Biorefinery: opportunities and barriers for petro-chemical industries

By M. Pervaiz and M. Sain

Abstract: Recent climate changes have confirmed that global warming is the most pervasive threat to delicate ecosystem of our planet and there is an urgent need on world-wide basis to control and reduce the CO_2 emissions. Time has come for both research institutes and industries to follow an environmental sustainable path and develop new technologies based on renewable biomass independent of fossil fuels. Among various products, the bio-plastics and natural fiber composites represent a significant potential of growth and success by utilizing renewable feedstock.

Traditionally, the bio-products made from different renewable feed stocks had played a pivotal role in every walk of human life. However, the industrial revolution of 20th century opened the door to large- scale exploitation of hydrocarbon reserves and petrochemical-based products became the backbone of almost every industrial and consumer application. The current annual output of biomass from plant vegetation on global basis is about five times the world's annual need of energy and chemicals [1] but with the exception of wood and cotton, very few renewable materials are being used to manufacture consumer goods on mass scale.

Plastics, used in every segment of today's economy, have been traditionally manufactured from petroleum based synthetic resins. The true advent of petroleum based plastics started in 1910 with the discovery of Bakelite. Rapid growth was seen during 1930s and during Second World War [2]. By 1950, about 2.3 million metric tonnes of synthetic resin was produced in the USA alone which grew by 5-7% annually over the next half century as shown in Figure 1.[3]

Currently, 150 million tonnes of plastic is consumed on global basis of which Canada consumes about 2% as shown in Figure 2 [2].

NEED FOR CHANGE

Petroleum to bio-based plastics and composites.

There are a number of environmental potential hazards which have forced the plastics industry in the industrialized world to explore renewable feedstock, including the need to address tougher pollution laws. Some of the main concerns are; *possible links between plastics and endocrine disruptors, extensive use of chlorine for PVC plastics, generation of volatile organic compounds (VOC)*, and solid waste disposal due to limited recycling. Similarly, glass fiber, the main re-enforcement material of thermoplastic composites, has various environmental concerns, including extensive energy consumption and potential health risks during production and handling.

CURRENT STATUS

Market Size and Line of Products.

The development of biodegradable plastic (BP) industry is happening around the world, however, the EU and the USA have both seen particularly significant growth in this area over the last decade. There is a highly competitive and dynamic BP market in EU, consuming about 40% of total world output [4, 5] as shown in Figure 3.

In Europe, biodegradable polymers and bioplastics have been developed by major chemical companies like Eastman Chemicals, BASF, and DuPoint. These companies have spent more than 28 million CDN$ in recent years in material development to produce their brand name biopolymers and plastics such as "Eastar", "Ecoflex", and "Biomax"[5].

In North America, various multi-nationals are competing hard to install manufacturing facilities at ideal locations for efficient networks of supply and distribution. Cargill has installed a biopolymer manufacturing plant in Blair, Nebraska, having a 140,000 tonnes annual production capacity of polylactic acid (PLA) from corn starch. The product, NatureWorks™, has a world market of about US$ 10 billion and is being used in the manufacturing of thermoformed trays and lids of food packaging and fibre-fill comforters and pillows [6]. Other major players involved in commercial production of corn starch based biopolymers are Shell and DuPont, the latter has built a plant in North Carolina to manufacture a copolymer named "Sorona".

Starch-based bioplastics are entering into every sector of commercial applications traditionally served by petro-based plastics including packaging, building and construction, automotive, electronics and agriculture and horticulture. Of all these, industrial and food packaging is growing particularly fast with a product range that includes biowaste bags, BP loose-fill and films, and shaped/blocked packaging for electronics and toys. Bio-packaging for organic food has been received very well by consumers, especially in the EU, due to the water permeability characteristics of this material that keeps fruits and vegetables fresh (see Fig. 4). It also gives added advantage of being a compostable packaging after the expiry date.

Bio-packaging for dairy products is another innovative area, including tubs for margarine,

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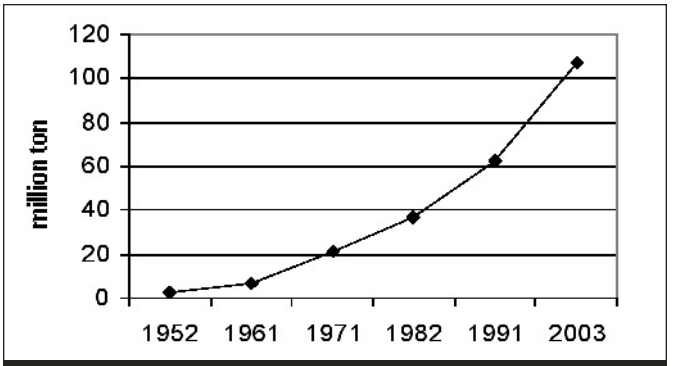

FIG. 1. Consumption of petroleum based synthetic resins in USA to produce plastic.

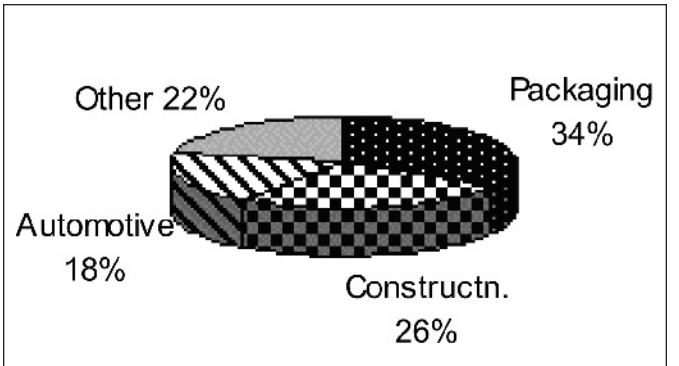

FIG. 2. Plastics market distribution-Canada.

yoghurt and cheese, etc.

The automotive industry, consuming 2.5 million tonnes of plastic annually, is another potential growth area for bioplastics and natural fiber composites. However stringent technical requirements like durability and performance pose many challenges in developing a true functional and biodegradable plastic. So far, only Toyota Motor Corporation and GoodYear Tire have made significant efforts in this regard. Toyota is already utilizing an auto-grade bioplastic, EcoPlastic, made from polylactic acid (PLA). It is also installing a new plant in Japan to manufacture PLA from annually renewable resources such as sugar cane. GoodYear has been marketing successfully its Eco-tyre series for the last 3 years utilizing Novamonts MaterBi.

The use of natural fibers as reinforcement material in thermoplastic resins for automotive applications has been already established as mature industry, especially in Europe. Annual renewable plant fibers including flax, hemp and sisal can improve the mechanical performance of natural fiber composites (NFC) and reduce the weight of end products, thereby, improving the fuel efficiency of vehicles [7].

The European automotive industry has already taken the initiative and uses around 22,000 metric tons of natural plant fibers annually in low-stress applications within luxury cars [4]. In North America, the interest within the industrial, research, and agricultural sectors has been high, but the market demand has only recently picked up. Current consumption levels of BPs in the North American industry are about 45,000 metric tonnes.

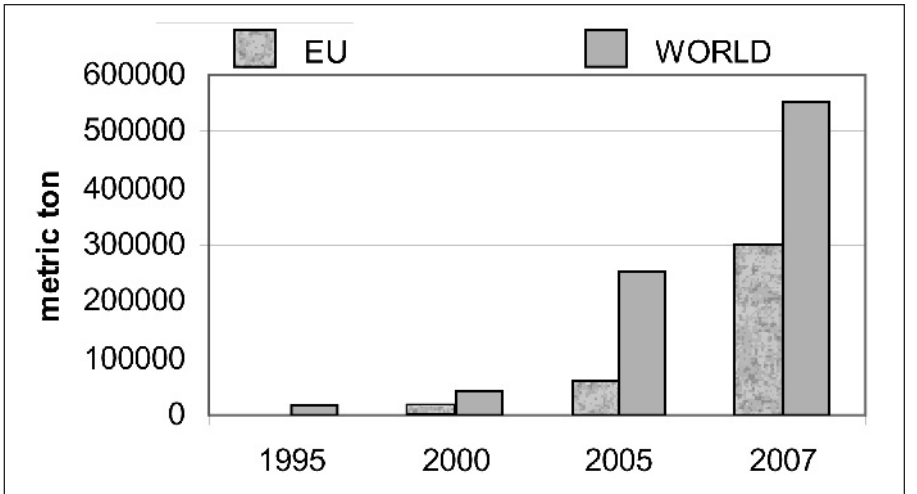

FIG. 3. EU and World capacities of bioplastics.

OPPORTUNITIES AND CHALLENGES

Significant R&D efforts over the last decade have been conducted to develop new bio-products on a commercial scale and bioplastics have emerged as one area of developmental focus in both Europe and North America. But, unfortunately, very high material development costs and small production capacities have resulted in non-competitive prices of basic raw materials for bioplastics compared to conventional plastics. As shown in Table 1, there exists a very un-favorable ratio of 2.2 to 7.8 between average prices of similar biodegradeable and petro-based polymers.

• Although price remains the main challenge, the consumer awareness of the environmental issues has resulted in a proactive buying behavior. After the industry succeeds in achieving a viable scale of economy, the price gap should become more competitive.

The extraordinary potential of bioplastics and natural fiber composites in reducing CO_2 emissions, shown in Table 2, can be utilized as a potent marketing tool and also serve as "emission trading" incentive which is going to be implemented by 2008 under Koyoto Protocol [5].

There is a tremendous scope of new opportunities for "value added" niche products based on bioplastics and chemicals including;

- Edible packaging based on vegetable and animal proteins.
- Heat/water proof packaging; single use bottles for shampoos, and cosmetics.
- Bio-degradable motor oil, cheese coatings and pressure sensitive adhesives.
- Composite fillers; using corn starch and silica to carbon black in tires.
- Unique bio-products, otherwise not possible to make from fossil fuels, like enzymes and sensors.

In addition to these opportunities and advantages, there are challenges which must be addressed to ensure sustainable development of bioplastics and composite industry. These include:

• *Political Initiative/Urgency.* Unfortunately, in the whole biorefinery debate, bioplastics and bio composites have not been able to get as much attention as biofuels. A firm commitment from top level of governments is necessary for these products to succeed.

• *Feed-stock Availability.* There is a need for efficient biomass harvesting and a reliable supply chain network with adequate crop storage and separating systems.

• *Technology Development.* The hydrophilic characteristic of starch and protein based bioplastics is the main bottleneck in mass production of these otherwise environmental friendly products. Some R&D efforts in this area in progress, especially in the Netherlands and France, but there is a need for a coherent approach to overcome this issue.

• *Food Safety.* This is one of the most important future research themes in food packaging. The presence of additives, cross-linking agents and preservatives, normally not present in traditional plastic

TABLE I. Price ratio between average prices of biodegradeable and traditional polymers in Europe.[5]

	Traditional polymers	Price Ratio
Foamed Starch	HDPE (PE)	2.2
Starchblends (film type)	LDPE (PE)	4.4
Polyesters (synthetic BDP)	PP	5.8
Polylactic acid (PLA)	PS	2.9
Cellulose Acetate	PVC	7.8
Cellophane	PET	3.5

TABLE II. Environmental advantages of bioplastics and NFC compared to petro-based counterparts.
• Based on hemp fiber/polypropylene composite [7].

Environmental	Bio-plastics [4]	Natural Fiber
Advantages		Composites[7]
Saving in CO_2 emissions	3.2 ton/ton product (starch base) 1.5 ton/ton product (oilseed base)	3.0 ton/ton product*
Energy Savings	–	50,000 MJ/ton product.*
"End of Life" Options*	Compost-able Waste (no need of landfill) Renewable energy from natural biomass Use as "soil conditioner"	

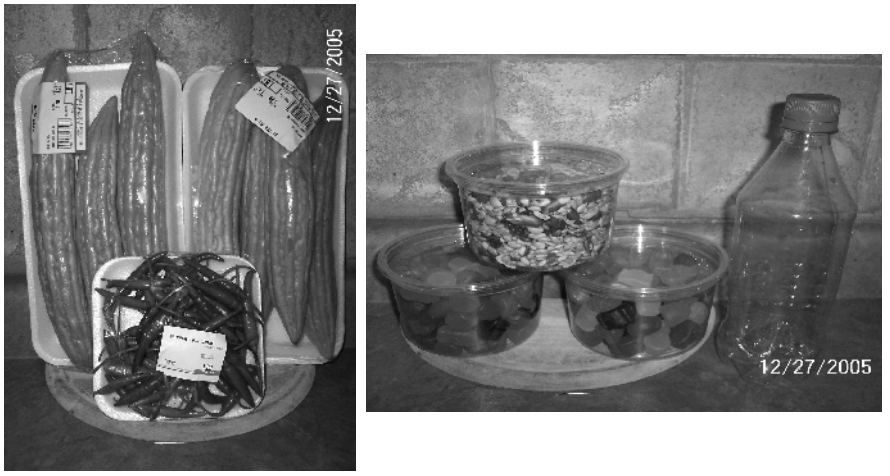

FIG. 4. The market of bio-plastic packaging, especially for organic food, has great potential of growth as a true "green product"

packaging products, and moisture sensitivity make the bioplastics vulnerable to a high degree of risk.

The natural fiber composite industry has some unique technical challenges as well. On top of the list is the optimization of mechanical performance, especially impact strength of NFCs. Further, improvements in fiber opening/treatment technology, establishing reliable technical specifications and achieving true bio-degradability are roadblocks on the path towards commercial success.

CONCLUSIONS

To replace hydrocarbons with carbohydrates, derived from renewable feedstocks, as the building blocks of consumer goods presents an alluring and urgent agenda to research institutes, industry and governments all over the globe. The main motives behind all this 'biorefinery" research is the reduction of greenhouse gases (GHG), curtailing our dependence on non-renewable resources, and value addition to farm-based products with new industries.

The bioplastics and NFCs, emerging but functional bio-products with the potential to save significant CO_2 emissions, have tremendous scope of commercial success. However, as outlined in this review paper, there are also technical and commercial roadblocks which must be removed on a priority basis to achieve meaningful development in these otherwise small-scale industrial sectors. A feasible strategy in the current scenario seems to remain focused on developing renewable technologies integrated to the existing manufacturing infrastructure. Only this approach seems to make good economic sense. The plastics and composites manufacturing sectors need to make a cautious and smart move to drive their present technology in this transition period towards the bio-based economy. Those industry leaders who welcome this strategic direction in their corporate culture will be the clear winners of the future.

REFERENCES

1. White K, Gunther P. Acton White Associates Inc. "Innovation Roadmap on Bio-Based Fuels and Industrial Products. 2004" http://www.actonwhite.ca/
2. Canadian Plastic Products Industry 2005. Industry Canada. http://strategis.ic.gc.ca/epic/internet/inplastics-plastiques.nsf/en/pl01383e.html#1
3. Baumann M. History of Plastics Industry and Future Trends. GH Associates Plastics USA.2004, http://www.4spe.org/training/seminars/past/pusa04/plastics_history.pdf
4. Canadian Agri-Food Research Council (CARC). "An Assessment of the Opportunities and Challenges of a Bio-Based Economy. 2003", http://www.carc-crac.ca/common/Opportunities%20and%20Challenges%20of%20a%20Bio%20based%20Economy.pdf
5. The bioplastics Industry in Europe. 2004. Norocon Innovation Consulting Kaeb. eMail: kaeb@narocon.de
6. Executive Summary. Non-Food/Non-Feed Industrial Uses for Agricultural Products. Phase 1, 2002. Agriculture and Agri-Food Canada. http://www.agr.gc.ca/misb/spec/index_e.php?s1=bio&page=non
7. Pervaiz M, Sain M. "Carbon Storage Potential in Natural Fiber Composites", Resources, Conservation and Recycling 39 (2003) 325-340

Résumé: Les récents changements climatiques ont confirmé que le réchauffement de la planète est la menace la plus généralisée pour le délicat écosystème de notre planète et qu'il faut absolument que partout dans le monde on contrôle et réduise les émissions de CO2. Le temps est venu tant pour les instituts de recherche que pour les industries de suivre la voie du respect durable de l'environnement et de développer de nouvelles technologies basées sur la biomasse renouvelable indépendamment des combustibles fossiles. Parmi les divers produits à notre disposition, les bioplastiques et les composés de fibres naturelles offrent une possibilité appréciable de croissance et de succès grâce à l'utilisation de matières premières renouvelables.

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