Bio-based chemicals: In need of innovative strategies

The bio-based chemicals value chain begins with generation of renewables which are converted through enzymes/microorganisms to platform chemicals and value added specialities. It also includes the challenges of finding market access amidst complex logistics, evolving policies/ regulations and sustainability challenges.

This discussion focuses on issues ranging from present directions in green chemistry and technology, shifts to a bio-based chemical economy, market drivers and changing global trends. It discusses the challenges of producing value added chemicals from platform chemicals as also the complexities involved in forming alliances. Finally, barriers to a sustainable bio-based chemical industry are discussed.

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Bio-based chemicals: Emerging opportunities

Industrial green chemistry has seen several strategic approaches in the last decade. These cover a wide gamut – catalysis, solventless systems, alternate synthetic routes and raw materials, intensive processing and micro-reactions, to name a few. Of these, progress has been marked in three areas:

- Waste minimisation [traditional processes];
- Green products/processes [replacing existing ones]; and
- Bio-based products [from renewables].

The bio-based routes incorporate key green chemistry principles such as reduced energy usage & waste generation, selective catalysis and biodegradable products. Recent examples of successful reduction in greenhouse gases (GHG), energy and inputs using renewable resources are listed in Table 1.

Research in bio-based products from a wide range of renewables has been at the forefront of the chemical industry's attempts to seek newer growth opportunities through greener products and processes. Though holding much

Table 1
Use of renewables for greener processes/products

Company	Product/process	Reduction in GHG/energy/inputs	Remarks
Cargill, US	Bio flexible foam polyols	Energy: 23% GHG: 36%	From vegetable oils/soyabean oils
Pfizer, US	Biocatalysis	Energy: 83% Input: 80%	Pregabalin (Lyrica) neuropathic drug, water based process
Evonik, Germany	Myristyl myristate	Emission: 90% Energy: 62%	Enzymatic route to cosmetic ingredients, less wastes, increased yields by around 70%
DuPont, US	1,3-Propane diol	GHG: 20% Energy: 40%	Corn based route
Telles, US	PHA resin	GHG: 200% Energy: 40%	JV between ADM/Metabolix
NatureWorks, US	PLA resin	GHG: 80-90% Input: 70%	Corn feedstock, wind power
Hoffman La Roche, Switzerland	Vitamin B2	Air: 50% Input: 75%	Water reduction: 66%
DSM, Netherlands	Cephalexin	Energy: 65% Input: 65%	Cost reduction: 50%, fermentation/enzymatic, water based

Table 2
Recent developments in bio-based products: Varied approaches

RED BIOTECHNOLOGY	WHITE BIOTECHNOLOGY	GREEN BIOTECHNOLOGY	BLUE BIOTECHNOLOGY
Novel drugs Vaccines Stem cell applications	Microorganism Biocatalyst Biochemistry Biochem engineering Fermentation	Discovery/use of novel genes, processes, materials, in plants, crops, forestry	Discovery/use of novel genes, processes, materials in marine systems

promise, the transition from a fossil based economy to a bio-based economy is likely to lead to profound shifts in the industry structure as new technologies in agriculture and bio-processes usher in new complexities.

The bio-based products are projected to account for nearly 50% of the chemical markets by 2050 as developments in bio-transformation technologies, bio-catalysis, genomics and metabolic engineering matures. The potential for bio-based products has also led to a large number of initiatives and alliances by the chemical, biotechnology players etc. Since 2008, we have seen a number of new alliance announcements. The period also witnessed large number of alliances in technology, supply chain, and product development. Since 2004 the industry has attracted venture capital investments of nearly $3.1-bn. However, in 2011 there has been a marked decline in such funding due to high risk perceptions and long term profit horizons. The funding have been limited by lack of clarity on key issues such as status of many projects, unrealistic market projections, low technology capability, insecure feedstock sourcing and complex regional markets, policies and regulations. A strategic move by the industry has been to develop and integrate bio products into existing value chain to enable faster move to markets.

Bio-based vs fossil based chemicals: Wide gap

As the bio-based chemicals industry moves along the path from development to maturity several roadblocks need to be resolved. At present, there exists a large gap between the well established petroleum based industry and the nascent bio-based industry. How fast the industry matures will depend on access to new technologies, capital and alliance partners.

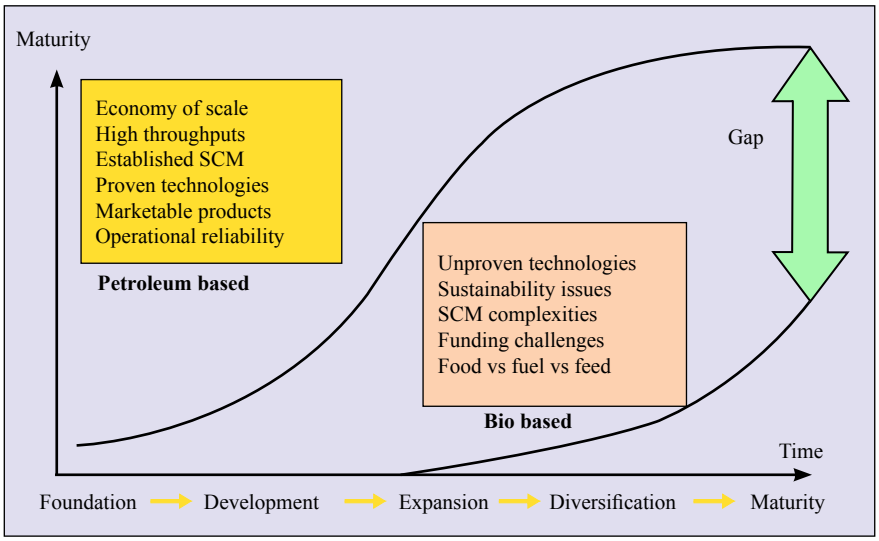

Fig. 1: Closing the gap with petro-route: An uphill task for bio-based chemicals industry

Market influencers, projections and penetrations

Several key market drivers and influencers are shaping the commercialisation of the bio-based chemicals. Of these, the following are key issues:

- Rising oil prices & volatilities
- High environmental footprint in fossil based products
- Advances in:
  - High volume biomass conversion technologies
  - Biotechnology, genomics, metabolic engineering
- Consumer interest in safer product attributes
- Growing demand for bio-based chemicals.

Bio-based chemical markets have been influenced by traditional feedstock prices, land and bio-feedstock availability, bio-transformation technology and finally competition with food chain. A primary influencer has been the increasing consumer preference for bio-labelled products. Several product categories have been awarded bio labels in the last few years. These are hand soaps, sanitizers, cleaning

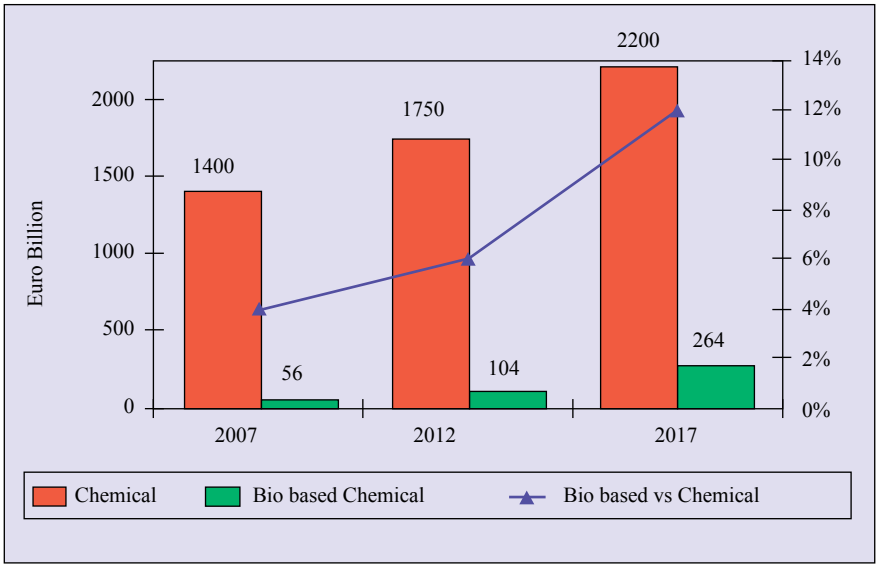

Fig. 2: Bio-based chemicals: Market projections

Source: KnowGenix

Table 3
Some leading players in bio-based chemicals market

Chemicals	Companies
Acetic acid	ZeaChem
Acrylic acid	OPX Biotechnologies, Arkema
Bio-butanol	Green Biologics, DuPont/Butamax Advanced Biofuels
1,3-Propanediol	DuPont/Tate & Tyle, METabolic Explorer
Bio-BDO	Mitsubishi Chemical and Genomatica; Genomatica/ Chemtex; Metabolix and Davy Process Technology, Myriant; Cobalt Technologies/API
Isobutene	Lanxess/Gevo
Levulinic acid	Segetis
Isosorbide	Roquette, Mitsubishi/PTT
Glucarates	Rivertop Chemicals
Cellulosic ethanol	Novozymes/Mossi Chisolfi Group
Bio-methionine plant	CJ CheilJedang/Arkema
Bio-greases	Elevance Renewable Sciences/NL Grease LLC; Solazyme and Amyris
Bio-waxes	Elevance/ISP
BioPB	Sinoven Biopolymers (BioAmber)

products, engine oils, lubricants, fibres and food packaging.

Bio-based chemical markets are projected to touch Euro 104-bn by 2012 and grow to around Euro 264-bn by 2017. Percentage of bio-based to chemical markets which was at 4% in 2007 is projected to rise to 6% by 2012 and 12% by 2017. These will, of course, depend on how technologies mature, ability to attract capital, form alliances and resolve supply chain complexities.

It is in fine chemicals that bio-based products are projected to make deep market penetration moving from 20% in 2010 to nearly 35% by 2025. Specialities are projected to move from 20% to 30% by 2025, polymers from 5% to 15% by 2025 while commodities are projected to move from 2% to 6% of markets by 2025.

Global trends in bio-based products

The pursuit of bio-based chemicals has been witnessed across the world and significant commercial developments have occurred. China, USA, Japan, Canada have been leading major forays. In recent years EU has also caught up.

According to an Arthur D. Little report, globally there are three tiers of companies involved in bio-based product development and all of them follow different strategies. The categorisation is as follows:

- Traditional companies focused on developing greener alternatives within their existing product lines;
- New companies focused on novel products; and
- Technology players focused on using metabolic engineering to develop technologies and develop existing and new products without producing the chemicals.

Few of the key players are listed in Table 3, while Table 4 gives the top 30 bio-based chemical companies in 2011-12 based in a global poll conducted by Biodigest Online to identify key players in this area. The criteria were innovation, accomplishments, and material development.

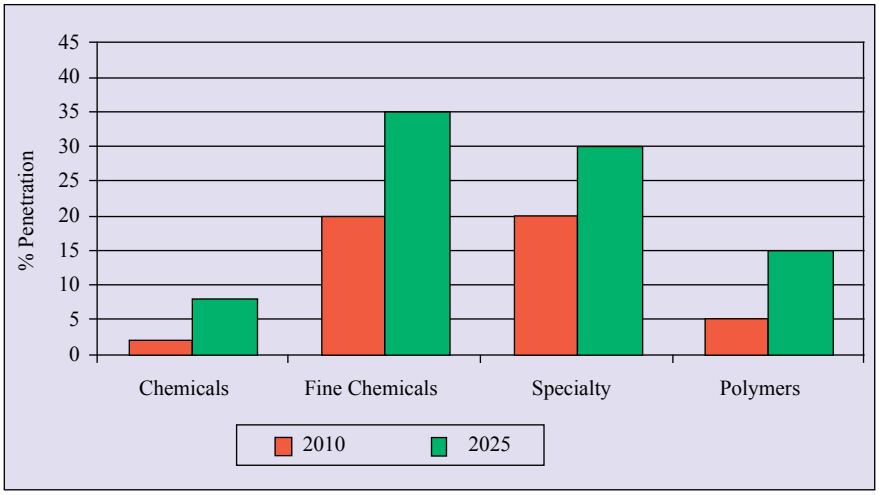

Fig. 3: World bio-based chemicals market: Percentage penetration
Source: KnowGenix

Table 4
Top 30 bio-based chemical companies (2011-12)

Rank 1-10	Rank 11-20	Rank 21-30
Genomatica*	Cargill	Myriant*
Solazyme	Cobalt Technologies	Cosan
Amyris	Waste Management	Mascoma
Gevo	Ceres	KiOR
LS9	Elevance Renewable Sciences*	DuPont Danisco
DuPont	Dow Chemical	Virent
Codexis	Enerkem	LanzaTech
Genencor	Coskata	POET
Novozymes	OPX Biotechnologies*	Metabolix*
ZeaChem	DSM	Honeywell's UOP

** Pure play companies*
Note: Renewable chemicals: 7; Strategic investors, suppliers: 9; Integrated bio refineries: 14
Source: www.biodigest.com

Platform chemicals: Technologies at a nascent stage

Future progress of bio-based chemical industry is based on how fast technologies for platform chemicals develop. Technologies for key platform chemicals are still at a nascent stage and there are several barriers related to bio-catalyst development, bio-separation processes and conversion processes. There has been a lot of work done by US agencies in identifying new value chains based on key platform chemicals based on renewable resources. Table 5 lists the top 12 platform chemicals.

Bio-based technology platforms are categorised into:

- First generation products (Commercial)
  - By thermo chemical conversion (Propane diol, polylactic acid, etc).

Table 5
Top value added chemicals

Building blocks
1,4-Succinic, fumaric, malic acid
2,5-Furan dicarboxylic acid (2,5-FDCA)
3-Hydroxy propionic acid (3-HPA)
Aspartic acid
Glucaric acid
Glutamic acid
Itaconic acid
Levulinic acid
3-Hydroxybutyrolactone
Glycerol
Sorbitol
Xylitol/Arabinitol

Source: Top value added chemicals from biomass Vol 1: US DOE, 2004

- Second generation products (Pilot)
  - By metabolic engineering and bioprocessing technologies (glycerine, alcohols, esters, caprolactam, hydroxy alkanoates, succinic acid, 1,4-butanediol, etc).
- Third generation products (early discovery)
  - Based on plant expression through genetic engineering
  - Chemicals with designed functionality (High oleic oils, ricinoleic acid, etc, in canola; epoxy oil crops; lubricants, coatings, polymers).

Bio-based value chain

The bio-based chemical value chain is based on sugar, oil/fats and lignin sources. The sugar based chemicals are converted into several products from C3 to C6. These have been identified by US-Dept of Energy among 12 key value added platform chemicals as mentioned in Table 5. Oil/fats based products have been well established, while lignin based products are yet to be taken to commercial levels.

Among sugar based platform chemicals, succinic acid has attracted major

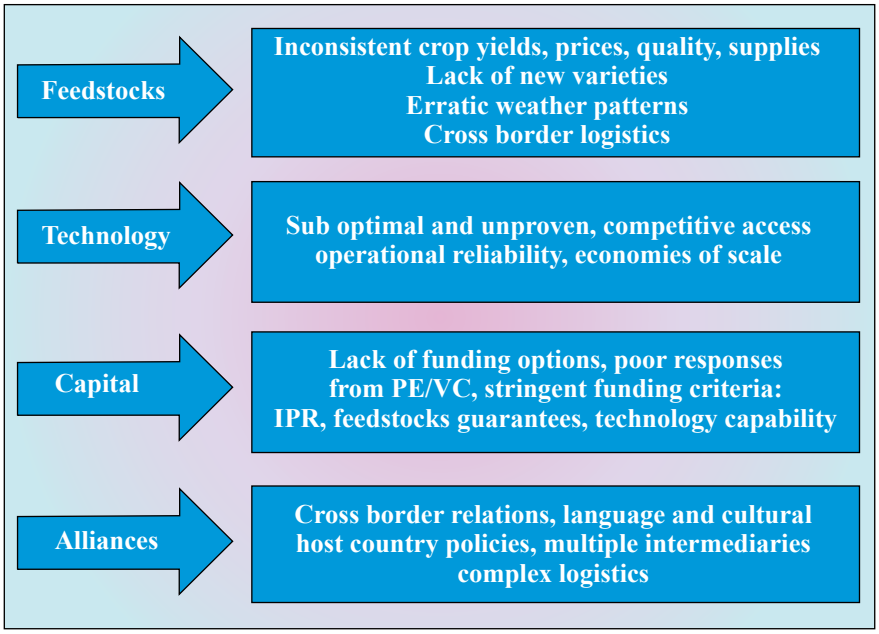

Fig. 4: Bio-based chemicals: Macro level barriers

investments with a host of leading layers competing in this space. Commercial operations are in place. However, technologies and chemistries are needed for downstream product like THF, NMP etc. 1,4-butanediol has also seen major activities at BASF, Purac, Myriant, Bio Amber, DSM, Roquette (based on sugar platforms) while Genomatica has followed both biomass and sugar based processes.

Other platform chemicals like 3-HPA, 2,5-FDCA, sorbitol and glycerol have opened up new avenues for several raw materials for fine and speciality products. Development of value added derivatives will need several technological issues to be resolved. Lignin platform offers key routes to several commodities and specialities. Future developments in microbial conversions, enzymatic oxidations, and pyrolysis will drive the move towards downstream value added products.

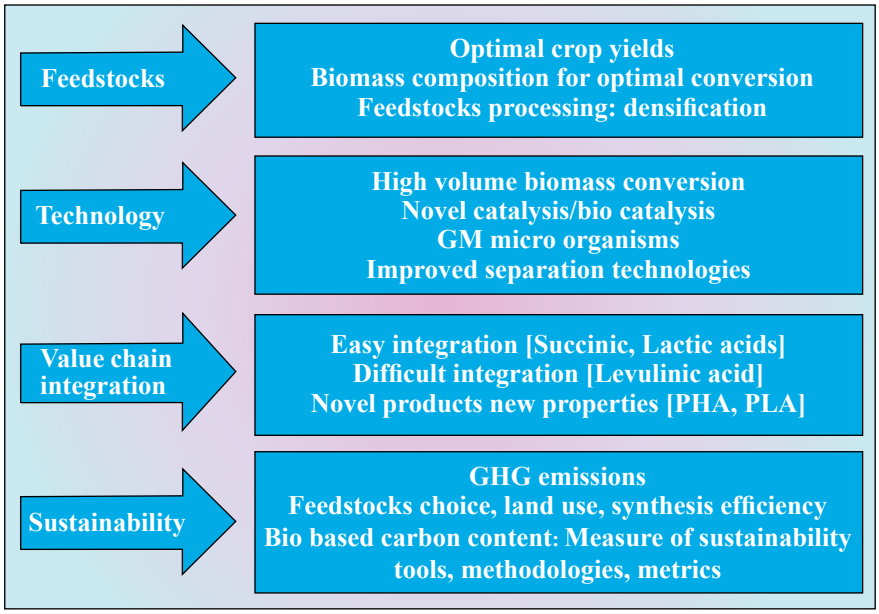

Fig. 5: Bio-based chemicals: Micro level barriers

Strategic alliances

Bio-based chemicals industry faces several barriers to commercialisation (technology, feedstock and capital access) apart from several risks. To tackle these challenges, one of the strategies adopted by leading players has been to form alliances in key areas; many of them spanning across the world. Key drivers for such strategic alliances are access to new markets, R&D resources, technology, domestic markets, distribution channels, bio feedstock and intellectual property. Alliances enable global coordination and lead to cost rationalisation. In particular, it offers a way for risk diversification.

Supply chain challenges are major issues and several alliances are formed to tackle these challenges. Table 6 lists some examples of such alliances.

Barriers to commercialisation

Bio-based chemicals face macro and micro level barriers to commercialisation. At a macro level, key barriers are feedstock, technology, capital generation and alliance formation. At a micro level, there are issues related to feedstock, technology, value chain integration and sustainability factors which pose barriers.

Integration into existing value chains poses serious challenges

A key challenge in commercialisation of bio-based products is the complex issue of integrating the new products into existing value chain. These fall into three categories:

Table 6
Strategic alliances in bio-based chemicals

Companies	Area of collaboration
Amyris and Kuraray	Replacing butadiene, isoprene with farnesene
Global Bioenergies (France) and Synthos (Poland)	Renewable-based butadiene
Elevance and Hutchinson Worldwide	Bio processing aids in rubber compounds
Ford and Recycled Polymeric Materials	Gaskets and seals
Myriant, Purac, BASF, OPX Biotechnologies, Bio amber, DSM, Roquette, Mitsubishi	Bio 1,4-butanediol
Global Bioenergies, Gevo and Lanxess	Bio-based isobutene
Novomer/Eastman Kodak	Propylene carbonate
Rohm & Haas/Ceres	Methyl methacrylate
Braskem and Novozymes	Green polypropylene
ChemPro Group Boonton, Mo-Fuel, Dupont Danisco Cellulosic Ethanol, Genera Energy	Cellulosic ethanol
Metabolix/Meredian	Polyhydroxyalkanoates (PHAs)
Cargill/Novozymes	Acrylic acid
Genencor/Goodyear	Isoprene
Dow Chemical / Algenol Biofuels; ExxonMobil/Synthetic Genomics; Chevron/Solazyme; Valero/Solix; Shell/Cellana; BP/Martek	Algae based chemicals

- Direct replacement in existing value chains. Eg: Use of biobased succinic acid or acrylic acid is easy
- Products that cannot easily be integrated into existing value chains. Eg: Levulinic acid – no established large-scale chemical processes exist to integrate into current production platforms
- Novel products with different properties. Eg: Tedious commercialisation process for PHA, PLA

Regulatory barriers

Regulatory barriers impact bio-based materials and alternate fuels in different ways. Feedstock and processing have shared regulations while their derived products like bio-based materials and chemicals (BBMC) and alternate fuels (AF) have different regulations. These need to be understood as it varies regionally.

Sustainability management

Managing sustainable bio process is a very complex task. Regional variations in agro-climatic conditions, social structures, land policies, etc will pose major challenges. Besides, several complex questions need to be resolved in ensuring sustainability across the value chain. Some of these are:

- Is there a need for an international instrument that identifies best practices?
- How can they be implemented?
- What are key assessment methodologies?
- What sustainability pillars are covered?
- What constitutes minimum parameters?
- Can one set of parameters be applied to different groups of bio-based products?
- Can the current bio-fuel methodologies expanded for assessing bio-based products?

Future directions

Developing a sustainable bio-based economy that uses eco-efficient bio-processes and renewable bio-resources is one of the key strategic challenges in the next two decades. Improved understanding of biodiversity, ecology, biology and biotechnology is needed to enable sustainable biomass production as well as to utilise that biomass and waste organic materials in a highly efficient way. There is a need for improved understanding of science and technologies in several areas. These relate to agricultural technologies, bio-process technologies, sustainability issues and risk management. It is imperative for the bio-based chemical industry to develop innovative strategies from feedstock generation to final market access to ensure sustainability of the entire value chain. Feedstock generation will be located in sensitive rural economies in developing nations. Bio-based chemicals industry needs to understand and interpret changing technology and social landscapes to sustain its business and revenue models.

[This analysis is based on a presentation made at IGCW 2011, December, 2011 at Mumbai]