Executive summary

In India, the interest in biofuels has grown substantially during the last few years. The primary reason for this is that energy security, better environmental performance, greening of wastelands and creation of new employment opportunities are seen as some of the advantages of biofuels. Biofuels may be considered and accordingly developed as a multi-dimensional beneficial energy alternative for our nation. The two types of biofuel that are currently in focus of attention in India are (i) Bioethanol and (ii) Biodiesel.

Biofuels have attracted a lot of debate in the recent past over its status as a “Green Fuel”. The environmental, economic and community benefits associated with biofuels depend largely on how biofuels are developed and manufactured. Just as different crops have different yields in terms of biofuel per hectare, wide variations also occur in terms of energy balance and Greenhouse Gas emission (Carbon dioxide) reductions across feedstocks, locations and technologies. The contribution of a biofuel to energy supply depends both on the energy content of the biofuel and on the energy going into its production i.e. biofuels are heavily dependent on various set of input and throughput parameters which are inherently either energy positive or energy negative in nature and contribute to the energy balance of the respective processes. The latter includes the energy required to cultivate and harvest the feedstock, to process the feedstock into biofuel and to transport the feedstock and the resulting biofuel at various phases of its production and distribution. As regards the impact on GHG emissions from the production of biofuels, it depends on the GHG emissions avoided by biofuels (compared to fossil fuel) and the GHG emissions during the production of biofuels. Therefore, a positive balance on the net energy supplied and net GHG emissions avoided, is one of the key parameters to decide on promotion of biofuels as a sustainable alternative to the fossil fuels.

Globally, significant number of studies have been undertaken to assess the energy balance and carbon balance of biofuels. Energy balance is defined as the net quantity of energy supplied by the biofuel and associated co-products at the end use minus the energy required during various developmental and manufacturing stages of biofuel. Carbon balance is defined as the net quantity of GHG (CO_2) emitted or avoided to the atmosphere during the various stages of activities like manufacture, distribution and end use of fuel. The coverage of these studies includes assessment of energy and GHG balance for more traditional feedstocks like soybean, corn, rapeseed, sugarcane, etc. using various technologies for production of biofuels. Some of the studies also focus on the feedstocks like Jatropha, Sweet Sorghum, and Cellulosic Biomass as well. Most of the studies focus on the technological and climatic conditions, relevant to specific geographies like USA and Europe, however, hardly any study relevant to Indian conditions is available, which focus on the relevant feedstocks and the suitable technological pathways available in India.

Recognising the need to assess the energy and environmental sustainability of the biofuels, National Committee on Biofuels of Confederation of Indian Industry (CII), under the guidance & support of Department of Biotechnology, had proposed to carry out the study with real time data from the industries and other stakeholders' domain, to estimate net energy and carbon balance of various biofuels, in India.

A constituted core committee, under this initiative has conducted the comprehensive estimation of energy and carbon balance of selected biofuels, across their value chains, i.e., feedstock development, manufacturing process, blending and end use, pertaining to Indian conditions. The study has considered the following categories of biofuels to estimate the energy and carbon balance in Indian context:

1. Bioethanol from Molasses

Molasses – a by-product of sugar manufacture is currently the most widely used feedstock for ethanol production in India. The sugar present in molasses is fermentable sugar and can be used to produce bioethanol.

2. Bioethanol from Sweet Sorghum

Of late, bioethanol production from Sweet Sorghum has demonstrated significant potential. Sweet Sorghum is a crop with wider adaptation and grows rapidly and results in higher production of biomass as well. It has a four-month crop cycle which results in two crops per year as compared to only one in case of sugar cane.

3. Bioethanol from Cellulosic Biomass

Hydrolysis is the technology which is majorly used for production of bioethanol from cellulosic biomass. The technology is still in its infancy and seems promising in the Indian scenario because of the excess availability of cellulosic biomass feedstock in the country. The report estimates the energy and carbon balance for bioethanol from two most widely available biomass residues in the country, i.e., Bagasse and Rice straw. The steps involved in manufacturing bioethanol from both these feedstocks are similar but the difference in yield of bioethanol and the co-products result in some difference in the final results obtained.

4. Straight Vegetable Oil (SVO) from Jatropha

Jatropha has been discussed as one of the key source of biofuels in the Indian context for a while. With a large number of Jatropha plantations being initiated across the country, Jatropha may play a major role in the future of the Indian biofuel sector. SVO from Jatropha can be used directly as a fossil diesel substitute in simpler engines. It is also one of the economical fuels, for decentralized usage, especially in the Indian rural areas.

5. Biodiesel from Jatropha

To overcome the shortcomings of SVO, it is further treated and processed for production of biodiesel. The most widely used technology for conversion of oil to biodiesel is transesterification. This fuel can be used in diesel engines as it is and can also be blended with petro-diesel for end use.

The study has successfully come out with a suitable framework for estimation of energy and carbon balance of various categories of biofuels (Bioethanol & Biodiesel) in India context. The framework and boundary for the study has been set in consultation with stakeholders. The study has analyzed the inputs and data received from various industries, R&D labs, academic institutions involved in production and research of biofuels. It has also referred various published data available in the National and International domain. Data collected from various sources have been normalized to the possible extent based on the detailed stated set of assumptions in the main report. ***The above study has evolved with a generic framework to estimate the energy and carbon balance in Indian context, which, may be suitably used by various stakeholders to examine the energy balance and carbon neutrality in their specific cases.***

The report captures the net energy balance of biofuels, estimating the energy supplied by the respective biofuel and its co-products at the end use and the energy required at different stages of production. The total energy consumed during manufacturing process has been deducted from the total energy supplied by the biofuel and its co-products, to arrive at the net energy balance for the biofuel. Net energy ratio for the biofuel, i.e. the ratio of the net energy output and the net energy input has also been estimated in the report.

The report also captures the carbon balance for biofuel and its co-products. The carbon avoided or emitted during each lifecycle stage has been estimated and a net carbon balance for biofuel has been arrived over the lifecycle within the study boundary. The carbon emitted during the production process has been accounted based on direct energy and material usage. The biofuels and co-products have been considered to displace fossil fuel (diesel or petrol); displacement has been based on energy equivalence. The percentage carbon emission reduction has been arrived at by calculating the total carbon input per Kilo Litre of biofuel produced and comparing it with the emission factor of fossil fuel displaced.

For the purpose of this study the parameters studied are defined as follows:

Net Energy Balance: *The energy supplied by the biofuel and associated co-products at the end use minus the energy required during various manufacturing stages of biofuel*

Net Carbon Balance: *The net quantity of Greenhouse Gas emitted / avoided to the atmosphere during the various stages of manufacture, distribution and end use of fuel.*

Net Energy Ratio: *The ratio of energy output obtained from the end use of the biofuel and energy input used for the production of the biofuel.*

% Carbon Emission Reduction: *The net quantity of Greenhouse Gas emissions avoided compared to the use of the petro fuel substituted by the biofuel.*

The biofuels under study demonstrated a favourable energy balance, with the net energy ratio being >1, (i.e., the total energy output is greater than total energy input). The study has also estimated negative carbon emissions, i.e., the biofuels help reduce net carbon emissions to the atmosphere. The results of the net energy balance and carbon balance for the above selected categories of Biofuels are summarized in the table below:

Biofuel Type	Feedstock	Net Energy Ratio	Net Energy Balance (GJ /kl)	Net Carbon Balance (tCO_2e/kl)	% Carbon emission réduction
Bioethanol	Molasses[1]	4.57	19.11	- 1.1	75%
	Sweet Sorghum[2]	7.06	21.57	-1.4	86%
	Cellulosic Biomass (Bagasse)[3]	4.39	25.41	-1.7	70%
	Cellulosic Biomass (Rice Straw)[4]	3.32	22.79	-1.6	68%
1Biodiesel	Jatropha - Transesterification[5]	3.41	63.76	-4.0	30%
	Jatropha – SVO[6]	4.38	66.73	-4.5	50%

[1] Table 08
[2] Table 14
[3] Table 20
[4] Table 26
[5] Table 32
[6] Table 38

Based on the analyses, biodiesel from Jatropha oil appears to be having favourable characteristics in terms of energy and carbon balance as compared to other biofuels. On the other hand, Sweet Sorghum based bioethanol appears to have the best conversion efficiency in terms of converting input energy to output energy. The study also presents a comparative analysis amongst all the lifecycle stages of the biofuel production, which shows that the feedstock development stage has the highest contribution to the energy input and carbon emissions, for all the biofuels studied in the report, except for bioethanol production from cellulosic biomass. In the feedstock development, the major contributors to the energy consumption are irrigation and usage of fertilizer. The outcome of the study highlights fertilizer use as one of the major contributors to the energy and carbon input during feedstock development. The report has also considered the energy and carbon input required for production of fertilizer along with any N_2O emissions during the fertilizer application for the analyses. It is observed that sugarcane cultivation requires maximum fertilizer input, amongst the chosen feedstocks, followed by Sweet Sorghum and Jatropha.

The analyses highlight the significance of energy contribution from the co-products obtained during the biofuel production as these contribute to a major share of the total energy generated during the end use stage. The study does not consider any material input offsets by the co-products (viz. seed cake as fertilizer) but it has considered the usage of the same for meeting the energy requirement of the inherent steps in the production processes.

The study also shows that the net energy and carbon balance per year is highest for Jatropha based biodiesel. This is due to significant energy contribution from the co-products obtained during biodiesel production, namely seed husk, seed cake and glycerol, which contribute almost 48% of the total energy generated during the end use stage. Similar reasons explain the high energy and carbon balance of Jatropha SVO as well, where the co-products include seed husk and seed cake.

The report further captures a sensitivity analysis of the results obtained, performed against the variation in energy and carbon contribution of irrigation and usage of fertilizer.

The results presented in this study are based on number of assumptions and input parameters, which can significantly impact the results of this study. The assumptions and input data have been considered to suit the Indian context, and have been mentioned in each section. Hence the results of this study should be interpreted in conjunction with the various assumptions considered in the study. A snapshot of certain upcoming processing technologies and feedstocks which may form the future biofuel industry has also been presented in the Appendix-C of the report. As these feedstocks and the corresponding processing pathways for production of biofuels are not yet conclusively proven to be commercially viable in the Indian scenario, only an overview for them has been provided.