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REVIEW ARTICLE

The Indian Sugar Industry: An Overview

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Abstract Sugar industry is the second largest agro-based industry in India and contributes significantly to the socio-economic development of rural population. It supports 50 million farmers and their families and provides direct employment to over 0.5 million skilled and semi-skilled persons in sugar mills and integrated industries. The Indian sugar industry plays a leading role in global sugar market being the world's second largest producer after Brazil, producing nearly 15 and 25% of global sugar and sugarcane, respectively. The sugar industry which encompasses 599 operating sugar mills, 309 distilleries and 180 cogeneration plant and numerous pulp, paper and chemical making units is supported by four leading sugarcane research institutions, twenty-two state sugarcane research stations, world class sugar machinery manufacturers, suppliers and technical experts. Currently, the industry produces around 300–350 million tonnes (Mt) cane, 20–22 Mt white sugar and 6–8 Mt jaggery and *khandsari* to meet the domestic consumption of sweeteners. Besides, about 2.7 billion liters of alcohol and 2,300 MW power and many chemicals are also produced. The industry is able to export around 1,300 MW of power to the grid. Indian sugar industry is fully capable of meeting demand of potable alcohol as well as 10% blending in gasoline. Industry is gradually transforming into sugar complexes by producing sugar, bio-electricity, bio-ethanol, bio-manure and chemicals; these contribute about 1% to the National GDP. Emerging businesses like fuel ethanol, raw sugar and structural changes in global market have provided new horizons for the Indian sugar industry. The sector today has transformational opportunities that would enable it not only to continue to service the largest domestic markets but has also emerged as a significant carbon credit and green power producer and has the potential to support an ethanol blending programme of E10 and beyond.

Keywords Indian sugar industry · Economy · Sugar · Export potential · Molasses · Bagasse

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Introduction

India has been known as the original home of sugar and sugarcane. Indian mythology supports the above fact as it contains legends showing the origin of sugarcane The Indian sugar industry is second largest agro based industry in the country after cotton and has a turnover of US$ 10.25 bn per annum with a significant social and economic impact at the national level. Sugarcane is one of the most important industrial crops in the country occupying about 5.0 million hectares (Mha) in area. Sugar industry contributes significantly to the rural economy as the sugar mills are located in the rural areas and provide large scale employment to rural population. About 0.5 million people in sugar mills and 50 million sugarcane farmers, their dependents and a large mass of agricultural labour are involved in sugarcane cultivation, harvesting and ancillary activities, constituting 7.5% of the rural population. The sugar industry in India has been instrumental in accelerating the socio -economic development in villages through mobilizing rural resources leading to generation of employment, increase in income and overall improvement in facilities for transport and communication. Further many sugar factories have established schools, colleges, medical centers and hospitals for the benefit of rural population. A large number of sugar factories have diversified into

byproduct based industries and have invested and set up distilleries, organic chemical plants, paper and particle board factories and cogeneration plants.

The Indian sugar industry is a green industry i.e. self sufficient in its energy needs and also generates surplus exportable power through co-generation. The various by-products of sugar industry also contribute to the economic growth by promoting a number of subsidiary industries. Sugarcane has emerged as a multi-product crop used as a basic raw material for the production of sugar, ethanol, electricity, paper and boards, besides a host of ancillary products. The green tops of sugarcane are important source of bio-energy (feeding of cattle) and much in demand in rural area. Molasses is an important feed-stock for the distilleries and the large part of the ethanol requirements is met by the distilleries in the country. The ethanol requirement of the country is going up steadily; generation of electricity using bagasse has become a standard option for the sugar industry. The use of bagasse as a substitute raw material for wood pulp in paper industry is vital for economic and environmental sustainability.

Size of the Sector and Spread

India ranks second in cane area and sugar production after Brazil. The production of sugar is spread across the country and about 2.5% of cultivable land is under sugarcane. The states of Maharashtra, Uttar Pradesh, Karnataka, Tamil Nadu, Gujarat and Andhra Pradesh are the major sugar producing states in the country. In 2009–10, these six states together accounted for almost 94% of the total sugar produced in India. The State of Maharashtra and UP together account for almost 60% of the total sugar produced in India. UP is the largest sugarcane-producing state in the country and accounted for about 36.2% of the total sugarcane output in 2010–11 followed by Maharashtra with 23.6%. Even though, UP is the largest sugarcane-producing state in the country it is the second-largest sugar producer in India as drawal and recovery rates in UP are one of the lowest in India (Anonymous 2011).

The Indian sugar industry is marked by co-existence of different ownership and management structures since the beginning of the 20th century. There are about 660 installed sugar mills in India (STAI 2011), of which 324 in cooperative sector, 274 in the private sector and rest in state owned public sector. At one extreme, there are privately owned sugar mills in U.P. that procure sugarcane from nearby cane growers. At the other extreme there are cooperative factories owned and managed jointly by farmers, especially in the western state of Gujarat and Maharashtra. The plant size varies from 2,500 to 5,000 t cane per day and recently a number of sugar mill have expanded to a capacity of 7,500 to 15,000 t cane per day. There exists a huge growth potential due to factor like emerging energy dynamics, progressive demise of the subsidized sugar regimes, migration of rural population etc.

Tropical and Sub-Tropical Region

The major sugarcane producing states in the tropical areas of India includes Maharashtra, Andhra Pradesh, Tamil Nadu, and Gujarat. Sugarcane yield in these states are in the range of 70–100 tonnes per hectare (t/ha) which are substantially higher as compared to the sub-tropical regions. The sub-tropical regions include U.P., Bihar, Punjab and Haryana where the yield is around 40–70 t/ha as the crop faces severe weather conditions during its growth and maturity. The tropical belt accounts for 45% while the sub-tropical region constitutes around 55% of total cane area in the country. The cane yields are lower in the sub-tropics due to short growing season, moisture stress, frequent infestation of pests and diseases, high transit losses, floods and water-logging and very poor ratoons.

Contribution to the National Economy

Sugar factories are mostly located in rural areas and support substantial socio-economic activities in these areas such as education and rural infrastructural support. Nearly 50 million sugarcane farmers and their dependents are involved in sugarcane agriculture. Besides, the industry also provides employment to rural population directly or indirectly. In India sugar is an essential item of mass consumption and the cheapest source of energy, supplying around 10% of the daily calorie intake. Apart from sugar, sugarcane also supplements the energy sector through ethanol and electricity production. The decentralized sector which produces 6–8 Mt jaggery and *khandsari* also provides employment to rural population and has great export potential (Table 1).

A large number of sugar factories have diversified into byproduct based industries and have invested and set up distilleries, organic chemical plants, paper and particle board factories and cogeneration plants. The annual turnover of the industry in about Rs. 410 billion (U$ 10.25 billion) and the industry pays Rs. 25 billion (U$ 625 million) in taxes to exchequer (1 US$ = Rs. 45.00). Sugarcane crops and its products contribute about 1% to the National GDP which is significant considering that the crop is grown only in 2.57% of the gross cropped area. Contribution of sugarcane to the Agricultural GDP has steadily increased from about 5% in 1990–91–10% in

Table 1 Indian sugar industry and its importance in national economy

Area under sugarcane cultivation = 5.07 Mha
Subtropics = 2.74 Mha
Tropics = 2.33 Mha
Number of sugarcane growers = 50 millions
Number of people directly employed in sugar industry = 0.5 millions
Number of sugar mills installed = 660
Number of sugar mills functioning (2009–10) = 504
Average cane yield = 68 t/ha/year
State with highest sugarcane yield = 102 t/ha (Tamil Nadu)
Utilization percentage of sugarcane for sugar (2009–10) = 63.48%
Sugarcane production (million tonnes) = 355 Mt
Average duration of crushing = 140–150 days
Average crushing capacity (t/day) = 3,800
Sugar production (2006–07) = 28.37 Mt
Production of jaggery and *khandsari* sugar (2009–10) = 7.19 Mt
Molasses production = 13.10 Mt
Recovery of sugar = 10.19%
Highest sugar recovery recorded (Maharashtra) = 13.52%
Total sugar consumption = 23 Mt
Per capita consumption of sugar = 19.6 kg/annum
Total per capita consumption of sweeteners (including jaggery) = 29.2 kg/annum
Sugar exported (2009–10) = 2.0 Mt
Export potential of Indian sugar = 4–6 Mt
Closing stock of sugar (2009–10) = 5.30 Mt
Number of distilleries = 306
Annual installed capacity (2009–10) = 4.29 BL
Highest production of alcohol = 2.70 BL
Number of sugar mills with co-generation unit = 180
Potential of co-generation = 9,700 MW
Total co-generation capacity = 2,800 MW
Power supplied to the grid = 1,300 MW
Sugarcane price fixed by Central Government (FRP) = US$ 31/t
Average sugar price = US$ 625/t

2010–11. During the last two decades, the average annual growth of sugarcane agriculture sector was about 2.6% as against overall growth of 3% in agriculture sector in the country.

Growth of Sugar Industry

The growth of the sugarcane agriculture in the country had been spectacular (Table 2). From 1.17 Mha in 1930–31, the cane area increased to 5.1 million ha by 2006–07; almost a fourfold increase. During this period the productivity went up by from 31 to 68 t/ha, sugar production increased from 0.12 to 28.4 Mt. Sugar recovery also showed an improvement from 9.05 to 10.27%. The number of sugar factories went up form 29 to over 660 (including non-operating mills) at present with an annual sugar production of 24.1 Mt. The growth in cane and sugar production was contributed by two factors; a fourfold increased in cane area and improvement in productivity by more than 100%. Both these were possible because of the development of new, well adapted varieties, efficient crop production and crop protection technologies. After 1961, the production of sugarcane increased at a compound annual growth rate of 2.42%. This was due to increase in area (1.55%) and improvement in yield (0.86%). The improvement in sugar recovery during the period was only marginal. These achievements were possible because of the improved varieties, better agri-management practices and expansion and modernization of sugar mills which is well reflected in our record production of 28.4 Mt sugar during 2006–07. India has 20% of the total sugar mills in the world and accounts for about 15% of the global production. The interesting feature of the Indian sugar industry is that its growth is largely internal consumption centric i.e. it has its own domestic market and the production normally follows consumption except aberrations which takes place due to extrinsic factors.

Table 2 Decade-wise trends in sugarcane area, yield, recovery and sugar production in India

Period	Average cane area (Mha)	Average productivity (t/ha)	Average cane production (Mt)	Average sugar production (Mt)	Average sugar recovery %
1930–39	1.46	35.0	55.25	0.58	9.05
1940–49	1.41	34.0	48.36	1.03	9.38
1950–59	1.77	38.0	67.63	1.53	9.89
1960–69	2.37	45.0	106.11	2.76	9.83
1970–79	2.77	51.0	140.71	4.51	9.69
1980–89	3.04	58.0	175.98	7.11	9.99
1990–99	3.81	68.0	258.07	12.92	9.91
2000–09	4.38	68.0	290.69	19.01	10.27

Source Nair (2010)

Sugarcane Production and Pricing Policy

The Government of India (GOI) supports research, development, training of farmers and transfer of new varieties and improved production technologies to cane growers in its endeavor to raise cane yields and sugar recovery rates. The Indian Council of Agricultural Research conducts sugarcane research and development at the national level. State agricultural universities, regional research institutions, and state agricultural extension agencies support these efforts at the regional and state levels. The central and state governments also support sugarcane growers by ensuring financial services and input supplies at affordable prices. To increase the area of cultivation and production in the country, a centrally sponsored sustainable development fund for sugarcane based cropping systems is being implemented in various sugarcane growing states. Sugarcane is the main raw material for sugar industry and accounts for more than 70% of the total cost of production of sugar. It is also the major source of income for millions of farmers. The determination of price for sugarcane is therefore, a matter of critical importance both for the sugar industry and the cane growers. The Central government fixes a statutory minimum price (SMP) in respect of each sugar season. The SMP announced by the GOI every year is used as a benchmark by the state governments to fix their State Advised Price (SAP). The pricing procedure has been adopted so as to protect the farmers and ensure them a good price for cane. In 2009 the GOI announced a new system of fair and remunerative prices (FRP) that would link cane prices with sugar price realization by the sugar mills.

Sugar industry is one of the few industries that still remain under government control. Due to the politically sensitive nature of the industry, the government still continues to regulate sugar release; sugarcane procurement area and pricing of sugar cane. The GOI also regulates the release mechanism for sugar, classified as free sale sugar and levy sugar. Free sale sugar refers to the quantity that mills are permitted to sell in the open market. Levy sugar refers to the quantum of sugar that mills have to give to the government for sale through the public distribution system (PDS). Since 1993, the regulatory environment has considerably eased, but sugar still continues to be an essential commodity under the Essential Commodity Act. There are regulations across the entire value chain- land demarcation, sugarcane price, sugarcane procurement, sugar production and sale of sugar by mills in domestic and international markets.

Sugar Production and Marketing Policy

The GOI levies a fee of Rs. 240 ($5.4) per tonnes of sugar produced by mills to fund a Sugarcane Development Fund (SDF), which is used to support research, extension, and technological improvement in the sugar sector. The SDF is also often used to support sugar buffer-stocks operations, provide a transport subsidy for sugar exports, and provide an interest subsidy on loans for the installation of power generation and ethanol production plants. In March 2008, the GOI enacted the Sugar Development Fund (Amendment) Bill, 2008 that enables the government to include the use of the funds for debt restructuring and soft loans to the sugar mills. The GOI follows a policy of partial market control and dual pricing for sugar. The local sugar mills are required to supply 10 percent of their production to the government as levy sugar at below-market prices, which the government distributes through the public distribution system (PDS) to its below-poverty line population at subsidized rates. Mills are allowed to sell the balance of their production as free sugar at market prices. However, the sale of free-sale sugar and levy-sugar is administered by the government through periodic quotas, designed to maintain price stability in the market.

Social Welfare Programs

Indian sugar Industry has been a focal point for socio-economic development in the rural areas by way of mobilizing rural resources, generating employment, providing higher income opportunity, and transport and communication facilities. Further, many sugar factories have established schools, colleges, medical centers and hospitals for the benefit of the rural population. Sugar factories are now diversifying into byproduct based industries and have invested and started distilleries, organic chemical plants, paper and board factories and cogeneration plants. The industry generates its own replenishable biomass and uses it as fuel without depending on fossil fuel. Thus, the sugar industry has been a focal point for socio-economic development in the rural areas by mobilizing rural resources, generating employment & higher income, besides giving a fillip to transport and communication facilities.

Sugar Requirement in India: Sugar Vision 2030

The Indian sugar industry's shared vision is a reflection of the aspirations of key stakeholders- farmers, millers, consumers and the government. The sector has a vision for achieving high economic growth, improving cane productivity, minimizing risks, enhancing farmer-miller relationships, meeting growing domestic demand and contributing to the nation's food and energy needs.

Table 3 Projections of sugarcane and sugar requirements in India till 2030 to meet the domestic demand of sweeteners

Year	Area (Mha)	Yield (t/ha)	Cane (Mt)	Drawl %	Cane to be milled (Mt)	Recovery %	Sugar production (Mt)
2010	4.50	68.9	310	65	202	10.50	21.20
2020	4.50	88.5	398	65	259	11.00	28.50
2030	5.00	100	500[a]	65	325	11.00	35.75

[a] Projected requirements to meet the domestic demand of sugar. An additional 100 Mt cane would be needed to produce extra sugar for export, molasses for E20 blending and surplus bagasse for integrated industries

The Indian sugar industry is capable of meeting sugar demand of most populated nation in the world (1.31 billion). The consumption of sugar in India has been growing at a steady rate of 3% and is currently at 23.0 Mt; per capita consumption at 19.6 kg white sugar indicates potential upside from a demand standpoint. The current production can meet the domestic requirements with occasional surplus. Despite being the second largest producer of sugar, Indian export share is minimal due to huge domestic demands and occasional fluctuation in sugar production. With the extensive research and development support, the current sugarcane agriculture is able to meet the huge domestic requirement, which otherwise would have warranted massive imports. However, meeting such huge demands of domestic requirements is an important contribution of sugarcane agriculture to the food security of the country.

The sugar requirement of the country is growing consistently with the population growth. Sugar consumption in 2010–11 and 2011–12 are expected to increase to 24.5 and 26.5 Mt, respectively due to improved domestic supplies and strong demand–fuelled by a growing population and continued growth in economy (Anonymous 2010). Many bulk consumers of sugar such as bakeries, candy, local sweets, and soft-drink manufacturers account for about 60 percent of mill sugar demand. Most of the *khandsari* sugar is consumed by local sweets manufacturers; jaggery is mostly consumed in rural areas for household consumption and feed use. The population in the country is set to reach 1.50 billion by 2030 at the present compound growth rate of 1.6% per annum. The projected requirement of sugar for domestic consumption in 2030 is 36 Mt, which is about 50% higher than the present production. To achieve this target, the sugarcane production should be about 500 Mt from the current 350 Mt for which the production has to be increased by 7–8 Mt annually. The increased production has to be achieved from the existing cane area through improved productivity (> 100 t/ha) and sugar recovery (11%) since further expansion in cane area is not feasible. In view of the high cost of imports and the strategic importance of food security, India would need to target its production in excess of domestic consumption. The emerging need of energy will require additional ethanol for blending in petrol and it is presumed that all possible routes of ethanol production viz. molasses, direct fermentation of cane juice and cellulosic ethanol will be utilized to meet the demand. Besides, the demand for integrated industries like paper, pulp, energy and other alternative sweeteners etc. also has to be taken into account. According to author, around 600 Mt of sugarcane, 125–140 Mt bagasse and 18–20 Mt molasses will be needed to have exportable surplus of sugar and meet the requirements of integrated industries.

The projected sugar requirement for 2020 is 28.50 Mt which the country has achieved in 2006–07 itself. It indicates that the prevailing varieties, agro-technologies and processing technologies are good enough to achieve the projected target (Table 3). This also signifies that both cane and sugar sectors in the country are capable of meeting the sugar and energy requirement of the country in 2030.

Constraints in Sugarcane Production

Sugarcane is grown under a wide array of agro-climatic conditions in India extending from the tropics to sub tropics. The crop experiences various types of biotic and abiotic stress, which affect the productivity. The cane productivity in tropical India is comparatively higher due to even sunshine all through the year, well distributed rainfall and ideal conditions for the luxurious growth. Whereas in the subtropics crop experiences pronounced winter, which affects sprouting and growth, erratic rainfall and drought and high temperatures during late season. Consequently the productivity in the subtropical regions is relatively low compared to the tropical regions. The average yield in tropical India is about 80 t/ha and about 60 t/ha in sub tropical India. At national level productivity hovers between 66 and 70 t/ha/year. The average sugar recovery in the country is about 10%, with Maharashtra state leading the table with the highest recovery of over 11.5%, due to the ideal climatic conditions prevailing in the state for sucrose accumulation.

Sugar Cycle

The Indian sugar industry is cyclical in nature and follows predictable cycle of at least 4–5 years. Shortage of sugar leads to an increase in prices. Mills pay higher prices for cane which tempts the farmers to switch to sugarcane. This

result in a glut in both cane and sugar and this depresses sugar prices. Cane payments to farmers get dwindled and delayed as inventory buildup; farmers switch to other cash crop which leads to a fall in sugarcane and sugar production. The consequent shortage of sugar results in an increase in sugar prices. This of course, does not take into consideration the effect of monsoon, which also have similar consequences. The sugar production in India has fluctuated between 12 and 28 Mt. In view of this, Central and State Governments are announcing better cane prices to minimize the cyclicality in cane production. The Indian sugar industry lacks the flexibility of the Brazilian sugar industry, where the processing of cane for sugar or alcohol depends on the prevailing market trends with respect to these commodities, which ensures sustained growth and profitability of the industry (Hapse 2011).

Yield Gaps

The experimental maximum yield in sugarcane is 325 t/ha, which is hardly achieved though individual farmers have reported yields close to this. There is a wide gap in productivity between the tropical and the subtropical regions of the country, the former averaging about 80 t/ha and the latter 60 t/ha. Wide gap exists between the potential yield and the yield levels achieved at present in all the states/regions without exception.

Cost of Sugarcane Production

Sugarcane is a labour and input intensive crop which remains in the field for more than a year. The cost of cultivation of sugarcane has gone up significantly due to the increase in cost of labour and inputs. Cost of production in different regions vary from Rs. 45,000/ha (US$ 1,000) to Rs. 100,000/ha (US$ 2,500) depending upon the practices adopted and prevailing cost of inputs and labour. The cost of harvest in some areas is more than 25% of the total cost of production due to non-availability of laborers' and therefore agro-technologies suited for mechanization has become imperative to tackle this problem. The spiraling cost of fertilizers is another major expenditure in sugarcane agriculture (Deshmukh 2011).

Declining Soil Health and Productivity

There had been no improvement in sugarcane productivity in the country for the past two decades which is hovering between 65 and 70 t/ha/year. This productivity level has not changed despite the introduction of improved varieties and better management technologies. Continued monocropping of sugarcane for several decades have depleted the soil fertility considerably. Productivity of the soil has come down and soil management concerns like physical, chemical and biological degradation and declining organic carbon content are also becoming increasingly relevant.

Abiotic Stress

Abiotic stress such as salinity, alkalinity, drought and waterlogging affect cane production significantly in many States. Approximately 2.97 lakh ha of cane area is prone to recurrent drought, affecting the crop at one or other stage of growth and brings down the yields by 30–50% and in severe drought situations the loss could be as high as 70%. Floods and waterlogging are serious problem in Eastern UP, Bihar, Orissa, Coastal Andhra and Kolhapur area in Maharashtra. Approximately 2.13 lakh ha of sugarcane area is flood prone in different States. Waterlogging affects all stages of crop growth and can reduce germination, root establishment, tillering and growth resulting in yield reduction. Sugarcane is cultivated in about 7–8 lakh hectares under saline condition. Though the crop is moderately tolerant to salinity, the losses are significant.

Depleting Water Resources

Sugarcane is a water intensive crop. It requires about 30–40 irrigations on an average in tropics. In many cases this is hardly possible, which invariably affects the crop yield. Moderating the water use for sugarcane cultivation is the need of the hour, since water is a limited resource. In this context micro irrigation systems have greater relevance. Continued mono cropping has also resulted in depletion of water resources at an alarming rate.

Diseases and Pests

Sugarcane diseases and pests are constraints to crop production throughout India and losses due to disease are estimated to be about 10–15%. Among them red rot, smut, wilt and sett rot are the important fungal diseases. Bacterial diseases like leaf scald disease and ratoon stunting disease are found to cause considerable yield loss in certain regions. Among the viral diseases mosaic is prevalent in all the States however its severity is felt in specific situations. Besides these, grassy shoot caused by phytoplasmas is also a potential disease, which can cause considerable damage to sugarcane production. Emergence and spread of newly recorded yellow leaf disease has become a major constraint in many locations. Borer pests, pyrilla, scale insect, white fly, termite and mealy bugs are present almost throughout the country and one of the major constraints in achieving the targeted productivity in sugarcane.

Climate Change

The Indian sugarcane industry will also be influenced by the impacts of climate change (rise in the temperature, decreased or altered rainfall pattern, drought, floods, waterlogging, increased CO_2) and an understanding the long-term impacts of climate change and climate variability is essential. High temperature is likely to impact plant growth, yield (yield reduction 20–30%) increased weed competition, increased incidence of pests and diseases and most importantly juice sucrose content *vis-à-vis* recovery. The sucrose losses in standing crop (stand-over) and after harvest (post-harvest) are bound to increase due to high temperature. If the industry is to minimize the risks associated with climate change, every sector needs to be aware of what impacts such change could have right along the value chain. It is also imperative that futuristic research strategies concerning improved cane production, sugar recovery and disease and pest management be made keeping recurrent and unpredictable changes in environment.

Sugarcane agriculture could be sustained only if the profitability can be ensured by reducing the cost of cultivation and improving the productivity per unit area. This is possible through new research innovations, mechanization and technological interventions in cane agriculture. In view of the food and energy security concerns of the country, especially when the cane area is limited, systematic research and development efforts on sugarcane is required especially in sub-tropical region where cane yield and sugar recovery need to be improved substantially.

Indian Sugar Industry: Transformation Opportunities

Productivity Improvement Opportunities

Given the projected growth in domestic and international markets, the sector would need to produce at least 600 million Mt of sugarcane by 2030 to meet domestic requirement of sweeteners, bioelectricity and ethanol for E 10 blending. Increase in sugar production would be primarily through productivity improvements and increment in milling capacity of existing mills. The sector has the potential to improve sugarcane yields to 100–120 t/ha and also improve the recovery to 11.0–11.5% by 2030. This would enable the sector to produce additional 6.0 million Mt of sugar over and above the domestic requirements. The cane area will remain around 5.0 Mha and this would also ensure minimal impact on other crops. A higher drawl or greater increase in farm productivity will also enable the target demand to be met, without any substantial increase in cane acreage. In order to crush the additional cane, the crushing capacity would need to increase which can be met through expansion of the existing units rather than new mills being established. In order to improve sugarcane and sugar productivity per unit area, greater investments in research and development of seed nurseries, cane varieties, bio-fertilizers and adoption of improved farm practices will be key imperatives. Some important drivers which may help in increasing cane productivity are:

- Location specific recommendation of varieties, fertilizers and micro-nutrients and agri-management practices,
- Enhancing productivity of ratoon cane and multi-ratooning,
- Use of growth regulating chemicals in specific situations viz. winter sprouting, plant population management, late-planting,
- Application of combination ripeners in certain locations/varieties to advance cane maturity and improve sucrose content,
- Development and cultivation of improved varieties (high tonnage, moderate sugar and high biomass) tolerant to major biotic and abiotic stress with longer field stability,
- Improved nutrient efficiency through rhizosphere engineering and INM technology
- Improved water use efficiency through micro- irrigation
- Land use efficiency through companion cropping,
- Biological umbrella for major diseases and pests in the country i.e. IPM and IDM,
- Mechanization of sugarcane farming esp. planting, harvesting and ratoon management,
- Use of bio- fertilizers (*Azospirillum*, *Gluconacetobacter, Herbaspirillum* and Phosphobacteria)
- Residue recycling and improving carbon sequestration efficiency,
- Use of IT in crop management; GPS/GIS in disease surveillance and crop management,
- Innovative crop management strategies to mitigate the adverse impacts of climate change,
- Management of post-harvest sugar losses in field and milling tandem,
- Improving the overall technical efficiency of sugar units; minimizing process losses.

Going forward, the sugar industry would have to play a greater role in funding research initiatives for cane, and work closely with research institutes for setting a focused research agenda. It will also have to identify relevant future research activities according to their specific needs. Also, the government's share of investment in agriculture in the areas of irrigation technologies, pest and disease management and seed variety development needs to increase to enhance sugarcane productivity. Government has sponsored

Sustainable Development of Sugarcane Based Cropping System in 22 states and union territories to help farmers to improve their production and productivity of sugarcane.

Cyclicality Management Opportunities

The sugar sector is frequently impacted by cyclicality. This cycle is caused by natural cyclicality like climatic variations, pest, drought etc., as well as induced cyclicality. The high sugar and sugarcane prices lead to increase in production at the cost of other crops. The resulting low prices for sugar impact the ability of mills to pay the farmers, thus leading to creation of arrears. High arrears lead to a significant fall in cane cultivation in the next year, leading to high sugar prices and increased attractiveness of cane. Cyclicality management is the opportunity to minimize arrears, thereby reducing the need for any financial support from the government. The removal of arrears would also remove induced cyclicality; thereby reducing the incidence of surplus and deficit production phases. Economically, this would translate into reducing the incidence of excess inventory build up in surplus phases and the need for potentially costly imports and government support during deficit phases. Thus, ensuring the alignment between sugarcane and sugar prices would be the major policy imperative for managing cyclicality. The farmer's economic profit is impacted by the cane price, farm productivity and the cost of cultivation. The key controllable risks for farmers are the risks related to off-take of cane and non payment of dues by the mills and therefore, the farmer-miller relationship can have a significant impact on both these risks (Anonymous 2007). The sustainability in sugarcane production is another important issue in cyclicality management.

Domestic Demand Opportunities

In 2010–11, the domestic sugar consumption is estimated to be 24.5 million Mt. It is expected that the drivers for consumption i.e. the GDP growth and population growth would continue to grow at current rates. Based on the past growth in consumption and estimates from various independent sources, it is expected that in 2030, the domestic white sugar consumption would be approximately 36 million Mt. Given the high cost of imports and the strategic importance of food security, India would need to target its production in excess of domestic consumption. It is imperative that farm and mill efficiency be improved at all levels to achieve the desired sugar production. The experimental maximum yield in sugarcane is 325 t/ha/year and considerable scope exists to augment sugar production in field through use of improved varieties, plant protection measures and better agri-management practices. In 2008 world sugar consumption grew by a healthy 3.8%, to 163.1 Mt. World per capita consumption also increased to 24.5 kg; in India this is still around 19.6 kg which is much below the world average indicating great potential for the industry in imminent future. The consumption of white sugar in India is generally urban based; in rural areas the alternative sweeteners i.e. jaggery and *khandsari* are consumed predominantly. The consumption of sugar in urban areas in some of the states of Indian union with high GDP and income level (Punjab, Haryana, Maharashtra, Gujarat and Kerala) compare favorably with various developed countries (USA, Switzerland, Netherland, Brazil and Australia). The growth in sugar consumption in India has been quite impressive and is higher than the average world sugar consumption (Table 4). The fulfillment of rising domestic demand of sugar is first and foremost challenge before the industry.

International Trade Opportunity

International trade is of strategic importance to India as it can help maintain stability in the domestic market, despite the cyclicality in production. If there is a sugar surplus either due to excess production or due to greater economic attractiveness of cane for ethanol and co-gen in the future, exports could be used if the surplus cannot be managed in the domestic market. Acceptability as a credible exporter will provide the Indian sector an alternate set of markets for diverting surplus sugar production. Similarly, in case of deficits, raw sugar imports could help bridge the supply gap. India has the potential to export to major Indian Ocean markets, due to freight competitiveness with respect to key competitors, Brazil and Thailand. With EU exports gradually reducing world prices of sugar are expected to increase and this could potentially make exports more viable for India. However, due to the increasing emergence of destination refineries, key markets are importing greater share of raw sugar, and India's competitiveness for raw exports is relatively lower as of today. Currently, India's

Table 4 Growth in production and consumption of white sugar in India and world

	1990	2001	2010	Growth
India				
Production	12.1	19.9	24.7	200
Consumption	11.1	17.2	24.5	225
World				
Production	110.4	130.6	168.9[a]	150
Consumption	108.7	130.9	167.6[a]	150

[a] ISO estimates

competitiveness is higher in markets, where share of white sugar imports as percentage of cumulative imports is higher. Going forward, India would need to build the capability to produce raw sugar and refined sugar of international quality standards, in order to leverage the export opportunity.

India would be able to leverage this opportunity through productivity improvements and alignment of cane and sugar prices in the domestic market. India's competitiveness can also be increased by enhancing export infrastructure like loading rates and draft in Indian ports. In case of surpluses, exports would enable lower stocks in the domestic market, thus benefiting both mills and farmers through higher sugar realization. In 2011–12 sugar production in India will be around 26.5 Mt and country has the potential to export 4.0 Mt compared to around 2.6 Mt a year ago. India is located close to major sugar deficient markets. The Indian Ocean countries of Indonesia Bangladesh, Sri Lanka, Pakistan, Saudi Arabia, UAE and some East African countries are sugar deficient and import sugar regularly. India has a natural freight advantage to these countries due to its geographical proximity. Historically, India has exported sugar to the identified deficient countries. During years of surplus domestic production, India can export to these geographies. To be able to export to the target markets, India would need to improve its cost structure through productivity and efficiency improvements in the long term. In addition, to export raw sugar, mills would need to make the necessary investments. Currently, India only produces plantation white sugar. Considering that export demand for raw sugar and refined sugar of 45 ICUMSA will increase. India would need to develop the capability to produce these varieties in order to leverage the export opportunity.

Recent developments in the Global Ethanol Market suggest the emergence of ethanol as an internationally traded commodity. Demand growth is robust, and for the first time, strongly supported not only by higher oil prices and greater need for energy security, but perhaps more importantly, by global environmental and sustainability concerns. Bio-fuels, such as ethanol, are central to worldwide efforts to abate greenhouse gases and mitigate climate change. Reports indicate that bio-energy could supply a maximum of slightly more than thirty percent of total global energy demand. India has much under utilized land and natural resources that could be used to significantly expand liquid bio-fuels production if oil prices stay high or increase further and become a leading exporter of ethanol like Brazil.

Diversification Opportunities

The sugar industry co-products viz. bagasse, molasses, press mud are vast potential reserves for human and animal consumption as well as capable of providing energy as renewable source. The sugarcane and its by-products are useful raw material to over 25 industries such as ethanol, pulp and paper, boards, pharmaceuticals, and many valuable chemicals. The Indian sugar industry has necessary technology to tap their commercial potential in the following ways.

Fuel Ethanol

Fuel ethanol and surplus power production through co-generation provide the two key by-products' related opportunities. Globally energy security and environmental concerns are driving the adoption of fuel ethanol across countries. Leading countries including Brazil, U.S., EU, Australia, Canada and Japan have established fuel ethanol programmes. In the future, global fuel ethanol demand is likely to grow exponentially. Global ethanol exports, currently at 6.5 billion litres are expected to increase to 50 to 200 billion litres by 2020. This increase would largely depend on world crude prices and regulatory evolution. India also faces similar environmental concerns and an increasing energy demand and would need to consider developing fuel ethanol programmes with high levels of blending.

The GOI approved the national policy on bio-fuels on December 24, 2009. The biofuel policy encourages use of renewable energy resources as alternate fuels to supplement transport fuels (gasoline and diesel for vehicles) and proposes a target of 20% bio-fuel blending (bio-ethanol) by 2017. Presently, the government is unable to implement compulsory blending of 5% ethanol in petrol (gasoline) due to the short supply of sugar molasses in 2009–10 and 2008–09 because of overall low sugarcane crop production in India. With a bumper sugarcane and sugar production outlook for 2010–11 and in subsequent years, the government is likely to renew its focus and implement the mandatory 5% ethanol blending in petrol.

At present there are about 309 distilleries operating in the country which have a total installed capacity of 4,000 million litres of alcohol in a year are totally dependent on sugar production. The estimated ethanol requirement for fuel, potable and industrial use would be 5,700 million liters in 2030 which means that the production should be more than double to meet the projected requirements. The regulatory environment will need to facilitate the transition to higher blending programme through necessary changes that would be made to the sugarcane control order. Higher levels of blending will also need mills having the flexibility to shift from sugar to ethanol, based on market dynamics.

Bio-Butanol

Sugarcane ethanol today is made predominantly from the cane molasses. This current process taps only one-third of

the energy sugarcane can offer. The other two-thirds remains locked in leftover cane fiber (bagasse) and straw. Bio-conversion of sugarcane bagasse and cellulosic biomass to ethanol and butanol is another emerging area which requires huge R & D investments. This is particularly important for countries like India, where scope for increasing the production of ethanol from molasses or sugarcane juice is very limited. However, the limitation so far had been the lack of cost effective technologies to convert bagasse to ethanol. Butanol—a promising next-generation biofuel—packs more energy than ethanol is an aliphatic saturated alcohol that can be used as a transportation fuel. Butanol has higher octane value than ethanol, can be used in the existing engines and is non- hygroscopic and non corrosive to engines. Butanol can be produced from sugarcane juice and molasses using bacterial strains. Researchers from the Tokyo University of Agriculture reported butanol production from crystalline cellulose by co-cultured *Clostridium thermocellum* and *Clostridium saccharoperbutylacetonicum* N1–4. New strains of *Clostridium bejerinckii* capable of efficient conversion of sugarcane juice and molasses to butanol had been identified and the technology holds promise as an alternate bio-fuel.

Bio-Plastics

Sugarcane ethanol has emerged as an important ingredient to substitute for petroleum in the production of plastic. These so-called "bioplastics" have the same physical and chemical properties as regular plastic (the most common type is known technically as polyethylene or PET) and maintain full recycling capabilities. The green plastics and polyethylene made from sugarcane bagasse have huge market potential. Each metric ton of bio-plastic produced avoids the emission of 2–2.5 metric tons of carbon dioxide on a lifecycle basis. Use of bio-plastics is still developing and there is a great potential in India. A number of leading companies have established themselves as major players in this emerging area.

Bio-Hydrocarbons

Bio-diesel from sugarcane is one of the most successful examples of bio-hydrocarbon production in Brazil. Farnesene, a chemical compound that can be the basis for a number of renewable chemicals, including diesel fuel is produced from sugarcane. Amyris Biotechnologies, based in California, is one of the pioneers in developing farnesene. In partnership with its Brazilian subsidiary, São Martinho Group, Amyris is producing sugarcane-based diesel that is currently being tested by the city of São Paulo, Brazil. Bio-based hydrocarbons will have great scope in near future, General Electric (GE) and Amyris are planning to stage the first-ever sugarcane jet fueled flight in 2012.

Power Co-Generation

For the cogeneration opportunity, in 2030, there is a total exportable power potential of approximately 9,700 MW. Promotion of cogeneration and generation of electricity from renewable sources is a declared policy of the GOI. Cogeneration based on bagasse and cane biomass is an environmentally safe and viable option to augment the power requirements of the country. The current installed capacity is only 2,200 MW and the capacity realization to the extent of 5,000 MW has to be achieved to suitably augment the growing power requirements. This is possible only when the sugar plants operate to their full capacity to generate the required quantity of bagasse. The sector can also generate around 50 million carbon credits through co-generation. Obviously the cane availability (production) should increase to meet the capacity utilization of the mills. In this direction development of high biomass, high fiber and moderate sucrose varieties will be of immense use to the Indian sugar factories. The ethanol production and cogeneration are totally dependent on sugar production as the respective feed-stocks are generated as byproducts during the sugar production. If the sugar production goes up the cogeneration and ethanol production will also correspondingly go up.

Paper and Pulp Industries

Bagasse pulp is an ideal substitute for wood pulp in paper industry. The large scale use of wood pulp for paper manufacture is of grave concern for environmentalists, in view of the dwindling forest resources. This has forced the Industry to look for alternative raw material for paper production. Sugarcane bagasse, which has comparable fiber properties, has been used for paper manufacture in India and Thailand since long. At present sugarcane bagasse accounts for nearly 20% of all paper production in India, China and South America. The paper industry utilizes 10% of the world bagasse production.

The future of Ethanol is locked in bagasse and therefore new and innovative methods are needed to utilize this precious resource. Around 100–125 Mt bagasse would be available by 2030 and 50% of this could be diverted for the commercial production of ethanol/butanol, paper, bio-plastics and other industrial products. The following areas will be of much practical and economic significance:

- Development of energy cane (high biomass/fiber),
- Replacement of bagasse with trash or other crop residues as boiler fuel in a phased manner,

- Energy plantation in mill area to be used as fuel & save bagasse; use of degraded lands for biomass production
- Suitable microbial consortium for conversion of cellulosic biomass to bio-fuels and improving the fermentation efficiency.

The sugarcane agriculture and sugar industry in India offer immense potential to produce food, feed, fibre and energy, particularly co-generation of electricity and ethanol. Strong linkages between world sugar and oil prices have emerged in recent years, driven in part by the relationships between sugar as the primary ethanol feed-stock. Global demand for fuel ethanol has increased significantly over the past few years, driven by concerns over energy security, environmental sustainability and the need to mitigate climate change through the reduction of greenhouse gas emissions. According to F.O. Licht survey, 61% of world ethanol production is from sugar crops (sugar-beet, sugarcane or desugarization of cane and beet molasses). The linkages between sugar, oil and ethanol prices are clear and very important considerations as the ethanol market continues to develop. At the world level, it is estimated that about 15 percent of sugar crops are converted into ethanol rather than sugar. India, which is second largest producer of sugarcane and has tremendous potential to augment productivity, could be a major player in global sugar–ethanol market. The future growth of the sector would need to rely heavily on productivity and efficiency improvements especially at plant and farm level. In order to attain higher sugar productivity (>10 t/ha/yr) it is imperative that the R & D challenges in sugarcane development are revisited afresh with a clear cut focus, renewed approach and newer tools, encompassing agro-technology, biotechnology and active national & international collaborations. Efficiency improvements at the mill side will enable greater production, sugar factories will have to gradually transform into integrated sugar–ethanol–power–chemical complexes without added pressure on scarce resources. The cyclicality in the sugar industry is partly natural and partly induced, necessary incentive related to cane and sugar pricing would minimize the induced cyclicality and promote mechanisms that would enable better management of the downturn. Greater participation in international trade of Sugar–Ethanol by the Indian industry would be a necessary futuristic strategy and will help keeping the sugar industry viable and vibrant.

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