What is the role for biorefineries? Part 1 – world energy, greenhouse gases and biorefineries

This paper, by GEOFF COVEY¹ and STEPHEN GRIST² was presented at the 62nd Appita Annual Conference and Exhibition, Rotorua, April 2008.

ABSTRACT

In recent years there has been considerable interest in the concept of biorefineries – factories that will use biomass as a feedstock to produce a range of chemicals similar to those currently produced from crude oil in an oil refinery. One point of debate is whether the development of biorefineries will be an opportunity or a threat to the pulp and paper industry. It is the view of the present authors that much of the current discussion is based on an incorrect understanding of the issues and of the scale of the industry. This paper will address the markets which the first few generations of biorefineries are likely to serve. Over a longer period of time the situation is likely to change.

Currently products are made from oil because this is the cheapest route. The pulp industry produces about as much by-product lignin as it does chemical pulp. This is available as a very low cost raw material (fuel replacement value at most) and yet the quantity of lignin that is converted into profitable products is minute. The difficulty is that lignin is not an ideal feedstock, and is unlikely to become one until crude oil prices are much higher than at present.

Over half of the oil produced is used to make transport fuels. In the near future, these are likely to be partly replaced with ethanol or other liquid chemicals produced from sugars and poly-saccharides. The technology used here is much more familiar to the pulp and alcoholic beverage industries than to the oil industry, and there is scope for the pulp industry to grow by serving this market.

The next largest use for oil is probably as a fuel for stationary units. At the present state of development of synthetic fuels, it is much more economic to fire such units with solid biomass (or in some cases to use gasified biomass) than to go to the expense and complexity of producing synthetic liquid fuels.

Only about 15% of oil ends up as ‘other products’ – including bitumen, petrochemicals, polymers, fibres and solvents. As oil becomes scarcer and more expensive, we can expect bio-mass to replace it for some of the ‘easier’ applications (such as ethanol). The remaining oil produced will be used to produce these other chemicals – but in competition with organics derived from biomass. We can expect there to be a gradual shift with the products which can be most easily (and cheaply) be made from biomass moving to this route first.

Thus any shift to bio-refining could represent an opportunity rather than a threat to the pulp and paper industry – possibly through alliances with oil companies and perhaps agricultural processing companies. The challenge will be to take this opportunity.

WORLD ENERGY, GREENHOUSE GASES AND BIOREFINERIES

Undergraduate students in commerce are often introduced to the workings of the stock market by a statement of the form “All our analysis is based on the assumption that the market is rational”. This is followed by “So that destroys all the analysis at the start”. Attempting to predict the role for biorefineries/biofuels/bio-processing faces similar problems as the drivers are a mixture of economic, resource, climate, political and emotive factors – with little or no certainty of what the facts are. Despite this difficulty, this paper will attempt to describe possible needs, markets and products for future biorefineries.

In recent years there has been considerable interest in the concept of biorefineries – factories that will use biomass as a feedstock to produce a range of chemicals similar to those currently produced from crude oil in an oil refinery.

Most presentations on alternative energy tend to concentrate on rather small areas, such as one particular type of technology or feedstock, or on one reason for developing alternative energy sources. The present paper will instead attempt to discuss the magnitude of energy needs, the sectors of the energy industry that most usefully be addressed, and the practicalities of scale of operation to achieve the desired outcomes.

One point of concern for the pulp and paper industry is whether the development of biorefineries will be an opportunity or a threat to it.

It is the view of the present authors that much of the current discussion is based on an incorrect understanding of the issues and of the scale of any significant bio-refining industry. This paper will address the markets that the first few generations of biorefineries are likely to serve. Over a longer period of time the situation is likely to change but in ways that are difficult to predict at this time.

One factor that is critical in understanding the probable development of biorefineries is the purpose for which the products might be used. There are many possibilities here that might include:

• Reducing greenhouse gases
• Countering the effects of declining fossil fuel availability/increasing price
• Economic benefit
• Replacement of natural gas
• Better utilisation of agricultural and other biological waste

The specific drivers for the change to biofuels will do much to determine the nature and timing of biorefineries (or even whether they are needed).

Current situation

According to the Energy Information Administration (EIA) world energy consumption in 2004 was about 475 EJ (1). The primary sources of this energy were distributed as shown in Table 1.

It will immediately be seen that fossil fuels accounted for over 85% of world energy use. Further, of the 7% of energy that comes from renewable sources, by far the greatest component is from hydroelectricity. Data from the US Geological Survey (2) presented in Table 2 suggest that the dependence on fossil fuels increased slightly between 1998 and 2004.
January 2009

wind power and solar energy.

The advantage is that to become significant, renewable energy producers have a capacity to produce some 19% of Denmark’s electricity demand. However, it has not been possible to shut any of the conventional power stations – because the actual amount of energy generated at any time is dependent on the cube of the wind velocity (which cannot be predicted far in advance) and there is no way of storing surplus energy generated when wind speeds are high (3).

In general, actual power generation from wind turbines averages only 15-25% of the rated capacity, and in some cases much of this power is generated during low demand periods and cannot be utilised effectively (4-6). However, some installations have a utilisation factor of over 40% (7).

The difficulties of large scale solar power are demonstrated by a proposal put forward recently by PrimeStar Solar (6). They proposed to supply 69% of the 2050 USA electricity demand (equal to 35% of its total energy demand) by construction of massive photovoltaic and concentrated solar power generators coupled with energy storage based on subterranean compressed air reservoirs.

The plan calls for massive installations of solar collectors in south-west USA plus similarly large scale ancillaries:

- 80,000 sq km of cadmium telluride photovoltaic cells (current total world installations 25 sq km)
- 40,000 sq km of concentrated solar power collectors (parabolic mirrors focussing onto tubes filled with brine which generate steam to drive turbines) (current total world installations 25 sq km)
- 10^9 m^3 of compressed air storage, plus associated compressors and power turbines (no existing installations)
- 200,000 – 1,000,000 km of new high voltage DC grid to transmit electricity from point of generation to point of consumption (currently about 1000 km exist).

It is suggested that the installations be built in desert areas on publicly owned land. It is claimed that there should not be environmental problems. The area selected would be regarded by many as ‘wilderness’ and it seems improbable to the present authors that such large areas of land (19% of the ‘suitable’ land in USA) could be converted to industrial use without considerable objections.

The land selected for the proposal receives high solar radiation (about 8kWh/m^2/day). However, energy is only generated for about 8 h/d, therefore some form of storage is required. The proposal calls for the electricity to be used to mechanically compress air to 75 bar (not a highly efficient process and requiring compressors of enormous capacity) and to store this gas in underground cavities. Energy is then recovered by using this compressed gas in gas turbines fuelled with natural gas. It is claimed that this saves about 60% of the fuel that would otherwise be required to run such turbines.

The land to be used is arid and has high air temperatures, but to run steam turbines (especially low pressure turbines as proposed for the concentrated solar power collectors) requires a condensing sink. Although such a sink can be provided from atmospheric air, it is an expensive and inefficient method.

In addition to these problems, there is the issue of the materials needed to make the solar collectors. The plan calls for about 2-3% of the facilities to be built by 2020, and the rest to be built by 2050. This creates considerable issues relating to the rate of supply of construction materials:

- Assuming the facility is to be built over a 30 year period.
- For the concentrated solar power, if stainless steel mirrors 1mm thick are used this will require about 10.8 million t of

<table>
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<tr>
<th>Table 1</th>
<th>World consumption of primary energy in 2004</th>
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<tr>
<td></td>
<td>EJ/a</td>
</tr>
<tr>
<td>Liquids</td>
<td>179</td>
</tr>
<tr>
<td>Coal</td>
<td>127</td>
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<tr>
<td>Natural gas</td>
<td>111</td>
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<tr>
<td>Renewables</td>
<td>32</td>
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<tr>
<td>Nuclear</td>
<td>26</td>
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<td>Total</td>
<td>475</td>
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<th>Table 2</th>
<th>World consumption of primary energy in 1998</th>
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<tr>
<td></td>
<td>EJ/a</td>
</tr>
<tr>
<td>Oil</td>
<td>160.4</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>90.2</td>
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<tr>
<td>Coal</td>
<td>93.5</td>
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<tr>
<td>Nuclear</td>
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<tr>
<td>Hydroelectric</td>
<td>28.1</td>
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<tr>
<td>Biomass and other#</td>
<td>2.6</td>
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<tr>
<td>Total</td>
<td>400.6</td>
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# Includes biomass, geothermal, wind and solar

These figures show that renewable energy other than hydroelectric power accounted for only 0.7% of world energy production, and this includes biomass for domestic and industrial use in third world countries.

The EIA projections are that by 2030, renewable energy (including hydropower) will still only account for 8% of the world’s energy use.

This information shows that renewable energy will be growing form a very small base and that there will need to be enormous changes in the culture of energy generation and use for it to become other than a token contributor to the world energy supply.

This low starting point could be both a disadvantage and an opportunity for renewable energy producers.

- The disadvantage is that it is such an insignificant contributor at the moment that it could easily be overtaken by other technologies, and just a small improvement in efficiency of utilisation of non-renewable energies could have a much greater effect than, say, doubling the amount of energy generated from renewable sources.

- The advantage is that to become significant, renewable energy production would have to rise to perhaps 10-50 times its current output. To achieve this level of expansion in an economic and timely manner is likely to require disregarding most of the current technology and working in new directions. Fortunately, the current energy production is so small that not expanding existing approaches will not have a significant effect. More importantly, there are alternative technologies – many based on biomass – that might meet the objectives of large-scale renewable energy in an economic manner.

Examples of the difficulties of applying current renewable energy technology to large scale applications can be found in wind power and solar energy.

Denmark has installed some 6000 wind turbines that together have a capacity to produce some 19% of Denmark’s electricity demand. However, it has not been possible to shut any of the conventional power stations – because the actual amount of energy generated at any time is dependent on the cube of the wind velocity (which cannot be predicted far in advance) and there is no way of storing surplus energy generated when wind speeds are high (3).

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- Assuming the facility is to be built over a 30 year period.
- For the concentrated solar power, if stainless steel mirrors 1mm thick are used this will require about 10.8 million t of
stainless steel per year – this represents 40-50% of the present **worldwide** production of stainless steel (25 million t/a).

- According to Desai et al (10) the thickness of the cadmium telluride in a photovoltaic cell is 3-10 µm. Karpov et al (11) give 1.5-7 µm. For the present purpose it is assumed that a thickness of 5 µm will be used. This implies that to make the photovoltaic cells in the PrimeStar Solar plan, a total of 1.1 million t of cadmium and 1.28 million t of tellurium would be required.

- Current world production of cadmium is about 21,000 t/a (12). Therefore the amount of cadmium required for this one project for the thirty years of its duration would be about twice the present annual world production.

- The world annual production of tellurium is about 180t (13,14) so each year this project would require a quantity of tellurium equal to about 240 times the amount currently produced. Furthermore, there is little prospect for increasing tellurium production significantly as tellurium is one of the rarest elements in the earth’s crust (15-17) and it is rarely found at high concentrations (estimates give its total abundance as a high of similar to platinum, down to about 1/40 of the abundance of platinum).

Clearly this proposal is impractical or even impossible. Further, despite the magnitude of the proposal, it is only covering part of the power supply of one country (albeit the world’s largest energy user). Currently the USA uses about 23% of the world’s energy, but this proportion is falling. It is expected to be down to less than 19% by 2030 (1). Longer term projections are very unreliable, but by 2050, if current trends continue, the USA will be responsible for no more than 15% of the world energy consumption.

This means that to have the same impact globally as PrimeStar Solar envisage for the USA would require seven times the resources of land and material described above.

On first impressions, solar electricity is an attractive proposition. Even at an average daily solar radiation of 4.5 kWh/m²/d (most of the USA and similar temperate lands will receive at least this) and a conversion efficiency of 14%, the rate of fuel generation is about 15 times what can be achieved with most types of biomass over an equivalent area.

The problem is that, as shown above, present methods of using solar energy will be impractical on a large scale unless there is an enormous change in our industrial infrastructure to produce greatly increased quantities of special materials. Such changes are conceivable in the times scale of 30-50 years, but as noted above currently about 83% of energy is derived from fossil fuel, and if there were an objective to counter greenhouse emissions a significant portion of this would need to be replaced by renewable sources.

From the data above, world fossil fuel consumption is about 420 EJ/a. Fuel value of biomass is about 18 GJ/dry t (10).

Therefore, annual dry biomass to replace all fossil fuel 23 x 10⁹ t.

Assume an average growth rate of 20 t/ha/year (this is a fairly conservative figure (19)). Total land area required to be dedicated to fuel biomass production 11 million km².

The question then arises of whether there is enough land available for such plantations.

There are various published surveys of global land use. One of the more recent is the MODIS Project (20). However, the results of this work are not presented in a manner suitable for the present purpose, so the older, but still widely used data of Matthews has been used here (21). Land coverage (excluding ice covered areas) in 1983 are shown in Table 3.

The total biomass produced each year has been estimated as 1.5-2.2 x 10¹³ dry t (18). This means that to replace all fossil fuels with biomass would require about 10-15% of the annual production (this is in agreement with Klass (22) who estimates 10%). It will also be seen that the area corresponds to about 10% of the global landmass (excluding ice, tundra and desert). Furthermore, the land area required is less than that currently under cultivation – even without considering grasslands used for grazing of domestic animals.

Of the areas listed in the table, the land under cultivation will still be required to grow food; similarly much of the grassland is already used for grazing of domestic animals (often in association with wild animals). The tundra and desert is obviously unsuitable for cultivation. Large-scale irrigation might make some desert areas available for cultivation, but this would itself require significant energy consumption.

This leaves nearly 50% of the world’s land surface in the form of various forms of forest, woodland and shrub-land, of which only a small proportion is currently used as a productive source. At least a portion of this area is potentially available for production of fuel crops – but clearly there are

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<tr>
<td><strong>Tropical rainforest</strong></td>
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<td><strong>Other rainforest</strong></td>
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<td><strong>Woodland</strong></td>
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<td><strong>Shrubland</strong></td>
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<td><strong>Grassland</strong></td>
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<td><strong>Tundra</strong></td>
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<td><strong>Desert</strong></td>
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<td><strong>Cultivation</strong></td>
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<td><strong>TOTAL</strong></td>
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conservation/political/priority issues that will determine how much of this land could be so used.

It is most improbable that serious consideration would be given to working on this scale, but as will be discussed in Part Two of this paper, it would be quite possible to use biomass to replace a very significant portion of current fossil fuel consumption. Also, as already noted, this could largely be done by harvesting and replanting existing vegetation species, rather than by replacing the natural cover with other species as is normally the case with cultivation, commercial forestry and even with improvement of natural pasture.

It is important to note that if climate change is significant, there will be substantial changes in land availability. Overall rainfall can be expected to increase, but there is predicted to be significant local variations in this. Rising sea levels will result in loss of some land (much of it presently cultivated). Against this, warming will result in large areas that are currently too cold for significant vegetation becoming productive – some of this land is at high elevations, but much of it is in Canada, Russia and Greenland (the last of these got its name because in the last warm period its coastal regions were widely used for grazing). Further, warming of a few degrees and increased carbon dioxide (and rainfall) can be expected to lead to increased vegetative growth in most regions – this is truly a greenhouse effect!

Figure 1 presents FAO data (23) that show how forest plantation area has changed since 1990. In 2005 there were about 140 million ha (1.4 million km²) of plantations – less than one-tenth of the area under cultivation, and only about one-fiftieth of the area covered by natural forest, woodlands and shrubland.

In summary, there is land available for biofuels production without encroaching on existing crop-land, but there will be non-technical issues that determine how much land is made available for this purpose.

In addition there is the issue of the ‘useful’ yield of biomass from land. The analysis presented above assumes that essentially all of the biomass from a ‘farmed’ area is used as fuel in some form (even is some of it is burned for thermal electricity generation). However, some proposals (and actual facilities) for biofuels production convert only a small part of the biomass to the most important product - liquid fuels. Well known examples are ethanol from grain and bio-diesel from seed oils. The effective yields from such crops are very low, and in many cases more energy is consumed in growing, harvesting and manufacturing than is produced (19,24-27). This problem has now been recognised, and the US Department of Environment has recently announced funding for three projects for converting cellulose to ethanol (28).

At the other extreme of useful yield from biomass is the growth of algae for fuel. Algae is a very efficient photosynthesiser and up to 50% of the biomass it produces is fats, which are good starting materials for bio-diesel and other petrochemical substitutes. According to Hodge (29), around 110 t/ha year of oil can be produced by algae, plus a similar amount of other biomass. This can be compared with around 1 t oil/ha a from canola and perhaps 48 t/ha a of total biomass from eucalyptus (30).

Obviously, this approach is very attractive in terms of land area, but there may be some issues related to water use etc, and considerable new technology would be required for the large scale commercial growing of algae. Also, the areas to grow algae would probably be greatly altered from their natural state (a problem that can be avoided with fuel forests). However the potential advantages are such that several companies including Royal Dutch Shell, Green Fuel Technologies, Chevron and ARBe are actively involved in its development (31,32).

If this route is successful it will not present any obvious opportunities for forest-based industries. Instead it will compete with them as a source of biofuels.
Australasian perspective

Australia has plentiful cheap coal and natural gas and a moderate supply of oil. This is reflected in current energy use as shown in Table 4 (derived from data from ABARE (33)).

The method of presentation of the information from which Table 4 is derived is rather different from that used in most other countries, and a completely different system is used for future projections. This makes comparing past use and future predictions difficult, but ABARE forecast that coal oil and gas will still account for 94% of primary energy in Australia in 2029-30.

Renewable energy production is presented in Table 5 (again based on data from ABARE).

Again, different reporting methods are used for past and future energy. In particular, only renewable energy for producing electricity is predicted.

Despite these limitations of the data, it is seen that renewable energy in Australia is predominately derived from biomass, with hydroelectricity being the only other significant source. Despite dramatic growth in solar electricity and wind power, these are still expected to be only minor contributors to energy use in the next twenty years. It is also interesting to note that despite the relatively large use of solar hot water systems, the amount of energy that they contribute is a very small fraction of the country's total.

There is unlikely to be substantial increase in hydroelectricity generation, both because of lack of suitable new sites and for political reasons.

New Zealand's position is somewhat different. It has rather limited reserves of all types of fossil fuel but significant capacity to generate both hydro and geothermal power. Energy usage in New Zealand in 2004 is given in Table 6.

Both Australia and New Zealand have significant areas of plantation that are not fully committed. Therefore both have scope for relatively large-scale biomass based industries.

The global case for biorefineries

Counter effects of declining fossil fuel availability/increasing price. As will be discussed in Part Two, the oil reserves to production ratio remains at a fairly constant level, and scarcity is unlikely to become an issue for several decades. Despite this there are probably very good strategic reasons for researching oil from biomass processes and even in building demonstration plants, but it is unlikely that true commercial production will be necessary to counter scarcity in the foreseeable future.

Economic benefit. The present high price of oil is not entirely due to scarcity of resources, or even of production capacity, but largely to manipulation of the market by some OPEC countries by restricting production. The effect of this is to increase production from marginal wells in non-OPEC countries. This results in depletion of such reserves, so the marginal cost of recovery of non-OPEC oil rises, and it becomes easier for OPEC countries to manipulate the market (see also ref 37). The ability of producers to manipulate the market is enhanced by the rapidly increasing demand in some countries that are being industrialised (particularly India and China).

In such circumstances, it is tempting for OECD countries to develop synthetic fuel programs. However these have very long lead times and require large quantities of capital. It is then possible for the large oil producers to allow oil prices to fall just before investment commitments are made and so make the facilities unattractive to build. Once the oil prices have been depressed for a while, the momentum to build the synthetic fuel plants is lost and oil prices can be raised again.

This sequence of events has been seen in the past whenever oil form coal, shale or oil sands (also known as tar-sands) projects have come close to commitment, OPEC has increased production and lowered oil prices. However, Alberta is now producing about 1 million barrels/day of oil from oil sands, and this represents about 40% of Canada's total oil production (38,39).

However, there is no reason to assume that oil price manipulation by OPEC will not happen again to discourage biofuels projects from progressing to large-scale production.

Replacement of natural gas. At various times in the past natural gas has become scarce. There are substantial natural gas fields in non-OPEC countries, so manipulation of natural gas prices is probably more difficult than is manipulation of oil prices. It is also comparatively easy to gasify biomass to produce hydrogen (and carbon monoxide). This makes synthetic gas from biomass more attractive. However, natural gas reserves are not considered restricted now, and the development of cryogenic shipment of liquefied natural gas has ended the one-time situation where surplus gas was flared in some countries while other countries experienced a shortage.

There is certainly a potential to produce fuel gas from biomass in some regions, but this is likely to remain a niche market for some time.

Better utilisation of agricultural and other biological waste. As noted above, the global energy use corresponds to about 10-15% of the global biomass generation. This is also approximately the fraction of the vegetated land mass that is devoted to agriculture. Agriculture has developed so that the ratio of food to by-product is minimised, and uses have been found for much or most of these by-products (fodder, bedding, composting and industrial uses). So the quantity of agricultural waste that is freely available as a fuel source is small relative to total agricultural biomass generation. Clearly the available biological wastes could only meet a comparatively small portion of the world's energy needs. However, there could be substantial benefits for some conversion of such materials into fuels, for at least two reasons:

- Many countries have mandated that a certain fraction of the energy consumed must come from renewable sources. For some densely populated countries (e.g. much of Western Europe) there is limited biological waste available and limited scope for wind, solar or hydro generation. Therefore, to meet mandatory requirements the most practical approach is...
to import biomass to burn in power stations. This has resulted in importation of wood pellets and even importation of olive processing waste to UK for combustion (40, 41). This makes no economic sense and when the monetary and energy costs of transport are considered, it would be much wiser to burn the waste for energy close to its point of generation and then to sell a credit for the fossil fuel saved (a literal example of thinking globally and acting locally) but this would not meet the requirement of the legislation. However, it does give organisations with biological waste an opportunity to either sell it in its original form, or (better) to refine it to a more convenient and useful form.

• Although oil prices can be manipulated to prevent large-scale synthetic fuel production, this is not effective against small producers. Synthetic fuel equivalent to (say) 1-5% of the world market is not sufficient to restore the supply-demand balance and so does not represent a threat to the price fixers. However, the producers can sell at market price and hence projects that would not otherwise be attractive can become very profitable. In the present circumstances, the synthetic fuel producers can also benefit from incentives for renewable energy production, and the existence of mandatory renewable energy targets might even protect the bio-refiners during periods of oil price reduction.

Reduce greenhouse gases. This paper will not consider the magnitude or the cause of climate change. The Kyoto protocol and its proposed replacement international agreement call for reductions in carbon dioxide emissions. Much debate over the extent of emission reductions will continue over the next few decades and will probably result in changing legislation, subsidies or tax breaks to renewable energy producers and penalties for large carbon dioxide emitters. Therefore any investments in biorefineries will be taken in this climate.

Broadly, there are three approaches that can be taken to respond to this situation: tokenism, intermediate, or very large scale operation.

• Tokenism is a reasonable description of most of the present renewable energy projects (other than hydro-power). Such projects include domestic wind generators and most photovoltaic systems (other than those sited remote from existing power lines – and these are not done for carbon dioxide reduction). Probably the most extreme ‘token’ projects are those associated with such things as converting used cooking oil into synthetic diesel. The amount of diesel made this way cannot be significant, and the energy used in collecting the used oil and refining it probably represents a significant proportion of the energy recovered.

Another absurd outcome is the action taken by various European companies to meet mandatory renewable energy contributions by importing agricultural waste to supplement conventional solid fuel firing as described above.

There are many opportunities for such projects in the pulp and paper industry. Combustion or pyrolysis of most organic wastes can generate fuel or electricity that can be sold onto the grid as renewable energy, and then fossil fuel derived power can be purchased at a lower cost.

• Many of the projects associated with the pulp, paper and forestry industries go beyond tokenism in that they are genuine net contributors to energy and carbon dioxide production and are genuinely economic (at least while oil prices are high). However, they should still be regarded as ‘intermediate’, because, even with the contributions from the entire industry accumulated, they have only a small effect on greenhouse gas emissions.

• Very large-scale projects are really large enough that together they can significantly reduce fossil fuel consumption and carbon dioxide emissions. From the information presented above, it will be apparent that such projects would need to be on a very large scale. To have a significant effect they must utilise at least as much biomass as is currently used by the entire pulp and paper industry. This implies enormous capital investment and clearly this is no longer a by-product of existing forest, pulp and paper operations. The most obvious beneficiaries of such projects are likely to be foresters, sugar cane growers and other large-scale agriculturalists. There will also be scope for the down-stream processors and here there can be competition – or collaboration – between the pulp producers and the oil refiners.

Part Two will discuss the markets in which biorefineries can hope to compete.

REFERENCES

(3) Clark, J. - This has been my perfect week Sunday Times (London) 13 January, 2008
(8) Zweibel, K.; Mason, J. and Pthenakis, V. – A solar grand plan Scientific American 298(1), 48 (Jan 2008)
(9) Stainless steel production forecasts for the western world The Azo Journal of Materials Online Azo.com 2 November, 2005
(18) Lim Kong Oon – Renewable energy from biomass: state of the art Seminar on Energy from Biomass, FRIM, Kepong, 2006
(19) Covey, G., Harvey, R. and Shore – The next 100 years – challenges and opportunities for the forest industries, Appita J 61(1) 17 (2008)
(20) Validation of the consistent-year v003 MODIS land cover product http://geography.bu.edu/landcover/usrguide/conistent.htm
The new grade change strategy can be synchronised with the production schedule by specifying the desired start and end of the grade change to coincide with the beginning or end of the machine reel.

REFERENCES


SUMMARY

Today’s requirements for efficient production with minimal raw material usage require stable wet end processes. The key for stability is visibility of the process through fast, accurate and reliable measurements. The measurements are required to monitor and to understand what is going on in the process and, even more importantly, to control the process. The key measurements are total and ash content in the short circulation, together with charge and key chemistry parameters.

The full benefit of the wet end measurements can be achieved through advanced controls. The latest state-of-the-art controller optimises the control actions so that all the quality variables and wet end variables are stable. This can be achieved through a multivariable control strategy. Also grade changes can be done by utilising more feedback controls, resulting more stable and faster grade changes.