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Availability Assessment of Crop residue Potential for Electric Power Generation in Punjab, India: A Review

Harpreet Singh Dhaliwal[1], Yadwinder Singh Brar[2] and Gursewak Singh Brar[3]
[1]Research Scholar, Inder Kumar Gujral Punjab Technical University, Kapurthala (Punjab), India.
[2]Professor & Head, Department of Electrical Engineering,
Inder Kumar Gujral Punjab Technical University, Kapurthala (Punjab), India.
[3]Professor & Head, Department of Electrical Engineering,
Baba Banda Singh Bahadur Engineering College, Fatehgarh Sahib (Punjab), India.

(Corresponding author: Harpreet Singh Dhaliwal)
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ABSTRACT: Biomass residues are renewable, reliable and economical resource of energy for both developed and developing countries. Punjab being an agricultural dominating state has innumerable prospective of agricultural crop residues. This paper reviews the results obtained from various previous studies, which had estimated the crop residue potentials for power generation in the state. If we use this crop residue as a fuel in biomass power plants, it will not only provide enough electric power to the state but also provide solution to the biggest setback of burning the crop residues in the fields of state. The viability and practicability of exhilarate the new biomass power plants primarily depends upon the availability of fuel i.e. crop residue. Hence before planning to find the optimal locations of biomass power plants and centers for collecting the fuel in the state, it is quiet necessary to evaluate the availability of agricultural crop residues biomass and energy content of this biomass for electric power generation. In the end study summarizes that there is enough crop residue potential in the state for electric power generation.

Keywords: Punjab, crop residue, power generation, resources, agricultural biomass.

I. INTRODUCTION

Electrical energy plays an important role in our life. Electricity is necessary for improving the living standards and also a crucial input for socio-economic activities of any nation. Substandard electricity supply severely obstructs the health, education and agricultural activities in rural as well as urban areas [1]. The electricity demand in Punjab state is envisage rising significantly owing to increasing population, Sharp rise in agricultural and industrial applications and upliftment of the living standards of people [2]. It is a matter of dread that the available conventional sources in the country might not be able to fulfill the energy needs of the nation as well as the Punjab state [3]. The state is not rich in natural resources of fossil fuels, nor have the abundant sources of hydro electric power. The state has to rely far away states for supply of coal and to depend upon the neighboring states for hydro electric power [4]. As per the reports of World Energy Forum, the conventional energy sources of the country will deplete soon in the coming few decades [5]. Also the green house gases produced from the burning of coal and petroleum highly pollutes the air. These green house gases are the important factor for global climate change [6]. The diminution of fossil fuels and serious environmental issues raised from burning of fossil fuels leads the governments to switch the electric power generation to the alternate energy sources such as biomass [7]. Agricultural biomass residue is one of the most widely used fuels for electric power generation all around the world nowadays. The use of biomass as a fuel can decrease the green house gases emissions [8]. The carbon dioxide emitting from burning of crop residue is balanced by amount absorbed when the plants are grown, as a process of photosynthesis. Hence we can say that crop residues are of immense interest to the farmers of the state. The farmers burn a large amount of crop residues in their fields to prepare the fields for sowing of the next crop. Burning of crop residues particularly paddy residue is the most critical and serious issue for the farmers of north India. Punjab, Haryana, Rajasthan and Uttar Pradesh are the most affected states from north India. The problem of burning crop residue is most severe in mechanized rice-wheat system in the Punjab state [9]. Some of the main reasons of burning paddy residue are the short time frame between sowing of wheat crop and harvesting of rice crop, inadequacy of labour and economical issues related to labour, use of combine harvesters and lack of storage and collection centers and insufficient purchase of crop residues in the market.

The objective of this study is to review the availability of agricultural residue produced in agricultural sector of Punjab and the potential of this crop residue to generate electrical energy in the state of Punjab, which is one of the wealthiest states in terms of agriculture in the country.

A. Profile of Punjab state

The state of Punjab is also known as the bread basket of India. It is located between 73º 53′ to 76º 56′ E longitude and 29º33' to 32º32′ N latitude. The geographical area of Punjab state is 50,362 square kilometers, which is 1.53% of India's total geographical area [10]. Punjab is sharing its border with Indian states of Rajasthan, Haryana, Himachal Pradesh and Indian Union territory of Jammu & Kashmir. Indian union territory Chandigarh is the capital of Punjab state. The western side of state is sharing 300 km long international border with Pakistan. The name Punjab derives from two different words Punj (Five) and ab (Rivers). The state before partition of India was having five rivers flowing through it, from where it got the name Punjab. Sutlej, Beas, Ravi, Jhelum and Chenab were the rivers, which are the tributaries of Indus River. Nowadays Sutlej, Beas and some part of Ravi flows through the Indian Punjab. Jhelum and Chenab are now the parts of Pakistani Punjab. The state bears hot and humid temperatures upto 48ºC in the summers and chilling temperature of 0ºC in the winters. The average annual rainfall varies from 480 to 960 mm. Rainfall is high in hilly and sub mountainous areas located in North-Eastern parts of state and small in South-Western part of sandy areas of the state. Out of total geographical area, 83% is under agricultural use. The state has a very small area (6.12%) under the forests. Out of total area, 98% is cultivable and irrigated using ground water or canal water. Punjab consumes almost 28% of fertilizers of the country.

Administratively, the state has been divided into 5 divisions, 22 districts, 91 tehsils, 150 blocks, 74 towns and cities. There are 12,581 villages in the state. The population of state as per census of 2011 is around 277.4 Lakh. Out of total population, 62% is rural population. The population density of state is 484 people per km^2. Rate of literacy in the state is 75.8% [11].

Economy of the states highly relies on agriculture. Agriculture covers almost 83% of geographical area of state. Agriculture in the state is highly intensive and mechanised in terms of agriculture inputs. The cropping intensity of the state is 189%, which is one of the highest in the country. Most the land in Punjab is very fertile. Due to this fertile land, use of machinery in agriculture, high use of fertilizers and very hardworking farmers, Punjab has taken its cropping intensity to 189%. Punjab has the largest network of canals, which make most of its land irrigated.

B. Agriculture Scenario in Punjab

Punjab is one of the most fertile lands in this world. Atmospheric conditions and fertile land of the state is capable of producing various crops, many kinds of fruits and vegetables. Indian Punjab is known as "Granary of India" or "The bread basket of India". Major economic activity of the state is agriculture, which occupies 84% of its geographical area. The state has the highest cropping intensity in the country. With just 1.53% of total area of India, Punjab alone produces 23% of wheat, 11% rice and 13% cotton of the country [12].

Punjab is the state, which contributes highest amount of grains in the central pool of the country. The state has two main agricultural seasons "Kharif" and "Rabi". Kharif is the summer crop and Rabi is the winter crop. Chief crops produced during kharif season are rice, maize, bajra, sugarcane and moong. The major crops of rabi season are wheat, mustard, sunflower and cotton. Remarkable production of food grains in the state has witnessed in the state in last few decades.

The production outstandingly increased in the post green revolution in the state. Production of grains escalated to 31.67 Million tons (2017-18) from 3.16 Million tons (1960-61). The main reasons of such a big rise in production is hard working farmers, proper irrigation facilities, fertile land, highly mechanized farms, adoption of new technologies and introduction of high yield verities of food grains. The production of wheat in year 1980-81 was 7677 thousand metric tons, which elevated to 17,830 thousand metric tons in 2017-18. Similarly the production of rice in the year 1980-81 was 3233 thousand metric tons, which increased to 13382 thousand metric tons in 2017-18. On the other hand the production of pulses shows decrease from 12 thousand metric tons to 9 thousand metric tons from 2014-15 to 2017-18. The sugar cane production has shown different scenario in past few decades [13, 14].

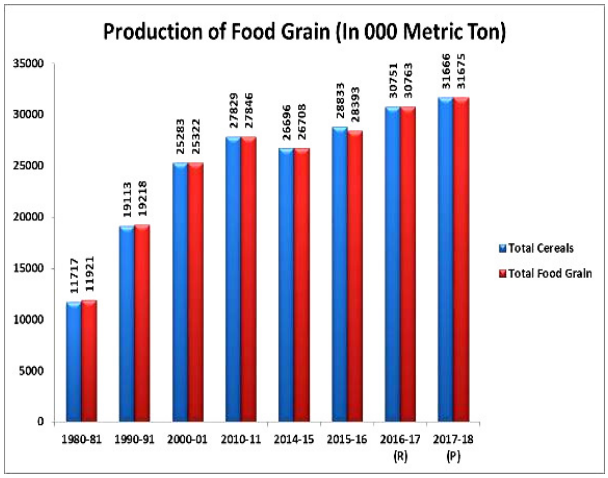

Fig. 1. Production of food grains.

C. Area under Major Crops in Punjab

The state has seen a distinguished change in the cropping pattern in the last few decades. The remarkable change in cropping patterns is witnessed after green revolution. Rice and wheat becomes the major crops of the state after green revolution, and it left behind its traditional crops such as bajra, jowar, maize, pulses and oilseeds etc. The area under the traditional crops had decreased significantly from 1980-81 to 2017-18.

Major portion of gross crops produced are occupied by wheat and rice. Area under wheat and especially rice has shown sharp increase. Area under wheat crop was 2.812 million hectares in 1980-81, which has increased to 3.512 million hectares in 2017-18.

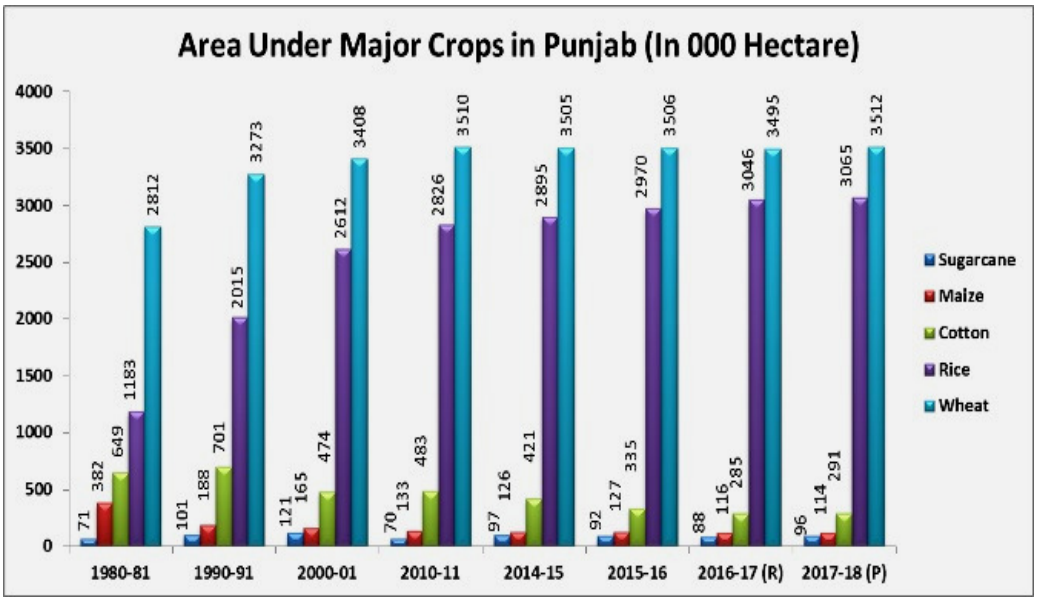

Fig. 2. Area under major crops in Punjab.

The area under rice was 1.183 million hectares in 1980-81, which has increased to 3.065 million hectares in 2017-18. Area under cotton was 0.649 million hectares in 1980-81, which decreased to 0.291 million hectares in 2017-18. Similarly the area under maize was 0382 million hectares in 1980-81, which has also decreased to 0.114 million hectares in 2017-18. Hence it can be seen that wheat, rice, cotton, sugarcane and maize are considered as major crops of the state [13, 14].

D. Production of major crops in Punjab

Wheat, rice, cotton and sugarcane are the major crops produced in the state, which shows manifold increase in their production over the last decades. The Fig. 3 shows that the production of wheat and rice has increased manifold from 1960-61 to 2012-13.

II. MAIN BIOMASS RESOURCES PUNJAB

Biomass is a clean and less environmentally destructive source of producing energy. It is becoming popular day by day. This is the best, almost freely available source of energy and can be used as a replacement of conventional sources of energy [15].

Food grain production in Punjab has witnessed a sharp rise after green revolution. Farmers of Punjab has the best agricultural machinery, better irrigation provisions, excellent agricultural infrastructure, high levels of research guidance in agriculture and most important its hardworking farmers. Having all these factors made it to produce rice crop between June-October and wheat crop between November-April. Because of having best provisions of irrigation, Punjab is producing rice crop, which is not a conventional crop of Punjab. But due to the above mentioned factors, the farmers of Punjab easily shifted to this cash crop. It is already mentioned that Punjab has seen the massive gain in grain productions over last few decades. Due to the high production of grains, large masses of crop residues have been produced. The disposal of these crop residues in an effective way became challenge for the farmers of Punjab. Especially the disposal of crop residues left after the harvesting of rice became complication for the farmers of Punjab State [9].

A. Major Crops and their sowing

The crops produced in the state are the seasonal crops. Main crops produced in the state can be subdivided into two types:

– Rabi crops
– Kharif crops

Rabi crops are also known as winter crops. These crops are sown in the winter season and harvested in the end of spring season. Preferably these crops are sown in mid November and they became ready to harvest in April. The chief Rabi crop produced in Punjab is wheat. Wheat is the primary food for people of Punjab. Besides wheat, cotton, mustard and sesame are also produced in the Rabi season.

After harvesting the wheat crop, the crop residue of wheat is left in fields, which is used to make fodder for cattle. Almost 80% of wheat straw is converted into fodder. The fodder of wheat is main food source for cattle of Punjab. Wheat fodder is also sold by the people of Punjab to the other states of country.

Kharif crops are also known as summer crops. These crops are sown in summer season, during the monsoon season of Indian sub continent. These crops are generally sown in 1st or 2nd week of June and harvested in the month of September/October, depending upon the type of crop. Rice is the major kharif crop of Punjab. Besides this, sugarcane, maize and bajra are also grown in kharif season. Although rice is the chief kharif crop but most of this crop is sold by Punjab as this is not a primary food for people of Punjab. The crop residue of rice is not used as fodder in Punjab to feed the cattle due to high silica content in rice residue [27]. These crops are dependent heavily on water. Rice need flooded field during the growth period. It requires a hot and humid weather to grow. Temperatures in summer go very high in Punjab, this high temperature helps to grow rice crop very well.

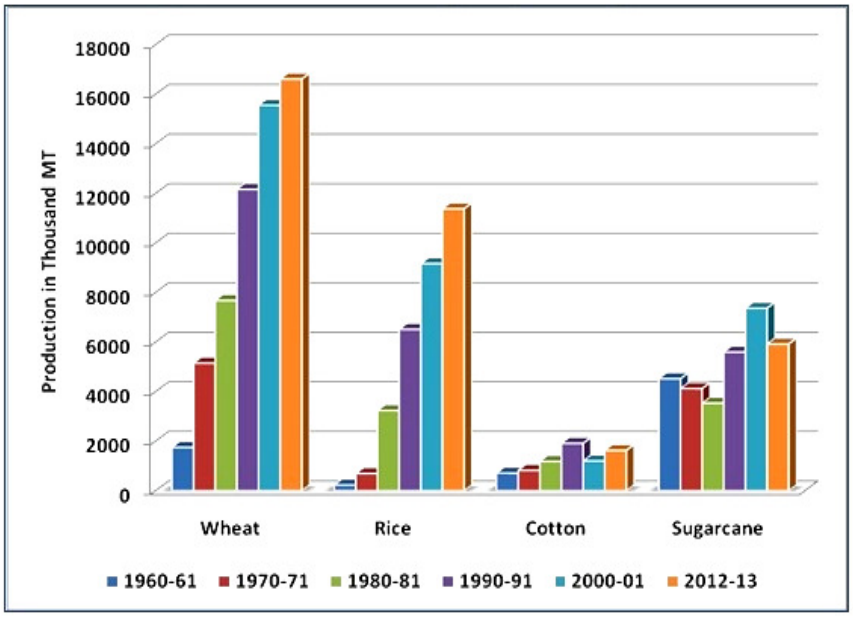

Fig. 3. Production of major crops in Punjab.

B. Crop residues

Crop residue is the leftover material in the field, when the grown crop is harvested. The crop residues can be categorized into two types; one is field residue and second is process residue. Field residue is the remainder of crop left in the field itself when the crop is harvested. This residue can be disposed off in many ways like ploughing back into field, utilized for energy generation, utilized for other agricultural usage or may be burnt into the field. It is important to clear the field from field residues so that next crop must be grown in the field. Process residue is the remainder of crop, which is produced when further processing of the food grain took place. Bagasse, husk etc are the examples of process residue. Punjab is being highly mechanised in farm practices. Combine harvesters are commonly used in Punjab for harvesting of wheat and rice, these combine harvesters left large amounts of residue in the fields. Wheat straw is collected and transformed into fodder. While the rice straw cannot be used as animal feed. Hence farmers show no interest in collecting this rice straw from the fields.

C. Crop Residue Burning

The farmers of Punjab are economically sound and they use superior machinery for agricultural use. The farmers mostly use the combine harvesters for harvesting the crops. These combine harvesters left abundant field crop residues with root bound straw in the fields. Wheat straw is collected and converted into fodder for feeding cattle. But owing to high values of silica content, the rice residue is not converted to fodder by the farmers. Rice residue also not has any other effective use in day to day life of farmers. The farmers need to clear their fields in just 10 to 15 days so that they could sow the next crop in their fields.

It became uneconomic for the farmers to clear their fields by using the labour. There are also some other factors such as non availability of labour, expensive tools, consumption of diesel on farm machinery to clear the fields. Hence due to these problems, the farmers prefer to burn the rice residue in their fields. The burning of this rice residue became convenient to the farmers, because there is no extra cost involved in this act. Farmers know that they are spoiling the environment and they are also affecting the soil fertility, but despite these factors, the farmers agreed to burn the rice residue [14].

Paddy straw burning in fields is very common in Punjab, Haryana and Uttar Pradesh states of the country. Burning of paddy resides raised serious environmental issue. Every year tons of crop residues are openly burnt in the fields of Punjab. A report reveals that for the year 2018, total rice straw produced in Punjab and Haryana states was 28.10 million tons [27]. Out of this, 12 million ton rice straw was burnt in fields by both the states [18].

As per the reports of National Green Tribunal, large amount of rice straw is burnt every year, which increases the AQI of the north India. Almost 78% of rice straw is burnt in Punjab, while only 10% is incorporated in soil. The Punjab government imposes heavy fines and has a provision to lodge an FIR on the farmers of state if they burn rice straw in their fields. But still there is no change in situation over the last couple of years in the state. Large scale paddy burning was confined in Sangrur, Ludhiana, Patiala, Ferozepur and Muktsar districts of the state [28].

Fig. 4. Burning of crop residue on field.

On the other side, only 12% of wheat residue is burnt in the fields, almost 76% of wheat residue is used as cattle fodder, almost 7% is incorporated in the soil. Just 2% is utilized as fuel and 3% of the wheat crop residue is utilized for other purposes. The state government needs to start a program so that farmers should not burn the price residues in their farms. Subsidy must be granted to farmers, who will not burn the residue. Similarly government must have to open the paddy purchase centers in the state so that farmers must sell their crop residue. One of the most convenient ways to solve the problem is to burn this crop residue in the biomass plants instead of burning in the open fields.

D. Categories of agricultural residues

There are many types of crop residues. Some are products and some are by products of agricultural residues. Predominantly crop residues may be categorized as field base and process based agricultural residues. After harvesting the rice crop, rice stalks are left behind the fields, this is known as field based crop residue.

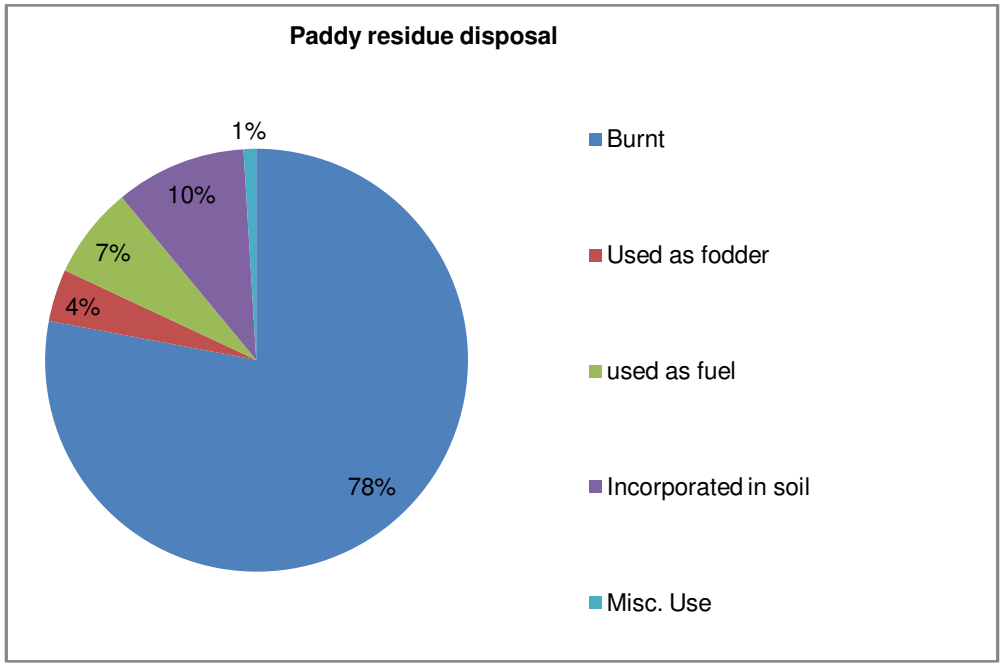

Fig. 5. Paddy residue disposal.

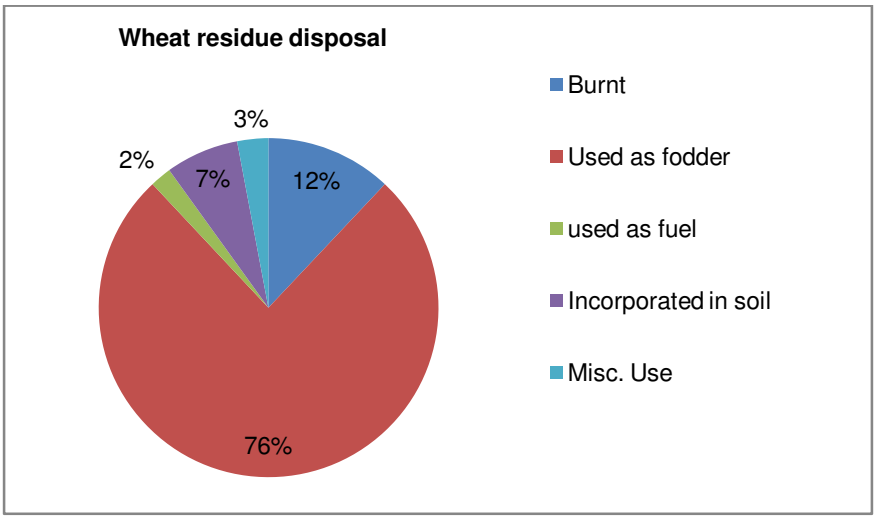

Fig. 6. Wheat residue disposal.

Table 1: Types of agricultural residues.

Name of crop	Type of residue	Category
Wheat	Stalks, straw	Field biomass
Rice	Stalks, straw	Field biomass
	Husk	Processed biomass
Maize	Stalks	Field biomass
	cobs	Processed biomass
Mustard	Stalks	Field biomass
	husk	Processed biomass
Sugarcane	Tops & Leaves	Field biomass
	Bagasse	Processed biomass
Cotton	Stalks	Field biomass
Soybean	Stalks	Field biomass
	cobs	Processed biomass
Sunflower	Stalks	Field biomass
	kernels	Processed biomass

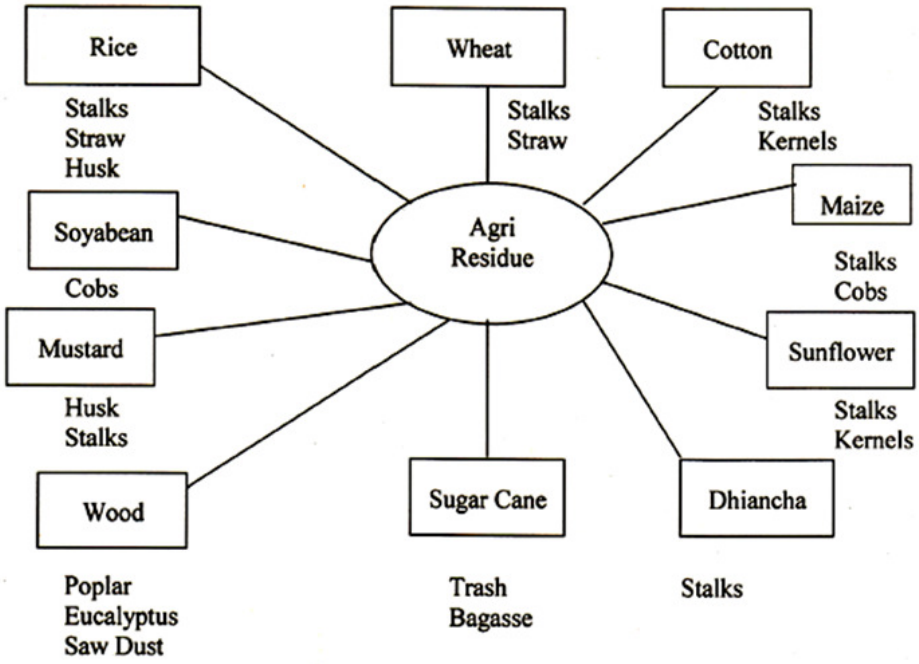

Fig. 7. Types of agricultural residues.

After extracting the rice from raw crop, the upper cover of rice is left behind; this is known as rice husk. This rice husk is the process based crop residue [15]. There are so many crops and each of them are having field and process crop residues. The main types of crops and their crop residues along with the category of crop residue are shown in the Table 1 and Fig. 7.

III. RESULTS AND DISCUSSION

A. Gross agricultural residue potential

A large number of studies had been taken place in order to investigate the production of gross agricultural residue in the state. Many investigators use GIS model to calculate the agricultural residues estimates. Some investigators had gone through the statistical data compilation and some of them gone through the field studies to investigate the gross crop residue assessment in the state.

As per the study by Singh *et al.,* (2003) [16] straw (both rice and wheat) is the main excessive available crop residue in the state of Punjab.

As per their study, 13.73 million tons of crop residues are available in the state, which came to be 74.81% of the total crop residue in the state. This crop residue is capable to fulfill 15% of energy requirements of the state. Gadde *et al*., (2009) also revealed that 48% rice residue is available for both Punjab and Haryana states [17]. Total 23% of rice straw is not collected from fields after harvesting in India. This large amount of straw is burnt in the fields. Chauhan (2012) in his study revealed that 40.142 million tons of crop residues are produced per year in the state . He included all the chief crops produced in the state in his study. He concluded that only rice straw and wheat straw contributes more than 85% of total crop residue if the state, followed by cotton (4.12%) and sugarcane (2.30%). Major crop residues are produced in Sangrur, Ludhiana, Patiala, Amritsar and Ferozepur districts of the state [10]. Singh *et al*., (2008) also revealed in their study that 83.5% rice straw is available in the state as crop residue [4]. In his study he also emphasized that wheat straw is being sturdy is used as animal feed, hence farmers do not prefer to burn the wheat straw. While rice straw is of no capable use, hence farmers burn them in the fields. Singh *et al*., (2013) also told that total residue generation from all the crops is approximately 14.46 million tons per year [21]. Singh (2015) in his study concluded that the agricultural biomass generated in country is around 650.23 million tons per year [22]. Being the chief crop produced in country, rice contributes 27.65% of total crop residue in the country. Straw of every crop is the largest component of residue produced during the harvesting of crops. Singh and Chauhan (2014) in their study concluded that 7.341 million tons of crop residues are produced in the state per year [23].

It is revealed by all the above researchers that large amount of crop residues are generated in the state per year. Rice straw is the chief component of this crop residue and it has no other viable use. These huge crop residues need to be collected from fields and must be utilized as a fuel in the biomass power plants for electrical power generation. But the available quantity of crop residues for power generation is very less as compared to the production of gross crop residues.

B. Available agricultural residue for electric power production

Availability of crop residue for electric power generation may never be equal to the gross residue production because some part of crop residue may have some alternative uses such as making fodder for cattle, domestic use of crop residue, use of residue as a fuel, animal bedding, heating etc [24]. Unused agricultural crop residue is that residue, which is of no use and is burnt by farmers in their fields. Available unused crop residue may be calculated by subtracting the utilization of crop residue for other use from gross crop residue generation [25]. As discussed earlier wheat straw residue is used to make animal fodder for cattle. People of Punjab convert almost 80% of wheat straw into animal fodder. Hence we can say that there not much wheat straw available as residue for power generation. But the rice straw is of no beneficial use; hence this rice residue is considered a waste by product by the farmers [26]. Farmers prefer to burn this rice residue in order to clear the fields, hence we can say that most of the rice residue will be available as crop waste for production of electric power. Singh (2015) in his study shows that surplus crop residue potential for energy production is approximately 22.315 million tons per year [22]. The residue produced by rice and wheat alone produce more than 75% of total residue Cotton and sugar cane also contribute handsome amount to the crop residues.

Although wheat is the main crop of state but rice residue contributes highest in crop residue production. Another study [28-30] conducted at Punjab Agricultural University, Ludhiana; it is revealed that approximately 28 to 30 million tons of residue are considered available for power generation in the state. Singh and Chauhan (2014) in their study found that 41.980 million tons of total crop residues are produced in the state. They also revealed that major crop residue available for energy generation is rice residue [23]. Singh *et al*., (2008) in their study revealed that total agricultural residue available unused is 13.73 million tons per year [4].

It is observed from the results of all the above researchers that rice straw is the major participant of unused crop residue available for power generation because of its no extra benefit to the farmers. It is also observed by the researchers that the crop residue is not only available in Punjab state but also in other parts of the country. As revealed by Singh (2015) [22] that total surplus agricultural residue available in India is 206.89 million tons, which is a great source of energy.

C. Potential of energy from available agricultural residue

Singh (2015) concluded that 0.35 EJ of biomass potential can be extracted from the surplus crop residues. By using this energy at 20% thermal efficiency of combustion technology, 3099 MW of electrical power can be produced [22]. It is also concluded that if the thermal efficiency of combustion system is improved to 25%, then the power generation can be increased to 3917 MW. It is revealed that there is potential of

approximately 2000 MW of electric power from the surplus crop residues available in the state [31].
Chauhan (2012) in his study also revealed that 1510 MW of electric power can be generated from basic surplus crop residue available in the state [10]. It is also shown that 1410 MW of electric power can be produced from net surplus crop residue available in the state. It is also observed that Sangrur, Ludhiana, Patiala, Ferozepur and Amritsar districts of state holds maximum power potential in the state due to high production of crop residues. Singh and Chauhan (2014) in their study concluded that 5667 MW electric power can be generated from surplus crop residue available in the state [23]. Singh *et al.*, (2015) also revealed the power potential of 900 MW from surplus crop residue in the state [22]. Singh *et al.*, (2008) in his study found that there 235.14TJ of energy potential is available from surplus crop residue in the state [4]. Singh *et al.*, (2013) in their study concluded that state of Punjab has an energy content of 222.5 TJ per annum [21].
Hence from the results obtained from all the above researchers, it is found that there is enough energy potential available in the surplus crop residue, which is considered as a waste material by the farmers and burnt in their fields.

D. Biomass power projects in Punjab
The government of Punjab has taken an initiative to cope with the issue of crop residue burning in the state. At present the Punjab Energy Development Agency (PEDA) has set up seven crop residue based power plants in the state. These are located in various districts of the state such as Mansa, Shri Muktsar Sahib, Jalandhar, Patiala, Ferozepur and Hoshiarpur. At present 62.5 MW of decentralized power is being produced in the state using the crop residue. Highest capacity of biomass power plant is 14.5 MW, located in district Sri Muktsar Sahib. Minimum capacity of such plant is 6 MW. PEDA is also planning to set up three more power plants of these types. But the collection, storage and transportation problems still exist in these plants [32].

IV. CONCLUSION

The conversion of surplus agricultural crop residue into electrical power may be an endowment for the poor and developing countries [31]. This initiative will help these countries to cope with the environmental issues and fulfill the energy requirements of the countries. Agricultural residues can be used as a surrogate fuel for electric power production instead of conventional fossil fuels. Punjab is a wealthy state in terms of agriculture. Owing to fertile land, sufficient irrigation, hardworking farmers and available farm machinery, Punjab is producing huge amount of crops, and heavy amounts of crop residues are left behind in the fields. This crop residue does not find any suitable application, hence farmers has no choice except burning of these crop residues in their fields.
The burning of crop residues creates serious environmental issues. Hence it is concluded that instead of burning these crop residues in field, it might be utilized to produce electric power in biomass power plants. This will not only provide solution to the issue of paddy burning but also helps the state to sustain in energy needs and reduces its dependability of state from fossil fuels. It is observed that approximate power potential of 2000 to 3000 MW lies in the surplus crop residues of state. Hence more biomass power plants locations must be optimized in different districts of the state. Special efforts must be made to set up the biomass power plants in the districts of Sangrur, Ludhiana, Patiala and Amritsar. These districts produce highest crop residues in the state and no biomass plant has been yet established in any of these districts.

V. FUTURE SCOPE

As it is concluded from the study that due to agricultural rich state, Punjab has sufficient amount of crop residue production every year, which is capable to generate 2000 to 3000 MW of electric power in the state. PEDA has already set up 7 biomass based power plant in the state, which are generating around 62.5 MW [32] of power as decentralized power generation. Three more biomass based power plants are under implementation in districts Hoshiarpur, Jalandhar and Moga.
But PEDA has not set any biomass plant in the districts of Sangrur and Ludhiana, which are the districts producing highest amount of crop residues in the state. The particulars precipitated in this paper will found to be helpful for setting up more biomass power plants in Punjab. Hence more biomass power plant locations can be found out, especially in the districts of Sangrur, Ferozepur, Amritsar and Ludhiana districts, where huge amount of agricultural residues are produced. The various technical, environmental, economical social, ecological and engineering problems associated with set up of new biomass power plants must be worked separately. The establishment of new biomass power plants in the state will provide power to the energy deficit state as well as generate employment for local people and provide solution to the environmental issues raised due to crop residue burning.
The state government must have to provide necessary commodities to the entrepreneurs for setting up new biomass power plants in the state. The state government has to take further steps to purchase and store the crop residues. The government must also have to provide subsidies to both the entrepreneurs and to the farmers of state.

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