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## November 2018

Sumitrra Ganguli, Abhishek Somani, Radha Kishan Motkuri and Cary Bloyd

U.S. DEPARTMENT OF
ENERGY

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# Executive Summary

India's dependency on fossil fuels to meet its growing energy demands has been on the decline owing to their limited supply and concerns about associated pollutants. Having ratified the Paris Climate Agreement of November 2016, this supports India's commitment to transition to a low carbon economy.

Also, at present, India imports more than 80 percent of crude oil to meet her annual demand, which poses a substantial price and quantity risk to a growing economy (90–95 percent of transportation in India is petro-based oil). These parallel realizations have led the Government of India (GOI) to increase its focus on developing a range of renewable energy sources owing to their eco-friendly nature and indigenous growth prospects.

Biofuels, primarily because of their ability to be blended with transportation fuels have been gaining preeminence, worldwide. Since India's domestic production of crude oil can meet only about 25 percent of her national demand, biofuels to blend in gasoline for the transportation sector present themselves as a natural alternative for reducing India's dependence on foreign oil imports. Understanding both the need and the benefits of using biofuels, the GOI has a mandated blend rate of 5 percent for ethanol as part of its Ethanol Blending Program (EBP), and a target of 20 percent by 2022. To meet its targets, GOI resorted to the adoption of first-generation technologies and thereafter (owing to the limitations of first-generation technologies) to second-generation technologies for the production of bio fuels in a bid to meet its blending mandates.

To that end, this paper starts by laying out the state of first-generation technology at a global level as well as in India. It then goes on to talk about the limitations of first-generation technology in India in meeting the GOI's blending mandate. It then proceeds to lay out what second-generation technology entails, what the cost numbers are for this technology and the possibility of deploying it on a commercial scale in India. It talks about some of the added advantages of second-generation technology – primarily that it addresses the problem of pollution from stubble burning. It ends by identifying the limitations of this technology both at the global level and in India and talks about policies (currently in use and recommendations) that both encourage and impede its adoption.

# Acronyms and Abbreviations

| | |
|---|---|
| 1G | first-generation technologies for Ethanol production |
| 2G | second-generation technologies for Ethanol production |
| B100 | pure (100%) biodiesel |
| bbl | barrel |
| Bgal | billion gallons |
| BPCL | Bharat Petroleum Corporation Limited |
| BL | Billion Liters |
| bn | billion |
| C | Carbon |
| CCEA | Cabinet Committee on Economic Affairs |
| $CH_4$ | Methane |
| CHBL | CREDA HPCL Biofuels Ltd |
| CMIE | Center for Monitoring of the Indian Economy |
| CO | Carbon Monoxide |
| $CO_2$ | Carbon dioxide |
| CREDA | Chhattisgarh Renewable Energy Development Agency |
| CWC | cellulosic credit waiver |
| EBP | Ethanol Blending Program |
| FAO | Food and Agricultural Organization |
| gal | gallon |
| GHG | Greenhouse gases |
| GJ/t | Gigajoules per ton |
| GOI | Government of India |
| GSR | General Statutory Rules |
| H | Hydrogen |
| HPCL | Hindustan Petroleum Corporation Ltd |
| HSD | high-speed diesel |
| ICBL | Indian Oil CREDA Biofuels Ltd |
| IEA | International Energy Agency |
| IGP | Indo Gangetic Plains |
| INR | Indian Rupee |
| JV | joint venture |
| K | Potassium |

| | |
|---|---|
| klpd | kilo liters per day |
| lge | liter gasoline equivalent |
| Ltd | Limited |
| Mha | Million hectares |
| MJ/l | Megajoules per liter |
| MMT | million metric tons |
| mn | million |
| MNRE | Ministry of New and Renewable Energy |
| MoPNG | Ministry of Petroleum and Natural Gas |
| MS | motor spirit |
| MSW | Municipal Solid Waste |
| Mt | Million Tons |
| N | Nitrogen |
| NBM | National Biodiesel Mission |
| $NH_3$ | Ammonia |
| $N_2O$ | Nitrous Oxide |
| NO | Nitric Oxide |
| $NO_x$ | Nitrogen Oxides |
| NREGA | National Rural Employment Guarantee Act |
| $O_3$ | Triatomic Oxygen |
| OECD | Organization for Economic Cooperation and Development |
| OMC | Oil Marketing Companies |
| P | Phosphorous |
| PIB | Press Information Bureau |
| R&D | Research and Development |
| RFS | Renewable Fuel Standards |
| $SO_2$ | Sulphur dioxide |
| $SO_x$ | Sulphur Oxides |
| $t_{DM}$ | ton of dry matter |
| UCSD | University of California, San Diego |
| UN | United Nations |
| UNCTAD | United Nations Conference on Trade and Development |
| USD | United States Dollars |

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## 1.0 Introduction

This report is an attempt at understanding the potential for the adoption of a second-generation biofuel technology in India. It starts by laying out the state of play in first-generation (1G) technology at a global level as well as in India. It then goes on to talk about the limitations of the 1G technology in India in meeting the Government of India's (GOI) blending mandate. It then proceeds to lay out what second-generation (2G) technology entails, what the cost numbers are for this technology and the possibility of deploying it on a commercial scale in India. It talks about some of the added advantages of 2G technology – primarily that it addresses the problem of pollution from stubble burning. It ends by identifying the limitations of 2G technology both at the global level and in India and talks about policies (currently in use and recommendations) that both encourage and impede its adoption.

## 2.0 State of 1G Ethanol Globally

First-generation bio fuels are defined based on the source from which the fuel is derived rather than the physical nature of the fuel itself. The main feedstock sources for 1G bio fuels are food crops such as starch, sugar and vegetable oil and animal fats (UNCTAD, 2015).

Even within this group, however, there is a hierarchy in terms of popularity, starting with biodiesel (produced mainly from canola, soybean, barley and palm oil), bioethanol (produced mainly from corn, wheat and sugarcane) and finally, other types of vegetable oil and biogas. According to the Renewable Energy Policy Network for the 21$^{st}$ Century (REN21, 2014), global biofuel production grew steadily from about 23 BL per year in 2002 to over 110 BL per year in 2012. However, between 2011 and 2012, growth rates plummeted and the annual production of biofuels in 2015 was back to its 2010 levels. Production of ethanol, however, has doubled since 2005, reaching 85.6 BL in 2010 and 94 BL in 2014, led primarily by Brazil and the United States (REN21, 2014).

A number of opposing forces work to both constrain and strengthen the growth of the global market. While perceived negative impacts on food and the availability of natural resources constrain the market, government policies (subsidies, market segmentation practices with minimum support prices like in the case of the US), national mandates to address climate change issues, rising oil prices and other political and environmental concerns work towards strengthening the market.

While both challenges and opportunities are different in different parts of the world (UNCTAD, 2015), a common global interest in de-carbonization of specific sectors of the economy (specifically, transport), a need to focus on energy security (and reduce dependence on foreign imports of oil) and an overarching mandate towards a more sustainable source of energy is what contributed to the tremendous advances in the field of 2$^{nd}$ generation (and beyond) biofuels (Juma and Konde, 2001; Kirscher, 2012).

## 3.0 State of 1G in India

According to Purohit and Dhar, 2015, if the entire sugarcane crop (342.4 Mt in 2010–11) is used for sugar production, the corresponding estimated production of molasses would be about 15.4 Mt. The associated estimated ethanol yield would be about 3.6 BL (Purohit and Fischer, 2014). In reality, however, only about 70 to 80 percent of the sugarcane that is produced in India is used for sugar production, with the remaining being diverted towards the production of alternative sweeteners (jaggery and khandsari) and seeds (Raju et al., 2009). Also, 32.5 percent of the available molasses is used in alcoholic beverages, 25 percent by industry, and 3.5 percent for other applications. The surplus available alcohol is diverted for blending with transportation fuel. Under the circumstances, if India is to achieve the 20 percent blending targets set out in the National Policy on Biofuels, without compromising industrial, potable and other needs, the country will need to produce 6.7 BL of ethanol by 2020 and 9.1 BL by 2030 (Purohit and Dhar, 2015), which is approximately three times the current level of production (see **Table 1** below for estimated yields).

**Table 1: Ethanol Availability for 1G Biofuels in India**

| Year | Ethanol production from molasses (BL) | Ethanol use (BL) | | | Net ethanol availability for blending (BL) |
|---|---|---|---|---|---|
| | | Potable | Industry | Other | |
| **2010** | 2.72 | 0.88 | 0.68 | 0.10 | 1.06 |
| **2015** | 3.01 | 1.04 | 0.79 | 0.11 | 1.08 |
| **2020** | 3.22 | 1.22 | 0.91 | 0.13 | 0.96 |
| **2025** | 3.43 | 1.44 | 1.06 | 0.15 | 0.79 |
| **2030** | 3.64 | 1.69 | 1.23 | 0.17 | 0.56 |

*Source: Purohit and Dhar,2015*

Considering the GOI's blending mandates and the estimated shortfalls, 2G (and beyond) biofuels seem like a natural route to follow, though not without its limitations.

## 4.0 2G Technology – A Primer

While both 1G and 2G biofuel production were spurred by some common drivers, most notably energy security (reduced demand on oil imports), lower GHG emissions and an all-around low carbon, sustainable economy, an additional impetus for 2G biofuels arose from the need for liquid biofuels from feedstocks *not used* for human consumption (see **Table 2** below for differences in the two technologies). This led to the use of lignocellulosic materials from herbaceous crops, hardwood and softwood, as the main feedstocks for the production of liquid biofuels, particularly ethanol.

**Table 2: Differences between 1G and 2G Biofuels**

| **First-generation biofuels** (from seeds, grains or sugars) | **Second-generation biofuels** (from lignocellulosic biomass, such as crop residues, woody crops or energy grasses) |
|---|---|
| • Petroleum-gasoline substitutes<br>◊ Ethanol or butanol by fermentation of starches or sugars<br>• Petroleum-diesel substitutes<br>◊ Biodiesel by transesterification of plant oils (FAME and FAEE)<br>» Can be produced from various crops such as rapeseed (RME), soybeans (SME), sunflowers, coconut oil, palm oil, jathropha, recycled cooking oil and animal fats<br>◊ Pure plant oils (straight vegetable oil) | • Biochemically produced petroleum-gasoline substitutes<br>◊ Ethanol or butanol by enzymatic hydrolysis<br>• Thermochemically produced petroleum-gasoline substitutes<br>◊ Methanol<br>◊ Fischer-Tropsch gasoline<br>◊ Mixed alcohols<br>• Thermochemically produced petroleum-diesel substitutes<br>◊ Fischer-Tropsch diesel<br>◊ Dimethyl ether (substitutes propane as well)<br>◊ Green diesel |

*Source: UNCTAD (2015)*

Second-generation biofuels (according to the IEA), are produced from cellulose, hemicellulose or lignin. Such biofuels can be blended with petroleum-based fuels or used in adapted vehicles (IEA, 2010). Cellulosic ethanol and Fischer-Tropsch fuels are an example of second-generation biofuels. Carriquiry et al., (2011) find that second-generation biofuels yield greater energy output than fossil fuels, can be extracted from a larger array of feedstock options, minimize competition on land and have much lower environmental impacts.

## 5.0 Available Technologies for 2G Production

There are two main channels for the production of second-generation biofuels from lignocellulosic feedstocks. Very briefly, they can be summarized as follows:

**Biochemical** – enzymes and other micro-organisms are used to convert cellulose and hemicellulose components of the feedstocks to sugars prior to their fermentation to produce ethanol;

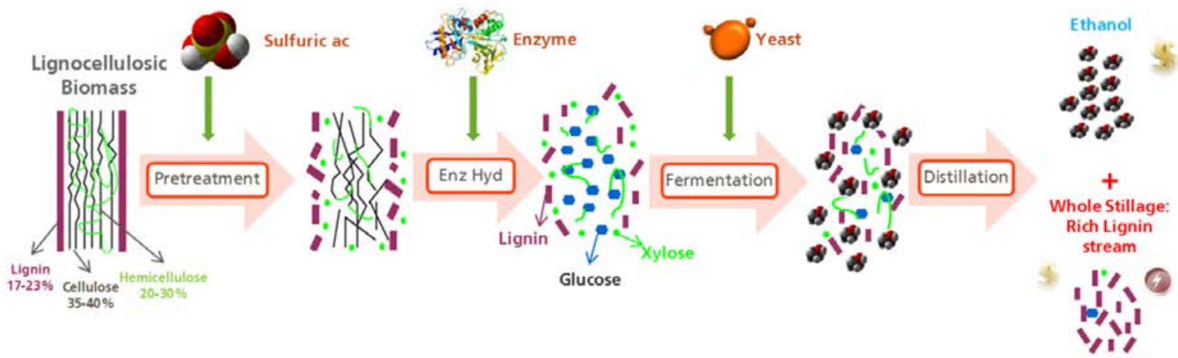
**Thermochemical** – pyrolysis/gasification technologies produce a synthesis gas ($CO + H_2$) from which a wide range of long carbon chain biofuels, such as synthetic diesel or aviation fuel, can be reformed.

While other pathways to produce 2G biofuels are available,[1] and many of them are still under evaluation in research laboratories and pilot plants, they do not represent the main thrust of research and development (R&D) investment.

**Figure 1** below shows the basic process of converting biomass in to biofuels and coproducts.

[1] They can produce biofuel products either similar to those produced from the two main routes, or several other types including dimethyl ether, methanol, or synthetic natural. (UNCTAD, 2015)

**Figure 1: 2G Biofuel Production from Lignocellulosic Biomass**




*Source: Abengoa et al., 2000*

While both routes have similar potential yields in energy terms, the yields are different in terms of liters per ton of feedstock (see **Table 3** below). The similarity in overall yield in energy terms (around 6.5 GJ/t biofuels at the top of the range), is because synthetic diesel has a higher energy density by volume than ethanol (Valdiva et al., 2016).

Another difference between the two production routes is the final product. While the biochemical route produces ethanol only, the thermochemical route can produce a range of longer-chain hydrocarbons which include biofuels that are better suited for aviation and marine purposes. Which of these will be the preferred production technology is dictated by a number of other factors as discussed below.

**Table 3: Indicative Biofuel Yield per Ton of Feedstock from Biochemical and Thermochemical Routes**

| | Biofuel Yield (liters/dry t) | | Energy Content (MJ/l) | Energy Yields (GJ/t) | |
|---|---|---|---|---|---|
| **Process** | **Low** | **High** | **Low Heat Value** | **Low** | **High** |
| **Biochemical** | | | | | |
| Enzymatic Hydrolysis Ethanol | 110 | 300 | 21.1 | 2.3 | 6.3 |
| | | | | | |
| **Thermochemical** | | | | | |
| Syngas to Fischer Tropsch Diesel | 75 | 200 | 34.4 | 2.6 | 6.9 |
| Syngas to Ethanol | 120 | 160 | 21.1 | 2.5 | 3.4 |

***Source: IEA/OECD, 2008***

## 6.0 Costs of 2G Production

Valdivia et al., 2016 classifies the cost of production of a second-generation plant based on the type of project. According to his classification, a **Greenfield/Stand-alone** which is a plant by itself with its own complete value chain management (core process, biomass handling, pretreatment, enzymatic hydrolysis, fermentation and distillation) is the costliest option. The **Colocation/Bolt-On**, is a project in which some existing infrastructures and operations can be shared owing to the proximity of other industries. While this scenario requires (at a minimum) construction of its own process area, a value chain for feedstock procurement and logistic must be completely developed, while construction of auxiliary operations units is limited. The last of these - **Hybrid/Integrated –** is the least costly option. The whole value chain is completely integrated within a 1G facility, taking advantage of the synergies in feedstock supply and product logistics.

For a greenfield/stand-alone project, a non-core area such as cogeneration increases the initial investment needed by more than 30 percent. In the absence of synergies with external utilities, additional costs are incurred through the use of storage equipment and other logistical issues. In comparison with a stand-alone plant, a co-located plant may require less than 50 percent in capital investment.

For a project to be commercially viable, after accounting for feedstock, reducing investment cost through a reduction in the auxiliary equipment is the second step in the process. In this context, the main challenge facing the industry is locational flexibility to avail of more viable technical and economical projects. According to their estimates, investment cost ranges between \$10 and 14/gal, for a plant with a nominal plate of 25 thousand gal/day depending on its location.

Outside of the main logistic model, other cost-cutting options include enzyme cost reduction by improving activity, valorization of the lignin contained in the raw material, increasing the pretreatment efficiency or improving the yeast production organism.

Within the entire process, “pretreatment” is the area that requires an investment of between 30 percent and 50 percent of the total equipment cost. The intrinsic recalcitrance of the lignocellulosic biomass which results in lower biomass to sugar yields contributes to higher pretreatment costs (Stephen et al., 2012), and this is a huge challenge that the industry currently faces.

Not all pretreatments are created equal. Pretreatment processes that show potential commercialization should satisfy most of the criteria below.

Common pretreatment methods include (i) physical pretreatment, which involves mechanical processing and extrusion where the objective is to reduce particle size but increase surface area, (ii) chemical pretreatment, which is carried out in acidic, neutral, or basic conditions, (iii) physiochemical pretreatment, which involves steam explosion (in the presence or absence of $SO_2$) and $CO_2$ explosion (using super critical $CO_2$ that produces carbonic acid), and (iv) biological pretreatment where microorganisms like brown, white, and soft-rot fungi are used to pretreat biomass (Balan, V., 2014).

However, not all pretreatments methods are equally commercially viable. The ease with which a (pretreatment) process can be commercialized depends on the following factors:

i. A pretreatment process that is ideal for decentralized biomass processing is one that involves opening of the cell wall to bring lignin to the surface. This has the potential to efficiently densify after pretreatment without the addition of any external binding agents and to increase the durability of biomass for long term storage.

ii. Commercial viability increases if the densified, pretreated biomass has dual application (fertilizer, soil amendments, animal feed, and biomass composites) in addition to using them as biorefinery feedstock.

iii. Pretreatment processes that require large amounts of water to remove toxins from the pretreated biomass make the process more expensive and therefore less profitable.

iv. Processes that can be scaled up to meet the biorefinery needs of handling more than 2000 tons per day or more are more viable.

v. Processes that consume less energy and cheaper chemicals, lower processing cost are therefore more profitable.

vi. Processes that preserve lignin during pretreatment (as opposed to pretreatments like alkaline hydrogen peroxide and ozonolysis that have the tendency to degrade lignin) and hence the energy density of lignin are far more viable (commercially).

vii. Pretreatments requiring moderate temperatures are preferred from a cost perspective.

viii. Processes that use supercritical fluids (water and $CO_2$) operate at a very high pressure and require additional cost.

After pretreatment, enzymatic hydrolysis represents the second main operational cost, accounting for 25–30 percent of the operational costs as compared with 1G which is below 3 percent. Viability of 2G technology depends critically on the contribution of the enzymatic cocktail cost and there is a consensus that the final enzyme cost contribution should be stabilized around $0.4/gal.

## 7.0 Biochemical vs. Thermochemical Cost Comparison

Actual numbers associated with each of these pathways are, however, fairly uncertain and more importantly, treated with a high degree of commercial propriety. Even within the industry, a comparison of these two technology routes has proven to be very contentious. Unavailability of published cost data has been the biggest limiting factor.

These limitations notwithstanding, the IEA has estimated the commercial-scale production costs of 2G biofuels to be in the range of USD 0.80 – 1.00/liter of gasoline equivalent (lge) for ethanol.

This range broadly relates to gasoline wholesale prices (measured in USD/lge) when the crude oil price is between USD 100-130/bbl (see **Table 4**).

**Table 4: IEA 2G Biofuel Cost Estimates (under alternative scenarios)**

| Lignocellulosic conversion technology | Assumptions | Production cost- By 2010 USD /lge | By 2030 USD /lge | By 2050 USD /lge |
|---|---|---|---|---|
| **Bio-chemical ethanol** | Optimistic | 0.80 | 0.55 | 0.55 |
| | Pessimistic | 0.90 | 0.65 | 0.60 |
| **BTL diesel** | Optimistic | 1.00 | 0.60 | 0.55 |
| | Pessimistic | 1.20 | 0.70 | 0.65 |

Evidently, fluctuating oil and gas prices make investments in 2G biofuels (at current production costs) a high-risk venture, especially when alternatives such as new heavy oil, tar sands, gas-to-liquids and coal-to-liquids can compete with oil when around USD 65/bbl.[2]

In light of the ongoing debate between the merits and demerits of the two technologies continues, a lot of studies have examined the economics of biochemical and thermochemical cellulosic production plants. Among them, Wright and Brown (2007), in a pioneering study to compare advanced biofuel production methods to grain-based ethanol production found that total costs per gallon would be 44 percent higher for the biochemical cellulosic ethanol process compared to the grain-based process and 48 percent higher for the thermochemical cellulosic biofuel process compared to grain-based ethanol production.[3] Further, they found that it would require approximately 6.8 times and 7.7 times the initial capital dollars to build a biochemical cellulosic ethanol plant and a thermochemical cellulosic plant, respectively, as compared to a grain-based plant that produced the same in terms of gasoline equivalents.

Rismiller and Tyner (2001), used a spread sheet model to estimate the net present value (pre- and post-tax) to compare the profitability of three biofuel production types – grain-based ethanol, cellulosic biochemical ethanol and cellulosic thermochemical biofuels. Given input and output prices and other technical and financial assumptions, they found that in the absence of subsidies and mandates, all three production types are unprofitable. However, when the 2008 Farm Bill (USA) subsidies were introduced in to the model, all three production types were projected to be profitable. Moreover, once the subsidies were allowed for, cellulosic biofuels were estimated to have higher net present values than grain-based ethanol.

They also found that when compared on an energy equivalent basis, the estimated cost of producing grain ethanol was $114/bbl crude oil equivalent, biochemical ethanol $141/bbl, and thermochemical gasoline $108/bbl.

Despite a lack of consensus on the favored technology choice, the potential for cost reductions is likely to be greater for ethanol produced via the biochemical route than for liquid fuels produced by the thermochemical route, because much of the technology for biomass-to-liquid plants (based on Fischer-Tropsch conversion) is mature and the process mainly involves linking several proven components together.

[2] This takes into account infrastructural requirements, environmental best practices and an acceptable return on capital but excludes any future penalty imposed for higher $CO_2$ emissions per kilometer travelled when calculated on a life cycle basis (IEA, 2014).

[3] The total costs per gallon consist of feedstocks, operation and management, credits and capital charges.

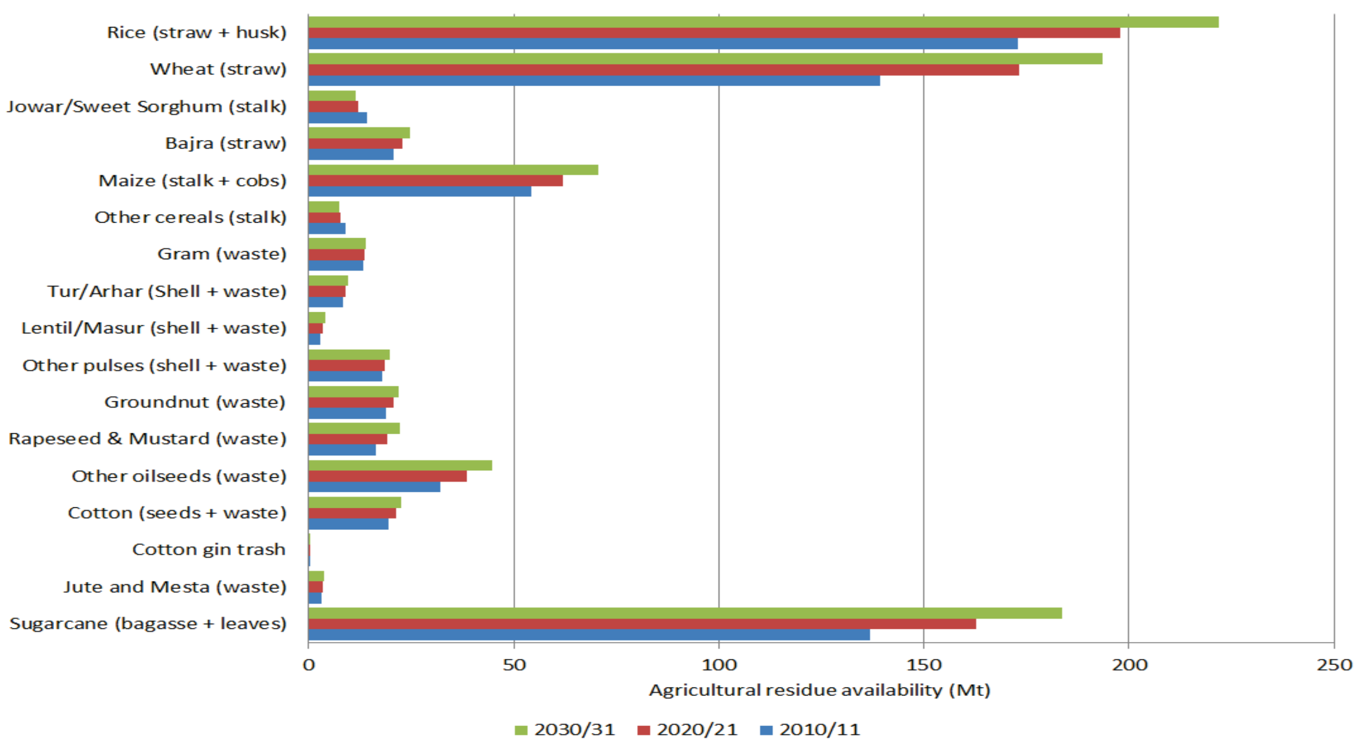
## 8.0 State of 2G Production in India

In India, the national target of 5 percent blending by 2012, 10 percent by 2017 and 20 percent after 2017 has been recommended in the policy which is likely to be met if India proceeds via the 2G route.

### 8.1 Potential for Adoption of 2G in India Using Crop Residues

As shown in **Figure 2**, India has enormous potential in the production of biofuels from crop residues (lignocellulosic materials). Residue use varies by region and depends on the calorific values, lignin content, density, palatability by livestock, and nutritive value. While a lot of cereals and pulses have fodder value, the woody nature of others (rice husk/straw, maize stalks and cobs, and ligneous residues) makes them a natural choice to be used as feedstock in the production of biofuels. The estimated total amount of residues used as fodder was 301 Mt in 1996–97 (CMIE, 1997), and 360 Mt in 2010–11 (Purohit and Fischer, 2014). This accounts for approximately 53 percent of total residue (Purohit and Dhar, 2015).

**Figure 2: Gross Residue Available from Crop Production in India**




*(Source: Purohit and Dhar, 2015)*

### 8.2 Potential Ethanol Generation from these Residues

Agricultural residues available for energy applications were estimated at 150 Mt in 2010-11 (Purohit and Fischer, 2014).

Under the assumption that 20 percent of agricultural residue is lost in collection, transportation and storage (Purohit, 2009 and Singh, 2015) and that ethanol yields of 214 lge/ton dry matter ($t_{DM}$) (IEA, 2010) for cellulosic-ethanol, 130 Mt of residue could be used to produce approximately 28 BL of ethanol annually.

According to their estimates, they predict that ethanol yields per $t_{DM}$ will improve up to 250 liters per $t_{DM}$ in 2020-21, 275 liters per $t_{DM}$ by 2025-26 and to 300 liters per $t_{DM}$ by 2030-31 (refer to Table 5). They estimate the net obtainable ethanol production at 37 and 50 BL by 2020-21 and 2030-31, respectively, and this would be sufficient to meet the 20-percent blending target by 2030-31 (refer to Table 5).

In the authors' (Purohit & Dhar, 2015) estimates (refer to **Table 5**), this potential biofuel production represents approximately one-fourth of the gross residue availability, if all crop residues (e.g., straw, husks, stalks, cobs, shells, bagasse, etc.) were to be converted in to biofuels. The Biomass Atlas of India (BRAI, 2015) estimates that an additional 104 Mt of biomass is available in India in forest and wastelands that can be converted into biofuels.

**Table 5: Biofuel Potential from Net Availability of Agricultural Residues**

| Crop Residue | Agricultural residue used for fodder, fuel, and other purposes (%) | | | Net agri-residue availability for biofuels (Mt) | | | Net Ethanol Availability (BL) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Fodder | Fuel | Other | 2010/11 | 2020/21 | 2030/31 | 2010/11 | 2020/21 | 2030/31 |
| Rice straw and husk | 80.8 | 11.1 | 8 | 13.8 | 15.8 | 17.8 | 3 | 4 | 5.3 |
| Wheat straw | 86.4 | 0 | 13.6 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jowar stalk | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bajra straw | 89.8 | 0 | 10.2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Maize stalk and cobs | 81 | 19 | 0 | 7.4 | 8.5 | 9.7 | 1.6 | 2.1 | 2.9 |
| Other cereals stalk | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gram waste | 0 | 100 | 0 | 9.5 | 9.7 | 10 | 2 | 2.4 | 3 |
| Tur shell and waste | 3.5 | 48.5 | 48 | 2.9 | 3.1 | 3.3 | 0.6 | 0.8 | 1 |
| Lentil shell and waste | 3.5 | 48.5 | 48 | 1 | 1.3 | 1.4 | 0.2 | 0.3 | 0.4 |
| Other pulses - shell and waste | 3.5 | 48.5 | 48 | 6.3 | 6.4 | 6.9 | 1.3 | 1.6 | 2.1 |
| Groundnut waste | 0 | 13.2 | 86.8 | 1.8 | 1.9 | 2.1 | 0.4 | 0.5 | 0.6 |
| Rape and Mustard Waste | 0 | 100 | 0 | 11.8 | 13.9 | 15.9 | 2.5 | 3.5 | 4.8 |
| Other oilseed waste | 0 | 100 | 0 | 23.1 | 27.8 | 32.2 | 4.9 | 7 | 9.7 |
| Cotton seeds and waste | 0 | 100 | 0 | 14.1 | 15.3 | 16.2 | 3 | 3.8 | 4.9 |
| Cotton gin and trash | 0 | 100 | 0 | 0.3 | 0.3 | 0.4 | 0.1 | 0.1 | 0.1 |
| Jute and Mesta waste | 0 | 100 | 0 | 2.2 | 2.6 | 2.8 | 0.5 | 0.7 | 0.9 |
| Sugarcane bagasse and leaves | 11.8 | 41 | 47.2 | 35.9 | 42.6 | 48.2 | 7.7 | 10.7 | 4.5 |
| Total | | | | 130.2 | 149.3 | 166.8 | 27.9 | 37.3 | 50.1 |

*(Source: Purohit and Dhar, 2015)*

### 8.3 India's Current State of Play in 2G Technology

As far back as 2011, the Indian Oil Corporation had signed a memorandum of understanding with the Government's Department of Biotechnology to set up a Centre for Advanced Research on Bioenergy to develop second and third generation biofuels at a cost of $11.6 million over the next five years.

As of August 2016,

i. The Indian Government was set to invest $74.8 million in a second-generation ethanol plant at the Indian Oil Corporation's (IOC) oil refinery in Panipat using crop residues as feedstock. IOC selected Praj as its technology partner for setting up multiple 2nd Generation bioethanol plants based on indigenously developed technology. IOC will be setting up three such 2G bioethanol plants, using ligno-cellulosic biomass feedstocks.
ii. The biofuels industry was set to invest $2.25 billion in new projects over the next few years to build up the industry's value towards $7.5 billion by 2022.
iii. A subsidiary of Bharat Petroleum Corporation announced it would build a 300,000 metric ton biofuel plant.
iv. Praj (the first 2G refinery in India) said it would undertake multiple biorefinery projects valued at $142 million,
v. CVC Biorefinery will set up two projects in Gujarat and Punjab,
vi. IOC planned to team with the Celanese to build a 1 million metric ton per year, synthetic ethanol production capacity in the eastern town of Paradip. Petroleum coke will be the feedstock for the facility.
vii. Bharat Petroleum will build a $75 million second-generation ethanol plant using (municipal solid waste) MSW and agricultural waste as feedstock in Kochi, where it will be located at the (Bharat Petroleum Corporation Limited (BPCL)-Kochi Refinery.

### 8.4 Environmental Concerns and 2G Technology

An added advantage of using agricultural waste (2G biomass) in the production of bioethanol is the avoidance of the environmental damage stemming from the burning of stubble (crop residue).

Biomass burning is a global phenomenon that has been contributing to poor air quality worldwide (Yang, et al., 2008). Typically, the burning intensifies in late March, reaching a maximum in May. It is also a significant source responsible for many chemically and radiatively important trace gases and aerosols in the atmosphere contributing to detrimental consequences. (Crutzen and Andreae, 1990).

Fishman *et al.*, 1991, through the use of satellite images found that vast areas of Central Africa and South America, over the tropical Atlantic, and the Indian Ocean showed elevated levels of $O_3$, CO and aerosols due to long-range transport of pollutants emitted from biomass burning.

India generates a large quantity of agricultural residues (as discussed in the section above). A part of these residues is used as animal fodder, thatching for rural homes, residential cooking fuel and industrial fuel, while the remainder is burned to clear the fields rapidly and inexpensively.

Jain et al. (2014) estimated that the maximum amount of crop residues was burned in the states of Uttar Pradesh (22.25 Mt) and Punjab (21.32 Mt), followed by Haryana (9.18 Mt) and Maharashtra (6.82 Mt).

The highest amount of cereal crop residues were burned in Punjab followed Uttar Pradesh and Haryana, while Uttar Pradesh was the highest contributor to the burning of sugarcane trash, followed by Karnataka. Oil seed residues were burned in Rajasthan and Gujarat, while burning of fiber crop residue was dominant in Gujarat (28.6 Mt), followed by West Bengal (24.4 Mt) Maharashtra and Punjab.

Of the different crop residues burned, the major contribution (93 percent) came from rice (43 percent), followed by wheat (21 percent) and then, sugarcane (19 percent).

**Emission of Gaseous and Aerosol Species**

They further estimated that, on farm burning of 98.4 Mt of crop residues led to the emission of 8.57 Mt of CO, 141.15 Mt of $CO_2$, 0.037 Mt of $SO_x$, 0.23 Mt of $NO_x$, 0.12 Mt of $NH_3$ and 1.46 Mt $NMVOC$, 0.65 Mt of $NMHC$, 1.21 Mt of particulate matter for the years 2008–09. $CO_2$ accounted for 91.6 percent of the total emissions. Of the rest (8.43 percent) 66 percent was $CO$, 2.2 percent $NO$, 5 percent $NMHC$ and 11 percent $NMVOC$. Burning of rice straw was the greatest contributor (40 percent) to these emissions followed by wheat (22 percent) and sugarcane (20 percent). The highest emissions were from the Indo Gangetic Plains (IGP) states with Uttar Pradesh accounting for 23 percent, followed by Punjab (22 percent) and Haryana (9 percent). Estimates of various pollutants ranged from 0.002 to 149 Mt.

Burning of agricultural residues resulted in conversion of 70, 7 and 0.66 percent of the C present in rice straw to $CO_2$, $CO$ and $CH_4$ emissions, respectively, while 20, 2.1 percent of $N$ in straw was emitted as $NO_x$ and $N_2O$, respectively, and 17 percent of the S in straw was emitted as $SO_x$ upon burning (Carlson *et al.*, 1992).

**Loss of Nutrients in Residues**

This practice not only adds to pollution but also results in loss of nutrients present in the residues. The entire amount of $C$, approximately 80–90 percent of $N$, 25 percent of $P$, 20 percent of $K$ and 50 percent of $S$ present in crop residues are lost in the form of various gaseous and particulate matter, resulting in atmospheric pollution (Raison, 1979; Ponnamperuma, 1984; Lefroy, 1994). According to Jain et al., 2014, the maximum loss of nutrients was due to sugarcane trash burning followed by rice and wheat straw. Burning of sugarcane trash led to the loss of 0.84 Mt, rice residues, 0.45 Mt, and wheat residue, 0.14 Mt, of nutrients per year, out of which 0.39 Mt was nitrogen, 0.014 Mt was potassium, and 0.30 Mt was phosphorus.

### 8.5 *Jatropha*: Source of 2G Ethanol with Huge Potential

While production of bioethanol from agricultural residue does not compete directly with food production (sugarcane, etc.), it does compete with alternative uses like cattle feed, construction material, straw board, paper and hardboard units as well as packing materials for glassware. *Jatropha* is another cellulosic feedstock that India could potentially capitalize on for the production of 2G Ethanol.

#### What is *Jatropha*?

*Jatropha* is an energy crop, i.e., it is another non-food oil seed that can be used for generation of bioethanol. A subtropical plant species, it grows primarily in the tropics and subtropics. The deoiled *Jatropha* cake, obtained from a biodiesel plant lends itself to the extraction of ethanol through a process of chemical and enzyme pre-treatments followed by a process of fermentation. A major problem that arises in the production of biodiesel is the disposal of the oil cake after extracting the oil from the seed. The cake which is neither fit for consumption by animals or for use in farming, owing to its toxic nature, lends itself quite naturally, to generation of bioethanol (Deshmukh and Marathe, 2015). On an average, the amount of oil extracted from *Jatropha Curcas* seeds is 30 percent by weight, and each ton of (extracted) oil generates about 2.3 tons of seed cake (dos Santos et al., 2014). Given the percentage of carbohydrates present in the residual biomass, 30 – 38 percent (dos Santos et al., 2014), production of bioethanol through hydrolytic and fermentative processes (steps: biomass pretreatment, enzymatic hydrolysis and ethanol fermentation) seems like a natural choice (Macedo et al., 2011). Demissie and Lele (2013) have shown that the bacterium *Zymomonas mobilis* (extracted from the *Jatropha Curcas* seed cake) naturally produces ethanol at near theoretical maximum yields (using a simultaneous saccharification and fermentation process), making it of interest for commercial scale production of ethanol. This method yields 28 ml of ethanol from 100 grams of deoiled *Jatropha* cakes (Demissie and Lele, 2013).

#### Ease of Cultivation, Adaptability for Genetic Improvement and Other Advantages

*Jatropha* is a very rapidly growing sub-tropical tree or shrub. Additionally, the plant has certain features that allows for agricultural and genetic improvements. First, *Jatropha* can reproduce both sexually and asexually via a clone. The former through pollination, and the latter by stem cuttings, which can be placed in soil to form new shoots. This allows for rare genetic combinations, which can be perpetuated through chrono propagation. Not too many plants can do that, and as easily. Second, it generates rapidly (within four to nine months) depending on the variety, and the time between planting the seed and generating new seeds takes between three to five years. These short generation times allow for more genetic crosses, thus lending itself to genetic improvements. The seeds of the *Jatropha* fruit have about 35 percent oil. So that is very high oil content that can be processed. Third, it can be grown in a wide range of soils including wastelands, poor soils, low rainfall and drought areas. Fourth, *Jatropha* plants are hardy and can tolerate water scarcity. Fifth, waste lands and other lands not suitable for crops can be utilized for growing *Jatropha* seeds. Sixth, it prevents soil erosion. Seventh, it does not compete with any other crop and supplements profits. Eighth, wasteland soil fertility can be increased through *Jatropha* plantation. Ninth, from a business perspective, one can obtain from $137 to $205 per cultivated 0.40 (approximately) hectares of *Jatropha*, starting with Year 4 (*Jatropha* Cultivation Information Guide).

The tropical climate in India, lends itself rather naturally to the cultivation of the *Jatropha* seed. Deshmukh and Marathe, (2015) estimate that one hectare of *jatropha curcas* plantation produces on an average, 3.75 metric tons of seed which yield about 1.2 metric tons of oil. Hence 400,000 hectares will produce 0.48 million metric tons of oil and 1.02 million metric tons of oil cakes from which ethanol can be extracted. The Indian Planning Commission has estimated that with appropriate availability of planting stocks, it would be possible to cultivate 13.4 Mha of *Jatropha* by the year 2012 (GOI, 2003). However, *Jatropha* plantations have been slow to take off. Lack of good quality plant stock, disputes over wasteland ownership, and other issues have hindered *Jatropha* cultivation. In July of 2014, INSEDA (Integrated Sustainable Energy and Ecological Development Association) reported the following efforts that are already underway to promote cultivation of *Jatropha* in India:

i. The Tamilnadu Government along with the Forest Department has planned a project for cultivation of *Jatropha* in 150,000 hectares in Tamilnadu.
ii. The Indian Railway is to raise *Jatropha* along the railway track and plan to plant *Jatropha* along 25,000 route kilometers on two sides of the track. A pilot project is already underway.
iii. A Tamilnadu firm is working on a project to grow 600,000 hectares of *Jatropha* on lands owned by farmers in various parts of Tamilnadu.
iv. The Maharashtra Agro-forestry Department has been actively encouraging the raising of *Jatropha* in watershed development projects.
v. A similar project as in Maharashtra is being attempted in the State of Madhya Pradesh.
vi. The Planning Board of Haryana Government. They are planning to grow *Jatropha* on approximately 20,234 hectares (approximately 2023 hectares every year).
vii. The Rural Community Action Centre (RCAC) in Tamil Nadu State is promoting the plantation and use of *Jatropha*.

Up until 2015, 0.5 Mha of land was estimated to have been planted with *Jatropha*. Over and above the natural advantages to *Jatropha* cultivation, are the boosts to the economy through employment generation. UNCTAD (2015) estimates (for the Ghanian economy), that for every 1 Mha dedicated to *Jatropha* cultivation, in excess of one million jobs will be generated.

## 9.0 Limitations in the Adoption of 2G Technology

Ironically, according to Carriquiry et al., (2010) the biggest limitation to the production of biofuels can be attributed to what caused an interest in it to begin with – rising oil prices. According to an OECD-FAO report (2009), while rising oil prices were in fact instrumental in driving the demand for biofuels (starting with the oil price shocks of the 1970s), in the absence of blending mandates, oxygenation mandates and other forms of policy intervention, if the price of oil were to drop below USD 60-70 a barrel, the market for biofuels would not be sustainable.

Globally, there are various other limitations to the adoption of second-generation biofuels, most of which stem from technological and policy considerations.

### 9.1 Global Limitations

According to Sims, et al. (2008), success in the commercial development and deployment of 2G biofuel technologies at the global level, requires a significant amount of technological progress in a bid to overcome the cost barriers that they currently face. Since most of these stems from technological considerations, they can mostly be addressed with increased amounts of R&D.

To begin with, investment in R&D towards a better understanding of the different varieties of available feedstocks, their geographic distribution and costs is required. More specifically, there is a need for research to pinpoint the ideal characteristics of the different feedstocks that would maximize their conversion efficiencies and to suggest ways to improve the potential for better quality feedstock over time.

There is also a need for R&D to assess the size and potential scale of production of the different cultivation areas to determine if they are economically viable (cost effective) for servicing different sized production facilities. While some areas may have enough crop residues (agriculture and forest) to support several processing facilities, larger scale production plants might require a dedicated crop as feedstock.

R&D towards improving feedstock pretreatment technologies (**used in the biochemical conversion route**) which at present are inefficient and costly. A related problem is the identification of natural organisms that have the ability to convert both $C_5$ and $C_6$ sugars (which are released in the pretreatment and the hydrolysis steps) at high yields in to ethanol - this is a key goal for commercialization of ligno-cellulosic ethanol. There is also a need to both understand and thereafter manipulate process tolerance to ethanol and sugar concentrations and resistance to potential inhibitors generated in pre-saccharification treatments and there is scope for significant research to apply this to actual ligno-cellulosic feedstocks.

R&D towards process integration in the conversion of ligno-cellulosic biomass into bioethanol thus allowing for lower capital and operating costs, while also ensuring that the production of co-products is optimized. At present this process requires a large number of individual processes, thus leaving a lot of potential room for process integration.

R&D towards developing a gasification process on a commercial scale (**used in the thermochemical conversion route**) to produce synthesis gas to the standards required for a range of biofuel synthesis technologies such as Fischer-Tropsch (FT). At present, there is a dearth of cost effective and reliable methods for large scale biomass gasification. Another cost cutting initiative would be the development of catalysts that are less susceptible to impurities and have longer lifetimes.

R&D towards a better understanding of the conversion process so as to maximize the value of the co-products. A lot of valuable co-products are generated in the process of producing 2G biofuels, thus offering the potential to increase the overall revenue from the generation process.

In general, to get a better understanding of the overall scope and limitations of 2G technology (globally), a more thorough assessment of both biofuels and co-products associated with biofuel production and their effects on rural development, employment, energy security, carbon sequestration, etc. needs to be undertaken.

### 9.2 Limitations Faced by India

The limitations faced by 2G technology in India, shares a lot of common ground with those faced by 1G technology and considering that the two are not mutually exclusive (as identified by IEA in its set of policy prescriptions), this comes as no surprise. GOI has undertaken several policy measures (higher procurement prices of ethanol from grains and crop waste being the latest in its line of measures[4] in a bid to augment the production of biofuels during the past decade (GOI, 2003; (Ministry of New and Renewable Energy (MNRE), 2009). Despite policy efforts, production of biofuels using 2G technology has a long way to go.

#### Land Constraints in the Cultivation of Biofuel Crops

While the National Bio Fuels Policy mandates that non-edible oil crops shall be grown only on 'wastelands' in the forest and non-forest areas, it does not define the term 'wasteland.' The other interesting question that arises in this respect is whether India has availability of enough wasteland to cultivate biofuel crops to meet the blending mandate. Interestingly enough, there also isn't any consensus among policy makers in this regard (Raju, S et al., 2009).

According to Kumar Biswas (2010), a related problem in this context is that a huge portion of the wastelands have been illegally acquired by landless laborers and other poor people and Government intervention to determine end use is imperative.

Moreover, the absence of a government mandate to demarcate non-cultivable wasteland for biofuel (and mainly *Jatropha*) cultivation, poses a major limitation to policy implementation and in its consequence, ethanol production (Choudhury and Goswami, 2013; Baka, 2014; Kumar and Biswas, 2010).

#### Limitations in the Cultivation of *Jatropha*

The National Biodiesel Mission (NBM) of 2003 had attempted to build entire new production chains centered on the cultivation of non-food crops on "marginal lands" (Kumar et al., 2009; MNRE 2009).[5] *Jatropha Curcas*, considering its capacity to resist pests and to yield well even on degraded soils, under water stress and without fertilizer inputs, (Jain and Sharma, 2010; Silitonga et al., 2011) was chosen to meet the NBM's mandate of replacing 20 per cent of the country's total diesel consumption by 2012.

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[4] While the cost of ethanol produced from B-Molasses (partial sugarcane juice) was increased to INR 52.43 per liter from the existing 47.49 per liter, that produced from C-heavy molasses (using grains and other crop waste) was raised to INR 53 from INR 43.46 a liter (July 2018), a 25 per cent boost. Source: https://www.theweek.in/news/biz-tech/2018/09/22/why-india-biofuel-policy-wont-work.html

[5] The policy rests on the estimate that there are 13.4 million hectares of such lands available for feedstock cultivation in India (Rajagopal 2008) and provides a package of economic and regulatory incentives (for example, tax reductions, credit provision through national banks, facilitated access to land) to private companies willing to develop industrial plantations or to engage in contract farming schemes with smallholders (MNRE 2009). The government has also made such feedstock cultivation eligible for its National Rural Employment Guarantee scheme (NREGA), which provides up to 100 government-paid days of manual rural labor per year.

Considering *Jatropha*'s potential in the production of bioethanol, limitations in its adoption and cultivation will pose a huge threat to the production of bioethanol.

To begin with, not only has *Jatropha*'s yield been highly overestimated by the academic community but also, "marginal lands" that were officially demarcated to produce *Jatropha* were often in use by the rural community for shifting cultivation, pastoralism etc. Thus, establishment of *Jatropha* monocultures by the authorities was an unwelcome initiative. (Rajagopal, 2008).

Going forward, though the government was able to put *Jatropha* monocultures in place, farmers would often participate in these programs solely to benefit from the NREGA payments and then sabotage the plantations. (Rajagopal, 2008).

Poor yields coupled with lack of agreement between the land owners and the government about sole cultivation of *Jatropha* on these lands, and the unavailability of committed buyers to complete the value chain, led to a huge failure in this policy. A lot of small farmers who had been persuaded into growing *Jatropha* ended up being worse off in the process.

### Differential Tax Structures at State Level

Movement of biofuel across State borders has been largely impeded by differences in State policies and restrictive administrative control.

### Inadequate R&D on the Different Species of Non-edible Oil Feedstock and their Suitability

Though the National Biofuels Policy had identified 400 species of non-edible seed-bearing trees in the country as potential sources of biofuels, a greater percentage of the practical experiments were confined to *Jatropha*. Additionally, most research efforts were focused on plant material to the complete neglect of accompanying factors like agro-climatic and soil conditions which are crucial to the entire equation. (Slette and Aradhey, 2014; Kumar, Biswas, and Purohit, 2013).

### Market Price of Agricultural Residues

Utilization of agricultural residues as feedstock for 2G biofuels depends on factors like availability, characteristics as fuel, and most importantly opportunity cost. Since residues are produced as a by-product (along with the main crops), they are assumed to be available at zero opportunity cost, which is not a valid assumption. Residues are used by the producers themselves and while their costs may not be explicitly determined, they are quite substantial and far from zero which is normally assumed in most analyses.

Variability in the procurement prices of residue across states makes it impossible to put a common valuation (single opportunity cost) on the price of residue which is the single largest determinant of residue use as feedstock. For example, in 2010 the price of rice husks varied from $18 to $74 per ton across states (Pandey et al., 2012).

## 10.0 Policies in India

The National Biofuel Mission (NBM), launched in 2003 under the aegis of the Planning Commission, GOI, was a pioneering effort towards the adoption of 1G biofuels.

It envisaged the phased expansion of area under biofuel feedstock crops (Jatropha and Pongamia) and several missions aimed at promoting large-scale plantation of feedstock crops in forests and wastelands, procurement of seeds, oil extraction, transesterification, blending, trade, and R&D.

The Ethanol Blended Petrol Program (EBPP) and Biodiesel Blending Program (BDBP) both of which were integral parts of the NBM were aimed at initiating the blending of biofuels with transport fuels such as petrol and high-speed diesel on a commercial scale.

In 2003 the Indian Ministry of Petroleum and Natural Gas (MoPNG), in a bid to make biofuel blending a binding obligation on the states, made 5 percent ethanol blending in petrol mandatory in 9 states and across 5 union territories. Unavailability of ethanol (attributable to low sugarcane yield), however, was a huge impediment to the adoption of this mandate. The blending mandate was further extended to cover 20 states and 8 union territories in 2006. Again, however, the mandate could not be fulfilled on account of insufficient availability of ethanol at the prevailing market prices.

In 2007, along with the mandated 5 percent ethanol blending across the country and 10 percent where feasible, the "National Biofuel Policy" was formulated by the Ministry of New and Renewable Energy (MNRE) in September 2008. Biofuels as a potential means to rural development and employment generation was envisioned as part of this policy. The NBP laid out R&D, capacity building, purchase policy, and registration for enabling biofuel use, including second-generation biofuels. While the policy was not feedstock specific, it maintained the government's position that energy crops should not have any adverse impact on the food sector.

This was followed up with another revised policy in May of 2018.

**Table 6** lists the various policies that were adopted by GOI, prior to the 2018 policy along with comments on their success/failure/impacts.

**Table 6: Policies Adopted by the GOI and its Ensuing Implications**

| Timeline | Action | Comments |
|---|---|---|
| **Ethanol Blending Program (EBP)** | | |
| January 2003 | The Ministry of Petroleum and Natural Gas made mandatory – 5 percent bending of ethanol with petrol across nine major sugar producing states and five Union territories in India. | Partially implemented due to unavailability of ethanol (due to low sugarcane production in 2003/04 and 2004/05). |
| October 2008 | Third phase of implementing EBP envisaged blending ratio to be increased to 10 percent. | Since there was no official notification released, oil marketing companies have not started 10 percent ethanol blending. |
| August 2010 | Government fixed an ad-hoc provisional procurement price in Indian Rupees (INR ) of 27 per liter of ethanol by Oil Marketing Companies (OMC) for EBP program. Decision was taken to constitute expert committee under Chairmanship of Dr. Choudhary, Member of Planning Commission, to recommend a formula for pricing ethanol. | Expert Committee in March 2011 had recommended that ethanol be priced 20 percent lower than gasoline price. No consensus yet on pricing policy of ethanol. In any event when ethanol supply runs short, government proposed to reduce import duty on alcohol and molasses. OMC stipulated that alcohol or molasses could not be imported for EBP but must be exclusively sourced from domestic-produced molasses. |
| November 2012 | In a bid to renew its focus and strongly implement the EBP, the Cabinet Committee on Economic Affairs (CCEA) on November 22, 2012, recommended five-percent mandatory blending of ethanol with gasoline (the blending target was already decided by the CCEA in the past).<br><br>Henceforth, the procurement price of ethanol shall be decided by between the OMC and suppliers of ethanol (CCEA recommendation).<br><br>According to one of the CCEA recommendations, in the case of any shortfall in domestic availability, the OMCs and chemical companies were free to import ethanol for EBP. Since OMCs were falling short by more than 820.3 million liters of ethanol, they | The Union government under the Motor Spirits Act on January 2 notified that a few states such as Uttar Pradesh, Delhi, Haryana, Punjab, Karnataka and Goa can even achieve up to 10 percent ethanol blending target, but the overall average for the country as a whole should reach five percent by end of June 30, 2013.<br>The interim (ad-hoc) price of INR 27 per liter would no longer hold as price would now be decided by market forces.<br><br>The fuel ethanol blend rate that could be achieved then was 1.6 percent. |

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| | floated a global tender in the third week of January to augment remaining supplies. | |
| CY 2014 | GOI considered raising the EBP program target from five to 10 percent in near future.<br><br>On December 10, 2014, GOI announced a price control schedule for fuel ethanol procurement for OMCs. The program fixes landed-ethanol prices at OMC depots from INR 48.50 to INR 49.50 per liter ($0.76 to $0.77/liter), a three to five percent increase over the previous price. | Total quantity accepted by OMC was thus 247 + 53 million liters = 300 million liters. Assuming that OMC shall come out with another tender soon for ethanol procurement for CY 2015, Post anticipated that OMC shall procure another 50 million liters in December 2014.<br>The cumulative volumes likely to be accepted by OMCs for blending with gasoline will be 350 million liters, which translates to market penetration at 1.4 percent.<br><br>This will likely accelerate India's EBP, infuse cash into the local sugar industry, help millers pay down debts, and curtail (by some estimates) upwards of $750 million in crude oil imports. In previous years, Post has observed that India has the capacity to fulfill its ethanol blending mandate, provided there are equal incentives for both the producers and blenders. |
| April 2015 | GOI removed 12.36 central excise duty levied on ethanol supplied for blending with gasoline. | The excise duty exemption will be applicable for ethanol produced from molasses generated during the next sugar season (October 2015-September 2016) and supplied for blending with gasoline. Press Information Bureau (PIB) Press Release. Industry sources claim that sugar mills are expected to benefit to an extent of INR five per liter on sale of ethanol for blending. |
| **National Biodiesel Mission** | | |
| April 2003 | Phase I (Demonstration) from 2003 – 2007:<br>Ministry of Rural Development appointed as nodal ministry to cover | Public and private sector, state government, research institutions (Indian and foreign) involved in the program |

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| | 400,000 hectares under *Jatropha* cultivation. This phase also proposed nursery development, establishment of seed procurement and establishment centers, installation of trans-esterification plant, blending and marketing of biodiesel. | achieved varying degrees of success. |
| October 2005 | The Ministry of Petroleum and Natural Gas announced the biodiesel purchase policy. OMC to purchase bio diesel from 20 procurement centers across India at INR 26.5/liter | Cost of biodiesel production higher (20 to 50 percent) than purchase price. No sale of biodiesel. |
| October 2008 | Phase II (Self Execution) from 2008 to 2012:<br>Targeted to produce sufficient biodiesel for 20 percent blending by end of XIth (2008-12) five-year plan | Lack of largescale plantation, conventional low yielding *Jatropha* cultivars, seed collection and extraction infrastructure, buy-back arrangement, capacity and confidence building measures among farmers impeded the progress of this phase. |
| October 2014 | GOI deregulated diesel prices in line with gasoline. | The retail price will now be decided by the market forces and GOI will no longer have to compensate OMCs for selling diesel below market prices. This step will incentivize firms engaged in biodiesel production in India. |
| CY 2015 | In January, Union Cabinet chaired by the Prime Minister, Shri Narendra Modi, gave its approval for amending the motor spirit (MS) and high-speed diesel (HSD) Control Order for Regulation of Supply, Distribution and Prevention of Malpractices dated 19.12.2005.<br><br>The Cabinet has also decided to suitably amend Para 5.11 and 5.12 of the National biofuel policy for facilitating consumers of diesel in procuring directly from private biodiesel manufacturers, their authorized dealers and Joint Ventures (JV) of OMCs authorized by the MoPNG. This decision will encourage the production and use of biodiesel in the country. | The amendment will allow private biodiesel manufacturers, their authorized dealers and JVs of OMCs authorized by the Ministry of Petroleum and Natural Gas (MoPNG) as dealers and give marketing and distribution functions to them for the limited purpose of supply of biodiesel to consumers.<br><br>The investment and production conditions (as applicable) specified in the marketing resolution dated March 8, 2002, of MoPNG will also be relaxed and a new clause added to give marketing rights for pure biodiesel (B100) to the private biodiesel manufacturers, their authorized dealers and JVs of OMCs authorized by the MoPNG for direct sales to consumers. |

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| | On August 10, GOI had issued notification to allow the sale of Biodiesel (B100) by private manufacturers to bulk (Gazette Notification No. General Statutory Rules (GSR) 621 (E)). The order is called the Motor Spirit and High-Speed Diesel (Regulation of Supply, Distribution, and Prevention of Malpractices) Amendment Order, 2015.<br><br>On August 11, 2015, Minister of State (I/c), Petroleum and Natural Gas, launched sale of B-5 Diesel on World Bio Fuel Day. (Source: News Release, IOC). | Bids were invited until August 19. The policy is meant to help with local price discovery ahead of a potential 20 percent blend for biodiesel in 2017. A 20 percent blend for ethanol has also been proposed but is unlikely since the current 5 percent blend has yet to be reached.<br><br>Federal government may permit the sale of biodiesel (B100) for blending with HSD to bulk consumers such as Indian Railways, State Transport Undertakings and other bulk consumers having minimum requirement of biodiesel for their own consumption by a tank truck load supply which shall not be less than twelve thousand liters.<br><br>As part of the initial run, B-5 was expected to be sold to customers at some retail outlets in New Delhi, Vijayawada, Haldia, and Vishakhapatnam. The Biodiesel Purchase Policy was announced in October 2005 and became effective January 2006. |
| March 2017 | The Cabinet Committee on Economic Affairs has approved closure/winding up of the biofuel venture between Chattisgarh Renewable Energy Development Agency (CREDA) and Hindustan Petroleum Corporation Limited (HPCL) called CREDA HPCL Biofuels Ltd (CHBL) and the one between Indian Oil CREDA called Indian Oil CREDA Biofuels Ltd (ICBL). | The offices of CHBL/ICBL have been closed. Joint Ventures (JV) between CREDA HPCL Biofuel Ltd (CHBL) and Indian Oil-CREDA Biofuels Limited (ICBL) were formed for carrying out energy crop (*Jatropha*) plantation and production of biodiesel in 2008 and 2009 respectively. The CREDA, an arm of Chhattisgarh state government, had provided wasteland to CHBL and ICBL through Land Use Agreement for plantation of Jatropha. Due to various constraints such as very poor seed yield, limited availability of wasteland, high plantation maintenance cost etc. the project became unviable and |

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| | | *Jatropha* plantation activities were discontinued. |
| **National Policy on Biofuels** | | |
| September 2008 | 5 percent blending mandatory across all states in the country | GOI deferred the plan again due to short supply of sugarcane and sugar molasses in 2008/09. |

*Source: USDA Gain Report, # IN7075*

In addition to the various schemes and programs (listed above), participation of both federal and state governments for clean energy initiatives, capital investments and tax credits was also mandated.

The latest addition to the Government's efforts comes in the form of the 2018 National Policy on Biofuels. This policy expands the scope of raw materials for ethanol production to include sugarcane juice, sugar containing materials like sugar beet and sweet sorghum, starch containing materials like corn and cassava, and food unfit for human consumption like damaged food grains (wheat, broken rice) and rotten potatoes. Acknowledging the fact that during the surplus production phase, farmers are at a risk of not getting an appropriate price for their produce, the new policy allows use of surplus food grains for production of ethanol for blending with petrol with the approval of National Biofuel Coordination Committee.

In a bid to promote R&D in 2G technology, the Policy indicates a viability gap funding scheme for 2G ethanol Bio refineries of INR.50 bn in 6 years in addition to additional tax incentives, and higher purchase price as compared to 1G biofuels.

The expected benefits of this policy (National Policy on Biofuels, 2018) can be summarized as follows

i. "**Reduce Import Dependency**: 10 mn liters of E10 saves INR.0.28 bn of forex at current rates. The ethanol supply year 2017-18 is likely to see a supply of around 1.5 billion liters of ethanol which will result in savings of over INR.40 bn of forex.

ii. **Cleaner Environment**: 10 mn liters of E-10 saves around 20,000 tons of $CO_2$ emissions. For the ethanol supply year 2017-18, there will be lower $CO_2$ emissions by approximately 3 mn tons. By reducing crop burning and conversion of agricultural residues/wastes to biofuels there will be further reductions in GHG emissions.

iii. **Health benefits**: Prolonged reuse of cooking oil for preparing food, particularly in deep-frying is a potential health hazard and can lead to many diseases. Used cooking oil is a potential feedstock for biodiesel and its use for making biodiesel will prevent diversion of used cooking oil in the food industry.

iv. **MSW Management**: It is estimated that, annually 62 MMT of Municipal Solid Waste gets generated in India. There are technologies available which can convert waste/plastic, MSW to drop in fuels. One ton of such waste has the potential to provide around 20 percent of drop in fuels.

v. **Infrastructural Investment in Rural Areas**: It is estimated that a one 100 klpd biorefinery will require around INR 8 bn capital investment. At present Oil Marketing Companies are in the process of setting up twelve 2G bio refineries with an investment of around INR 100 bn. Further addition of 2G bio refineries across the country will spur infrastructural investment in the rural areas.

vi. **Employment Generation**: One 100 klpd 2G bio refinery can contribute 1200 jobs in plant operations, village level entrepreneurs and supply chain management.

vii. **Additional Income to Farmers**: By adopting 2G technologies, agricultural residues/waste, which otherwise are burned by the farmers, can be converted to ethanol and can become a commodity, if a market for the residues/waste is developed. Also, farmers are at a risk of not getting an appropriate price for their produce during the surplus production phase. Thus, conversion of surplus grains and agricultural biomass can help in price stabilization."

Despite revisions to earlier policies, India has a lot to learn from some of the pioneers of 2G technology.

## 11.0 Successful Policies at the Global Level and Policy Recommendations by International Organizations

**According to a UN report,** globally, the policy instrument that has provided the greatest traction to advanced biofuels has been the market segmentation strategy in conventional/advanced/cellulosic biofuels used in the United States market. It works by granting price premiums for the production of cellulosic ethanol. Low interest rates and a venture capital culture have also been touted for advancing the deployment of second-generation biofuels in United States.

In the United States, drivers of 2G ethanol were developed under the Energy Policy Act of 2005 and were published as the Renewable Fuels Standard (RFS), which was later updated by the Energy Independence and Security Act of 2007. The RFS's objective is to increase the biofuel blend up to 36 billion gallons (Bgal) by 2022 from 9 Bgal in 2008. In addition to blending legislations, the inclusion of several value-generating aspects at the federal level, (case in point being the cellulosic waiver credit (CWC) which is a tax exemption that inversely correlates with gasoline prices) have helped in the adoption of 2G technology.

Besides, the rapid growth in the advanced cellulosic ethanol industry in China, as well as strong support to the sector by the National Development Bank in Brazil, have all come together to provide power to the industry globally.

In the European Union, along with the use of blending mandates, adoption of a roadmap (in 2011) for 'Competitive Low Carbon Economy' in which GHG's emission should be decreased to 40 percent, 60 percent and 80 percent by 2030, 2040, and 2050, respectively, via low-carbon technologies and robust energy efficiency scheme (Su et al., 2015; Bastos, Lima, and Gupta, 2014) have all contributed in leaps and bounds towards the adoption of 2G technology.

In addition to looking to the pioneers of 2G policy as a way forward, another potential avenue for improvement comes from the policy prescriptions of the UN and the IEA.

To grow and promote the market for adoption of 2G technology, the UN (UNCTAD, 2015, pg. 7) makes the following policy recommendations.

It encourages:

i. Creation of regulatory frameworks for advanced bioenergy tailored to national circumstances, which do not necessarily focus on the type of supply, but instead on the existing local demands.

ii. Technology transfer through cooperation between domestic organizations and foreign companies for joint ventures by means of investment agreements. Related to this is the need to maintain technical dialogue among the different production regions of advanced fuels in order to ensure compatible standards for feedstock and promote trade in advanced biofuels.

iii. Including biomaterials, in ways that avoid locking industrial development paths into specific sectors or technologies. This would provide some amount of flexibility for market players that operate biorefineries as they could target multiple markets, including materials, feed, food, and energy - both domestically and internationally.

iv. Drawing upon sustainability lessons applied for first-generation biofuels into near and midterm sustainability provisions or labels for advanced biofuels.

The IEA maintains that 2G technology will grow and develop using the existing infrastructure of 1G technology, thereby reducing overall costs, making it imperative that there are well designed support policies for both. Its recommendations therefore recognize that 1G and 2G technologies are not mutually exclusive and 2G technology can eventually benefit from the current support towards 1G technology (Sims et al., 2008).

Specifically, the IEA encourages:

i. Policies to support 1G or 2G biofuels should be part of a comprehensive strategy to reduce $CO_2$ emissions.
ii. Enhanced R&D investment in 2G biofuels.
iii. Accelerating the demonstration of commercial scale 2G biofuels.
iv. Deployment policies for 2G biofuels in the form of blending targets and tax credits.
v. Environmental performance and certification schemes to harmonize potential sustainable biomass certification methods.

## 12.0 Conclusion

This report was an attempt to document the global landscape for second-generation biofuel production technology and understanding India's position in that chronology. The Government of India, through its National Biofuels Policy, had announced an ethanol blending target of 5 percent by 2012, 10 percent by 2017, and 20 percent after 2017. The mandate which started off in 2003 to include nine major sugar producing States and five Union Territories in India was later extended to twenty states and seven union territories. Despite this, the blending targets remain a distant possibility, primarily because of the limitations of the first-generation technology. Under the circumstances, if India is to meet its blending mandates, large scale commercial adoption of second-generation technologies to produce biofuels is the way forward. Moreover, given the amount of crop residues that India generates on an annual basis, and the ensuing pollution owing to the current disposal mechanisms for these residues, adoption of a second-generation technology seems like a very natural choice.

Having said that, 2G technology is not without its fair share of limitations, and while India's latest Biofuel policy might be an answer (at least in part) to the limitations of its predecessors, a lot can be learned by way of polices adopted by some of the pioneers of 2G technology (USA and Brazil, for example) and recommendations by the international agencies (UN and IEA).

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