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Bio-fuels to Power Indian Agriculture

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Preface

Quantity and quality of energy use is reflective of level of civilization and economic prosperity of a nation. Rural India, which accounts for over twothird of its 1.2 billion total population, continues to be agrarian doing farming, livestock husbandry, fishery and forestry; involves in produce and by-products processing, marketing and consumption and uses traditionally natural and animate energy sources. However, efforts leading to increased production and productivity to meet needs of its growing population led to introduction of high yielding crops and exotic strains of animals and associated cultural techniques and equipment that used commercial energies such as electricity, diesel, chemical fertilizers and pesticides. Electricity is most convenient and efficient source of energy for most of the applications but is in short supply. The demand of commercial energies is steadily growing. India is not well endowed in commercial energy such as diesel essential to power tractors and other engine operated equipments, so much so that 70% is imported. Unlike industry where men and material are brought under one roof, agriculture requires to move men and materials to and from farm and farm stead as well as to carry out farm operations using tractive power. Shaft power is also required in large quantities to carry out stationary operations like pumping water, running threshers, cleaners, and other processing equipments. Poorly endowed in petrochemicals makes India and Indian agriculture and allied activities vulnerable and energy wise insecure. Alternatives to diesel, fully or partially, have to be found on priority.

With growing dependence on land, land holdings per family are steadily declining. Rural people are faced with livelihood issues; younger generation is losing interest in agriculture; as a result there is growing demand for farm mechanization to achieve timeliness and efficiency in farm operations, precision in metering and placement of costly inputs with minimum drudgery and with dignity. Traditional animate power sources are not only costlier but have become inconvenient, reduce freedom to seek off-farm supplemental income opportunities. There is rapid growth in use of electro-mechanical power and energy sources in agriculture, agro-processing and rural living. On-farm post-harvest processing and value addition and agro-entrepreneurship generating avenues of additional income and employment have become necessity. It can grow only if there is assured supply of electricity and fuels to run IC-engines at affordable prices. Farm power availability is not sufficient. The share of petrochemicals use has increased. The shortage of electricity keeps tubewells and pumping sets waiting for energization and proper operation.

To address the issue and identify alternate source of liquid fuel for IC engines that can power tractors, power tillers, combines, and other engines operated farm equipment supplementing and substituting diesel, the National Academy of Agricultural Sciences organized a Brainstorming Session on ‘Bio-fuels to Power Indian Agriculture’. Useful recommendations and a pathway have emerged towards alternate liquid fuels to power primovers of farming equipments. No doubt collection, conservation and production of energy value biomass and their efficient energy conversions and utilization offer long term solution to the problem. A sincere implementation of the suggestions made in this policy paper offer a solution to the problem to a great extent. I compliment Professors Dr. B.S. Pathak, Dr. Anwar Alam, Dr. A.K. Jain and other participants to this contribution.

S. Ayyappan
President

Bio-fuels to Power Indian Agriculture

1. PREAMBLE

The demand for energy is rapidly increasing to sustain global economic growth and development of technology. But the finite reserves of fossil fuels, the main source of energy, continue to deplete with time. Long term supply of these fuels in sufficient quantities has become highly uncertain. India's reserves of coal and lignite, supplemented with nuclear and renewable energy sources, are sufficient to meet its needs for power (Table 1). But its own crude oil resources are hardly adequate to meet the need for petroleum products, which include transport fuels like diesel and petrol. We are highly dependent on the import of crude oil from Middle – East and other oil exporting countries which makes Indian economy, including agriculture, vulnerable to a future energy crisis.

Table 1. Resources, production, import, export and availability of fossil fuel resources in 2011-12 (Anonymous 2013)

Resource	Reserves	Production	Import	Export	Availability
Coal & Lignite	335.56 (bt)	582.26 (Mt)	102.85 (Mt)	2.08 (Mt)	680.67 (Mt)
Crude Oil	759.59 (Mt)	38.09 (Mt)	171.73 (Mt)	-	209.82 (Mt)
Natural Gas	1330.26 (BCM)	47.56 (BCM)	N.A.	-	46.58 (BCM)
Petroleum	-	196.71 (Mt)	15.0 (Mt)	60.08 (Mt)	150.87 (Mt)

2. COMMERCIAL ENERGY USE IN INDIAN AGRICULTURE

Till 1950s imported heavy tractors and machines were used in India mainly for land reclamation and development of large government farms. The picture changed in sixties with the introduction of high yielding varieties of major crops. The farmers could not manage timely irrigation and threshing of crops and timely seedbed preparation with draft animal power. The number of diesel engine and electric motor powered irrigation pumps, stationary threshers, seed-cum-fertilizer drills, tillage equipment driven by tractors and a wide variety of farm machines, including self-propelled equipment, have been in operation for 50 years. Compared to 1971-72, the use of electro-mechanical power in Indian agriculture was over 11 times higher in 2005-06 (Table 2). With 4.5 million (M) tractors, over 7 M diesel engine powered pumps, power tillers, harvester-combines, etc., Indian agriculture has become a user of the largest number of diesel fueled agricultural prime-movers. Experts have estimated that in order to carry the benefits of mechanization to majority of the farmers, the availability of tractors and other machines will have to be doubled and the average availability of electro-mechanical power be raised to 3 kW/ha or more.

Table 2. Use of electro-mechanical power in Indian agriculture (Source: IASRI, 2013)

Year	Tractor (kW/ha)	Power Tiller (kW/ha)	Diesel Engine (kW/ha)	Electric Motor (kW/ha)	Total Electro-Mechanical Power (kW/ha)
1971-72	0.020	0.001	0.053	0.041	0.115
1981-82	0.090	0.002	0.112	0.084	0.288
1991-92	0.230	0.003	0.177	0.159	0.569
2000-01	0.480	0.006	0.238	0.250	0.974
2005-06	0.700	0.009	0.273	0.311	1.293
2011-12*	0.820	0.010	0.273	0.430	1.5332013

Note: The availability of animate power has declined from 45% in 1971-72 to 5.1% in 2012-13. Human power has declined from 15.4% in 1971 to 5.0% in 2012-13.

The average growth of commercial energy consumption (electricity and diesel) in agriculture in the last few years has been about 4%. Considering the increase in annual sale of tractors and the potential for development of lift irrigation in Eastern India, the growth rate is bound to escalate in future. Estimated energy needs of Indian agriculture in the years 2022-23 and 2032-33 at 4% and 5% growth rates are given in Table 3.

Table 3. Estimated energy needs of Indian agriculture - MTOE (Source: Pathak, 2009)

Year	4% growth	5% growth
2012 – 13	23.29	23.51
2022 – 23	32.85	38.30
2032 – 33	46.34	59.41

Mtoe ~ Million tonnes oil equivalent

Taking 2012-13 as the base year, energy needs of agriculture are estimated to increase by 40 to 60 percent in the next 10 years and by 100 to 150 percent in the next 20 years. In the past energy supply was shared equally by electricity and diesel. In the recent years the share of electricity has increased. According to Nielsen Report (Anonymous 2014) Indian agriculture consumed about 9 Mt diesel fuel in 2012-13. The distribution was as follows:

Tractors	5.11 Mt
Pumps	2.00 Mt
Self-propelled equipment	1.87 Mt

Due to the continuing increase in the numbers of tractors and self-propelled machines, requirement for diesel fuel is likely to increase @ 6% per year and it would exceed 14 Mt by 2020. Disruption in the supply of diesel might bring Indian agriculture to a halt. The country has to look for energy resources which can sustain supply of alternate fuel/fuels, preferably renewable, to ensure that millions of tractors, power tillers, selfpropelled machines and stationary engines used by Indian farmers continue to work in spite of the anticipated shortage of crude oil (Table 4). Biomass is most promising resource which can sustain as alternate source of energy to agriculture.

Table 4: Potential resources to sustain energy supply for 50 years and beyond (Source: prepared by Pathak, 2009)

Carbon Sources	**Application**	**GHG Emissions**
Coal	Electricity, Transport Fuel (by conversion), Heat	Major Contribution
Biomass	Electricity, Transport Fuel (by conversion), Heat	Neutral
Non-Carbon Sources		
Hydro	Electricity	No Emissions
Wind	Electricity	No Emissions
Solar	Electricity	No Emissions

3. BIOMASS

Crops and animals, agro- processing industries, forests, agro-forestry, road sides and waste land generate by-products and wastes, which are potential sources of biomass to produce bio-fuels. Countries with large resources of unused cultivable land raise

Fig. 1. Uncontrolled burning of rice straw (Punjab)

energy crops for the production of bio-fuels. Pressure on agricultural land does not permit large scale cultivation of energy crops in India.

An ambitious programme was launched in 1990s to plant Jatropha on degraded soil in low rainfall areas and use Jatropha oil ester or 'bio-diesel' as engine fuel with or without mixing it with petro-diesel in desired proportions. However, for more than one reason, Jatropha cultivation has failed to pick up. In the meantime micro algae are being projected as an oil bearing biomass of great promise with a per hectare annual yield potential of 100 t biomass and 40 t oil. Algal oil can be converted to bio-diesel like any other plant oil. It will however take time before algal bio-diesel is available in sufficient quantities to make an impact on the supply of liquid fuel to agriculture. It is reported that dead wood recovered from forests and agro-forestry and the biomass collected from road sides and waste land are fully utilized as domestic fuel and to some extent as construction material (Pathak *et al.*, 2005). The amounts of crop and agro-processing residues produced and the surplus available for energy generation in 2008-09 were estimated at 699 Mt and 233 Mt respectively (NAAS Policy Paper No. 49, 2010). It has been reported that 90-125 Mt of crop residues are burnt each year after harvest (NAAS 2012) (Figs. 1 and 2).

Fig. 2. The charred field (Punjab)

With increasing agricultural production, the amount of residues burnt after harvest will also increase leading to loss of organic matter and serious air pollution. One hundred million tonnes of biomass can produce sufficient traction and transport fuel to replace the present supply of diesel to agriculture (Pathak, 1986; Srivastava, *et al.,* 2010). Crop Residues (CR) are the most promising source of biomass for producing fuels and energy.

4. CHARACTERISTICS OF CROP RESIDUES

Unlike wood, CR vary widely in their characteristics which influence the selection of raw material and the conversion route to obtain the desired end-product/ bio-fuel. Characteristics of the residues of a crop vary according to crop variety and environmental conditions under which it is grown. In order to utilize CR for bio-fuel processes and technology, we need information on the following aspects:

1. Physical properties like bulk density, angle of repose, moisture content and equilibrium moisture content of CR. Bulk density of rice straw is 30 kg/m^3 and that of hardwoods 400 kg/m^3.

2. Thermal properties like higher and lower heating values and ash softening/fusion temperature. The HHV ranges between 15-18 MJ/kg.

3. Proximate analysis to determine fixed carbon, volatile matter and ash content.

4. Elemental analysis, also called ultimate analysis, to determine the chemical composition of the residue in terms of different elements like carbon, hydrogen, nitrogen, alkali metals, silica, etc.

5. Summative analysis, also called chemical analysis, to estimate cellulose, hemi-cellulose, lignin and benzene extract content.

6. Thermo- gravimetric analysis to obtain information on temperature dependent weight loss rate.

The work on characterization of crop and agro-processing residues and selected wood species was initiated at Punjab Agricultural University (PAU) Ludhiana in the ICAR project “Energy in Agriculture” in 1980. Tables 5, 6 and 7 are examples of the type of data collected. Similar data were generated for a large number of crop residues at I.I.T., Delhi. Proper understanding of the physical, thermal and chemical properties of biomass used as feedstock to produce bio-fuels is a basic need and characterization of the raw material should be a part of the work in any major project to develop bio-fuels technology.

Table 5. Some characteristics of crop and agro – processing residues (Pathak *et al.*, 1986)

Crop Residues	Bulk Density (kg/m^3)	EMC at 80% RH	Higher Calorific Value (MJ/kg)	Proximate Analysis		
				Fixed Carbon (%)	Volatile Matter (%)	Ash (%)
Rice Straw	30	36.70	15.00	11.10	69.70	19.20
Rice Husk	105	29.40	15.50	12.50	71.00	16.50
Wheat Straw	60	34.00	17.20	17.93	73.60	8.47
Groundnut Shell	100	30.00	20.01	11.67	83.63	4.43
Cotton Stalks	160	27.05	17.40	15.30	81.40	3.30
Sugarcane Bagasse	70	34.86	20.00	15.86	79.20	4.94

Table 6. Elemental analysis of crop residues (Pathak *et al.*, 1986)

Crop Residues	Elemental Analysis (%)									C:N ratio
	C	H	N	Na	K	P	Mg	Ca	SiO2	
Rice Straw	36.80	5.00	1.00	0.09	2.50	0.06	0.53	0.08	15.60	37:1
Rice Husk	37.80	5.00	0.30	0.02	0.30	0.03	0.17	0.10	16.77	126:1
Wheat Straw	43.80	5.40	1.00	0.06	0.78	0.04	0.35	0.10	7.08	44:1
Groundnut Shells	41.10	4.80	1.60	0.05	1.20	0.12	0.40	0.10	2.52	26:1
Cotton Stalks	51.00	4.90	1.00	0.09	0.61	0.08	0.43	0.12	1.33	51:1
Sugarcane Bagasse	48.20	6.10	0.20	0.06	0.51	0.04	0.36	0.14	1.30	241:1

Table 7. Chemical analysis of crop residues (Pathak *et al.*, 1986)

Crop Residues	Chemical Analysis (%)			
	Cellulose	Hemi-cellulose	Lignin	Bz Extract
Rice Straw	41.40	20.40	12.10	5.60
Rice Husk	44.10	17.80	17.20	3.40
Wheat Straw	39.60	24.10	17.00	7.30
Groundnut Shells	36.50	13.90	31.30	12.20
Cotton Stalks	41.90	19.00	27.20	9.30
Sugarcane Bagasse	40.00	22.60	14.80	15.90

Even in a small sample consisting of three crop residues and three processing residues, as in Tables 5, 6 and 7, bulk density varies from 30 kg/m^3 to 160 kg/m^3, ash from 3.3% to 19.2%, N from 0.2% to 1.6%, and lignin from 12.1% to 31.3%.

5. RECOVERY OF CROP RESIDUES

The logistics of supply of CR in large quantities for energy generation has always been questionable. Residues are thinly spread over very large areas. For example, the 14-15 Mt of rice straw burnt each year in Punjab has to be collected from an area of 2.7 million hectares. Rice is combine-harvested and the operation is completed in 20 days. The time available for mowing the standing stubble, windrowing the straw, baling and transporting it to storage sites will be 25-30 days only. Recovering and transporting 500,000 tonnes (3,500,000 cubic meter volume) per day will require a huge fleet of trucks, tractors, trailers with large number of mowers, windrowers and balers. Large scale utilization of crop residues for producing bio-fuels will not be feasible without mechanizing its management. Needed machinery is manufactured / can be manufactured in India. Fig. 3 shows a mechanization package for recovery of cereal straw from combine harvested rice and wheat fields. Normally larger an operation, more economical it is. But in the case of crop residues, greater the quantity to be collected, higher the cost/

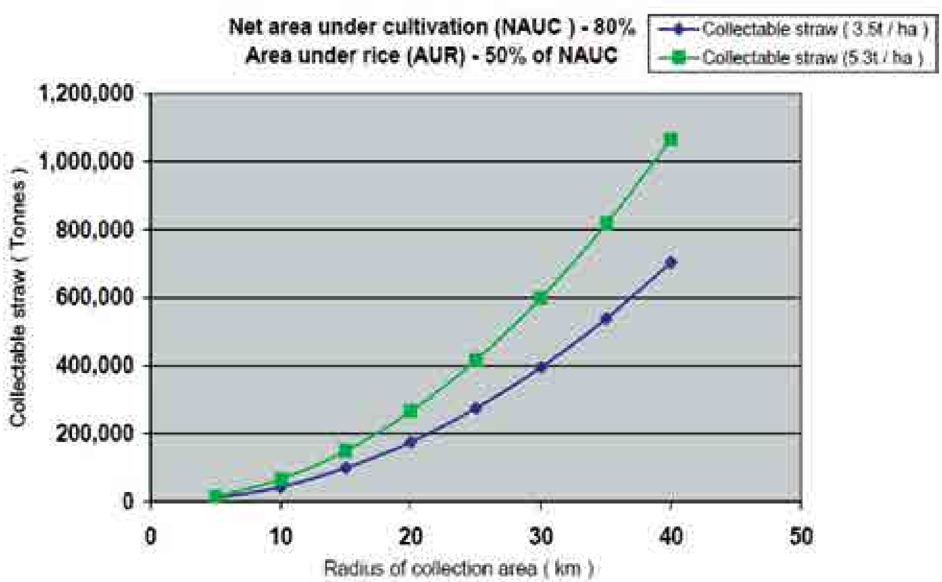

Fig. 3. Collectable straw vs radius of collection (Pathak 2009)

tone because of the longer distance over which it is to be transported. A reliable estimate of recoverable residue from a production area can be made by using the approach suggested below.

Q = GA × NAUC × AUC × Y × R × L

where,

Q = quantity of CR recoverable (tonnes)

GA = geographic area (km^2)

NAUC = net area under cultivation (% of GA)

AUC = area under a crop (% of NAUC)

Y = yield ($tonnes/km^2$)

R = CR: grain ratio

L = CR recovery (%)

This approach also makes it easy to arrive at the radius of potential collection area from which the required amount of residue can be recovered.

6. BIO-FUELS

Bio-fuels are produced from organic matter of recent origin or biomass. Carbon and hydrogen are the major energy providing elements in biomass. Fuels derived from oil, starch and sugar are called first generation bio-fuels and are the substrates for bio-diesel and ethyl alcohol. The crops primarily grown to provide raw material for first generation bio-fuels are known as energy crops i.e. *Jatropha curcas*, *Pongamia pinnata*, *Brassica napus*, maize and sugarcane. These crops use land and water resources. Fuels obtained through conversion of lignocellulosic matter like crop residues are known as second generation bio-fuels. Crop residues are the most abundant source of lignocellulosic matter in India (Pathak *et al*., 2005). Bio-fuels obtained from residues include solid fuels, bio-oil, alcohols, biogas and producer gas.

6.1 Solid Bio-Fuels

All solid biomass is combustible provided its moisture content is low. Woody residues like cotton and pigeon pea stalks are used as domestic fuel to cook food and heat in the rural areas. Rice husk and bagasse are used as boiler fuel. However, because of their low bulk density and irregular shape and size, crop residues are inconvenient to use as industrial fuel. Briquetting converts most of the

Fig. 4. Biomass Briquettes

crop residues into high density, better burning characteristics and low smoke fuel suitable for both domestic and industrial use. It is usually a binder less technology. The size (diameter) of briquettes varies from 10 mm to 90 mm (Fig. 4).

The cost of briquetting (excluding the cost of residue) is reported to vary from Rs. 570/t to Rs. 2000/t depending on the characteristics of the residue (Srivastava *et al*., 2010). Energy requirement is in the range of 20 to 60 kWh/t. Every kg. of briquetted biomass produces 1 kWh of electrical energy *i.e*. every tonne of briquettes can generate 1000 kWh. Production of briquetted biomass takes only 4 to 12% of the electrical energy that can be generated from it. Briquettes emit little smoke when used as fuel in cook stoves. However, as stated earlier, solid bio-fuels cannot replace hydrocarbons as traction and transport fuel.

6.2 Bio-diesel

It is defined as a fuel comprising mono-alkyl esters of long chain fatty acids derived from plant oils, animal fats and waste oils. Transesterification of natural oils and fats reduces their viscosity, improves fuel characteristics and eliminates substances which cause deposits in I.C. engines and dilution of lubricating oil. Bio-diesel is an ideal alternate fuel for compression ignition (diesel) engines. Table 8 gives a comparison of selected properties of petro-diesel, raw oil and bio-diesels. The percentage of bio-diesel blended with diesel is given by the term BX in which X denotes bio-oil percentage. A B_{20} blend has 20% bio-diesel and

Table 8. Selected fuel properties of petro-diesel, raw plant oil and bio-diesel (Source: Verma and Sharda, 2005)

Fuel	Kinematic Viscosity, CS	HHV MJ/kg	Density kg/m^3	Flash point°C	Pour Point°C	Acid Value Mg of KOH
Diesel	5.56	44.77	847.0	44.0	- 4.87	0.25
Linseed Oil	43.73	38.26	922.0	237.4	- 9.67	3.74
Bio Diesel of Linseed	7.14	39.50	890.5	198.8	- 6.67	0.32
Bio Diesel of Jatropha	6.7	34.5	867.0	175.0	- 6.0	0.50
Bio Diesel of Karanj	7.1	33.9	864.0	162.0	- 4.0	0.42

the rest is petro-diesel. Extensive trials on the use of bio-diesel blends in diesel engines have found that presence of bio-diesel reduces CO and hydrocarbon emissions, while NO_x content of the exhaust increases to some extent. The brake horse power and torque are marginally reduced and specific fuel consumption is increased due to the lower heating value of bio-diesel. Metallic parts of the engine are not affected by the use of bio-diesel. However, rubber and plastic parts deteriorate relatively faster. This problem has been solved by using alternate materials. Development of salt tolerant and efficient lipid producing algae and their large scale cultivation in the vast coastal area of India could make a significant contribution to the availability of bio-diesel. Technology for Transesterification of oils and fats is available. Data on biomass production and oil yield from large scale cultivation of algae is yet to be generated. Efforts are needed to exploit this renewable potential for engine fuels.

6.3 Ethanol

Sugar and starch have been used for few thousand years to produce ethyl alcohol, also called ethanol both for as human food product as well as industrial feed. Ethanol can also be produced from lignocellulosic materials like crop residues.

Until recently the cost of cellulase enzyme which hydrolyzes cellulose to produce fermentable sugar, was prohibitive. Many organizations are engaged in developing low cost cellulase, hemicellulase and xylanase enzymes which need to be produced on large scale for commercial purpose. The researchers are also looking for the yeast to ferment C5 sugars produced from hydrolysis of hemicellulose. Use of blend ethanol as a fuel additive in petrol engines reduces GHG, CO, particulate and NOx emission. The emission of formaldehyde and acetaldehyde increases.

Pure/200 proof alcohol is used as fuel. It is highly hygroscopic. The fuel properties of ethanol are given in Table 9.

Table 9. Typical properties of fuel alcohol (Ethanol CH_3CH_2OH) (Source: Alam and Chandra, 2015)

Characteristics	Values
Boiling point	78°C
Melting point	-114°C
Density	789 kg/m^3
Flash point	13-14°C
Auto ignition	363°C
Calorific value	30.14 MJ/kg
Viscosity	1.095 cp
Octane No.	108.6 (better than petrol)

Crop residues amounting to about 100 Mt, which are burnt for disposal after crop harvest, meet the requirements for a suitable feedstock for producing bio-fuels. The CR are lignocellulosic material, which can be converted to alcohol by two methods, namely cellulolysis and gasification.

Cellulolysis of CR includes pre-treatment to achieve small particle size of feedstock and a weakened ligno-cellulosic bond (delignification), hydrolysis to covert cellulose and hemicelluloses into simple sugars, separation of sugars from lignin, microbial fermentation to obtain alcohol, distillation and dehydration of alcohol to get 200 proof fuel alcohol. Hammer mill is used to grind CR to obtain the desired particle size. Steam explosion, ammonia treatment, dilute alkali treatment, all are reported to be effective in releasing cellulose. Biological method of delignification involves use of a fungus like *Trichoderma reesei* which attacks lignin without significantly depleting cellulose and hemicelluloses.

Enzymatic hydrolysis to convert cellulose and hemicelluloses into sugars is preferred over the chemical (acid) process because the later produces some substances like furfural and hydroxymethyl furfural (HMF), which could inhibit next stage processing. Enzymes are a costly input. Fifteen to twenty five kg enzymes are needed to hydrolyse one tonne CR. Many research groups are presently working on low cost sources of enzymes which could be produced on large scale. Initially the focus was on conversion of cellulose by employing cellulase. Now xylanase/ hemicellulase are also receiving attention because hemicellulose constitutes about 30% of the bio-degradables in crop residues.

Baker's yeast *Saccharomyces cerevisiae* is used for fermenting C6 sugars in the hydrolysate. Due to the complex nature of carbohydrates in lignocellulosic biomass, significant amounts of xylose and arabinose (C5 sugars) are present in the hydrolysate. Other micro-organisms like *Zymomonas mobilis* have been used to ferment C6 sugars. However, the engineered yeasts are reported to successfully convert xylose and arabinose. Search for micro-organisms which can be effective in the combined process of hydrolysis and fermentation continues. Bacteria *Clostridium thermocellum* has been mentioned as one of the possibilities.

The complex process of producing fuel alcohol from lignocellulosic feedstock has been scaled up in the USA to become a commercial technology. Indian R and D in this field is confined to laboratories. The current status of bioethanol production and blending with gasoline has been given in Table 10.

Table 10. Bioethanol production in India (Source: Alam and Chandra, 2015)

Parameter	2012	2015
Fuel ethanol output [tonnes (t)]	5,25,000	-
Fuel ethanol demand (t) E10	-	13,00,000
Total ethanol (t)	16,00,000	23,75,000
Total sugarcane area (million ha)	4.4	5.6
Mandatory blending (%)	5% in 9 States*	10% country wide
Production costs for ethanol (Euro/l)	0.36	-

*Andhra Pradesh, Goa, Gujarat, Haryana, Karnataka, Maharashtra, Punjab, Tamil Nadu and Uttar Pradesh

6.4 Butanol

It is an alcohol which has potential to replace petrol. Its formula is C_4H_9OH, density is 810 kg/m^3 and the melting point is –90°C. Compared to ethanol, butanol has a higher heating value (HHV) and it comes very close to petrol in its fuel properties. It can be used in petrol engines without any modification. Sugar is the feedstock for butanol also. Bacterium *Clostridium acetobutylicum* (Weizmann organism) is the fermenting agent. By-products include hydrogen, lactic acid, propionic acid, acetic acid, butyric acid, isopropanol, and ethanol. Conversion efficiency is low due to toxic effect of butanol and other by-products on the fermenting organisms. Research on bio-butanol is more recent compared to ethanol. Butanol producing algae with very high yield potential have recently drawn attention.

6.5 Bio-oil

Bio-oil is a free flowing brown colored thick complex mixture of oxygenated compounds produced in the fast pyrolysis process (Fig. 5). It has almost 25% water and has a HHV of about 17 MJ/kg. It is immiscible with other conventional

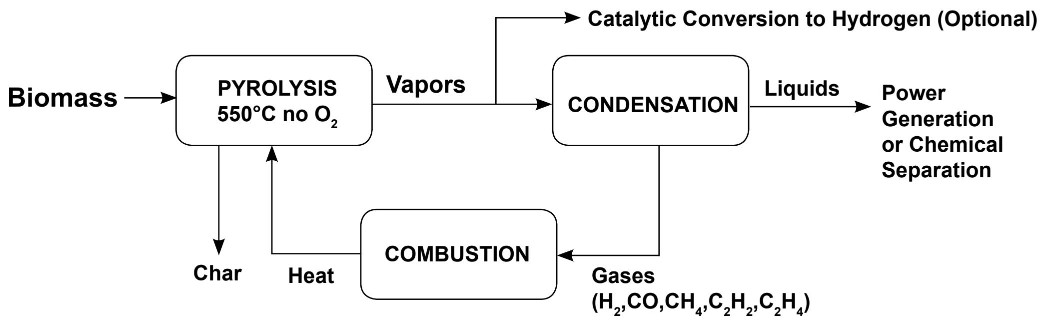

Fig. 5. Schematic view of fast pyrolysis process.

petroleum fuels. It provides an opportunity and a challenge for its application as energy source. Bio-oil acts as an excellent energy carrier because of its higher energy intensity. Because of the low bulk density the transportation and storage of biomass is very expensive. Whereas, if the biomass is converted at the site of production in to bio-oil, the density increases to 1250 kg/m^3 which makes it much easier to transport and store and thus serves as good energy carrier.

Bio-oil is a combustible product but not inflammable. It requires significant energy for initiation of ignition, but once ignited, it burns with self sustaining flame. Due to its burning capabilities it can be used for various thermal and mechanical applications. Representative values of the characteristics of bio-oil are given in Table 11.

Table 11. Typical characteristics of bio-oil (Source: Joshi *et al.*)

Characteristics	Value
Moisture content	25%
pH	2.5
Specific gravity	1.25
Elemental analysis	
Carbon	56%
Hydrogen	6%
Oxygen	38%
Nitrogen	0.1%
Higher heating value	17 MJ/kg
Viscosity	40-100 cp
Solid char	0.1%

Upgrading of bio-oil is necessary to make it usable as fuel or feedstock for chemicals. The important properties of bio-oil that adversely affect its application as fuel are high moisture content, high viscosity, high solid content and chemical instability. However, its quality can be improved significantly using the following techniques:

1. Physical	2. Chemical
a. Hot filtration	a. Hydro treating
b. Emulsion formation	b. Zeolite cracking
	c. Gasification

6.6 Producer gas

Also called synthesis gas, it is produced by thermo – chemical conversion of biomass under sub-stoichiometric conditions at temperatures exceeding 700°C. The supply of air/oxygen is limited to 25% - 35% of the quantity required for complete combustion. The carbonaceous contents of biomass (average composition of $C_6H_{10}O_5$) are converted into a mixture of gases (producer gas or PG) having HCV of 4-5 MJ/m^3 at normal temperature and pressure. The composition of the mixture is given in Table 12:

Table 12. Composition of producer gas (Source: Kaupp and Goss, 1984)

CO	20 – 30%
H_2	12 – 19%
CH_4	4 – 8%
CO_2	6 – 13%
N_2	45 – 55%

If oxygen is used in place of air, nitrogen is eliminated and the share of other gases increases. Producer gas can be used for a variety of applications, which include thermal energy for cooking, water boiling, steam generation, and drying; electro-mechanical power generation (as engine and turbine fuel); and as a feedstock for producing a large variety of chemicals and hydrocarbons by thermo-chemical processes using appropriate combinations of hydrogen: carbon ratio, temperature, pressure, residence time and catalyst.

During Second World War producer gas from wood was extensively used in North Europe as engine fuel. Interest in *gasification technology waned rapidly after the War because of the availability of cheap petroleum. It revived in 1973 after the* '*energy crisis.*' In the early nineteen eighties many institutions in India started working on the development of small wood gasifiers. Gasification research in the ICAR project 'Energy Agriculture' at PAU focused on the use of crop and processing residues in place of wood as the feed stock. Low bulk density, poor flow – ability, high ash and alkali metal contents were identified as the major problems in gasification of crop residues. Briquetting has helped in overcoming some of these difficulties. Small biomass gasifiers (<200 kW) are in use in limited numbers mainly for thermal application. Rice husk and fuel wood are the common sources of biomass for gasification. However, efficiency of small spark ignition (SI) engines fueled by producer gas and available in the market is low. And the gas quality remains a problem. Gasification process control, unless automated, requires constant attention. Industrially advanced countries have opted for gasification systems in MW range. These systems are well automated and mostly of integrated gasification combined cycle (IGCC) type designed to achieve high power generation and thermal efficiencies. Wood is the common feed stock for producer gas.

6.7 Biogas

A product of anaerobic digestion of plant and animal waste, it is a clean, environment friendly and renewable fuel. Anaerobic digestion serves the dual purpose of producing a high quality fuel gas and simultaneously making the process residue (solid or liquid) safer for disposal or further use. Some countries in Europe have started growing crops like maize for biogas production.

In India interest in possibilities of generating methane started way back in 1895 when a methane digester was installed at Matunga Leper Asylum in Bombay. NV Joshi patented a biogas design in 1946. Biogas plant design Gramlakhani was developed in 1951. Its modified version with double chamber was developed in 1954. This design was ultimately adopted by Khadi and Village Industries Commission (KVIC) for countrywide popularization of biogas technology and KVIC was entrusted with responsibility of handling Govt. of India fund for extension and popularization of biogas plants using cattle dung. According to GOI Energy Statistics by 2013, India had over 4.5 M biogas plants installed. However, as per 2011 census, only 1,018,978 families, constituting 0.41% of the total number of families in India, were using biogas as cooking fuel. This represented an increase of 2.5% over the number in 2001. Compared to biogas, the number of families using LPG in 2011 was 70,422,883, an increase of 58.6% over the number of users in 2001. It reflects large number of biogas plants not in use due to various reasons.

Biogas usually has methane 55-65%, carbon-dioxide 35-45%, nitrogen 0-3%, hydrogen 0-1% and hydrogen sulphide 0-1%. Methane (CH_4) has a calorific value of about 9100 kcal/m^3. The calorific value of biogas ranges between 4500-6300 kcal/m^3 depending upon the content of other gases in biogas. The production of clean and easy to use fuel (biogas) from organic wastes is the major advantage of biogas technology. It reduces dependence on fuel wood and commercial energy such as electricity, diesel etc in an environment friendly manner. At least 50% N in biomass is stabilized as nitrates which are easily used by the crops. It also increases availability of N above its normal range by 30-60%. The phosphate and potash contents and their availability are not affected. Anaerobic digestion reduces BOD and COD making handling and disposal of spent slurry and solids safe. This resultant residue is a very good soil conditioner. Anaerobic digestion keeps the biomass without oxygen for 15-50 d at temperatures of about 25-35^{o}C which is sufficient to inactivate many of the pathogenic bacteria, viruses and protozoa etc.

The KVIC anaerobic digester and its modified versions have played the key role in bringing the benefits of anaerobic treatment technology to a large number of Indian households, mostly rural, to meet their cooking fuel needs through family size biogas plants. Relatively larger plants of about 80 m^3 size are becoming popular with owners of large herds of cattle and buffalo. But two factors have severely limited the application of this technology for bio-converting urban and industrial waste and agricultural and processing residues on large scale. These are the slow rate of reaction (40-50 days) and process instability.

Suitable substrates for biogas production are often residues and waste material such as animal droppings, human excreta, fruit and vegetable crop residues. These are rich in carbon and nitrogen which are required for the growth of anaerobic bacteria which use carbon 20-30 times faster than nitrogen. Substrates with C:N ratio ranging between 20-30 are considered good raw materials for biogas generation. Besides, cattle-dung, dry crop residues, poultry litter, pig manure, fruit and vegetable wastes, agro-processing residues have been found satisfactory for biogas production. SPRERI Vallabh Vidyanagar have developed the process for biogas production from rice and wheat straw through anaerobic decomposition in thermophilic range of temperature and at high solid content.

Anaerobic digesters could be batch type, semi-continuous and continuous type. The most common operational biogas plants are semi-continuous type where feeding is done once or twice a day. Cattle-dung based biogas plants of different designs and capacities have been developed and are in use catering to the energy needs of individual farm families, community and dairy farms. Fixed dome digesters have been modified for solid-state digestion (16-18% total solids, TS, instead of 8-10% TS in liquid-state digestion). A number of 2-4 m^3 capacity solid-state biogas plants are operating in a few villages. Biogas finds multiple uses as cooking fuel, process heat, and space heating; illumination; and as fuel to both SI and CI engines. Diesel engines that run on dual fuel (biogas + HSD oil) are being manufactured in India. Up to 75% diesel fuel can be replaced with biogas.

Spent slurry of a biogas plant is quality manure better than Farm Yard Manure (FYM) and compost. It is used as rooting material for horticultural crops; also used in cultivation of Azolla and blue green algae. Spent slurry of solid-state fermenters is easier to handle than popular liquid-state biogas plants. Family and community biogas plants run on cattle dung and alternate feed stocks need to be promoted and made more efficient.

The development of second and third generation high rate reactors in the recent years has made it possible to treat industrial effluents, including those produced by agro-industries at a very high rate. These Second Generation High Rate Digesters / reactors include:

a. Anaerobic filter (AF) which consists of a vertical column packed with inert material like stone, plastic or ceramic rings, brick pieces, etc. As the waste water flows up through the column, an active microbial flora develops and gets attached to the surface of the packed material as a bio-film which acts as the converter of the bio-degradables into biogas. The process is suitable for dilute soluble wastes or wastes with easy to degrade suspended materials.

b. Down-flow stationary fixed film (DFSFF) reactors have the dame configuration as AF reactors but the waste water is fed from the top and it flows downwards through the packed material. The downward flow helps to avoid choking of the voids in the packed column.

c. Up-flow anaerobic sludge blanket (UASB) reactors do not any packing material. In these reactors, the active microbial biomass forms very dense granules which tend to settle at the reactor bottom. When the feed is introduced at the bottom, it creates an upward flow which lifts the granules to form an expanding column of microbial sludge. The reactor top is designed to separate the gas from solids and liquid. UASB reactors can operate at higher loading rates than AF reactors and their HRT is shorter.

d. Anaerobic fluidized –bed reactors have the active biomass grown on small inert particles which are kept in suspension by upward flow of waste water. These reactors are suitable for soluble or easily degradable materials.

The Third Generation High Rate Digesters have been developed to overcome the problems of clogging and washout of microbes from digesters, to enhance mixing within the reactor and to treat a wider variety of waste waters. Some of the new developments are:

a. AF-UASB hybrids are a combination of the features of AF and UASB. These reactors have the dual advantage of better retention of active biomass and better contact between the active biomass and waste organics.

b. Ultrafiltration (UF) membrane reactors are a combination of anaerobic reactors and membrane technology to better retain active biomass in the digesters. These reactors are reported to give higher methane yields.

c. Modified UASB reactors have more comprehensive arrangement for liquid gas separation. Two types of these reactors are available, viz. multi-plate anaerobic reactor (MPAR) and biopaq UASB reactor.

6.8 Hydrogen

It is produced from natural gas, naphtha, coal and water in a descending order of share. Development of fuel cell technology and the ambition to achieve energy generation with zero CO_2 emission have helped to project hydrogen as the fuel of the future.

Solar and wind energy systems can provide renewable energy to produce hydrogen through electrolysis. Other routes for producing renewable hydrogen are combination of concentrated solar thermal system with a thermo-chemical water splitting cycle and photo-biological water splitting. These routes will need considerable R and D input before becoming technically feasible and economically viable. Biomass is a promising renewable source for producing hydrogen using water gas and water gas shift reactions. But it will not be able to compete with natural gas in the near future because of a higher production cost.

The relative density of hydrogen is only 0.07. Its HCV is 12.1 MJ/m^3 and 172.9 MJ/kg. Storage of hydrogen is a problem. Research on use of metal hydrides to store hydrogen is in progress.

7. LIMITATIONS OF BIO-FUELS

Bio-fuels can partially substitute fossil fuels for traction and transport (T&T) only. Some of the limitations are:

- ✦ The availability of biomass is limited and India’s land and water resources cannot be diverted for large scale energy cropping.
- ✦ Bio-mass is too thinly scattered to allow quick and cost effective recovery with presently used methods and equipment.

- Low density and seasonal availability of biomass require large storage space.
- Usable data required to design and engineer unit operations and bio-conversion processes compatible with the characteristics of available biomass, particularly crop residues is yet to be generated.
- Limited availability of trained manpower to design and develop bio-fuel technology and systems, their operation and management.
- Unlike the countries which lead in the development of bio-fuels, the researchers in India do not pay due attention to the energy balance and economics of bio-fuels.
- Climatic variability and its seasonality makes bio-fuel production unstable.

8. POLICY AND STRATEGY ISSUES

(i) Need for a national policy on supply of electrical power and traction and transport fuels to agricultural sector for sustaining its growth and food security.

(ii) Absence of a plan to meet stationary power needs of agriculture, agro-processing and rural industries from electric grid power supply systems to reduce costs and improve availability of liquid fuels for traction, transport, and agro-processing operations.

(iii) Need to promote utilization of briquetted crop and agro-processing residues as industrial fuel and feedstock and introduce mechanized technology for quick recovery of surplus residues in large quantities.

(iv) Need for a medium term plan to develop, evaluate and demonstrate bio-fuel production processes and technologies utilizing latest knowledge and best available materials.

(v) Encouragement to private sector to participate in the development of technology and production of bio-fuels in public-private-partnership mode.

(vi) Exploring techno-economic feasibility of recovering co-products generated in bio-fuel production processes.

(vii) Adoption of end to end or integrated approach in the initial phase of development and growth of bio-fuel technology (example – diesel from algae, Fig. 6)

(viii) Development of trained manpower technicians, operators, engineers and R and D personnel

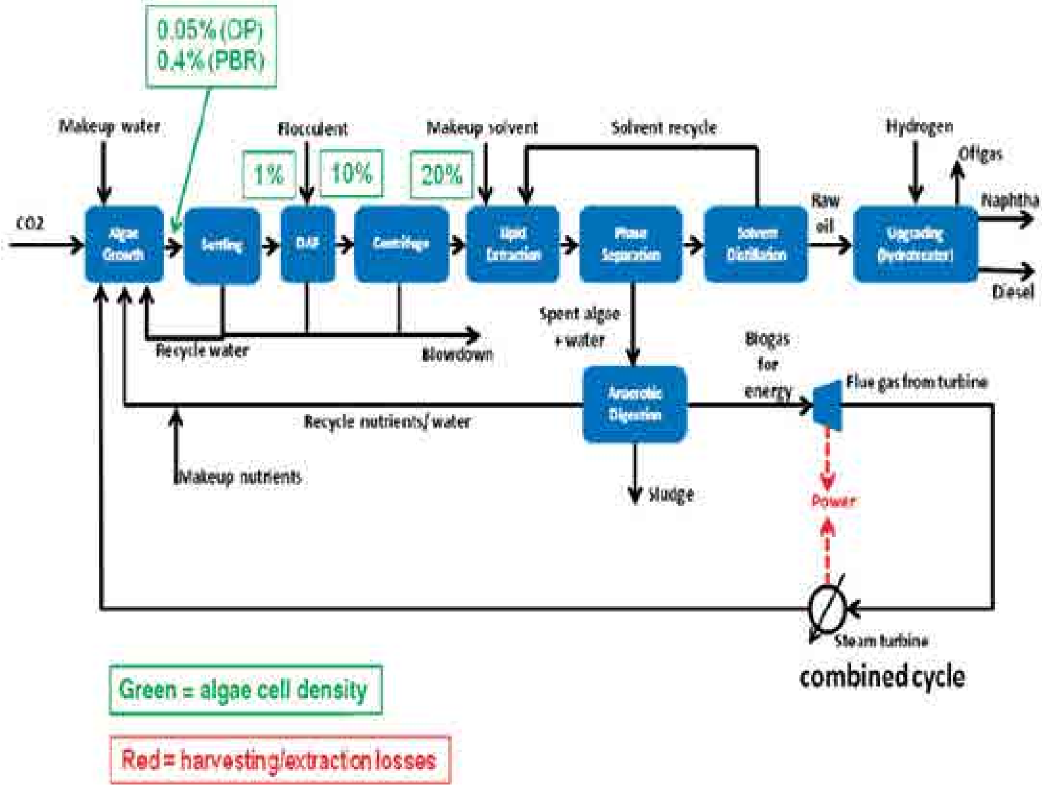

Fig. 6. Process Chain for Producing Diesel from Algae (Source: Pathak, 2009).

(ix) Development of supply chain management

(x) Mandatory targets for production and utilization of bio-fuels

9. SUGGESTIONS

A. Establish a strong 'Energy in Agriculture' Centre to plan and co-ordinate research on supply of energy to agriculture and its management. The Centre should be mandated to:

1. Develop methodology to project and forecast energy requirements of agriculture, agro-processing and rural living and propose energy / energy carrier supply targets for next 10 years at two year interval with focus on (i) to supply of sufficient electrical energy for stationary operations, (ii) to supply of diesel or substitute fuel for traction and transport work, and (iii) management of energy supply.

2. Review critically on-going bio-fuel related research, ensure good support for promising projects / researchers and improve interaction between groups engaged in bio-fuel research.

3. Carry out periodic energy audit in production agriculture and agro-processing as well as rural living to identify scope for improvement in energy conservation and energy use efficiency. Utilization of animate energies to be rationalized and optimized.

4. Develop integrated projects, using latest available information, processes and equipment, and covering all stages from feedstock logistics to application of the main products and utilization of by-products, to achieve the following outputs:

   (i) A bio-gasification pilot plant to efficiently anaerobically produce 500 m^3 biogas/h from crop residues; generate power to meet the energy needs of the pilot plant, supply compressed SNG for use as transport fuel, supply separated CO_2 to chemical industry and convert residue to compost for supply to farmers.

   (ii) A five-tonne per day pilot plant to produce ethanol from CR to be supplied to a major petrol supplier and utilize the sludge.

   (iii) A 100 tonne/year pilot plant to produce and supply algal diesel to a tractor manufacturer for extensive testing and utilization of the residue.

   (iv) Biomass and ethanol based power generation through gasification and / or steam generation.

   (v) Thermal cracking of biomass and/or vegetable oils

The Centre should organize participation of industries in planning and implementation of the three pilot projects. It will also identify and organize basic and strategic research support for realizing the objectives of the three projects. The Cell will ensure that the pilot plants remain functional and available for evaluation and integration of further improvements in processes and technology.

B. Centre should encourage and promote research on conversion of producer gas to fuels and chemicals; production and storage of bio-hydrogen; and support research to improve the performance of family size biogas plants.

It is presumed that the Energy Centre will have access to the expertise available in the Country and outside through advisory committees and professional consultancy. It is further assumed that the Centre will organize networks of institutions and experts for the implementation of each pilot project.

REFERENCES:

Alam, A. and Chandra, P. (2015). State of Indian agriculture – Energy, NAAS, New Delhi, p 249.

Anonymous-1 (2013). Energy statistics. National Statistical Organization, Ministry of Statistics and Programme Implementation, Govt. of India, (http://mospi.nic.in/mospi_new/upload/Energy_Statistics_2013.pdf).

Anonymous-2 (2013). Data Book, Indian Agricultural Statistics Research Institute, Indian Council of Agricultural Research.

Anonymous-3 (2014). Nielsen report. Press Information Bureau, Govt. of India (Ministry of Petroleum and Natural Gas).

Joshi, A.K. and P. Mohanty and F. Tinwala (2014). Bio-oil Production, Processing and Utilisation. Technical Report – AICRP one Renewable Sources of Energy for Agriculture and Agro-based Industries, ICAR (edited by K.C. Pandey).

Kaupp, A. and J.R. Goss (1984). Small Scale Gas Producer – Engine Systems, Deutsche Gesellschaft feur Technische Zusammenarbeit (GTZ) (http://pdf.usaid.gov/pdf_docs/PNAAV703.pdf).

NAAS (2012). Management of crop residues in the context of conservation agriculture. Policy Paper 58, National Academy of Agricultural Sciences, New Delhi (Convener: Dr H. Pathak) p 12 .

NAAS (2010). Agricultural waste management. Policy Paper 49, National Academy of Agricultural Sciences, New Delhi (Convener: Dr. N.S.L. Srivastava) p 30.

NAAS (2008). Sustainable energy for rural India. Policy Paper 41, National Academy of Agricultural Sciences, New Delhi (Convener: Dr Anwar Alam) p 20.

Pathak, B.S. (2009). Management of surplus crop and agro-processing residues to harness their potential for power generation. Sardar Patel Renewable Energy Institute (Unpublished).

Pathak, B.S. (2006). Crop residues to energy, *Environment and Agriculture*. (Editors: Dr. K.L. Chaddha and Dr. M.S. Swaminathan), 854-869, Malhotra Publishing House, New Delhi.

Pathak, B.S., Jain, A.K. and Singh, A. (1986). Characteristics of crop residues. *Agricultural Waste* (Elsevier), **16**: 27-35.

Pathak, P.S., Khan, T.A. and Sharma, P. (2005). Biomass production, its utilization and surplus for energy generation in India. In: Proceedings of the National Seminar on Biomass Management for Energy Purposes – Issues and Strategies, Sardar Patel Renewable Energy Research Institute, V.V. Nagar (Editors: B.S. Pathak and N.S.L. Srivastava). Technical publication No. SPRERI/2005/2, Sardar Patel Renewable Energy Research Institute, Vallabh Vidyanagar (Gujarat), 10-35, 2005

Singh, Gyanendra (2000). Agricultural machinery industry in India (http://agricoop.nic.in/05024-09.pdf).

Srivastava, N.S.L., Jena, U. and Vyas, D.K. (2010). Final Report of I.C.A.R. project on development of technology for pre-heating and briquetting of selected crop residues. Sardar Patel Renewable Energy Research Institute, V.V. Nagar.

Verma, S.R. and Sharda, A. (2005). Biodiesel: An Alternative Fuel for CI Engines – Global Scenario and Indian Perspective, Proceedings of the National Seminar on Biomass Based Decentralized Power Generation, (Editors: B.S. Pathak and N.S.L. Srivastava) Sardar Patel Renewable Energy Research Institute, Gujarat.

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