Accelerating India's Sustainable Energy Future by Leveraging BioSolutions

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Abstract

Biotechnology has been proved instrumental in addressing energy needs across the globe. In India's transition to sustainable energy mix, biotech is already playing and will continue to play a pivotal role. In addition, the benefit derived from biotechnology would benefit the entire value chain, spanning from farms to fork. India has benefited by introducing a sharp focus on ethanol mandate, with varying substrates. During the last 10 years the ethanol blending initiatives have enhanced farmer incomes, increased rural employment, reduced carbon dioxide (CO_2) emissions equivalent to planting 1.75 crore trees and resulted in savings of INR 85,000 crore worth of foreign exchange. While it is a great step forward, biorefining could leapfrog India into a league of select countries with a truly sustainable energy mix. There are challenges, as in any new technology adoption. However, they are surmountable and can be addressed through interventions by Industry and Policy.

1. Introduction

India is the 3rd largest energy consumer in the world and so India recognizes the need to balance development with environmental concerns and has set targets to achieve net-zero emissions by 2070. According to MOSPI (2024 Energy Statistics) the energy consumption of India in 2023 was 552 kToE2. And during 2022-23 out of the total energy production of 847 kToE, around 4 percent was from renewable energy sources. With a strategic goal to feed the growing energy needs sustainably, India is diversifying its energy mix expeditiously. The Government of India has been supporting emerging technologies through different approaches – allowing them to be deployed, at scale. If India needs to grow, all relevant sustainable technologies will be part of the solution, or they will co-exist to secure India's future energy. One of the promising ways to ensure sustainable growth, especially in terms of energy production and consumption, is to utilize renewable natural resource. Biosolutions offers a unique path for it and has been found helpful in addressing energy needs across the globe. In India's transition to a more sustainable energy mix, biosolutions are already playing and will continue to play a pivotal role. In addition, the advantages derived from biosolutions would benefit the entire value chain, spanning from farm to fork. India is the 2nd largest

producer of agricultural waste in the world, generating about 500 million tonnes per year, of which more than 50 percent is either discarded or burned. Over the next few years, integrating various possibilities under biorefining could generate significant value to India's energy or chemical sector. For example, in the case of bioethanol, India has benefited from introducing a sharp focus on ethanol mandate, with varying substrates. During the last 10 years, the ethanol blending initiatives led to enhanced farmer incomes, increased rural employment, reduced CO_2 emissions equivalent to planting 1.75 crore trees and savings of INR 85,000 crore worth of foreign exchange. The opportunities are almost boundless with biorefining.

2. Energy Needs of India's Transportation Sector

Transportation is the 2nd largest energy consuming sector (outside of industrial sector), accounting for 11.7 percent of India's total energy consumption. Most of the sector's energy needs are serviced through liquid fuels (petroleum products w/o blended with ethanol), followed by compressed natural gas (~13 percent). Around 3/4th of the energy consumption is attributed to road transport, followed by aviation space at 12 percent share. It is interesting to note that energy consumption in transportation has increased by a significant 83 percent between 2013 and 2023 (~2x vs. growth in overall energy consumption), contributed by growth in vehicle penetration and usage or miles driven. The ever-growing energy needs in the transportation sector come with certain headwinds including carbon emissions. According to an IEA report, road transport presently accounts for 12 percent of India's energy-related CO2 emissions and is a key contributor to urban air pollution. As India seeks to meet the increasing demand for private mobility and the transport of goods, energy use and CO_2 emissions from road transport could double by 2050. This is particularly important in the context of Government of India's focus on becoming a net-neutral economy by 2070. To achieve various milestones towards this ambition, decarbonization of transportation will become key. Similar to other sectors, the transportation sector is also transitioning to a more diversified energy mix, consisting of hydrocarbon fuels, bio-based fuels, CNG and electricity etc. Many other technologies such as Sustainable Aviation Fuel (SAF), hydrogen, fuel cell, methanol are in different stages of development for potential deployment in future, poised to support decarbonization initiatives. Globally, oil constitutes 88 percent of the energy used, while natural gas and biofuels contribute 6 percent and 4 percent respectively and electricity accounts for 1 percent. Mobility electrification is a dominant theme for energy transition across the globe, with many countries aiming to have Electric Vehicles (EVs) as a large share of new vehicles sales.

India is no exception, and it is projecting to have 30 percent of new vehicle sales to be powered by electricity by 2030. In FY 2024, EV penetration (of new vehicle sales) in India's road transport stood at 6.8 percent. While the penetration levels of EV are going to increase over the next decade, it needs to keep pace with a higher share of renewables (in power generation) to realize the intended ambition of decarbonization. As of 2023/24, the share of renewables in India's electricity generation is less than 22 percent. The energy mix is expected to change with new renewable capabilities to come online, however, the transition will be gradual. It means India will start realizing intended benefits of mobility electrification only once the share of renewables is scaled up significantly. A study opines that India needs about four-fifths of the electricity from greener sources if environmental benefits are to be accrued from transition to e-vehicles. It also means India needs to keep investing in decarbonizing liquid fuels for a foreseeable future which concurs with projections of the research paper, indicating relevance of liquid fuels in an average case - until 2051. In India, the development in the EV space coincides with the government's push towards

biofuels blending mandates and broad-based industry incentivization. The results of these policy interventions are very turning to be positive, with substitution of over 6.5 billion liters of gasoline by 2025. The biofuel ecosystem is expanding well to realize the 20 percent blending goal and will continue to complement the energy transition in road transportation space along with gradual electrification. Besides, the potential of biosolutions could be leveraged to further decarbonization ambitions in different transportation sectors and bring about a leapfrog change in the chemical space. Alongside current energy transition efforts, India could assimilate practices from regions who are in different phases to transition to sustainable energy future in transportation. Notably, Brazil which introduced the Proálcool plan, an initiative aiming to reduce the country's reliance on foreign fossil fuels by blending petrol with ethanol, investing heavily in research and development, expanding sugarcane cultivation, and increasing the capacity of ethanol plants. In the country, ethanol blending had been steadily increased to 27 percent, complemented by development of a strong ecosystem to support flex fuel vehicles (operating on E85/ E100 fuels) and a mandate to achieve 15 percent biodiesel inclusion. Thailand is also making strides to increase blending mandates (across road transport and aviation) in a growing domestic transport sector, using bio-based fuels.

3. Biorefining for a Sustainable Future

A strong biosolutions-enabled ecosystem (or Biorefining) has the potential to catapult India into an energy resilient economy, with a clear sight on realizing its sustainability ambitions. Biorefining concept assimilates multiple biological processes and transforms bio-feedstocks into fuels, power, heat, feed and other value-added materials/ chemicals. Because of this, biorefining plays a crucial role in the reduction of global carbon emissions and holds great potential to continue delivering even lower carbon emissions in the future. The central tenants of biorefining could provide[12a]:

3.1 Complementarity in Energy Supply and Demand

The biorefining platform plays an integral role in bringing together the green energy matrix and achieving its complementarity in both the supply and demand of energy.

- In the production of energy, the biorefining platform is valuable as a source of storable heat and power to balance intermittent power generation. Battery technology may be sufficient to economically stabilize sub-second or intraday variability, but storage of co-products from biorefineries (e.g., biogas, lignin, and vinasse) can provide longer-term low-cost grid stabilization.
- The end-use of biorefining products in the transport sector is complementary with other important ways to reduce GHGs emissions, such as improved fuel efficiency and electrification.
- In hard-to-electrify transport, sustainable biofuels are not only useful as a drop-in fuel for conventional drive trains based on combustion engines, but also as a fuel that is complementary with new drive system developments.

3.2 Adaptability and Scalability of Biorefineries

The ability of the biorefining platform to evolve over time is based on its compatibility with many types of downstream processing such as:

- Fermentation to ethanol or higher alcohols
- Further processing (i.e. catalytic conversion) of alcohols to other hydrocarbon fuels (e.g. gasoline, diesel, jet fuel) and chemicals
- Chemical catalysis or combination of biological and chemical catalysis of sugars to hydrocarbon fuels and chemicals
- Side streams from cellulosic biorefineries include off-gas or flue gas from the thermochemical process, or lignin and biogas from the biochemical process – all of which can be used flexibly for heat and power in the integrated energy matrix.

As light-duty road transport becomes increasingly electrified, biorefineries can adapt their process to transform the same feedstock to produce liquid fuels with higher energy density for heavy-duty road and marine transport. Even if electric motors eventually dominate all transport except aviation, the same biorefineries can shift production to jet fuels.

3.3 Carbon Capture Viability: The high-concentration stream of CO_2 emitted from (anaerobic) fermentation processes translate into a low-cost way to capture carbon. Carbon pricing that facilitates deployment of carbon capture and storage technologies at a biorefinery could enable negative carbon emissions, which are essential to keep global temperature increase below 2 ^{0}C in almost all climate scenarios.

3.4 Supports Ecosystem: Biofuels such as cellulosic ethanol expands revenue streams for farmers and generates commercial opportunities around aggregation and logistics. The co-products originating from corn-based ethanol support the animal feed industry through high-protein dried distillers grain solids (DDGS). Any new technology deployment entails a set of headwinds in any space, biorefining is not an exception to this cardinal rule.

3.5 Building A New Ecosystem: India's advanced biofuel infrastructure development is led by Oil Marketing Companies (OMCs)– which is critical to demonstrate technical and commercial viability. In the future, to attract private investment in second-generation (2G) and larger biorefining space, government interventions would be needed to scale up infrastructure deployment - through longer policy timeframes/ stability and use of financial instruments to promote capital investments. This is in addition to the significant development in the production capacities in the first-generation (1G) space, led by private players.

Scaling up the collection o**f** ag residues is one of the keys to the development of a cellulosic ethanol industry in India. The government administered agricultural residue price in India is much lower than other countries. If the price is raised by 50 percent to INR 5,300/tonne from the current average of INR 3,500/tonne, the levelized cost of production for cellulosic ethanol would only increase by less than 6 percent. At the same time, setting higher prices for agricultural residues could provide significant financial incentive to farmers in crop collection1. In addition to any financial incentives, local governments could also develop training and facilitation programs to address difficulties along the crop residue collection process.

3.6 Managing the Operational Costs: Advanced biofuel production such as 2G needs higher operational costs, because of the need for early-stage technological advancements. However, there are multiple precedence in past, where a clear policy direction and support has led to the sector to evolve and thrive. The success attained with solar photovoltaic cells and lithium-ion batteries (LIBs) is clear.

3.7 Skilling Resources: Developing capabilities and skill sets to deploy technology will be critical to the future of biorefining given its nascent stage. These could be enabled by forging partnerships by building an industry consortium and collaboration with academia.

4. Way Forward

A biorefining platform offers immense potential for India to transition to a sustainable energy mix, enabling different transport modes (passenger vehicle, aviation, marine) and value chains (agriculture, feed, biochemicals). It complements underlying shifts in the mobility space (such as EVs) and brings about multiple environmental and socio-economic benefits and can strengthen India's position as a leader in the renewable energy space. For India to truly harness its bioenergy capabilities, a steadfast commitment to long-term policy support and financial incentives is imperative. Such measures would catalyze the scaling of biorefinery technologies, mirroring the success observed in nations like Brazil. Moreover, the scope of cellulosic technology extends far beyond Ethanol (EtOH); it unlocks the potential of sustainable sugars. These sugars serve as foundational inputs for a plethora of processes, leading to the production of not just ethanol but also Sustainable Aviation Fuel (SAF), marine fuels, and an array of biobased alternatives to chemicals such as bio-based Monopropylene Glycol (bioMPG), bio-based Polyethylene glycol (bioPEG), and Polylactic acid (PLA). Embracing and adapting the best-in-class technologies from around the globe can accelerate India's journey in this space, optimizing the industry over time. This approach of leveraging existing knowledge and technology circumvents the need to start from scratch, fostering a more efficient and effective industry development. This can also strengthen the 'Make in India' initiative. This strategic adoption and adaptation is crucial for establishing a robust, self-sustaining bioenergy industry that can contribute significantly to India's energy security and economic growth.

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