of heat energy. The use of biomass has displaced some natural gas consumption in the pulp and paper sector. The British Columbia wood pellet industry also enjoys a one-sixth share of the growing European Union market for bioenergy feedstock."[42]

Against this backdrop, and in light of BC's unusual energy mix, and particularly the BIOCAP review, mentioned earlier, of the bioenergy potential in British Columbia, it is clear that much of the ongoing research and policy commentary dealing with reservations about conventional corn-based or sugar-based ethanol is largely irrelevant in BC. On the other hand, **funding or partnering in research on technologies for lignocellulosic ethanol production, and support for production of appropriate biomass crops on marginal lands seem to be obvious directions for public policy**. Perhaps most particularly, support of research into technological innovation and carbon management strategies to ensure that production of bioenergy from forests, forest residue and the one-time endowment of fuel source associated with the mountain pine beetle infestation can be accomplished with zero net emissions is the logical area for the Provincial Government to apply its financial resources.

The 2007 BC Energy Plan contains a commitment to support the recently announced federal commitment to achieve, through regulation, an increase in the ethanol content of gasoline to five per cent by 2010, as well as to implement in BC a five per cent average renewable fuel standard for diesel fuel by 2010 (by contrast with the federal commitment to 2% renewable content in diesel fuel and heating oil by 2012)[43]. It has also announced commitments for support of hydrogen fuel initiatives that may lead in the longer term to use of hydrogen as an energy carrier in transportation as well as other application. These developments can be seen as consistent with the timeline outlined above.

ANNEX I:
Scenarios for the structure of energy supply, including biofuels, to 2100

The structure of the global energy system has undergone major transitions over the past two centuries, and must be expected to do so again in the period to 2100. Figures 1 and 2 below chart two views of this historical and future evolution to 2100, while the energy triangle in Figure 3 displays 6 further scenarios and offers a possibly useful tool for visualizing these grand transitions. In Figure 3, the primary energy structure has evolved clockwise as coal replaced traditional renewable energy between 1850 and 1920, while oil and gas largely replaced coal between 1920 and 1990. Little seems to have changed in the structure of the global energy system since this last structural change, up to the present, but dramatic further change can be anticipated in the period up to the end of the present century.

As a glance at Figures 1 and 2 reveals, very different possible pictures of the future role of coal as an energy source might be entertained (depending on the expectations one might have for hydrocarbon supplies and the viability of new technologies for 'clean coal' through carbon management). A March, 2007 study released by an interdisciplinary MIT faculty group concludes that "CO2 capture and sequestration is the critical enabling technology that would reduce CO2 emissions significantly while also enabling coal to meet the world's pressing energy needs." This study envisages increasing coal use under any scenario. Nevertheless, the role envisaged for biomass in both outlooks displayed in the Figures below is similar: roughly 10%-15% of total energy supplied is envisaged to come from biomass by 2100.

In Figure 3, six scenarios illustrate different paths this transition might take, highlighting the 'decarbonization' that is anticipated to bring renewables and nuclear to account for 50% or more of energy consumption in 2100.

Two qualitative features of these transitions might be noted. The first is the long time scale involved, due to the very long lifetimes of the power plants, refineries, grids, distribution systems and other energy infrastructure and capital. This feature means that policy decisions made today to influence capital investment within the next few decades will largely dictate our trajectory for the rest of the century. On the other hand, the dramatic structural change from 1900 to 2000 reminds us that the similar transformation likely over the coming century is also plausibly within the adjustment capacity of the economy and society in the coming century as it has proved to be in the last.

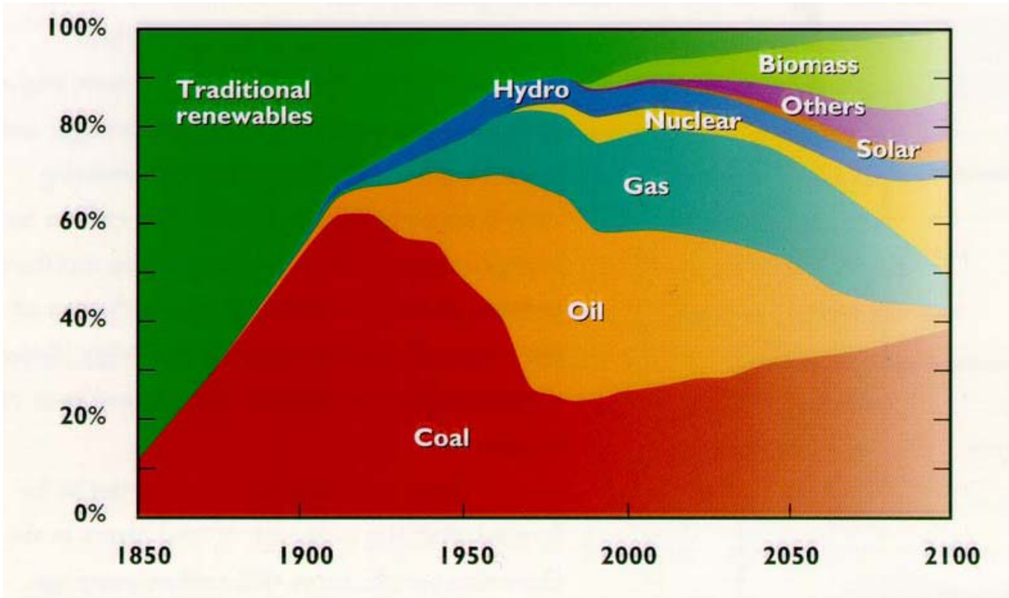

Figure A1. World Primary Energy Shares –
1850 to 2100 Given Oil and Gas Limitations[44]

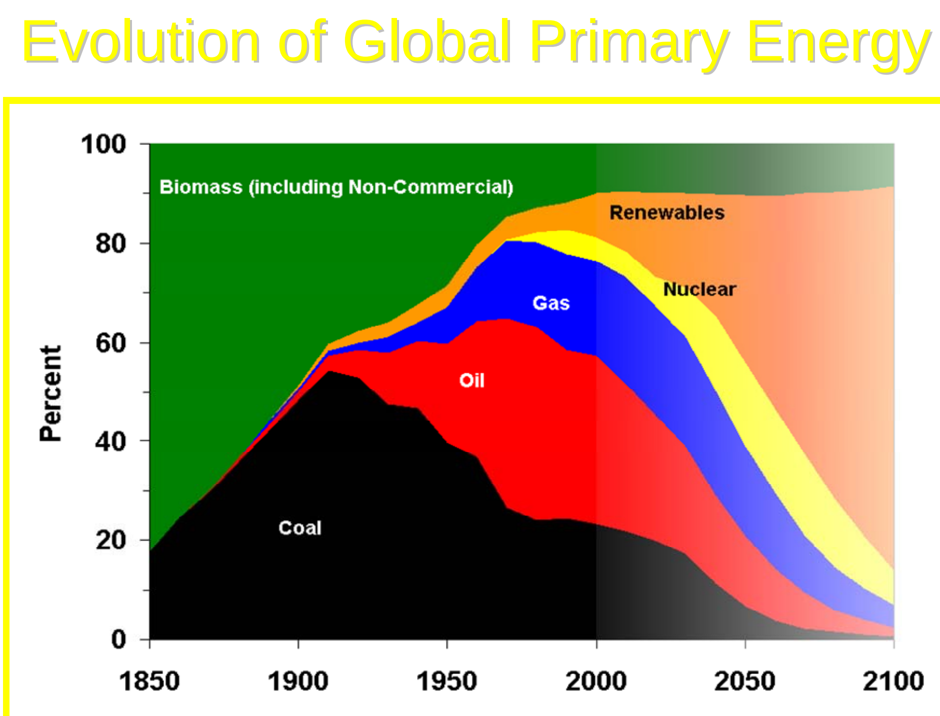

Figure A2. Evolution of Global Primary Energy.[45]

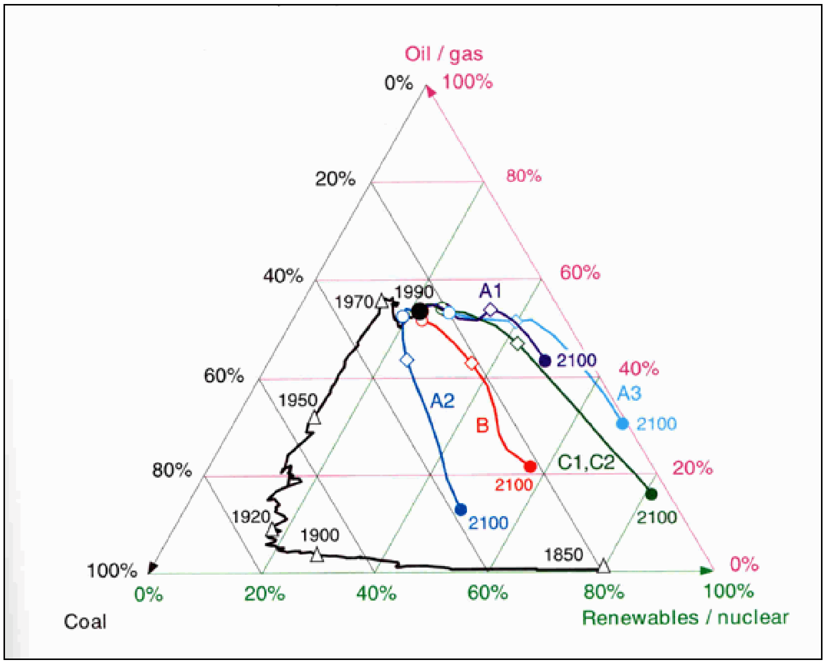

Figure A3: Evolution of Global Primary Energy Structure.[46]
The figure may be interpreted by focusing on the 3 vertices of the triangle, each representing a situation in which one of the 3 kinds of primary energy has a 100% share, with no contributions from the other two. The straight lines within the figure are lines of equal share (iso-lines) at distances of 20%. Since the triangle does not have a time dimension, selected points in time are marked on the curves. For example, looking at the end point at 2100 for scenario A1, one sees a projection of roughly 42% oil/gas (reading across the horizontal pink lines to the pink scale), roughly 48% renewables/nuclear (reading down the green diagonals to the green scale), and roughly 10% coal (reading up the black diagonals to the black scale).

ANNEX II[ii]:

The energy balance and greenhouse gas implications of lignocellulosic ethanol compared with traditional petroleum fuels and alternative fossil cycles including carbon capture and sequestration.

Introduction:

There have been many studies of the energy balance, and the flow of carbon and nitrogen compounds that constitute gases with significant greenhouse gas (GHG) warming potential (GWP) for alternative fuels. The best of these studies are based on lifecycle assessment approaches in which the system boundaries run from the resource to the energy storage onboard the vehicle which is often described as a Well to Tank (**WTT**) evaluation accounting for the energy expended and the associated GHG emitted in the steps required to deliver the finished fuel into the on-board tank of a vehicle, followed by a Tank to Wheels (**TTW**) evaluation accounting for the energy expended and the associated GHG emitted by the vehicle/fuel combinations. The combination of these two results is the Well to Wheels (**WTW**) integration for fuel/vehicle combinations.

WTW studies while complete in their methodology are very difficult to introduce and to explain even to energy informed audiences. In particular the best ones follow the standard methodologies of the International Organisation for Standardization (ISO) [1206] ; and introduce the concept of system expansion to accommodate the role of non-energy co-products such as distillers dried grains and solubles (DDGS) in the overall energy and mass accounting for corn ethanol. With the WTW-LCA in hand the flows of materials and energy can be used to evaluate non-renewable energy consumption, global warming impact, acidification and eutrophication of water bodies. In addition to defining the initial study boundaries and their expansion, these studies are tied to an appropriate unitary output from the viewpoint of the shareholders, whether it is the farmer perspective of the impact per unit area of land, or the driver perspective of the impacts for a
a unit of distance travelled.

It must be emphasized that the conclusions of an LCA are very affected by the flows in the energy and material sub-systems influenced by the outputs of the chosen energy pathway - for example a process plant with ethanol and electricity output will get a credit for carbon displacement in the largely fossil fuel electricity system - if the electricity grid comprised non fossil carbon sources (hydro, nuclear, biopower and wind) the credit would not exist.

This note derives only 3 fairly easy to visualize metrics at the WTT stage from published and peer reviewed reports/ papers for comparing renewable fuels and fossil alternatives: the R-value ((fossil inputs))$^{-1}$, the total energy input(TEI), and the GWP in carbon and CO_2 equivalent masses per unit of total energy input to the tank.

Methodology:

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The R value is a simple ratio of 1 unit of output energy - typically 1 MJ of fuel (lower heating value) to all of the fractional fossil energy inputs in the chain from growing a crop (or drilling for oil or gas) through to the finished fuel going into the vehicle tank. Thus in the case of biomass to fuel the WTT chain includes the fractional energy (i.e. referenced to the output energy unit) of each of the stages:

Agricultural/Silvicultural inputs
- field preparation
- seed production
- fertilizer
- harvesting

Raw material transportation
Process chemical input
Biofuel output
Biofuel distribution
Coproduct values (obtained by system expansion)
- CHP (exported)
- Animal feed

Effluent treatment

While some of these are inputs, others such as coproducts are outputs and can be used with appropriate application of the ISO rules to offset the inputs.

Wyman et al used the R-value to derive an energy balance of about R=5 for lignocellulosic conversion to ethanol by SSF using energy crops such as switchgrass. [1991].

The TEI (total energy input) includes both the fossil and the renewable energy inputs needed to produce one unit of fuel in the WTT analysis.

Finally the issue of carbon displacement per unit of final fuel energy is based on the global warming potential the carbon dioxide emissions and the CO_2 equivalent of the greenhouse gases N_2O, CH_4 using the atmospheric lifetimes and GWP factors from the IPCC.

Analysis: Several recent studies were utilized to evaluate the performance. Three of the studies included the current starch (corn or wheat) to ethanol pathway. One study included the perfomance of a syn-fuels option, namely shut in natural gas about 4000 km distant to the final fuel market. The natural gas is used to produce FTL(Fischer Tropsch Liquids) with one variant including carbon capture and sequestration (CCS).

Two of the studies apply the ISO methodology quite rigorously and this creates some differences by comparison with the remaining studies.

Results:

System	Ref	R-value	TEI	WTT CO2	WTW CO2
RFG - Farrell			1.19		94.00
COG1 PISI 2010 Reg Gasoline			1.14		76.90
GRSD2 DICI 2010			1.68	36.75	57.80
NNA NG to FT Naphtha - Wang			1.8	38.40	60
GRSDC2C DICI 2010 CCS			1.76	16.80	48.18
Corn - Farrel et al		1.27	2.80	81.00	
Corn to EtOH - Wang		1.12	2.8	7.30	8.1
WTET1a PISI 2010 EtOH wheat		1.13	2.78	-7.02	21.59
CC		6.45	1.84	17.21	
CC50		8.02	1.89	14.65	
CwC70		8.04	1.91	-3.35	
Lignocellulosic Crop - Lynd et al		5.90	2.24	13.55	
Lignocellulosic Crop - Farrel et al		8.38	2.20	11.00	
WWET1 PISI 2010 Wood Farm		3.65	2.95	-25.04	7.68
Corn Stover - Sheehan		8.42	1.87	-70.00	
Cellulosic 90% Wang		5.22	2.8	-64.00	13.13

Fossil Fuels: The gasoline reference case is taken from JEI - Case COG1 and Farrell. Absent any renewable energy input the R-value is by definition Unity. The Total Energy Input per unit of output is about 15 - 20 % greater than the fuel energy due to the efficiencies of refinery conversion and transportation costs. The CO_2 emission is typical at about 80g MJ^{-1} of fuel such as gasoline (note the typical vehicle modelled uses about 3.6 MJ km^{-1}). For the first two entries in the table the carbon dioxide emissions are much as expected.

The natural gas to liquids case GRSD2, and Wang has a higher TEI due to the lower efficiency of conversion in the FTL process relative to refining crude oil and the long transportation distance. In the cases described the starting fuel is Methane with a combustion value of only 65g CO_2 MJ^{-1}, so the final impact is a little bit less than regular gasoline with respect The effect of carbon capture and sequestation i.e. GRSD2 with CCS (GRSDC2C) is able to reduce the carbon dioxide emissions with only a small increase in the TEI. There are emissions upstream of the FTL processing plant resulting in there still being GWP gases in the case of the WTT value and of course the fuel is still fossil carbon based in the vehicle, though the WTW value is lower than regular gasoline.

Starch Crops: The R-value in 3 of the four cases is in the expected range of $1.0 < \text{R-value} < 2.0$; however, Kim and Dale applied a very rigorous ISO methodology and utilized advanced processes involving dry milling with corn oil recovery, and the production of corn gluten meal and corn gluten animal feed. Their R-value is high for the continuous corn crop case (CC).

The offset energy in their case also reduces the TEI values well below the traditional analysis value of about 2.8. The Farrell meta analysis assumed that lignite coal would be the fuel for the process plant and the carbon dioxide emissions here are the highest of all.

Kim and Dale also examined combined starch and lignocellulosic plants. Their two variants are one in which 50 percent of the corn stover is removed along with the corn kernels (CC50), and the final one is a case in which 70 percent of the stover is removed, and to offset potential soil erosion losses, winter wheat is planted as a green cover crop (CwC70). This cover crop is not harvested and not only reduces erosion but also increases the soil carbon. In these cases for only marginal increases in agricultural inputs, the final ethanol yield is increased by a significant factor and the lignin component of the fuel is used to generate electricity at >2 times the efficiency of the NREL process model thus offsetting a larger amount of fossil fuel electricity generation than the NREL case. The R-value increases, and the carbon dioxide equivalent emissions are reduced to the point that in the 40 year cycle of CwC70 that was simulated the system sequestered carbon (the capture part was the normal photosynthetic activity, the sequestration is in the soil). An additional reduction in GWP arises from a reduction in N_2O production due to less fertilizer use per unit of output.

Lignocellulosic crops: The R-value is significant with a range of 3.65 - 8.38 which brackets the original 1991 value of 5.9 derived by Lynd and co-workers. The TEI however is quite high (with the exception of Kim and Dale) with values between 2 and 3 which is even greater than the value of natural gas derived FTL with CCS. The GWP performance is generally better than the oil case with a number of negative values. These arise primarily from increased electricity offsets in the LCA along with increases in soil carbon - in the case of WWET1 a short rotation woody crop planted on agricultural land previously planted to row crops such as corn.

Conclusions

While the cited studies are not all equivalent in quality with respect to their LCA, and each uses different process assumptions, and system boundaries - there is a consensus that the ratio of output energy to fossil fuel inputs R-value is about 5 for lignocellulosic crop conversion to ethanol.

Unlike the highly controversial corn to ethanol history - there is no argument in the literature that there is no benefit from using lignocellulosic feedstocks.

Depending on the LCA system boundaries and the correct application of system expansion to allow for the non-energy co-products the GWP per MJ at the WTT stage is either negative or close to zero. In this area the biomass system has a better performance than fossil systems with carbon capture and sequestration (CCS). In part this is because there are GWP emissions upstream of the processing plants that cannot be captured (e.g. exploration, mining, coal oxidation, methane leaks etc).

Never the less the total energy input (TEI) relative to the energy in the transport fuel is rather high with a value of about 2. Improvements in this would result in much lower impacts of large scale biomass to fuel production in terms of land use, biodiversity, and landscape-social criteria.

Attention to the opportunities to offset fossil carbon electricity and heat generation along with agricultural and silvicultural practice that sequesters carbon in soils can result in carbon based fuels in vehicles that have negative GWP on a WTT basis. In this respect they can achieve similar WTW carbon dioxide equivalent emissions as hydrogen fueled vehicles over the entire WTW cycle of < 50 g CO_2 km^{-1} . The carbon based sources of hydrogen with CCS are generally > 50 g CO_2 per 100 km. Only nuclear, hydro and wind powered electrolysis to hydrogen fuel can achieve lower values of about 10 g CO_2 km^{-1}.

Annex III:
Agencies at Work

The International Energy Agency (IEA) is a policy advisor for its 26 member countries ensuring reliable, clean and affordable energy supplies. The IEA was originally founded during the oil crises of 1973-1974 to coordinate action during oil emergencies but its role has diversified and now focuses on market reform, climate change, technology and gloabla outreach focusing on the major producing and consuming countires such as OPEC coutries, China, Russian and India (http://www.iea.org/Textbase/about/index.asp).

The Energy Information Administration (EIA) manages the official energy statistics for the U.S. government. The goal of the EIA is to provide policy independent data, analysis, forecast and efficient markets. The EIA aids in the publics understanding of energy and its interaction with the both the environment and the economy (http://www.eia.doe.gov/neic/aboutEIA/aboutus.html).

BIOCAP focuses on capturing Canada's "Green Advantage" through networks of research partnerships with other institutions with aim to create a sustainable bioeconomy BIOCAP identifies solutions and strategies to address, sustainable renewable energy, climate change and rural economic development. By providing both scientific insight and technology BIOCAP has the ability to meet environmental and energy goals. (http://www.biocap.ca/)

The Energy Foundation has a geographic focus on the United States and China. The foundation acts primarily as a grant maker providing funding to agents striving to solve energy problems. The goal is to advance efficiency and new technology (http://www.ef.org/home.cfm).

The National Commission on Energy Policy is made up of 20 of the United States leading energy experts representing multiple aspects of society including: government, industry, academia, consumers and environmental protection. The Commission released an energy Statement in 2004 which aims to strengthen the American economy, increase national security, and protect both the environment and public health. (http://www.energycommission.org/site/page.php?index)

World Meetings

The 2006 World Biofuels Symposium (WBS) a four day conference held in Beijing from September 12-15 with upwards of 225 participants (Biodiesel Mag). The meeting focused on bringing together key stakeholders in the Chinese biofuel industry, exchange of valuable technology, discuss industry policy and marketing around the world and develop commercial partnerships. http://www.worldbiofuelssymposium.com/

United Nations Conference on Trade and Development was held in Geneva February 7-9 2005. Renewable energy and biofuels were an important issue discussed. In particular Brazils advanced ethanol industry was used as an example of sustainable fuel production at a relatively low cost.

Biofuels Finance and Investment World 2006 November 28-30 2006 in London England. It was the first congress to focus on the value chain evolving around the new Biofuels economy. Examined where real investment opportunities are in biofuels and the best way to gain exposure. http://www.terrapinn.com/2006/biofuelsUK/

Developments

Role of Genomics:

Genome Canada is researching the genetic makeup of organic material that produces biofuels to produce superior genotypes with higher outputs and greater stress tolerance. Large forests and agricultural land combined with research excellence puts Canada in apposition to be a world leader in biofuels and it is predicted genomic approaches will make biofuels replacement possible within 10 years (Genome Canada, 2006).[47] Advanced extraction mechanisms are necessary to increase the volume of bioethanol and meet oil demands. Genomics and develop new enzymes and processes to breakdown carbon backbones into usable sugars. Genomics can also play a large role in plant seed oils. Canadian oilseed rape (canola) is the third largest oil seed crop with 10 million acres produced and a six billion dollar annual contribution to Canadian economy. Geonomic research has potential to develop oilseeds with and increased oil content and enriched in useful fatty acids.

Specifically genetics may be a viable method to improve efficiency in cellulosic biofuel. To improve production and efficiency the US Department of Energy (DOE) has provided Genecor International received funding from and they in turn have developed genetically modified enzymes that react synergistically converting cellulose into glucose.[48]

Canadian Renewable Biofuel Strategy

July of 2006 the Canadian Renewable Fuels Association unveiled a plan to enforce the federal government's commitment to 5% renewable content in Canadian gasoline. The plan focuses not only on creating a market for renewable fuels but increasing production and becoming competitive on the world market. Policies recommended by the Canadian renewable fuel strategy are the creation of tax credits for the production of ethanol and biodiesel in replacement of the excise tax exemption presently in existence and the creation of programs for farmer equity investment in renewable fuels, supporting technology and production facilities.[49]

Country Profiles:

Brazil

With the largest population in Latin America and the 5th largest population in the world, Brazil is the largest energy consumer in Latin America and is leading the way with biofuels. Brazil is responsible for over half of global biofuel trade.[50]

Brazil has a progressive history in regards to ethanol use. In 1925 there were ethanol fuelled vehicles and in 1970 there were the first commercial ethanol fuelled vehicle. In 1975 the Brazilian government launched the National Alcohol Program which focuses on increasing the anhydro- alcohol mixture in gasoline and in addition launched hydrated alcohol fuelled cars. Presently there are 15.5 million gasoline fuelled vehicles on the road and 2 million hydrated ethanol fuel vehicles. Since July of 2003 the alcohol- gasoline mixture was set to 25%. In Brazil ethanol is made from sugar and ethanol is 20% of the transport fuel market in the country.[51]

The World Bank estimates Brazil can make ethanol for 1 dollar/ gallon but high import tariffs are in place increasing the cost on the world market.[52]

Canada

Canada is a net exporter of energy selling most of its energy to the United States. The Ethanol Expansion Program (EEP) was initiated by the Canadian government in August of 2003 to assist in lessening the impact of climate change.[53] EEP provides capital support for ethanol plant construction as well as upgrades. In addition, the Canadian Government has committed to 5% renewable content in all transportation fuel by 2010.[54] 118 million dollars has been allocated to federal tax exemption of $0.10 per litre as well as development, research and raising consumer awareness.[55]

China

The Chinese biofuel industry is heavily regulated by the government. Biofules are expected to meet 15% of total energy needs by 2020 (FAS). Nine of China's province are testing 10% blends with plans to offer it country wide (worldbiofuels symposium) Corn inputs account for 90% of the feedstock fuelling ethanol production and ethanol production uses 40% of the corn in China which has potential to affect the feed industry (FAS). Alternatives are being developed by the US owned company Sunopta with the first cellulosic ethanol plant which opened in the South and can produce ethanol from almost any organic material.[56] Cassava is presently the main input.

China is one of the largest diesel users in the world but although China is making progress with ethanol, biodiesel has been slow to advance due to a lack of readily available inputs. In 2004 China produced 60,000 tonnes of biodisel which is less than 1% of the diesel produced by the country.[57] China is the largest global importer of vegetable oil and imports all major edible vegetable oils which are an effective source for biodiesel.

80% of the current biodiesel being produced in China is from recycled restaurant waste oil.[58] To combat input shortages China must set up funds to encourage vegetable oil production.

Europe

Europe has been a leader in the biofuel world. In France there is national B5 biodiesel mandate. The success of biodiesel in Europe is in part because of advanced infrastructure and cooperation the government, farmers unions, and refinery and distribution companies creating a well organized and centralized venture.

Germany produces 80% of all biodiesel in Europe in 2005.

United States

The United States is experiencing growth in biofuels based on various factors. Increases in crude oil prices have sparked a search for alternatives. An increase in domestic soy bean production combined with a decreasing amount of oil and animal fat in the human diet as well as a competitive vegetable market has all led to a growth in biodiesel in the United States.[59] In addition the federal excise tax credit combined with state incentives and the support of automobile companies must also be credited. It is predicted the US will be able to produce 1.6 billion gallons of biodiesel/ year by 2008.[60] In addition the U.S. department of Energy estimates 10-14 billion gallons of ethanol will be produced annually by 2030; this is equivalent to 30% of worldwide ethanol production, but will still meet only 10% of US domestic gasoline demands.[61]

Despite the projected growth in biofuels the new EIA Outlook predicts that oil, coal and natural gas are expected to provide the same 86% of the total US, primary energy supply in 2030 as was provided in 2005.[62] Presently 98% of the U.S. transport sector runs on petroleum.

Annex IV:
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