The Biorefining Story: Progress in the Evolution of the Forest Products Industry to a Forest-Based Biorefining Sector

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Abstract
Continued global insecurity around oil supplies has helped keep oil prices volatile and relatively high, influencing the ongoing and significant investment in both conventional (sugar, starch, plant, and animal-oil-derived ethanol and diesel) and advanced (biomass-derived or 'drop-in' like) biofuels and chemicals. It is likely that 'pioneer' advanced biofuel plants will first use biomass residues as their initial feedstock as it is currently difficult to justify the investment in energy crops when there is no clear market for their use. It is also likely that agriculture-based advanced biofuel plants will be predisposed towards using a biochemically based process as sugar- and starch-based processes already use much of the equipment and processes that are conducive to the use of enzymes and microorganisms. In contrast, wood-based processing such as in pulp and paper manufacturing will be predisposed to using thermochemically based processes which build on already existing expertise in areas such as combustion, gasification and pyrolysis. The biorefinery concept has been proposed as a means to extract maximum value from lignocellulosic materials, with the higher value physical/chemical components used for biomaterials and chemicals and whatever is left used for bioenergy/biofuel production. The continued development of new conversion technologies has encouraged these nascent, newer biorefineries to assess a range of lignocellulosic feedstocks with the hope of producing additional value-added bioproducts and more efficient recovery of bioenergy. There are a number of complementary platforms for processing lignocellulosic feedstocks, including traditional platforms (i.e., existing pulping and starch-to-ethanol processes) as well as emerging technologies that are either biological, thermochemical or hybrid-based. However, there is as yet no clear candidate for 'best technology pathway' between the competing routes. Monitoring of larger-scale demonstration projects is one of the activities undertaken by IEA Bioenergy Task 39

to try to derive an accurate, comparative data base. Even at oil prices in excess of $100 a barrel, advanced biofuels will likely not become fully commercial for fivetoten more years without significant government support. The expertise, progress, and goals of the member countries and companies involved with IEA Bioenergy Task 39 will be used to describe progress in the biorefining area and our attempts to commercialise advanced biofuels.

Background

As oil becomes scarcer and more difficult and expensive to source and process, forestry-derived biomass is gradually shifting from being more of a sectoral resource (e.g., for products such as housing, furniture, pulp, and paper) to potentially becoming a major feedstock for the rapidly evolving ‘biorefinerysector’. Trends such as the unstable but generally increasing oil prices, global sustainability concerns including climate change and the ongoing economic malaise have all contributed to the growth in both interest and investment in what is generally termed the ‘bioeconomy’.

Oil and its derivatives have been the lifeblood of most of the world’s industrial economies since the middle of the last century.However, increasing demand for a finite resource is driving up its cost andthe environmental risk of its extraction, while all fossil fuels are known to be the primary cause of increasinggreenhouse gas (GHG) emissions. At the same time the establishedforest-based industrial sector has been going through some major upheavals with the US housing crisis greatly reducing traditional uses such as lumber for housing, while longer term trends, such as the rapid increase in digital media use,significantly reducing the market for products such as newsprint and writing paper. There is a growing realisation that the convergence of the five ‘F’s’ (fuel, food, feed, fiber,and fertiliser), will result in increasing competition for resources from nontraditional competitors. In countries such as Brazil, oil companies such as Petrobras have invested heavily in sugar-cane-to-ethanol production while at the same time becoming world leaders in deep-water oil drilling and extraction. Energy companies such as BP and Shell have invested heavily in a variety of technologies and companies, from wood pellets, through biomass-to-ethanol to algal biofuels. Chemical companies such as DuPont have acquired companies such as Danisco/Genencor, to diversify into areas traditionally associated with a food company (Danisco) whichitself had recently acquired the world’s second biggest enzyme company (Genencor). Thus, as various companies and sectors look to expand, the traditional industrial users of the world’s forests can anticipate other groups to increasingly look at whether a sustainably produced feedstock (such as a tree), which sequesters carbon from the atmosphere, might provide an alternative approach to making their traditional products of chemicals, fuels, and energy. The OPEC-generated oil crisis of the 1970s and the more recent concerns about GHG emissions have motivated significant R,D,D&D (research, development, demonstration, and deployment) investments in the bioenergy sector over the last few decades. However, there is an increasing realisation that, in the same way that the lower volume but higher value co-products such as plastics, chemicals, dyes, etc., make an oil refinery economically viable (with the bulk products of diesel/gasoline/petrol being of generally lower value), any future bioenergy sector will also require these higher value co-products (biomaterials, biochemicals, etc.) as the basis of a future biorefinery sector.

The agriculture sector is very much at the forefront of this evolution. In the ‘swinging sixties’ (1960–1969) the issue of the day was not energy but overpopulation and the world’s ability to feed all of its people. Oil was thought to be so plentiful and infinite that oil and chemical companies such as BP, ICI and Shell invested in “single-cell-protein” that was derived from the growth of microorganisms on oil derivatives such as methanol. However, primarily through what has been termed the ‘green revolution’, agriculturalproductivity per hectare has increased steadily over the last 50 years to the extent that agriculture is now the primary source of the most used renewable biofuels such as biodiesel and bioethanol! In the same way thatagriculture provides food, fuel, feed, chemicals, nutraceuticals, etc., it is increasingly likely that, as well as continuing to produce ‘traditional’ products such as lumber and pulp and paper, the forest sector will also evolve into a biorefinery mode of operation with bioenergy being one of the major complementary markets that will be developed.

Over the last couple of decades a range of biomass conversion technologies have been investigated that have used both forestry and agricultural feedstocks to try to produce fuels and chemicals. These biofuels/bioproducts can compete economically with current oil-derived products while proving to be much more desirable from an environmental and social perspective (i.e., lower carbon emissions, gains in rural employment, etc.)
In the next section we discuss the rapidly evolving bioenergy sector (and biofuels in particular), the potential for the forest sector to become a leading player, and some of the work that organisations such as IEA Bioenergy have played in trying to catalyse the development of a forest-based biorefinery.

The Current Forest Sector

As mentioned earlier, the forest sector is facing major challenges while new conversion technologies, emerging markets and increasing requirements for the sustainable production and use of materials/products are creating a strong drive for transformation in the sector. Traditional forest products such as construction and pulp andpaper represent a ‘business as usual’*modus operandi* for the forest-based sector,but they are not sufficient to ensure substantial future growth and revenues for the sector. A change is required to address these challenges and to harness the opportunities of diversifying the product range of the forest industry. This diversification can be achieved by selectively extracting further value from lignocellulosic biomass such as thermal value (bioenergy), chemical functionality (chemicals and fuels)and novel structural applicationssuch as biomaterials like nanocrystalline cellulose. Ideally, the future forestry facilities will be able to exploit a range of value categories from their biomass feedstock and, depending on market conditions, the future forest-based biorefinery sector will be able to move to the product streams that offer the highest economic as well as environmental/social values.
Of the various businesses that constitute the current forest products sector, thepulp and paper industry is best positioned to evolve into abiorefinery approach that would allow easier diversification of itsproduct streams. Most pulp mills already have in-house expertise and assets needed to enhance the fractionation of the cellulose, lignin, hemicellulose, extractives, and other components of forest biomass using a variety of approaches (e.g., Kraft lignin, dissolving pulp). The sector also has well-establishedexpertise in handling and recycling chemicals as well as dealing with waste streams and water recycling. These assets can be readily leveraged to

manufacture lignin and cellulose-derived products beyond traditional pulp and paper products into the wider biorefinery approach.

It should be noted that paper and packaging companies accounted for most forest-based revenue generated globally; the top 10 P&P companies are listed in table 1. Despite the considerable size and global reach of many of these companies, their investment in innovation and the limits to their product diversification tend to be in their traditional market areas, aiming at the production of **whiter** paper or **stronger** tissue paper, rather than making use of their expertise in sustainably producing, accessing and processing the biomass feedstock into different products and markets. Those companies thathave diversified to some extent, such asKimberly-Clark, have developedhigh-value speciality products (e.g.,laboratory and medical consumables). It should be noted that this iscurrently the company with the highest net income on a global basis (table 1).

Table 1: PricewaterhouseCoopers Top Global Forest, Paper & Packaging Industry Companies

Rank 2010	Company name	Country	Sales US $ millions	Net income (loss) US $ millions
1	International Paper	US	25,179	644
2	Kimberly-Clark	US	19,746	**1,843**
3	Svenska Cellulosa (SCA)	Sweden	15,202	773
4	Stora Enso	Finland	13,671	1,021
5	Oji Paper	Japan	13,097	284
6	Nippon Paper Group	Japan	12,502	343
7	UPM—Kymmene	Finland	11,848	745
8	Smurfit Kappa	Ireland	8,865	66
9	Mondi Group	UK	8,269	297
10	Metsalito	Finland	7,139	226

Source: PricewaterhouseCoopers, 2011

Over the last 100 years, at the same time as the forest products sector has been developing the various products that we now take for granted (kraft/mechanical/dissolving pulps, engineered wood products, etc.),the energy sector was evolving from a coal-based sector to one increasinglydependent on oil. There was also an increasing realisation that, although energy applications would continue to grow, lower volume but higher value co-products such as chemicals and plastics would increasingly become the profit centreof the‘oil refining sector’. More recently both cost (oil is getting more expensive and environmentally ‘risky’ to access and process) and environmental/social concerns have encouraged traditional coal- and oil-based sectors to consider if their currenthydrocarbon-based operations could evolve into one based more on sustainably produced carbohydrates.

The Potential, Evolving Forest Biomass Processing Sector

Over the last 50 years or so, the world’s economy has become less dependent on the resource and manufacturing industries with ‘white collar’industries such as banking, insurance, and education becoming bigger players in the 1980s through 2000. Since 2000, the growth of companies such as Apple, Google, and Facebook have also been contributing to the manufacturing sector's diminished influence. When the world's top companies are reviewed (table 2), although companies such as Toyota are still in the top 10, the fact that a retailer, Wal-Mart, is number one is quite telling. What is also apparent is that the world's increasing need for energy results in oil companies still predominating as the biggest and often most profitable companies. In contrast, the world's forest products companies might be considered to be 'middle-sized' players, with the company with the greatestrevenue in 2009, International Paper, listed as number 362 in the world in terms of revenue (table 2).

Table 2: Top global companies by revenue

Rank 2009	Company name	Country	Sales US $ millions	Net income (loss)US $ millions
1	Wal-Mart Stores	US	408,214	14,335
2	**Royal Dutch Shell**	The Netherlands	285,129	12,518
3	**Exxon Mobil**	US	284,650	19,280
4	**BP**	UK	246,138	16,578
5	Toyota Motor	Japan	204,106	2,256
7	**Sinopec**	China	187,518	5,756
10	**China National Petroleum**	China	165,496	10,272
11	**Chevron**	US	163,527	10,483
14	**Total**	France	155,887	11,741
17	**ConocoPhilips**	The Netherlands	139,515	4,858
362	International Paper	US	23,366	663

Source: CNN Money, 2011

Over the last decade or so, there is growing recognition that we need to think in human generational terms, rather than just short-term 'profitability'over thenextfinancialquarter, with nontraditionalforest-based players such as oil and chemical companies increasinglyassessing the viability of producing their traditional fossil-fuel-derived products from biomass. There have also been parallels in the way the oil- and forest-based sectors have evolved. Historically, the structural characteristics of wood result in its primary application in markets such as housing, furniture, and bridgeswith applications such as pulp and paper being developed relatively more recently (in the last 50 years or so). Similarly, oil was predominantly used for its energy/fuel applications with its potential asa chemical/polymer/plastics feedstock becoming fully realised at the same time as the processes such as kraft andthermochemical pulping were being commercialised in the 1950s and 1960s. There are also parallels when the volume and value of the products that can be derived from a forest- or oil-based feedstock are compared (figure 1). In the oil-based sector, transportation fuels (diesel/petrol/gasoline) represent the main product in terms of volume (70 percent) whileco-products and value-added materials such as plastics represent only 4 percentof the product volume.These nonfuel product categories contribute almost as much to the annual revenues of the industry as do the total fuels component(figure 3). The importance and use of wood as a structural material is reflected in both the high volume and value ofsolid-wood products (plywood, OSB, engineered wood, lumber, etc.) as well as pulp, paper and packaging products. In contrast, the current chemical and energy products/uses represent a lower volume and an even lowervalue forest product.However, the recent high value of dissolving pulp (although somewhat stabilised in recent months) has indicated how valuable a true forest-based biorefinery might be when pulp is valued more as a 'biomaterial' or 'chemical/polymer' feedstock rather than just a source of paper products. Although forest products companies such as Borregaard, Neucel, Tembec and Lenzinghave shown how a biorefinery can operate and evolve into marketing a range of speciality pulps, chemicals and fuels, a strategy that is being increasing pursued by forest companies is to form partnerships with companies that better understand the markets into which the bioenergy/biomaterials can be sold.Examples of such bioenergy collaborationsinclude Catchlight, which is the Chevron-Weyerhaeuser joint venture in the US and the Stora Enso-Neste oil collaboration in Scandinavia.Both collaborations are focussed on developing the biofuels/bioenergy area with the forest-based company better understanding the logistics, costsand complexity of sourcing, collecting and processing the biomass, and the energy company better understanding the markets and likely value that can be extracted from the renewably sourced carbon (table 3).

Table 3: Examples of collaborations between the petroleum and forest products industries

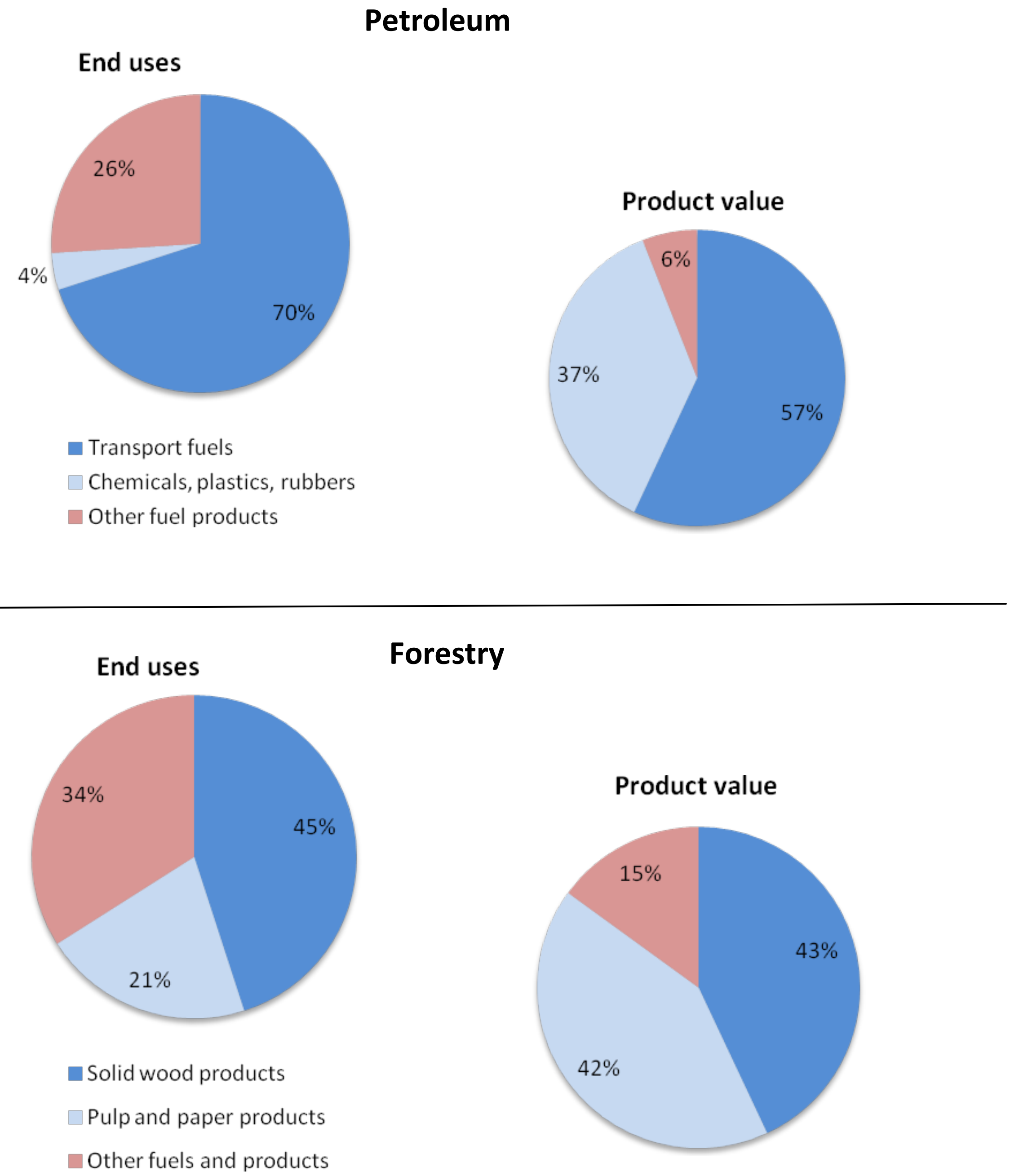
Oil refiner company ($m revenue in 2010)	Fibre expert company ($m revenue in 2010)	Country	Type of collabouration	Year initiated
Neste Oil (11,890)	Stora Enso (13,671)	Finland	50/50 investment on a demonstration facility in Varkaus	2009
Chevron (198,198)	Weyerhaeuser (6,552)	USA	50/50 Joint Venture named "Catchlight Energy"	2008

Source: Company Websites and annual reports.

As well as forming partnerships with traditional forest products companies, oil and chemical companies are also strategic investors in technology providers such as Amyris (Total), Codexis and Iogen (Shell) as well as purchasing companies (BP's purchase of Verenium) and investing in longer term R&D centre's (BP's investment in the Energy Biosciences Institute). These types of substantial short-andlong-term investments indicate that, while it will likely take a while, 'Big Oil'is assessing the potential of moving from depletingstocks of hydrocarbons to a renewable and hopefully sustainable carbohydrate feedstock!

From a sustainability point of view, the oil refiners find themselves under continuous pressure to develop "greener" fuel blends (e.g., compulsory ethanol blending in the US) and "greener" (biodegradable and/or renewable) materials. In this context, the scope for the petroleum and forestry industries to collabourate is projected to increase.

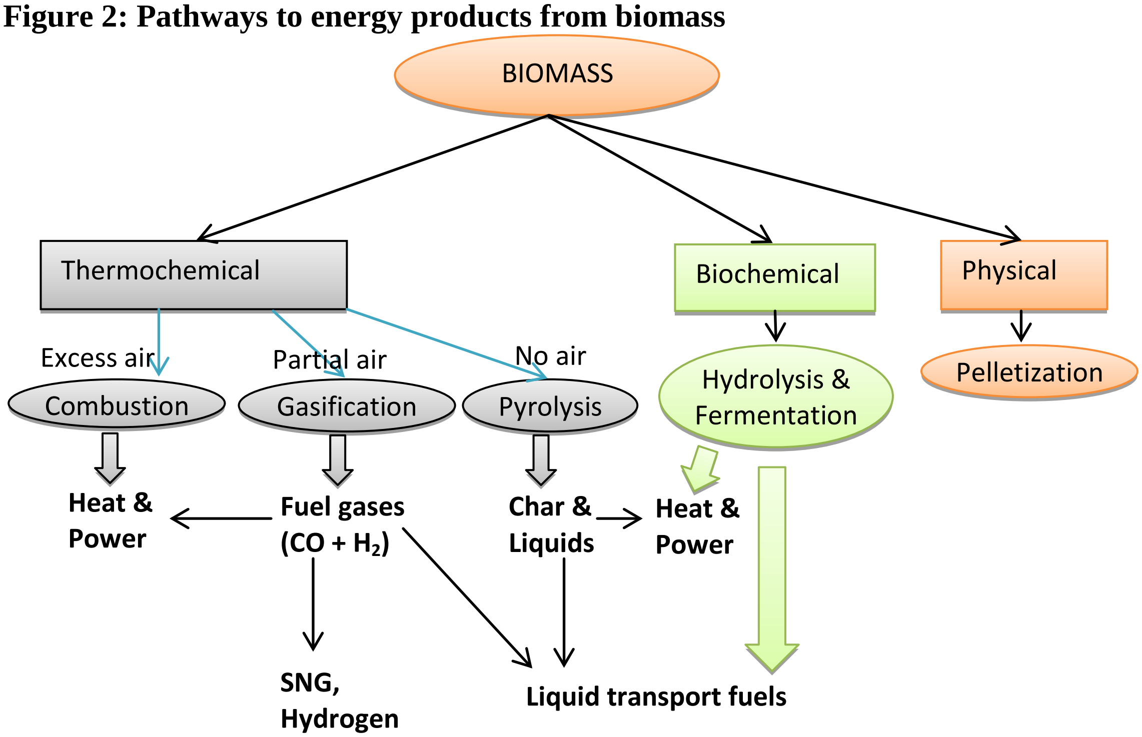
Figure 1: Comparison of value and volume distribution in the forest and petroleum industries Source: adapted from Browne et al., 2012.



Case Study:Development of Conventional (First Generation) and Advanced (Second Generation) Biofuels

As mentioned earlier, biofuels are the most widely used renewable alternative to oil-based transportation fuels such as diesel and petrol/gasoline. Biofuels can generally be defined as liquid transportation fuels that are derived from crops (such as sugarcane, corn, rapeseed, or sunflowers) or biomass (such as forestry and agricultural residues or energy crops such as switchgrass, fast-rotation trees, or algae). In direct response to the OPEC oil crisis, pioneering countries such as Brazil and the US greatly expanded their production of 'traditional'or 'conventional'biofuels such as sugarcane or ethanol derived from corn. Other countries such as Germany quickly followed suit by greatly expanding itsproduction of oil seed-bearing crops such as rape/canola. These so-called 'first generation'biofuels technologies (now better defined as 'conventional'or traditional biofuels production) have helped establish much of the infrastructure and policies that are in place to make bioethanol,and to a lesser extent biodiesel, significant commercial realities in many parts of the world. Countries such as Brazil continue to improve on many aspects of sustainability as well as the economics of making ethanol from sugarcane. However, in other parts of the world, various economic and social (e.g., food versus fuel) considerations have encouraged the development of 'advanced'biomass-based biofuels technologies based on biochemical, thermochemical and hybrid process routes (sometimes referred to as second- or third-generation biofuels). The technology pathways to biofuels and bioenergy from biomass are depicted in figure 2.

Figure 2: Pathways to energy products from biomass



Source: Adapted from BPN, 2011

International Biofuel Targets and the Quest for Economic Viability and Sustainability

As mentioned earlier, there has been significant investment in the development of renewable liquid transportation fuels with various countries developing mandates, directives, targets and roadmaps to facilitate the commercialization of biofuels (BD, 2011). The recently developed IEA (International Energy Agency) biofuels roadmap (IEA, 2011) is one example of a globally concentrated effort to prepare an action plan and determine global biofuel volume and specification targets. As detailed in the report, if the world aspires to reach the GHG reductions that are described in the "Blue Map" Scenario (energy-related CO_2 emissions are reduced by 50 percentin 2050 relative to their 2005 level), biofuels use will have to grow from its current 2 percentshare of global transportation energy to over 25 percentby 2050. In this way it is estimated that about 2.1 Gt CO_2 emissions per year could be reduced. Although production of some conventional biofuels such as sugarcane-derived ethanol are expected to continue to grow, as they can be produced both sustainably (good GHG savings) and economically (Brazil's experience and increasingly efficient production techniques), future advanced biofuels such as energy-dense hydrocarbon-type diesel and jet fuels will likely be produced by thermochemical means such as by Fischer-Tropsch conversion of gasified biomass and pyrolysis oils.

IEA Bioenergy Task 39: An Example of an International Forum that Can Promote Biorefinery Collabourations

An international example of an organization thatfacilitates collaboration and information exchange in the biofuel-biorefinery sector is IEA's Task 39. The Task is focused on biofuel commercialisation in a biorefinery approach and operates for the interests of its member countries and the overall mission of the IEA. The origins of the International Energy Agency (IEA) coincided with the first of several 'oil price disruptions' initially caused by the OPEC oil crisis of the 1970s. Since then, the IEA has evolved from an agency that tried to better anticipate oil price disruptions to now having a mandate to 'improve the world's energy supply and demandstructure by developing alternative energy sources and increasing efficiency of energy use'. The work of IEA Bioenergy Task 39, 'Liquid biofuels' (http://www.task39.org) is very much at the forefront of the renewable fuels strategy of many countries.With dwindling petroleum reserves and soaring transportation fuel demand from China, India, and other emerging economies, the world needs alternatives such as biofuels and biomaterials. This organization and other global collabouration efforts are indispensable tools in ensuring the success of the evolving bioeconomy.

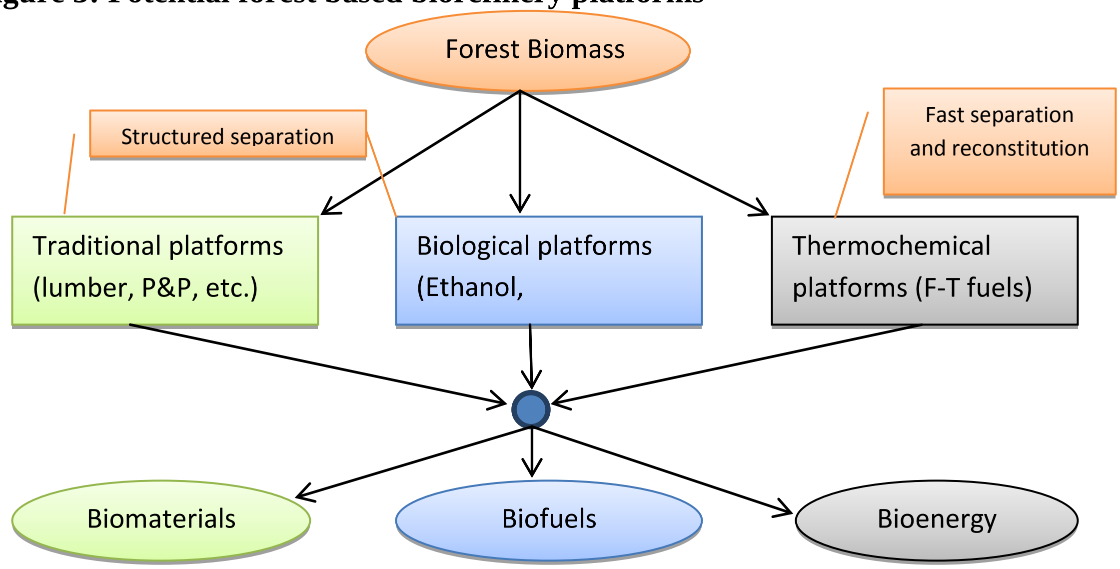
What is the Likely Structure/Operation of Forest-Based Biorefineries?

Just like oil refineries, biorefineries can provide a wide range of molecules and materials that act as the precursors or products for transportation fuels and commodity/specialty chemicals. Bioenergy, biofuels and biomaterials are the main categories of products that can be produced from forest-derived biomass depending on the feedstock and the process involved (figure 3). It is likely that traditional high-value products such as engineered wood or specialty pulps will continue to be the mainstay of many forest-based biorefineries.Nature designed trees to be primarily composed of 'structurally robust polymeric components' such as cellulose, hemicellulose and lignin and it thus makes sense to first take advantage of wood's'structural' characteristics before conspiring its chemical/energy potential!

There are several conversion technology platforms that are current and potential candidates for a forest-based biorefinery employing either thermochemical processes such as pyrolysis/gasification or biological processes such as microorganisms/enzymes (biochemical platforms). Although both the thermochemical and biochemical platforms have the capacity to produce fuels, chemicals and to generate power (figure 3),the biochemical approach tends to fractionate the cellulose, hemicellulose, lignin, extractives, etc. through processes such as pretreatment while the thermochemical process carries out this fractionation after all of the biomass has been pyrolysed or gasified first. In either type of biorefinery, the ‘energy products’ such as biopower and biofuels are likely to result in the greatest product volume while biomaterials/biochemicals such as xylitol or nutraceuticals will havesignificantly smaller markets but with much higher value. In this way it has been suggested that the forest-based biorefinery can develop a diverse range of products, analogous to an oil refinery, and therefore be in a much better position to deal with both market fluctuations and market opportunities. Future forest-based biorefineries should also be ‘flexible’ or ‘modular’ in theirdesign so that theycan readily shift from one product stream to another, depending on market prices. Some excellent examples of the development of the biorefinery conceptcan be seen over the last 20 years in the US corn and the Brazilian sugar-based industries. In the early 1980s, Brazil wasthe first country to try to become less dependent on imported oil by aggressively developing an ethanol industry based on itsconsiderable sugarcane industry. However, the Brazilianssoon found out the advantages of being able to diversify their product mix by shiftingto more sugar production when the value of sugar is high (as it currently is) or to ethanol production whenever the international price of oil is high. Similarly, the US corn sector is still a substantial animal feed supplier with corn’s use as an ethanol feedstock only recently superseding this traditional market for corn. Thus when oil prices are high (as they are currently) ethanol will continue to look attractive, with the concomitant high price for animal feed resulting in famers planting more corn than other less-profitable crops such as soya. It should be noted that the different biorefinery platforms have advantages and disadvantages. For example, the traditional and biological platforms tend to have lower throughput rates but achieve cleaner product streams (e.g., purer ethanol and chemicals), while the thermochemical platforms tend to provide faster throughput but poorer separation and quite heterogeneous product streams (e.g., pyrolysis oils). In general, each biorefinery platform will involve some form of compromise or tradeoff at more than one level. As a result it is difficult to identify a‘best technology pathway’.

Although several pulp mills could be evolved into more of a biorefinerymode of operating,viaeither a thermochemical or biochemical approach, it is likely that ‘pioneer’ plants will first use any energy produced in-house viadirect combustion, combined heat and power, or black liquor gasification types of approaches.Pulp mills have existing equipment that can be easily retrofitted to perform either pretreatment or biochemical conversion (e.g., pulping digestors) or pyrolysis/gasification (e.g., black liquor gasification) for thermochemical conversion. Althoughthese technologies can fractionate biomass and produce value-added biorefinery-type products, they are likely to be more mid-tolong-term solutions for the forest sector. Biopower is already being used within several pulp mills inexisting operation units such as lime kilns and black liquor gasifiers, although most older pulp mills are rarely self-sufficient in power generation and they often have to buy natural gas or electricity to complement their in-house power.

Figure 3: Potential forest based biorefinery platforms



Feedstock-Process Compatibility and Logistics Aspects

In comparison to oil, biomass is a feedstock that is less energy dense, higher in moisture, much more heterogeneous, dispersed in its distribution and, somewhat surprisingly, often requiring more of a 'social license' for itscollection does drillingforoil! Accordingly, biorefinery facilities will have some logistic challenges, which will undoubtedly influence the choice of technology platform, feedstock and markets that might be pursued. For example, thermochemical facilities are likely to be more amenable to scale-up because, in contrast to biochemical processes, they can process highly densified and more hydrophobic forms of biomass such as torrified pellets or bio-oils, which in turn can be transported longer distances than raw biomass(Stephen et al., 2010).Similarly the seasonality of fibre harvest, moisture and ash content, accessibility of fibre, bulk density, and amenability to densification are other characteristics that can vary between different feedstocksand should be taken into account when choosing abiorefinery technology. Matching the right technology to the appropriate feedstock and securing the availability of the raw material will be paramount to the sustainable and profitable operation of asuccessfulforest-based biorefinery.

TheForest Products Association of Canada's (FPAC) 'Biopathways'Strategy

In North America, the current, ongoing financial crisis was partially precipitated by the subprime mortgage crisis that resulted in housing starts (predominantly made out of wood) going from record highs around 2007/2008 to almost record lows in recent history. The evaporation of this core market and the increasing value of the Canadian dollar versus the US dollar resulted in dire financial/employment conditions for the Canadian forest products sector. As one part of an evaluation of how the sector might survive and evolve, the Forest Products Association of

Canada (FPAC), with financial support from the Canadian Forest Service's (CFS) of the federal Natural Resources Canada (NRCan) and input from the recently merged R&D organisation, now termed FP Innovations (formerly Forintek, Paprican, FERIC and part of CFS), created the Canadian Forest Innovation Council (CFIC),whichhelped identify the need to develop a 'biopathways' strategy. The work carried out within the Biopathways project involved a detailed and thorough evaluation of potential strategies for renewal and diversification of the Canadian forest products sector. In its initial work the group assessed both traditional and emerging manufacturing pathways in three selected regions within Canada (northern Ontario, interior British Columbia and the Lac St. Jean region of Quebec) (BPN, 2011). This initial study indicated that, generally,the pathways thatmaximise greatest return on capital expended (ROCE) are the ones that combine current sawmill operations with bioenergy and engineered wood products (EWP)applications and markets, while current pulp and paper operations are best blended with bioenergy and biorefinery technologies and applications. However, it was also apparent that the strategies thatmaximise ROCE are not necessarily the ones that maximise employment indicators and vice versa. It was also evident that different pathways perform differently in each ofthe three regions studied. These recommendations again indicated that there is no 'best technology pathway' and that the desired 'win-win' situations have to be carefully assessed and customised to the industrial and social background of each region. However, the study strongly emphasised the urgent need for renewal in theforest products sector as the opportunities are too great to miss out on and 'business-as-usual' would be unlikely to be successful in the future. The report indicated that, on average, a new technology added to an existing pulp mill will improve ROCE by 3.7 percent, GDP contribution by 10 to 25 percent,and employment by 1 to 4 percent(BPN, 2011).Overall, the report recommendedthat (a) better integration of traditional and novel technologies/products/markets, (b) increased cross-sectoral synergies and (c) better leveraging of existing infrastructure will be key components for the future success of the evolving forest sector. It was also noted that policy support,improved communication between sectors (such as the Catchlight joint venture between Weyerhaeuser and Chevron), increased investment in R&D and hiring new people with the skills and training needed for the future biorefining sector, are all essential components to ensuring the success of the proposed biopathways strategy. More recently, a network of university-based networks working in the forest products sector has been formed (the FIBRE network,http://www.reseauxfibrenetworks.ca) with the goal of helping commercialise university-derived research while training the highly qualified personnel (HQP) that will be needed by the future forest products/biorefining sector. The better integration and close collaboration between FPAC, NRCan, FP innovations and the universities is seen as key to ensuring the effective development of Canada's future forest-based biorefining sector.

Conclusions

The forest-based biorefinerywill continue to have traditional products and markets (lumber, engineered wood, pulp and paper) at its core, making use of wood's inherent structural characteristics. However, the increasing costs (economic, environmental and social) of using fossil-fuel-derived feedstocks to make many of the products from an oil refinery will encourage oil/chemical companies to continue to evaluate carbohydrates as a possible replacement for hydrocarbon-based feedstocks. The commercialisation of the forest-based biorefinerycomes with a number of challenges, several of which could be addressed through selected partnerships and collaborations, leveraging the relative expertise of sectors such as the forest products and the chemical/oil refining industries. There is considerable potential for the forest products sector to 'learn'from the strategies of the oil refinery, and more recently the agriculture-based biorefinery sectors. It can do this byextracting the maximum value from biomass by supplementing fossil-fuel energy sources with biomass-derived energy and developinghigh-value co-product streams such as nanocrystalline cellulose andnutraceuticals.Although various thermochemical and biochemical-based processes are currently being evaluated as the basis of a 'biorefinery platform', there is as yet no 'best technology platform' and the choice of process is more likely to be influenced by feedstock specificity and the peculiarities and logistics of each region. Althoughthe biorefinery approach to processing forest-derived biomass is poised to play a central role in the future of the forest products sector, part of its success will depend onthe careful selection of technology and markets that will capture the synergistic opportunities between complementary industries and other stakeholders. These collabourations and synergisms can be facilitated via national networks such as the Canadian Biopathways Network and international networkssuch as the Bioenergy Implementation Agreement (IA) of the International Energy Agency (IEA).

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