EX-SITU
CROP RESIDUE MANAGEMENT OPTIONS

भाकृअनुप
ICAR

Indian Council of Agricultural Research
New Delhi
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त्रिलोचन महापात्र, पीएच.डी.
सचिव एवं महानिदेशक

TRILOCHAN MOHAPATRA, Ph.D.
SECRETARY & DIRECTOR GENERAL

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कृषि अनुसंधान और शिक्षा विभाग एवं
भारतीय कृषि अनुसंधान परिषद
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Foreword

A LARGE portion of crop residues is burnt 'on-farm primarily to clean the field for sowing the next crop. The problem of crop residue burning is intensifying in recent years due to mechanized harvesting of crop, narrow time gap between harvesting of the previous crop and sowing of the next crop and shortage of human labour for removing the crop residues from field. As per the available estimates, burning of crop residues is predominant in northern and central states, namely, Punjab, Haryana, Uttar Pradesh, Rajasthan and Madhya Pradesh.

A Central Sector Scheme on *In-situ* Crop Residue Management is in operation for the past three years and it has yielded increasing results in reducing the residue burning incidents. There are various *ex-situ* crop residue management options are available today. Options like conversion of the crop residue biomass into pellet and utilization of pellets as fuel supplement in power plants, biogas production from paddy straw at domestic level, production of compressed bio-gas / bio-CNG from paddy straw at industrial level, alcohol production from paddy straw and composting of paddy straw are some of the known alternative technologies. The choice of any of these options depends on their effectiveness and the cost economics. A committee was constituted by ICAR to analyse various *ex-situ* crop residue management options for their technical feasibility and economic viability. Based on the committee's analysis, a document entitled '***Ex-situ* Crop Residue Management Options**' is being brought out. I hope that the analysis contained in this document will support decision making for appropriate alternative use of crop residues.

I congratulate the Committee members and the Agricultural Engineering Division of ICAR for their valuable inputs in preparation of this document.

Date: 2nd June, 2021

(T. Mohapatra)

Acknowledgements

THE Committee on economic analysis of alternative/ex-situ options of crop residue management likes to express its sincere and whole hearted thanks to Dr. Trilochan Mohapatra, Secretary, DARE and DG, ICAR for his foresight in formulating concepts and ideas for *ex-situ* management of crop residues, for instituting this Committee and further for providing his valuable inputs at various stages for finalizing the "*Ex-situ* Crop Residue Management Options" document.

The Committee also extends its sincere thanks to the AS (DARE) and Secretary (ICAR), Secretary, Ministry of Power, and Secretary, Ministry of Petroleum and Natural Gas and Director, ICAR-NIAP for valuable guidance all through for drafting the recommendations.

Thanks are also due to all the members of the High Level Monitoring Committee on *In-situ* Crop residue Management Central Sector Scheme, Director ICAR-CIAE, Bhopal, Dr. KC Pandey, Project Coordinator of AICRP on Energy in Agriculture and Agro Industries, Dr. Nalini Ranjan Kumar, Principal Scientist, ICAR-NIAP, Dr. S.S. Sooch, Principal Scientist (Renewable Energy Engineering), PAU, Ludhiana, Dr Mukesh Jain, Assistant Professor (FMPE), CSHAU, Hissar, Dr. Panna Lal Singh, Principal Scientist, Agricultural Engineering Division, ICAR for their outstanding support and cooperation during the process of discussions and in finalizing the recommendations.

Member Secretary of this Committee Dr. Kanchan Kumar Singh, Assistant Director General (Farm Engineering) is appreciated, by the rest of the Committee, for his strenuous efforts in collating the information and drawing a conceptual framework that formed the basis of our discussions and for the overall coordination in formulation and finalization of the recommendations.

K. Alagusundaram
On behalf of the Members of the Committee
on Economic Analysis of Alternative /
Ex-situ Crop Residue Management Options

Committee Report on
Ex-situ Crop Residue Management Options

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Executive Summary

A LARGE portion of the paddy straw / crop residues in Punjab, Haryana and neighbouring states are burnt in the field primarily to clear the field after the harvest of the preceding crop for the sowing next crop. The paddy straw is burnt in the field because it is a very easy and quick method of disposal. In Punjab and Haryana about 3.1 million ha area is under rice-wheat rotation and 1.25 million ha under rice-potato rotation. Burning of crop residues results in emission of gases such as CH_4, CO, N_2O and NO_x; particulate matters, loss of plant nutrients and adversely affect the atmosphere, the environment and the soil health. In addition to these losses the straw burning also causes deterioration of soil physical health, health hazards and accidents, air pollution and emission of greenhouses gases and loss of micro-biodiversity.

Crop Residue Management Options can be classified as in-situ and ex-situ management options. Retaining, incorporating or mulching the crop residues in the field and decomposing using consortia of microbes developed by various Institutes are the two possible in-situ crop residue management options. A Central Sector Scheme on "Promotion of Agricultural Mechanization for *In-situ* Management of Crop Residue in States of Punjab, Haryana, Uttar Pradesh and NCT of Delhi" has been approved by the Government of India and it is being operated through DoAC&FW. Budget allocated to the scheme was ₹ 1151.80 crore for two years (for 2018-19: ₹ 591.65 crore, and for 2019-2020; ₹ 560.15 crore) and it is further extended for one more year (2020-21) with a budgetary allocation of ₹ 600 crores.

Baling and transporting straw from the field, though appear to be an option for safe disposal, will be feasible only when alternate, effective and economically viable usage methods are identified and facilities and infrastructure for *ex-situ* management methods are created. The Secretary, DARE and DG, ICAR constituted a committee for the economic analysis of the alternative / ex-situ options of the crop residue management.

Following are the various options for *Ex-situ* management of crop residues considered by the committee and the respective recommendations of the committee:

Biomass pellets from crop residues as a fuel substitution in thermal power plants

This option is recommended for further consideration. Substituting biomass pellets from crop residues at the rate of 10% of the coal, will increase the cost of production by 20 paisa per unit of power. If all the existing power plants in North India (with an installed capacity of 44,560 MW) substitute their fuel with paddy straw based pellets then they will consume 17.82 million tons of paddy straw every year. Nearly the entire problem will be solved. There is no additional expenditure or subsidy needed from Government.

Biogas production from paddy straw at domestic/community level

This option is recommended for further consideration. Cost of PAU Model–II biogas plant is ₹ 2.1 lakhs and its life is 20 years. For a breakeven on expenditure for the farmer the government need to extend a onetime support at the rate of 60% of the cost of the plant. If one biogas plant per farm in Punjab is established then the budget required for one time subsidy will be ₹ 13,860 crores (for nearly 1.1 million land holdings). These 1.1 million biogas plants will consume 5.28 million tons of paddy straw every year.

Industrial level production of Biogas / Bio-CNG / Compressed Bio-gas (CBG) from Paddy Straw

This option is recommended for further consideration. Cost of establishing one bio-CNG plant with a capacity of 5,600 kg of bio-CNG per day will be ₹ 30.20 crores. Such a plant will consume 40 tons of paddy straw every day or 11000 tonne in a year with 275 working days. If 50% of the cost of plant and machinery are supported by the Government then the annual profit will be ₹ 209.23 lakhs per year. If 1,000 such plants are established then support at the rate of 50% will cause an expenditure of ₹ 15,100 crores to the Government. 1,000 bio-CNG plants will consume 11 million tons of paddy straw every year.

Power Generation from Biomass

This option is recommended for further consideration. The cost of establishing one 18 MW biomass based power generation unit will be ₹ 150 crores. This plant will produce 10 crore units of power every year and will have an average life of 15 years. If 1,000 such plants are established then the electricity produced will be 10,000 crore units per year. If 40% subsidy on the cost of the plant and machinery is given then the profit per plant per year will be ₹ 29.80 crores and the breakeven will occur in 5 years. Total money required for subsidy at the rate of 40% will be ₹ 60,000 crores. Total paddy straw consumed by 1000 such units will be will be 16.20 million tons per year.

Alcohol production from paddy straw (lignocellulosic biomass)

This option is not recommended for further consideration. Technical and commercial data on the plant performances are not available at this point of time. The experience of India is also limited. Cost of plant and machinery for a plant with a capacity of 300 lakh litres of alcohol per year will be ₹ 800 to 1,000 crores. Such a plant will consume 0.15 million tons of paddy straw every year. Based on the cost estimates available in the literature (Japanese estimates) the loss incurred from such a plant will be ₹ 15,993 crores per year.

Ex-situ Composting of Paddy Straw

This option is not recommended for further consideration. The loss incurred by a farmer by composting off the field will be ₹ 1,500 per ha per year. 1% of the land area will be lost for composting yard resulting in a loss of 43,500 ha in Punjab and Haryana and a grain production loss of 4.35 lakh tonnes every year. The process of collecting and transporting the straw from the field to the compost site and managing it over the composting period are labour intensive and cumbersome.

❑

Introduction

A LARGE portion of the paddy straw / crop residues in Punjab, Haryana and neighbouring states are burnt in the field primarily to clear the field after the harvest of the preceding crop for the sowing next crop. Burning of straw causes pollution problems in the atmosphere and huge nutritional loss and physical health deterioration to the soil. In Punjab and Haryana about 3.1 million ha area is under rice-wheat rotation and 1.25 million ha under rice-potato rotation. The time available between the rice harvesting and wheat sowing is very narrow and in the range of 20 to 25 days. The paddy straw is burnt in the field because it is a very easy and quick method of disposal.

Burning of crop residues results in emission of gases such as CH_4, CO, N_2O and NO; particulate matters, loss of plant nutrients and adversely affect the atmosphere, the environment and the soil health. The entire amount of C, approximately 80 to 90% of N, 25% of P, 20% of K and 50% of S present in the crop residues are lost in the form of various gaseous and particulate matters resulting in atmospheric pollution. It is also estimated that about 70% CO_2, 7% CO, 0.66% CH_4 and 2.1% N emitted as N_2O from crop residue burning, which impacts on environment heavily. It is estimated that one tonne rice residue on burning releases 13 kg particulate matter, 60 kg CO, 1460 kg CO_2, 3.5 kg NOx, 0.2 kg SO_2. Burning of 23 million tonnes of rice residues in North-West India leads to a loss of about 9.2 million tonnes of C equivalent (CO_2-equivalent of about 34 million tonnes) per year and a loss of about 1.4×10^5 t of N (equivalent to ₹ 200 crores) annually. In addition to these losses the straw burning also causes deterioration of soil physical health, health hazards and accidents, air pollution and emission of greenhouses gases and loss of micro-biodiversity.

Crop Residue Management Options

In-situ management of straw or removing the straw from the field for other uses are the two alternate and safe methods for straw management.

1. *In-situ* Crop Residue Management

There are two major options under this method:

A. Retaining, incorporating or mulching the crop residues in the field

In order to curb burning and reducing winter smog pollution, a Central Sector Scheme on "Promotion of Agricultural Mechanization for In-situ Management of Crop Residue in States of Punjab, Haryana, Uttar Pradesh and NCT of Delhi" has been approved by the Government of India and it is being operated through DoAC&FW. Budget allocated to the scheme was ₹ 1151.80 crore for two years (for 2018-19: ₹ 591.65 crore, and for 2019-2020; ₹ 560.15 crore) and it is further extended for one more year (2020-21) with a budgetary allocation of ₹ 600 crores.

Under this scheme, there is financial assistance on purchase of following straw management implements:

- Super Straw Management System (Super SMS) to be attached with Combine Harvester
- Happy Seeder
- Paddy Straw Chopper/ Shredder/Mulcher
- Shrub Master/ Rotary Slasher
- Hydraulic Reversible M.B. Plough
- Zero Till Seed cum Fertilizer Drill
- Super seeder
- Bailing machine
- Crop reaper.

The paddy residue burning events were monitored by multiple satellites with thermal sensors during the paddy harvest period from 01 October to 30 November in the states of Punjab, Haryana and Uttar Pradesh. There is considerable reduction in the burning events of the crop residue. Overall, the total burning events recorded during 2019 in the three states (Punjab, Haryana and UP) were 18.8% less as compared during 2018, 31% as compared to 2017, and 51.9% as compared to 2016. However, our target is zero crop residues burning in the states. To achieve this, it has been suggested that the *ex-situ* management options may also be used for straw management.

During the project period, 1.53 lakh machines were delivered to the farmers in the region. Of this 68,762 were delivered to Punjab farmers, 50,934 to Haryana farmers, 32,829 to Uttar Pradesh farmers and 54 to NCT Delhi farmers. For the benefit of small and marginal farmers, about 28,730 Custom Hiring Centres (CHCs) were established in the region (19,301 in Punjab, 3,936 in Haryana, and 5,497 in Uttar Pradesh.

Out of about 3.0 million ha of total paddy area in Punjab there was 23.3% decline in the paddy area burnt in 2019 compared with 2017. Green House Gases (GHGs) and Particulate Matters (PMs) estimated to be emitted from paddy residue burning in the three states was reduced from 28 million tonne during 2017 (before the scheme period) to 23 million tonne (18.3 % less) during 2018 and to 19.7 million tonne (29.6% less) during 2019.

Continuously adopting in-situ method of straw management will result in a saving of 30 to 35% Nitrogen; 20 to 25% Potassium and substantial amount of organic carbon, nearly 25% of irrigation water and further helps in restoring microbial activities in the soil.

B. Decomposing using consortia of microbes developed by various Institutes

This method is being tested for its effectiveness in decomposing the paddy straw residues in a short span of around 20 days before the next crops like wheat or vegetables are grown.

2. *Ex-situ* crop residue management

Baling and transporting straw from the field, though appear to be an option for safe disposal, will be feasible only when alternate, effective and economically viable usage methods are identified and facilities and infrastructure for *ex-situ* management methods are created.

The Secretary, DARE and Director General, ICAR constituted a committee of the following members for economic analysis of the alternative / *ex-situ* options of the crop residue management (a copy of the committee order is given in Annexure) :

1. Deputy Director General (Engg.), ICAR – Chairman
2. Representative of the Ministry of Power – Member
3. Representative of the Ministry of Petroleum and Natural Gas – Member
4. Representative of Joint Secretary (M&T), DAC&FW – Member
5. Dr. Suresh Pal, Director, ICAR – NIAP or his representative- Member
6. Director, ICAR – CIAE, Bhopal – Member
7. Dr. S. S. Sooch, Pr. Scientist (Renewable Energy Engg.), PAU, Ludhiana
8. Dr. Mukesh Jain, Asst. Prof. (FMPE), CCSHAU, Hissar
9. Assistant Director General (Farm Engg.), ICAR – Member Secretary

The committee met several times and discussed on the possibility of using one or more of the following various options for *ex-situ* crop residue management options:

- Biomass pellets from Crop Residues as a fuel substitution in thermal power plants
- Biogas production from paddy straw at domestic / community level
- Industrial level production of Biogas / Bio-CNG / Compressed Bio-gas (CBG) from Paddy Straw
- Power Generation from Biomass
- Alcohol production from paddy straw (lignocellulosic biomass)
- *Ex-situ* Composting of Paddy Straw.

Utilization of crop residues as fuel for power generation will not only discourage in-field crop residue burning abating air pollution, but will also reduce carbon footprint of coal based power plants. Bio-CNG / Compressed Bio-gas (CBG) producing projects may be integrated with existing retail networks of Oil PSUs and other industries relying on gas based energy. It will provide off take assurance for crop residues to the CBG project developers. Government of India has allowed procurement of ethanol produced from non-food feedstock cellulose and lignocelluloses based materials besides molasses, subject to meeting the relevant BIS standards.

The details of these various options and their economic analysis are given in the following sections of the report.

❑

Biomass Pellets from Crop Residues as a Fuel Supplement in Thermal Power Plants

THE biomass pellets are preferred in the thermal power plant because of the small diameter and sizes and the good binding strength they possess. They burn also very easily along with coal, the common fuel in power plants. Biomass pellet making is a standard method for the production of high density, solid energy carriers from biomass. Pellets are manufactured in several types and grades as fuels for electric power plants, other industrial uses, homes, and other applications. Pellet-making equipment are available at a variety of sizes and scales, which allows manufacture at domestic as well industrial-scales. Pellets have a cylindrical shape and are about 6-25 mm in diameter and 3-50 mm in length.

Size Reduction of Biomass: Before feeding biomass to pellet mills, the biomass should be reduced to small particles of the order of not more than 3 mm. If the pellet size is too large or too small, it affects the quality of pellet and in turn increases the energy consumption. Therefore the particles should have proper size and should be of consistent in size. Size reduction is done using a hammer mill equipped with a screen of size from 3.2 to 6.4 mm. If the feedstock is quite large, it goes through a chipper before grinding.

Binders for Pelletizing: Binders or lubricants may be added in some cases to produce higher quality pellets. Binders increase the pellet density and durability. Wood contains natural resins which act as a binder. Similarly, sawdust contains lignin which holds the pellet together.

However, agricultural residues do not contain much resins or lignin, and so a stabilizing agents needs to be added in this case. Distillers dry grains or potato starch are some commonly used binders. The use of natural additives depends on biomass composition and the mass proportion between cellulose, hemicelluloses, lignin and inorganics.

Pelletizing: Due to the friction generated in the die, excess heat is developed. Thus, the pellets become very soft and hot (hot up to a temperature of about 70 to 90°C). They need to be cooled and dried before its storage or packaging. The pellets may then be passed through a vibrating screen to remove fine materials. Commercial pellet mills and other pelletizing equipment are widely available across the globe. The cost of the commercially available biomass pellets is ₹ 9,000-10,000 per tonne.

Economic Analysis of Using Biomass Pellets in Thermal Power Plants

Following are the basic information based on which the economic analysis of using biomass based pellets for thermal power plants have been done:

- Total installed capacity of coal based thermal power plant in North India (including states like Punjab, Haryana, Uttar Pradesh, Rajasthan, Chandigarh, Uttarakhand, Himachal Pradesh, and Jammu & Kashmir) is 44,560 MW.
- Coal consumption in power plants is (@ 4,000 tonne per MW of power per year at 85% Plant Load Factor (PLF).
- Recommended biomass based pellet substitution in thermal power plant is 10% with coal.
- Cost of biomass pellets at the plant site including production and transport costs is approximately ₹ 10 per kg of pellets.
- Cost of coal is approximately ₹ 6 per kg.
- Based on these data, the increase in operating cost of power generation due to the substitution of 10% percent pellet with coal will be 6.7%.
- To balance this increase in cost of production, the sale price of the electricity need to be increased by 6.7% of the current sale prices.
- According to Motghare and Cham (2014), the cost of production of power from coal based power plant is ₹ 3.05 per Unit (kWh).
- Due to the addition of crop reside based biomass pellets the cost of production will increase by ₹ 0.20 per Unit (kWh) of power.

Table 1. Summary of costs and quantitative estimates of substituting 10% of crop residue based biomass pellets with coal as fuel for thermal power production in the existing installed capacity of 44,560 MW in North Indian States

Particulars	Quantitative Values
Total Installed capacity in North India	44,560 MW
Percentage of pellet substitution with coal as a fuel for power generation	10%
Cost of biomass pellets at the plant site	₹ 10.00 per kg
Cost of coal at the plant site	₹ 6.00 per kg
Increase in cost of production due to the substitution of 10% pellets with coal as a fuel	@ 6.7%
The actual increase in cost of production due to this substitution based on the cost of production estimates	@ ₹ 0.20 per Unit
Paddy straw consumption for 44,560 MW capacity	17.82 Million tons per year

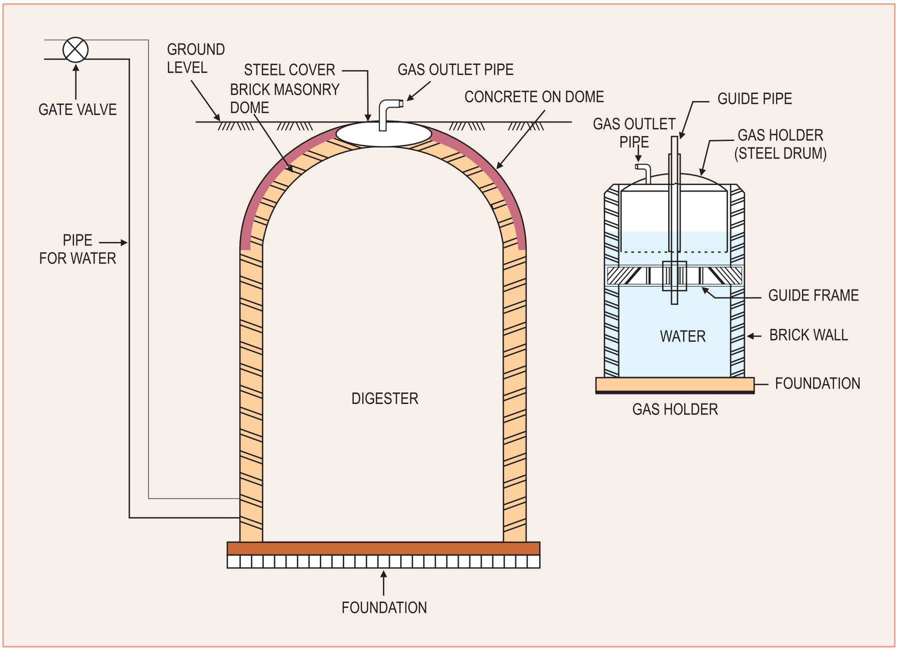
Biogas Production from Paddy Straw at Domestic/Community Level

PADDY straw can be digested by anaerobic means for the production of biogas as a fuel for the kitchen as well as for power generation. The semi dry fermentation of organic wastes are carried out in the anaerobic digester. The digested material so produced from such anaerobic digestion is good quality manure ready for use in the fields. The anaerobic digestion and production of biogas is the most efficient way in terms of energy output per unit energy input for handling biomass resources.

PAU Model Biogas Plant for Paddy Straw Based Biogas Production: The PAU, Ludhiana centre of the AICRP on Energy in Agriculture and Agro-Industries has developed a biogas plant considering the alternate use of paddy straw for bio-gas production. This is a very simple and efficient technology for extraction of biogas from paddy straw. This technology may be a viable alternative for individual farmer, a cluster of farmers or a community based biogas plant in a small village. Anaerobic digestion of paddy straw cannot be done by conventional anaerobic process for bio-gas production owing to the floating characteristics of straws in water.

The PAU, Ludhiana has constructed masonry structure as digester. The digester diameter is about 3.0 m and height is 2.7 m and the volume is about 19 m^3. The advantage of the masonry structure is that the whole structure is underground on which cold ambient temperatures have little effect during winter months. This process of semi-dry fermentation is a batch process and each batch of biomass produces biogas for a period of about 3 months after loading and activation. Each batch can hold 1.60 tonnes of paddy straw and 0.40 tonnes of cow dung as feed material. Water is added in plant to saturate the paddy straw. Gas production starts after about 7-10 days. The quantity of gas produced in such a plant will be about 3 to 4 m^3 per day or it is equivalent to 2 to 3 cylinders of LPG per month. This may be used for cooking operations or other such energy options. Gas production continues for about 3 months and reloaded after 3 months after emptying it.

The estimated cost of the biogas plant for handling about 1.6 tonne paddy straw is ₹ 1.2 lakhs which is about four times costly as compared to



conventional animal dung based biogas plant of same capacity (biogas production). One biogas plant can manage 4.5-5.0 tonne of paddy straw per year. Six such biogas plants have been installed in Punjab and all the plants are working very well.

A. Economic Analysis of 1.6 Tonne Paddy Straw Domestic Biogas Plant (PAU Model-I with RCC Digester Placed Below the Ground)

Following are the basic information based on which the economic analysis PAU Model – I biogas plant was done:

- Cost of installation of a batch type PAU Model – I biogas plant with RCC digester placed below the ground level is ₹ 1.80 lakhs
- Total yielding life of plant is 20 years
- Paddy straw holding capacity of the unit per batch of operation is 1.6 tonnes
- Quantity of animal dung required per batch of operation is 0.4 tonnes
- Each batch will produce biogas for a period of 3 months and in an year 3 such batches can be loaded and biogas can be produced for 9 months in a year.

- Biogas produced per day is 3 m^3/day or equivalent to 1.30 kg per day of LPG (at a specific density of 0.43 kg per m^3)
- Cost of 1 kg of LPG is ₹ 56.34 (considering the commercial selling price of 1 cylinder of 14.2 kg of LPG is around ₹ 800).

Table 2. Estimation of returns and costs when farmer invests 100% of the cost of the PAU Model-I biogas plant

Sl. No.	Cost Particulars	Costs ₹ Per Year
	Price Realised	
A.	Price realized (cost of LPG equivalent of biogas produced at 1.3 kg per day at ₹ 56.34 per kg for a production span of 270 days per year)	19,775.00
	Operational Costs	
1.	Charges for crane for emptying the digested straw (at ₹ 2,000 per batch for 3 batches)	6,000.00
2.	Labour charges for straw/dung collecting/loading etc. (@ 15 man days per year at a labour wage of ₹ 250 per day)	3,750.00
B.	Total Running Costs	9,750.00
	Fixed Costs	
1.	Depreciation (assuming 20 years life and 10% scrap value)	8,100.00
2.	Interest on capital investment (assuming 100% capital is invested by the farmer)	16,200.00
C.	Total Fixed Costs	24,300.00
D.	Total Costs (Operational + Fixed Costs) B+C	34,050.00
E.	Net Loss to the farmer when he invests 100% of initial cost	-14,275.00

An analysis was done to determine the breakeven point for the farmer assuming various rates of subsidies on the initial cost of the PAU Model – I biogas plant. The following chart shows the rate of return and costs per year at various rates of subsidies:

From the chart (Fig. 1) it is obvious that when the rate of subsidy is about 60% of the initial cost, the farmer will achieve the breakeven point for his investment on PAU Model – I biogas plant (meaning that the farmer need

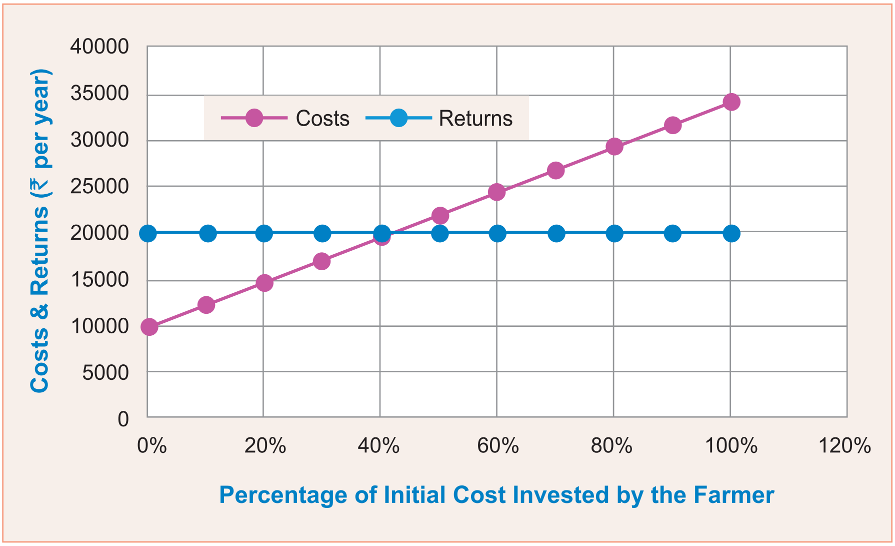


Fig. 1. Costs and returns as a function of Percentage of initial cost invested by the farmer

not spend any money for installing and running the plant). In addition he gets the fuel for domestic cooking at free of cost.

B. Economic Analysis of 1.6 Tonne Paddy Straw Domestic Biogas Plant (PAU Model-II with Mild Steel Digester Placed Above the Ground)

Following are the basic information based on which the economic analysis PAU Model – I biogas plant was done:

- Cost of installation of a batch type PAU Model – II biogas plant with RCC digester placed below the ground level is ₹ 2.10 lakhs
- Total yielding life of plant is 20 years.
- Paddy straw holding capacity of the unit per batch of operation is 1.6 tonnes
- Quantity of animal dung required per batch of operation is 0.4 tonnes
- Each batch will produce biogas for a period of 3 months and in an year 3 such batches can be loaded and biogas can be produced for 9 months in a year.
- Biogas produced per day is 3 m^3/day or equivalent to 1.30 kg per day of LPG (at a specific density of 0.43 kg per m^3)
- Cost of 1 kg of LPG is ₹ 56.34 (considering the commercial selling price of 1 cylinder of 14.2 kg of LPG is around ₹ 800).

An analysis was done to determine the breakeven point for the farmer assuming various rates of subsidies on the initial cost of the PAU Model – II biogas plant. The following chart shows the rate of return and costs per year at various rates of subsidies:

Table 3. Estimation of returns and costs when farmer invests 100% of the cost of the PAU Model – II biogas plant

Sl. No.	Cost Particulars	Costs ₹ Per Year
	Price Realised	
A.	Price realized (cost of LPG equivalent of biogas produced at 1.3 kg per day at ₹ 56.34 per kg for a production span of 270 days per year)	19,775.00
	Operational Costs	
1.	Labour charges for straw / dung collecting / loading and unloading (@ 30 man days per year and at a labour wage of ₹ 250 per day)	7,500.00
B.	Total Running Costs	7,500.00
	Fixed Costs	
1.	Depreciation (assuming 20 years life and 10% scrap value)	9,450.00
2.	Interest on capital investment (assuming 100% capital is invested by the farmer)	18,900.00
C.	Total Fixed Costs	28,350.00
D.	Total Costs (Operational + Fixed Costs) B+C	35,850.00
E.	Net Loss to the farmer when he invests 100% of initial cost	-16,075.00

When the rate of subsidy is about 57% of the initial cost, the farmer will achieve the breakeven point for his investment in PAU Model – II Plant (meaning that the farmer need not spend any money for installing and running the plant). In addition he gets the fuel for domestic cooking at free of cost.

Following are the additional advantages of installing on-farm biogas plants in each farm holdings:

- Farmer gets the slurry as a fertilizer for his land
- Demand for non-renewable LPG is reduced
- Environmentally safe method of disposal of the straw

Table 4. Summary of costs and quantitative estimates for establishing one PAU Model–II biogas plant per land holding in Punjab

Sl. No.	Particulars	Quantitative Values
1.	Paddy straw consumed per plant per year	4.8 tonnes
2.	Cost of biogas unit	₹ 2.10 lakhs
3.	Life of one unit	20 years
4.	Biogas equivalent of LPG produced	1.30 kg per day
5.	Assuming cost of LPG cylinder	₹ 800 per 14.20 kg
6.	Cost realized	₹ 19775 per year
7.	Breakeven will occur if the subsidy is	57% or say about 60%
8.	Assuming one unit per land holding in Punjab, total units required for Punjab	1.10 millions
9.	Total subsidy at 60% value of the initial cost of the PAU Model – II biogas plant	₹ 13,860 crores
10.	Paddy straw consumed per year in 1.10 million units of biogas plants	5.28 million tonnes

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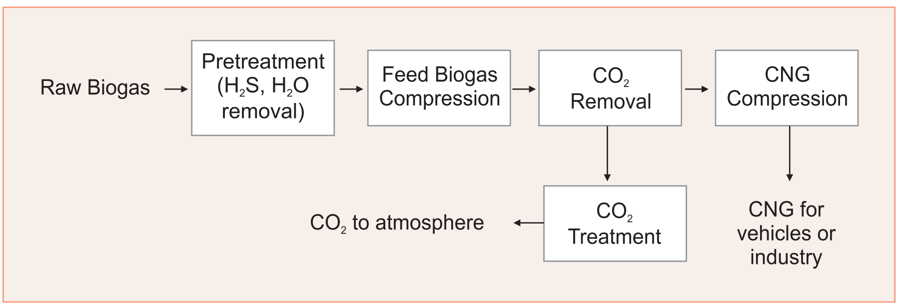
Industrial Level Plant for Production of Biogas / Bio-CNG / Compressed Bio-gas (CBG) from Paddy Straw

UTILIZATION of surplus crop residue especially the paddy straw to generate biogas / Bio-CNG / CBG creates better opportunities for reducing environmental pollution and employment generation. The estimated total energy yield per tonne of paddy straw is 8.0 GJ when converted to bio-methane compared with the energy yield of 5.6 GJ when converted to bio-ethanol. Operation of paddy straw bio-methanation plant for power generation or bio-CNG production in decentralized mode could be a better option to manage the crop residue.

The large quantities of raw biogas generated from the paddy straw by anaerobic digestion can be used for producing bio-CNG or bio-power (electricity). The process of bio-CNG production generally includes feedstock collection, segregation, pre-treatment, bio-methanation, biogas scrubbing and compression & bottling of scrubbed biogas. Bio-CNG comprises of more than 90% methane with a calorific values ranging from 11200 to 11,500 kcal per kg. Biogas production potential of paddy straw ranges from 250 to 300 m^3 per tonne of straw with methane content of 55 to 60% and from this volume about 120 to 140 kg of CNG or about 550 to 600 kWh of electricity can be obtained.

During the year 2008-09, a new initiative was taken by MNRE for technology demonstration on biogas bottling projects in entrepreneurial mode, for



Schematic diagram of the production bio-CNG from raw biogas installation of medium size mixed feed biogas plants for generation, purification and bottling of biogas under Research, Design, Development and Demonstration (RDD&D) policy of R&D. Installation of such plants aims at production of CNG quality of Compressed Biogas (CBG) to be used as a vehicular fuel in addition to meeting stationary & motive power, electricity generation and thermal application. This was a decentralized establishment of a sustainable business model in this sector. There is a huge potential for installation of such plants in various geographical areas. So far, 11 numbers of animal dung based biogas bottling projects of various capacities and technologies have been commissioned in the country after obtaining required licenses for filling and storage of compressed biogas in CNG cylinders from Petroleum & Explosives Safety Organization (PESO), State Pollution Control Board (PCB) etc. The IIT, Delhi is assigned for technical monitoring & handholding of the consultants / promoters and preparation of documentation on different types of technology which may emerge out of these projects.

The purified biogas is filled in CNG cylinder and supplied to mid-day meal scheme, mess, Hotel, industries etc. for various purposes such as cooking & heating etc. Calorific value of purified biogas is equivalent / similar to CNG. The biogas bottling plants are one of the most potent tools for mitigating climatic change by preventing black carbon emission from biomass chulha since biogas is used as a cooking fuel and methane emissions from untreated cattle dung and biomass wastes are also avoided. The purified biogas can be bottled in CNG cylinders and the biogas bottles can be used wherever CNG is currently used.

Indian Oil Corporation had signed a MoU with Punjab Energy Development Agency (PEDA) for setting up 400 CBG projects. Rika Biofuel Development Limited signed the MoU on May 11, 2018 through Invest Punjab, which would invest ₹ 700 crore in Punjab to set up Biogas / Bio CNG plants. Oil PSUs have also launched 'Sustainable Alternative towards Affordable Transportation' i.e. 'SATAT' initiative on 1st October, 2018. Under this initiative, IOCL, HPCL, BPCL, GAIL and IGL have invited Expression of interest (EOI) to procure CBG from potential entrepreneurs for establishment of 5000 CBG plants across the country with an estimated production of 15 MMT CBG per annum by 2023. Oil PSUs have offered a price of ₹ 46/- per kg of CBG. The CBG, so procured, will be supplied to transport sector and industries from the channels of Oil PSUs.

Initiatives on Paddy Straw Based Biogas and Bio-CNG / CBG Production

M/s Mahindra Waste to Energy Solutions Ltd. and Government of Punjab have signed a MoU to set up bio-CNG / CBG plants and organic fertiliser from paddy straw with an investment of ₹ 17 crore in pilot projects for handling about 10,000 tonnes of paddy straw per year.

M/s Sampurn Agri-Venture Pvt. Ltd., Chandigarh has established Paddy Straw Based Biogas Power Generation Plant at Fazilka in Punjab in collaboration with technology partner IIT Delhi. Presently the plant is successfully producing biogas from paddy straw since last three years and utilizes 10 tonne paddy straw per day. However, the company has future plan to expand to 40 tonne per day paddy straw consumption capacity. The plant is producing 300 m^3 of biogas per day from paddy straw. The biogas generated from paddy straw is being used to generate electricity (1 MW capacity). The company also has a future plan to generate bio-CNG from biogas produced from paddy straw. The ICAR-CIAE, Bhopal Scientists visited the plant and it was found to be in good working condition. The plant is efficient in production of biogas and manure. This plant also has biological H_2S scrubber. It is claimed that the plant is operating since last three years but not at its designed full capacity.

Collection of paddy straw and storage

Presently, the plant buys paddy straw through the vendors / aggregators who bring paddy straw in the form of rectangular bales and dump at the plant site. The cost of such bales is around ₹ 1,500 to 2,000 per tonne of paddy straw depending on the plant location from the collection point of straw. The farmers get the advantage of cleaning their fields by a third party and making it ready for the next crop without burning. They do not, however, get any financial benefit at present. The team visited paddy straw based power generation plant site as explained above; collected detailed information of the biomass logistics, plant specification, operation of biogas plant, problems associated in functioning of the unit, power generation, Grid supply system, bio-fertilizer disposal/utilization, etc.

Storage of paddy straw

Baled paddy straw received at plant site is stacked in the premises of the plant campus and also stored in the biomass storage shed. It was found that due to weather changes and long term storage in changing weather conditions the straw in the top few layers get damaged. Covering the bales with water proof sheets will prevent the damages due to rain or condensing water particles.

Operation of plant

The plant comprises of i) Feed preparation unit, ii) Substrate feeding unit, iii) Biogas reactors, iv) Hydrogen sulphide scrubbing unit (Biological Scrubber), v) Power generation and grid feeding unit, vi) Bio-fertilizer preparation unit.

A view of paddy straw based biogas power generation unit of M/s Sampurn Agri-Venture Pvt. Ltd. at Fazlika, Punjab.

Cost-economics of paddy straw based Bio CNG plant

Following are the basic information based on which the economic analysis PAU Model – I biogas plant was done:

- The cost calculations are made for a plant which has a paddy straw handling capacity 40 tonnes per day.
- Quantity of animal dung required per day of operation is 6 tonnes.
- Cost of installation of a biogas plant or Bio-CNG plant is ₹ 3,000/- lakhs
- Total operational life of the plant is 20 years.
- Cost of pipe lines for connecting the biogas / bio-CNG with the nearest grid point is ₹ 20/- lakhs.
- Quantity of biogas produced is 12,000 m^3 per day (or equivalent of 5,600 kg of bio-CNG per day).

Table 5. Estimation of returns and costs for a bio-CNG plant with a paddy straw handling capacity of 40 tonnes per day

Sl. No.	Cost Particulars	Costs ₹ Per Year
	Price Realised	
1.	Price realized from bio-CNG (cost of bio-CNG at ₹ 46 per kg, for a production of 5,600 kg per day and for 275 days of operation per year)	708.40
2.	Price realized from bio-CNG (cost of compost at 5,000 per tonne, for production of 45 tonnes per day and for 275 days of operation per year)	61.88
A.	Total price realized by selling bio-CNG and compost	770.28
	Operational Costs	
1.	Purchase cost of paddy straw per year (@ 40 tonnes per day for 275 working days and at a cost of ₹ 2,000 per tonne of paddy straw)	220.00
2.	Purchase cost of paddy straw per year (@ 6 tonnes per day for 275 working days and at a cost of ₹ 2,000 per tonne of paddy straw)	33.00
3.	Lease rent cost for the land used for the plant and straw storage (2.5 ha of land for the plant and 2.5 ha for the storage and at ₹ 70,000 per ha per year)	3.50
4.	Storage cost of paddy straw (at ₹ 50 per tonne for 11,000 tonnes in a year)	5.50
5.	Size reduction, loading and unloading costs for the feed material (at ₹ 200 per tonne for 11,000 tonnes in a year)	22.00
6.	Salary / Wages for the manpower lat ₹ 2.4 lakhs per person for 10 persons)	24.00
7.	Other miscellaneous costs (lump sum)	10.00
8.	Repair and maintenance cost (at 1% of initial cost of the plant and machinery)	30.20
9.	Interest on the operational costs as starting capital (at 9% for a total of ₹ 100 lakhs)	9.00
B.	Total Running Costs	357.20
	Fixed Costs	
1.	Depreciation (assuming 20 years life and 10% scrap value)	135.90
2.	Interest on capital investment (assuming 100% capital is invested by the farmer)	271.80
C.	Total Fixed Costs	407.70
D.	Total Costs (Operational + Fixed Costs) B+C	764.90
E.	Net profit to the promoter when he invests 100% of the cost of plant and machinery	5.30

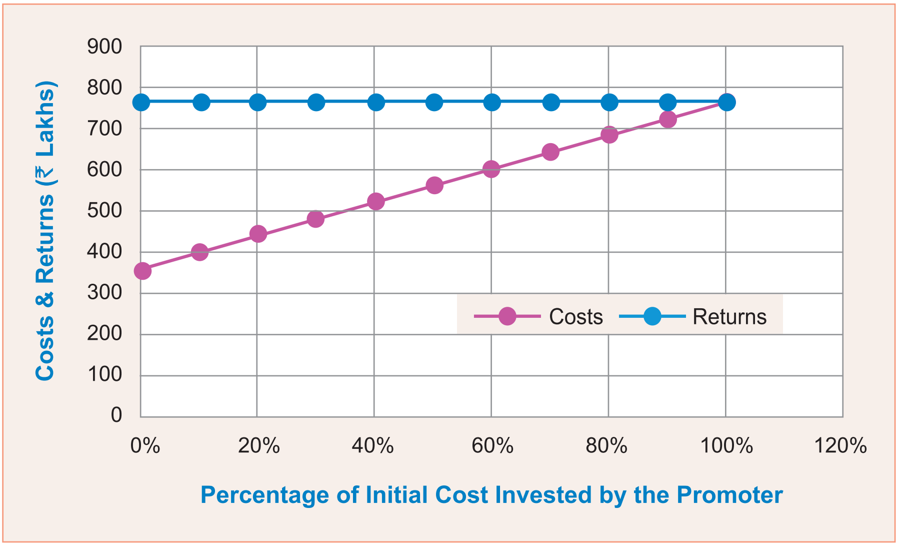


Fig. 2. Costs and returns as a function of Percentage of initial cost invested by the promoter (₹ Lakhs)

Table 6. Summary of costs and quantitative estimates for establishing 1,000 bio-CNG plants

Sl. No.	Particulars	Quantitative Values
1.	Cost of one plant	₹ 30 crores
2.	Cost of pipeline up to distribution point	₹ 0.2 crores
3.	Paddy straw consumed	40 tonnes per day
4.	Bio-CNG production	5,600 kg per day
5.	Manure compost production	45 tonnes per day
6.	Number of working days in a year	275
7.	Selling cost of Bio-CNG	₹ 46 per kg
8.	Selling cost of manure	₹ 500 per tonne
9.	Net profit when 50% of the plant and machinery costs are provided as subsidy by the Government	₹ 209.23 lakhs per year
10.	Total paddy straw consumed per unit	11,000 tonnes per plant per year
11.	Total paddy straw consumed per 000 units	@ 11.00 million tonnes per year
12.	Total subsidy required for 1000 plants	₹ 15,100 Crores

- Manure (Compost) produced per day from the plant is 45 tonnes.
- Number of working days per year is 275 days
- Purchase cost of paddy straw and animal dung are ₹ 2,000 per tonne (which includes ₹ 1,500 per tonne for collection and transportation and ₹ 500 per tonne of price for straw or dung)
- Selling cost of bio-CNG produced is ₹ 46 per kg (procurement announced by the oil PSUs).
- Selling cost of manure (compost) is ₹ 500 per tonne.

The profit to the promoter increases linearly with the increase in the rate of subsidy (Fig. 2). At a subsidy rate of 50% of the initial investment the annual profit will be ₹ 209.23 lakhs per year.

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Power Generation from Biomass

BIOMASS power based power generation process includes installations from biomass combustion, biomass gasification and bagasse co-generation. India has an installed capacity of over 5,940 MW biomass based power plants comprising 4,946 MW grid connected and 994 MW off-grid power plants. Out of the total grid connected capacity, major share comes from bagasse cogeneration and around 115 MW is from waste to energy power plants. The off-grid capacity comprises 652 MW non-bagasse cogeneration, mainly as captive power plants, about 18 MW biomass gasifier systems being used for meeting electricity needs in rural areas, and 164 MW equivalent biomass gasifier systems deployed for thermal applications in industries.

The states have been meeting their electrical power requirements primarily through conventional thermal and hydro power generation. Hydro power generation has a tendency to fluctuate depending on the availability of water. Thermal power generation has to depend on coal which has to be transported from eastern part of India involving large transportation distances. Continuous escalation of coal costs and pollution caused by emissions from coal burning are the problems of coal based thermal power plants.

Biomass Power projects have been the following inherent advantages over thermal power generations:

- They are environmentally friendly because of relatively lower CO_2 and particulate emissions.
- They displace fossil non-renewable fuels such as coal.
- They are decentralized, load based means of generation, because electricity is produced and consumed locally. Therefore, the losses associated with transmission and distribution are reduced.
- They offer employment opportunities to locals and help in local revenue generation and up-liftment of the rural population.
- They have a low gestation period and low capital investment.
- It is an established and commercially viable technology option.

Table 7. Biomass Power Projects Commissioned in the State by Punjab Energy Development Agency (PEDA), Chandigarh

Company & Location	Capacity MW	Paddy Straw Used Per Year Tonnes	Operational From
M/s. Malwa Power Ltd., Mukatsar	6.00	54,000	May 2005
M/s. Dee Development Engineers Pvt. Ltd., Fazilka	8.00	72,000	Feb 2009
M/s. Universal Biomass Energy Pvt. Ltd., Mukatsar	14.50	1,30,500	Oct 2009
M/s. Green Planet Energy Pvt. Ltd., Hoshiarpur	6.00	54,000	Mar 2012
M/s. Green Planet Energy Pvt. Ltd., Jalandhar	6.00	54,000	Feb 2013
M/s. Viaton Energy Pvt. Ltd., Mansa	10.00	90,000	Jul 2013
M/s. Green Planet Energy Pvt. Ltd., Hoshiarpur	4.00	36,000	Aug 2018
M/s. Green Planet Energy Pvt. Ltd., Moga	6.00	54,000	Aug 2019
M/s. Sampuran Agri Venture Pvt. Ltd., Fazilka	1.00	8,000	Feb 2015
M/s. Sukhbir Agro Energy Ltd., Faridkot	18.00	1,62,000	Dec 2019
M/s. Sukhbir Agro Energy Ltd., Ferozepur	18.00	1,62,000	Dec 2019
Total	**97.50**	**8,76,500 Tonnes**	

(Source: http://www.peda.gov.in/main/Bio-massPower.html)

Punjab has substantial availability of biomass / agro waste in the state which is sufficient to produce about 1000 MW of electricity. PEDA has planned to develop some of the available potential taluks / tehsils with the aim to promote and install biomass / agro waste based projects.

The power plants are not able to utilize biomass to their full capacity due to various factors such as poor biomass supply chain exist during the season and round the year non-availability of biomass at affordable prices. The straw collection in the field was a major bottleneck in whole straw management chain, hence, the use of balers may be encouraged for collection of straw from the field. It was realized that the time for collection of straw is very limited and man power for collection of straw is also scarce during this period, hence, collection through baler seems to be most feasible and economical option.

Table 8. Detail of Biomass Projects under Implementation by PEDA in Punjab

Name of the Company/ Location of the project	Capacity MW	Paddy Straw Used Per Year Tonnes	Status
M/s. Green Planet Energy Pvt. Ltd., Jalandhar	4.00	36000	Will be commissioned by Aug 2021
M/s. Sukhbir Agro Energy Ltd., Sahib	10.00	90000	Will be commissioned by Jun 2021
Total	**14.00**	**12600**	

(Source: http://www.peda.gov.in/main/Bio-massPower.html)

Table 9. Estimation of returns and costs for a paddy straw based power generation plant with a capacity of 18 MW power generation

Sl. No.	Cost Particulars	Costs ₹ lakhs Per Year
	Price Realised	
1.	Price realised by selling electricity (at ₹ 8.00 per unit for 1,000 lakh units per year)	8,000.00
A.	Total price realised	8,000.00
	Operational Costs	
1.	Cost of paddy straw (at ₹ 2,000 per tonne for baling and transporting to the plant site)	3,240.00
2.	Labour costs per year	60.00
3.	Repair and maintenance costs per year	150.00
4.	Storage costs of paddy straw per year	20.00
5.	Other miscellaneous expenses	200.00
B.	Total Running Costs	3670.00
	Fixed Costs	
1.	Depreciation (assuming 15 years life and 10% scrap value)	900.00
2.	Interest on capital investment (at 9% and assuming 100% capital is invested by the farmer)	1,350.00
C.	Total Fixed Costs	2,250.00
D.	Total Costs (Operational + Fixed Costs) B+C	5,920.00
E.	Net profit to the promoter when he invests 100% of the cost of plant and machinery (A-D)	2,080.00

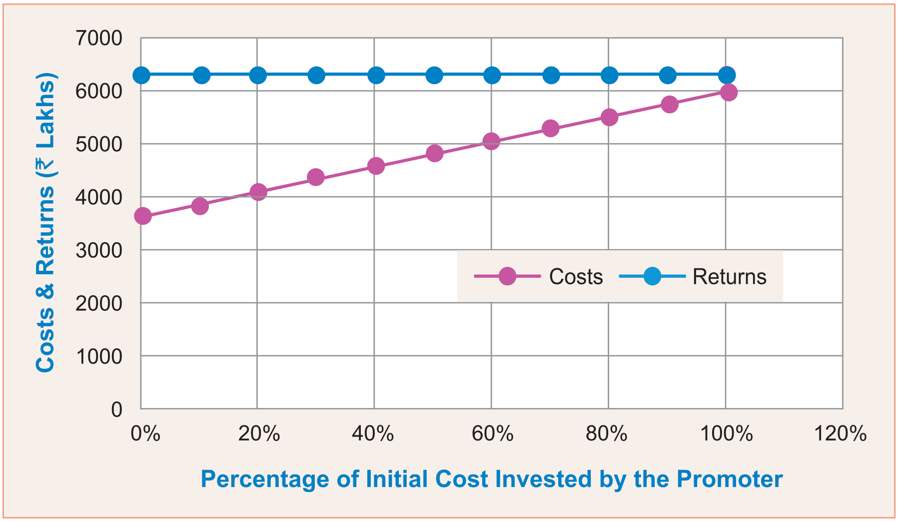

Fig. 3. Costs and returns as a function of Percentage of initial cost invested by the promoter (₹ Lakhs)

If a subsidy of 40% on the cost of plant and machinery is provided then the net profit for the promoter will be ₹ 29.80 crores per year.

There is a requirement of considerable area for the safe storage of bales for their utilization during off season periods. Hence, the land available in the village may be undertaken on lease or Panchayat land may be made available for decentralized storage of bales. Ultimately, transportation distance is a decisive factor in the economics of biomass pellets based power plants. It was opined by the experts that transportation of bales is quite feasible and economical from a distance of 15 km radius. Hence, transportation of the bales up to the safe storage place and the smaller size plants of capacities from 4 to 10 MW power generation may be encouraged. There is some environmental problem with biomass based power plant such as no satisfactory disposal of the ash coming out from plant. The biomass consumption in power plant about 30 tonne/day/MW and ash coming out from the plant is about 4.5 tonne per day/MW plant.

Cost Analysis of Biomass based Power Generation Plants

Following are the basic information based on which the economic analysis PAU Model – I biogas plant was done:

- For cost analysis purpose a biomass based power plant with a capacity of power generation of 18 MW is taken.

- Approximate actual production of electricity is 10 crore units (based on power load factor, break downs, number of working hours in a day and 300 days in a year)
- Total life of the plant 15 years.
- It is assumed that the plant uses 100% paddy straw for power generation.
- Cost of plant and machinery for a plant of 18 MW power generation capacity is ₹ 150 crores.
- Number of working days in a year is 300.
- Paddy straw consumption by this plant in an year is 1,62,000 tonnes.
- Cost of paddy straw ₹ 2,000 per tonne for baling and transporting to the plant site.

Table 10. Summary of costs and quantitative estimates for establishing 1000 for a paddy straw based power generation plants of 18 MW capacity each

Sl. No.	Particulars	Quantitative Values
1.	Capacity of the plant	18 MW
2.	Electricity produced per year (taking into account 300 days of working per year, power load factor and break downs etc.)	10.00 crore units per plant or 10,000 crore units from 1000 plants
3.	Cost of one plant	₹ 150 crore (₹ 90 cr by promoter and ₹ 60 cr support from Government)
4.	Operational life of the plant	15 years
5.	Sale price	₹ 8.00 per Unit
6.	Net Profit	₹ 29.80 crores per year
7.	Paddy straw consumed per year of operation	0.162 million tonnes per year
8.	If 100 such plants are established then the total paddy straw consumed per year	16.2 million tonnes per year
9.	Total subsidy for 100 plants at the rate of 40% subsidy on the cost of plant and machinery	₹ 60000 crores

Alcohol Production from Paddy Straw (Lignocellulosic Biomass)

GOVT. of India has allowed procurement of ethanol produced from other non-food feedstock besides molasses, like cellulosic and lignocelluloses materials including petrochemicals route, subject to meeting the relevant BIS standards. The next generation of technologies which can produce ethanol from non-food feedstock are being termed as second generation (2G) technologies. The ethanol being produced from these technologies is being termed as "2G Ethanol".

Presently, bio-ethanol in India is mainly produced from C-heavy molasses, a by-product of the sugar industry. Ethanol derived from sugarcane molasses emerged as a major potential substitute component for gasoline and is being presently being blended up to 10% in Petrol under Ethanol Blended Petrol (EBP) Programme run by Government of India. National Policy on Biofuels-2018 allowed production of ethanol from damaged food grains, B-Heavy molasses, sugarcane juice and surplus food grains which is expected to augment the ethanol supplies further.

The production of ethanol from any lignocellulosic biomass generally involves four steps – feedstock pre-treatment, enzymatic saccharification, fermentation and ethanol recovery. One kg of rice straw contains roughly 400 g of cellulose which is theoretically enough for producing 250 to 300 ml ethanol. There is another thermo-chemical route for ethanol production from crop residues wherein the biomass is gasified and converted to syngas and then to ethanol using chemical processes. Presently, there are more than 7-8 commercial projects worldwide which have been set up on 2G Ethanol technology. The details of few of the commercial projects is given in the Table:

There are two showcased technologies at demonstration scale available in India. These are explained below:

a) DBT-ICT technology: The Institute of Chemical Technology (ICT), Mumbai has developed India's first home grown technology to convert biomass to ethanol with funding from Department of Biotechnology. The demo plant of 10 tonne/day from Biomass to ethanol based on ammonia and acid

Table 11. Details of 2G Technology based Ethanol production plants worldwide

Company	Location	ML/yr	Feedstock	Products	Costs USD M	Start Date
Beta Renewables	Italy	76	Wheat & rice straw, bagasse, corn stover	Ethanol & 13 MW	200	Jun 2013
POET-DSM	USA	76	Corn Crop residue	Ethanol & biogas	250	Sep 2014
DuPont Danisco	USA	113	Corn stover	Ethanol	276	Oct 2015
GranBio	Brazil	82	Straw & bagasse	Ethanol & 15 MW	265	Sep 2014
Raizen	Brazil	42	Sugarcane residue	Ethanol	72	Dec 2014
IneosBio	USA	30	Citrus, oak, pine & pallet wood waste	Ethanol & 6 MW	130	Aug 2013
Enerkem	Canada	38	MSW	Ethanol & methanol	151	2015

process followed by enzyme hydrolysis has been developed and installed at Kashipur, Uttarakhand.

A view of Multi-feedstock biomass based Continuous Flow 2G-Ethanol Demonstration Plant developed by DBT-ICT, Uttrakhand

b) Praj technology: A demonstration project of 12 tonne per day capacity has been set up by M/s Praj Industries in Pune. The project was set up in 2017 and has been running since then.

Oil PSUs are in the process of setting up twelve 2G Ethanol project in the Country with an approximate investment of ₹ 10,000 crore. One such project will be set up by Hindustan Petroleum Corporation Ltd. in Bathinda, Punjab for which foundation stone was laid in December, 2016. Foundation stone for Bio refinery in Numaligarh, Assam has been laid by on 09.02.2019.

It is estimated that one 100 kl per day bio-refinery will require around ₹ 800-1,000 crore of capital investment. A typical 100 kl per day will consume around 0.15 million tonnes of biomass per annum and will produce around 300 lakh litres of ethanol per annum.

The 2G Ethanol projects are also fraught with few challenges such as lower commercial viability at lower feedstock scale; nascent technology; in-consistent feedstock availability; higher enzyme/ chemicals cost, higher OPEX etc. The same are being addressed jointly by Oil PSUs, technology providers, biomass suppliers, enzyme suppliers etc. and the Oil PSUs are going ahead with their first few projects.

Govt. of India has recently announced a scheme viz. "Pradhan Mantri JI-VAN Yojana" for providing financial support to Integrated Bio-Ethanol Projects using lignocellulosic biomass & other renewable feedstock, with a total financial outlay of ₹ 1,969.50 crore for the period 2018-19 to 2023-24. The scheme focuses to incentivize 2G Ethanol sector and support this nascent industry by creating a suitable ecosystem for setting up commercial projects and increasing Research & Development in this area. Under this Yojana, 12 Commercial Scale and 10 demonstration scale Second Generation (2G) Ethanol Projects will be provided a Viability Gap Funding (VGF) support in two phases:

a) Phase-I (2018-19 to 2022-23): wherein 6 commercial projects and 5 demonstration projects will be supported.

b) Phase-II (2020-21 to 2023-24): wherein remaining 6 commercial projects and 5 demonstration projects will be supported.

Other endeavours are also underway to provide necessary support to nascent 2G Ethanol industry.

Cost Analysis of Alcohol Production from Paddy Straw

Following are the basic information based on which the economic analysis PAU Model – I biogas plant was done:

- The quantity of alcohol that can be produced from 1 ton of paddy straw is 200 litres.
- The costs of plant and machinery for a 100,000 litre alcohol production capacity per day is about ₹ 800 to 1,000 crores (We shall take it as ₹ 900/- crores)
- A 100,000 litre alcohol per day capacity plant will consume around 0.15 million tonnes of biomass per year and will produce around 300 lakh litres of ethanol per year.
- Amount of compost manure produced as a by-product is 6 kg compost per litre of alcohol produced or 1800 lakh kg per year.

- Procurement price of alcohol by the government of India is ₹ 45.69 per litre (for 'C-heavy molasses)
- Sale price of the compost manure is ₹ 1.0 per kg.

It was not possible to obtain direct or indirect data on costs of production of alcohol from rice straw plant. The costs of production of alcohol based on costs of a unit in Japan was available from a literature. That cost was converted to INR for further analysis. Based on the literature data, cost of production of alcohol from paddy straw (operational costs) is ₹ 105.00 per litre.

Table 12. Estimation of returns and costs for a paddy straw based alcohol producing plant

Sl. No.	Cost Particulars	Costs ₹ lakhs Per Year
	Price Realised	
1.	Price realised by selling alcohol (at ₹ 45.69 per litre 300 lakh liters)	13,707.00
2.	Price realised by selling manure (at ₹ 1.00 per kg for 1800 lakhs kg manure)	1,800.00
A.	Total price realised	15,507.00
	Cost of Production	
1.	Total cost of producing 300 lakhs litres of alcohol per year from paddy straw (based on the data from: Takimura *et al.* 2013)	31,500.00
B.	Total Running Costs	31,500.00
C.	Net loss per year from a plant of alcohol production capacity 300 lakh litres per year (A-B)	-15,993.00

Due to heavy monetary loss for a plant of alcohol production capacity of 300 lakh litres per years (of the order of about ₹ 16,000/- lakhs per year), the option of alcohol production from paddy straw was not considered as a viable option and was dropped from further consideration.

Composting of Paddy Straw Off the Cultivating Area

COMPOST contains a range of micronutrients and microorganisms that are beneficial to crop growth and soil health, and which are not usually contained in inorganic fertilizers. Although organic fertilizers, including paddy compost, are often low in major nutrients such as nitrogen (N) and phosphorus (P), they contain beneficial micronutrients, enzymes and micro-organisms.

The key to make good compost is adequate supply of N, moisture content, and abundant microorganisms. For better composting, paddy straw/biomass should be chopped into small pieces (of sizes 3 to 5 cm). If possible, compost heaps should be built in layers consisting of cereal crop material (high C and low N content) combined with legume or manure wastes (higher N content). To aid decomposition, a dilute solution of N fertilizer (such as urea) and/or with a micro-organism solution (e.g., Trichoderma harzianum commonly called "tricho") are sprinkled on the composting biomass. The farm compost can be made either in trench after cutting straw in to small pieces or making heap formation of straw.

Compost making in trench

Farm compost is made by placing farm wastes in trenches of suitable size, say, 4.5 m to 5.0 m long, 1.5m to 2.0 m wide and 1.0 m to 2.0 m deep. Crop/farm waste is placed in the trenches layer by layer. Each layer is well moistened by sprinkling cow dung slurry or water. Trenches are filled up to a height of 0.5 m above the ground.

Compost making with heap formation

Minimum 4 feet height should be maintained for composting. The composting area should be elevated one and have sufficient shade. While heap formation, all the crop residues should be mixed together to form a heterogeneous material rather than a single homogenous material. Alternate layers of carbon and nitrogen rich material with intermittent layers of animal dung are essential. After heap formation the material should be thoroughly moistened.

Aerating the compost material

Sufficient quantity of oxygen should be available inside the compost heap. For this external air should be freely get in and comes out of the material. Normally to allow the fresh air to get inside, the compost heap should be turned upside down, once in fifteen days. In this process top layer comes to bottom and bottom layer goes to top. This process also activates the microbial process and compost process is hastened. In some cases air ventilating pipe may be inserted vertically and horizontally, to allow the air to pass through. The wood chip that is available as waste in wood processing industry may also be used as bulking agent in the composting process. This bulking agent gives more air space to the compost material.

Moisture maintenance

Throughout the composting period, 60% moisture should be maintained. On any situation, compost material should not be allowed to dry. If the material becomes dry, all the microorganisms present in the crop residues will die and the compost process gets affected. The heap can be covered with straw thatch to protect from sunlight and reducing moister evaporation.

Compost maturity

Volume reduction, black colour, earthy odor, reduction in particle size are all the physical factors to be observed for compost maturity. After satisfying with the compost maturity index, the compost heap can be disturbed and spread on the floor for curing. After curing for one day, the composted material is sieved through 4 mm sieve to get uniform composted material. The residues collected after composting has to be again composted to finish the composting process.

Compost enrichment

The harvested compost should be heaped in a shade, preferably on a hard floor. The beneficial microorganisms like Azotobacter or Azospirillum, Pseudomonas, Phosphobacteria (0.2%) and rock phosphate (2%) have to be inoculated for one ton of compost. Forty per cent moisture should be maintained for the maximum growth of inoculated microorganism. This incubation should be allowed for 20 days for the organism to reach the maximum population. Now the compost is called as enriched compost. The advantage of enriched compost over normal compost is the quality manure with higher nutrient status with high number of beneficial microorganisms and plant growth promoting substances.

Nutritive value of Bio-compost

The nutritive value of Bio-compost varies a lot based on varying input materials. But in general Bio-compost contains all the macro and micro nutrients required for crops. Even though the quantity available is low it covers all the requirements of the crop.

Necessity for Off-cultivating Area Composting

The composting process of crop residue takes about 8 to 10 weeks. Whereas, in the combine harvested paddy field, farmer has 15 to 20 days to vacate straw for field preparation for next crop. Hence, straw should be collected and composted at a corner of the field itself or in a nearby suitable empty field.

Cost Analysis of Off-Cultivating Area Composting of Paddy Straw

Following are the basic information based on which the economic analysis PAU Model – I biogas plant was done:

- Total paddy straw available from 1 ha of field is 6 tonnes.
- Quantity of compost produced from 6 tons of paddy straw is 5 tonnes.
- Field space required for composting 6 tons of paddy straw is 50 square metres and space required for processing and packing is 50 square metre for a total of 100 square metres or 1% of 1 ha.
- Sale price of compost is ₹1,000/- per tonne.

Hence, for composting of the straw by farmers in their field, government support may be required to start and to continue the practice.

The option of composting of paddy straw off the field was not considered as a viable option for the following various reasons:

- It causes a monetary loss of ₹ 1,500/- per ha of land. For a total area of 4.35 million ha under paddy cultivation in Punjab and Haryana this loss translates to ₹ 653 crores. This amount is either a loss to the farmer or needs to be supplemented by Government every year.

Table 13. Summary of costs and quantitative estimates for off the field composting of paddy straw

Sl. No.	Details	Costs ₹
1.	Cost of collecting 6 tonnes of straw and transporting to a corner of the field or in a different and nearby field	2,500.00
2.	Cost of animal dung required for the composting is 2 tonnes of paddy straw and at a cost of ₹ 250 per tonne	500.00
3.	Cost of nitrogen fertilizer and Trichoderma for composting 6 tonnes of straw	500.00
4.	Wages for handling during the composting process	2,000.00
A.	Total costs for making 5 tonnes of compost from 6 tonnes of paddy straw	5,500.00
B.	Monetary loss due to production loss in this occupied area	1,000.00
C.	Total costs involved in producing 5 tonnes of compost (A+B)	6,500.00
D.	Price realised by selling 5 tonnes of compost	5,000.00
E.	Net loss to the farmer per ha of land	-1,500.00

- It also causes a cultivable land area of 1% for composting yard space and operational space. This is equivalent to 43,500 ha every year and will cause a reduction in yield of 4.35 lakhs tonnes every year.
- The process of collecting and transporting the straw from the field to the compost site and managing it over the composting period are labour intensive and cumbersome.
- In-situ composting using consortia of microbes developed by various Institutions of ICAR, which are currently being tested, may become more viable and easier option than the off the filed composting

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Recommendations

THE various options for *Ex-situ* management of crop residues considered by the committee are as follows:

- Biomass pellets from crop residues as a fuel substitution in thermal power plants
- Biogas production from paddy straw at domestic / community level
- Industrial level production of Biogas / Bio-CNG / Compressed Bio-gas (CBG) from Paddy Straw
- Power Generation from Biomass
- Alcohol production from paddy straw (lignocellulosic biomass)
- *Ex-situ* Composting of Paddy Straw.

Utilization of crop residues as a fuel for power generation will not only discourage in-field crop residue burning abating air pollution, but will also reduce carbon footprint of coal based power plants. Bio-CNG / Compressed Bio-gas (CBG) producing projects may be integrated with existing retail networks of Oil PSUs and other industries relying on gas based energy. It will provide off-take assurance for crop residues to the CBG project developers. Govt. of India has allowed procurement of ethanol produced from non-food feedstock cellulose and lignocelluloses based materials besides molasses, subject to meeting the relevant BIS standards.

The following table shows the cost economics and other related details of each of the six options of *ex-situ* crop residue management:

Table 14. Summary of Options and Recommendations of the Committee

Sl. No.	*Ex-situ* Management Option	Remarks
1.	Biomass pellets from crop residues as a fuel substitution in thermal power plants	• This option is recommended for further consideration
		• Substituting biomass pellets from crop residues at the rate of 10% of the coal, will increase the cost of production by 20 paisa per unit of power.
		• If all the existing power plants in North India (with an installed capacity of 44,560 MW) substitute their fuel with paddy straw

Sl. No.	*Ex-situ* Management Option	Remarks
		based pellets then they will consume 17.82 million tons of paddy straw every year. Nearly the entire problem will be solved.
		• There is no additional expenditure or subsidy needed from Government.
2.	Biogas production from paddy straw at domestic/ community level	• This option is recommended for further consideration
		• Cost of PAU Model – II biogas plant is ₹ 2.1 lakhs and its life is 20 years.
		• For a breakeven on expenditure for the farmer the government need to extend a one time support at the rate of 60% of the cost of the plant.
		• If one biogas plant per farm in Punjab is established then the budget required for one time subsidy will be ₹ 13,860 crores (for nearly 1.1. million land holdings).
		• These 1.1 million biogas plants will consume 5.28 million tonnes of paddy straw every year.
3.	Industrial level production of Biogas/ Bio-CNG/ Compressed Bio-gas (CBG) from Paddy Straw	• This option is recommended for further consideration
		• Cost of establishing one bio-CNG plant with a capacity of 5,600 kg of bio-CNG per day will be ₹ 30.20 crores.
		• Such a plant will consume 40 tonnes of paddy straw every day or 11,000 tonnes in ayear with 275 working days.
		• If 50% of the cost of plant and machinery are supported by the Government then the annual profit will be ₹ 209.23 lakhs per year.
		• If 1000 such plants are established then support at the rate of 50% will cause an expenditure of ₹ 15,100 crores to the Government.
		• 1000 bio-CNG plants will consume 11 million tonnes of paddy straw every year.
4.	Power Generation from Biomass	• This option is recommended for further consideration
		• The cost of establishing one 18 MW biomass based power generation unit will be ₹ 150 crores.

Sl. No.	*Ex-situ* Management Option	Remarks
		• This plant will produce 10 crore units of power every year and will have an average life of 15 years.
		• If 1,000 such plants are established then the electricity produced will be 10,000 crore units
		• If 40% subsidy on the cost of plant and machinery is given then the profit per plant per year will be ₹ 29.80 crores and the breakeven will occur in 5 years.
		• Total money required for subsidy at the rate of 40% will be ₹ 60,000 crores.
		• Total paddy straw consumed by 1000 such units will be will be 16.20 million tons per year.
5.	Alcohol production from paddy straw (lignocellulosic biomass)	• This option is not recommended for further consideration
		• Technical and commercial data on the plant performances is not available at this point of time. The experience of India is also limited.
		• Cost of plant and machinery for a plant with a capacity of 300 lakh litres of alcohol per year will be ₹ 800 to 1,000 crores.
		• Such a plant will consume 0.15 million tonnes of paddy straw every year.
		• Based on the cost estimates available in the literature (Japanese estimates) the loss incurred from such a plant will be ₹ 15,993 crores per year.
6.	*Ex-situ* Composting of Paddy Straw	• This option is not recommended for further consideration
		• The loss incurred by a farmer by composting off the field will be ₹ 1,500 per ha per year
		• 1% of land area will be lost for composting yard resulting in a loss of 43,500 ha in Punjab and Haryana and a grain production loss of 4.35 lakh tonnes every year.
		• The process of collecting and transporting the straw from the field to the compost site and managing it over the composting period are labour intensive and cumbersome.

Based on the facts and data collected from various sources and technical and economic analysis done of the various possible options of *ex-situ* management of crop residues following recommendations are made:

1. Following options are not recommended for further consideration:

a. Alcohol production from paddy straw (lignocellulosic biomass)

b. *Ex-situ* Composting of Paddy Straw

2. Following options are recommended for further consideration:

a. Biomass pellets from crop residues as a fuel substitution in thermal power plants

b. Biogas production from paddy straw at domestic / community level

c. Industrial level production of Biogas / Bio-CNG / Compressed Bio-gas (CBG) from Paddy Straw

d. Power Generation from Biomass.

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http://www.peda.gov.in/main/Bio-massPower.html)

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Annexure

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F. No. A. Engg. 17/22/2020-AE Date: 26.10.2020
(Computer No.: 86968)

OFFICE ORDER

Sub: Constitution of committee for economic analysis of alternative/*ex-situ* options of crop residue management - reg.

There are various alternative *ex-situ* options like conversion of the crop residues biomass into pellet and utilization of biomass pellets as fuel in power plant, biogas production from paddy straw at domestic/community level, Industrial level Plant for production of compressed bio-gas/ Bio-CNG from Paddy Straw, Alcohol production from paddy straw (lignocellulosic biomass), Composting of paddy straw etc.

The Secretary, DARE and Director General, ICAR is pleased to approve a committee of the following members for economic analysis of the alternative /*ex-situ* options of the crop residue management.

1. Deputy Director General (Engg.), ICAR – Chairman
2. Representative of the Ministry of Power – Member
3. Representative of the Ministry of Petroleum and Natural Gas – Member
4. Representative of Joint Secretary (M&T), DAC&FW – Member
5. Dr. Suresh Pal, Director, NIAP or his representative – Member
6. Director, CIAE, Bhopal – Member
7. Dr. S. S. Sooch, Pr. Scientist (Renewable Energy Engg.), PAU, Ludhiana
8. Dr. Mukesh Jain, Asst. Professor (FMPE), CCSHAU, Hissar
9. Assistant Director General (Farm Engg.), ICAR – Member Secretary

The committee is requested to complete the task by mid November 2020.

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Distribution:

1. Secretary, Ministry of Power (with request to kindly nominate suitable expert for the committee)
2. Secretary, Ministry of Petroleum and Natural Gas (with request to kindly nominate suitable expert for the committee)
3. Joint Secretary (M&T), DAC&FW Gas (with request to kindly nominate suitable expert for the committee)
4. Dr. Suresh Pal, Director, NIAP, New Delhi (with request to kindly nominate suitable representative/expert for the committee)
5. Director, CIAE, Bhopal
6. Dr. S. S. Sooch, Principal Scientist (Renewable Energy Engg.), PAU, Ludhiana
7. Dr. Mukesh Jain, Assistant Professor (FMPE), CCSHAU, Hissar

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