Frequently Asked Questions on Biomass Co-Firing

Pankaj Kumar Gupta[1], Dipankar Halder[2], Ashwini Kumar Verma[3]

Energy Transition and Policy Research, Engineering Division, NTPC Limited

Abstract: ***NTPC took blue sky initiative of biomass co-firing in coal fired power plant in year 2017 to solve the issue of stubble burning by farmers while mitigating CO2 emission from coal fired power plant by partial substitution of coal with carbon neutral biomass pellets. This will create a large-scale market for agricultural residue in the power sector to enable farmers to start selling it rather than burning. In May 2021, Govt. of India launched National Biomass Mission for expansion of biomass co-firing across country. Nevertheless, many myths are still associated with biomass co-firing which kept on hovering in the minds of masses which remains an inhibiting factor so far. This paper aims at bringing clarity among different stakeholders and instilling a sense of confidence among them for nationwide promotion and adoption of biomass co-firing.***

Keywords: biomass co-firing; carbon neutral; pellet; torrefied; stubble burning; ex-situ; air pollution; energy transition; renewable; smog; biomass; agricultural residue; paddy straw, FAQ on biomass co-firing NTPC, biomass NTPC.

1. Background

Biomass co-firing involves engagement of multiple stakeholders on national level to drive the initiative. Even after 5 years since beginning, coherence between stakeholders is lacking due to lack of general clarity on the subject. Questions are frequently asked about carbon neutrality of biomass, carbon footprint of supply chain and logistics, rationale behind adoption of biomass co-firing over decentralized biomass power plant, impact of biomass co-firing on animal fodder security, land fertility, concern related to seasonal availability of biomass, and long-term economic viability of biomass co-firing etc. Lack of well documented information about these aspects often led to the spread of misinformation among stakeholders which has remained an inhibiting factor so far. This issue of paper in form of FAQ is aimed at bringing clarity and instilling a sense of confidence among stakeholders for wide scale promotion and adoption of biomass co-firing.

2. FAQ on Biomass Co-firing

2.1 Why agricultural residue is set on fire by farmers in many parts of the country? How biomass utilization in power plants can resolve this issue?

Mechanized harvesting leaves almost 2/3rd of crop portion as residue in field whereas manual harvesting involves cutting crop from bottom. Clearing this 2/3rd portion of agricultural residue from fields involves certain cost. If that cost is not recoverable by sale of agriculture residue, it will not be a viable option for farmers. In that case, farmers find burning agricultural residue as the easiest, quickest, and cheapest solution to clear the field in wake of small available window for sowing next crop. Animal fodder provides a major market for sale of agriculture residue. However, with the increasing human to animal population ratio as depicted in Table-1, agricultural residue surplus is increasing over a period. Therefore, various agricultural residue least preferred or not used as animal fodder such as residue of oil seed crop, cotton, pulses etc. and paddy straw in some states like Punjab and Haryana find no alternate market and setting them on fire remains only viable alternative available with farmers. Utilization of these agricultural residues in power industry for biomass co-firing will create a large-scale market which shall not only discourage farm fires but also increase farm income.

Picture 1: Paddy straw set on fire

Table-1: Human to Domestic Animal Population Ratio

Year	**1961**	**1966**	**1972**	**1977**	**1982**	**1987**	**1992**	**1997**	**2003**	**2007**	**2012**	**2019**
Human Population (Million) [1]	460	510	581	652	732	820	909	1001	1112	1183	1266	1383
Animal Population (Million) [2]	337	345	353	369	420	445	471	485	485	530	512	536
Human to Animal Ratio	1.37	1.48	1.65	1.77	1.75	1.84	1.93	2.06	2.29	2.23	2.47	2.58

2.2 Use of agricultural residue for power generation through biomass co-firing may pose risk to availability of animal fodder. How same is being taken care of?

The initiative intends to use surplus and non-animal fodder agricultural residue in power plants for power production and this aspect has already been covered in technical specification of biomass pellets. Moreover, agricultural residues preferred as animal fodder as listed in table-2 are always sold at higher price than non-fodder agricultural residue. Hence, agricultural residues which are most preferred as animal fodder shall remain secure through market mechanism itself and only those agricultural residues shall come to energy market which is surplus and least preferred/ not preferred as animal fodder. In future, appropriate sustainability certification mechanism may further ensure utilization of only non-fodder agricultural residue in energy market.

Picture 2: Animal Fodder

Table 2: List of Animal fodder and Non-Fodder Agricultural Residue

Animal Fodder Agricultural Residue	Agricultural residue least preferred/ not preferred as animal fodder
Wheat, gram, jowar, bajra ground nut residue, alfalfa, paddy straw, ragi etc.	Paddy straw (mostly non-basmati) in some states such as Punjab, Haryana, dry corn stalk, cotton, chili, pulses, oil seeds residue, sugarcane trash, bagasse, coconut shell, coffee, tea, mehndi Stalk, mehndi husk etc.

2.3 In-situ agricultural residue management for increasing soil fertility is a better option. Then, why should we go for ex-situ management such as co-firing in power plant?

In-situ agricultural residue management to increase soil fertility may be done by following methods-

1) Peat composting
2) Direct mixing with soil

Peat composting has an issue of methane, and it is going to be banned in some western countries [3]. Direct Mixing despite being environmentally friendly, and a better option is not getting acceptability among farmers with current practice of farming. Farmers report difficulty in directly mixing it with soil in view of the short time available for sowing the next crop. Farmers also report increased cost of production.

Even if in-situ management is practiced, it is reported that it is difficult to put 100% agricultural residue back to the soil. Therefore, despite the government program for in-situ management, agricultural residue burning remains an issue and ample surplus residue remains unused. This entails the need of ex-situ management such as its utilization in power plant.

Burning of agricultural residue destroys micro-organisms and moisture in soil which reduces land fertility. Therefore, burning in power plants to extract energy while replacing coal is anyway better than burning in the field. Rather it will help preserve soil fertility.

2.4 Fuel requirement of power plant is very huge. Is there sufficient agricultural residue available near the power plant to replace a significant amount of coal in the power plant? What is the generation potential?

Almost 754 million metric tons [4] [5] of agricultural residue is produced in India. Out of which, 30% (i.e., 225 million metric tons) is surplus and is often set on fire by farmers in the fields due to lack of alternate markets. All India annual coal consumption of coal fired power plant is almost 700 million metric tons. Thus, available surplus biomass has the potential to replace almost 25-30% coal of the power plant. This has the potential to generate 300-325 billion units of electricity which is equivalent to electricity generation of 200 GW of solar PV. Nevertheless, to avoid risk of slagging, fouling and corrosion due to high alkali and chlorine content present in agriculture residue, coal replacement with pellet made of the agricultural residue has been kept limited to 10% only. However, biomass fuel conditioning and torrefaction routes are also being explored to increase the co-firing ratio above 10%.

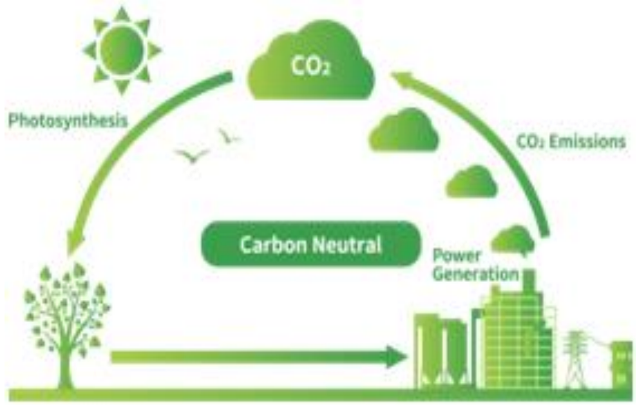
2.5 Availability of agricultural residue is seasonal; how shall it cater the round the year demand of power plants?

The food grains we eat round the year are also produced in a particular season. Well established supply chain of food grains ensures round the year supply to consumers. Currently, the supply chain of agricultural residue is at its infancy stage. As soon as the supply chain matures, round the year supply of biomass for power production shall also be ensured.

Picture 3: Biomass Supply Chain and Logistics

2.6 Biomass pellet burning in power plant also emits CO2, then how is it different than burning coal? Why is biomass termed as carbon neutral or renewable resource?

Fundamentally, biomass is nothing but solar energy in chemical storage form. Through the process of photosynthesis, solar energy keeps on getting fixed in biomass in from of chemical energy using atmospheric CO2 as medium. Biomass combustion is regarded as carbon neutral/ renewable resource when it is obtained from sustainable sources such as agriculture and agroforestry. It is because gradual combustion of biomass in power plants is complemented by gradual plant growth in agriculture and agroforestry systems causing simultaneous neutralization of CO2 through process of photosynthesis. All living creatures emit CO2, but their CO2 also neutralizes in same manner. Coal is also biomass which gets buried under earth crust millions of years before due to tectonic activities. However, this much amount of carbon was captured from atmosphere over a period and sequestered by nature under earth crust. Hence, coal combustion adds net CO2 to atmosphere in any case. Carbon neutrality is achieved when there is a balance between the rate of CO2 emission and the rate of CO2 absorption. Maintaining the balance does not necessarily require any mathematical calculation or regulation but establishing a sustainable biomass supply chain which can supply biomass to the power plants throughout the year. This is because sustainable biomass supply chain can only be established when there is balance between rate of agricultural residue generation and consumption.



Picture 4: Carbon Neutralization Process

2.7 How is burning agricultural residue-based biomass pellet in power plants better than burning in open field by farmers? Is burning plants not polluting?

Superficially, it may appear that burning agricultural residue in fields is no more different than burning in power plants except energy extraction in latter case, but fact is opposite to this perception which may be seen from following table 3.

Table 3: Burning of Agricultural residue in field versus burning in power plants.

Attributes	Burning in fields	Burning in Power Plant
Impact On CO2 Level in atmosphere	A sudden spike in CO2 level in atmosphere due to burning of huge quantity of stubble within short span but gradual absorption in crop cycle makes burning temporarily CO2 positive. Instead of field burning, many times agricultural residue is collected through manual cutting and stockpiled or composted which may be considered as temporarily CO2 negative. But biomass decomposes over a period and adds CO2/ methane back to the atmosphere.	No appreciable change in CO2 level in atmosphere as gradual combustion of biomass in power plant is complemented by gradual plant growth in agriculture enables simultaneous neutralization of CO2. Coal saving due to its replacement with biomass saves CO2 and makes it net CO2 negative. Further, in case of biomass co-firing, equivalent amount of coal is saved which does not decompose to generate CO2, so it provides permanent CO2 negative balance in comparison to stock piling or composting.
Air Pollution and Health impact	Simultaneous burning of large quantity of agricultural residue within short span injects huge amount of ash, unburnt carbon, smoke, particulate matter (PM 10, PM 2.5), combustion gases etc. in atmosphere and that too below inversion layer of atmosphere where it gets trapped and results in severe air pollution and smog causing health hazard.	Burning in power plants ensures complete combustion leading to negligible unburnt carbon in flue gas. Further, ash/ particulate matter gets absorbed in electrostatic precipitator (ESP) ensures stack emission within statutory limit. Flue gas is injected from chimney above inversion layer which enables its dispersion in atmosphere without causing any local air pollution.
Land Fertility	Reduces due to destruction of micro-organisms and moisture in soil.	Preserved as microorganisms and moisture in soil remains undisturbed.
Farm income and employment	Farmers rather spends money for burning agricultural residue to clear field.	Farmers earns extra income through sale of agricultural residue.

2.8 Biomass pelletization and transport involves more carbon footprint than using it in small, decentralized biomass power plants. What is the rationale behind adopting biomass co-firing over decentralized biomass power plants?

Large coal fired power plants have twice as better efficiency as small biomass power plants. Carbon footprint in palletization, long distance transport and utilization in power plant remains far less than CO2 saved by substitution of coal with biomass pellets. Typically, pelletization, transport by road, utilization has carbon footprint of 86 kg per ton, 36 kg per **1000** km per ton, 126 kg per ton of biomass pellet, respectively. Whereas almost **1329** kg CO2 is saved if a ton of coal is substituted by biomass pellet.

Further, by using the same amount of biomass almost twice CO2 is saved while generating almost double the amount of power. This makes biomass co-firing greener than decentralized biomass power plants even if biomass pellet is transported from Kanyakumari to Kashmir located 3600 km apart. In addition to this, other techno-economic and strategic aspects of adopting biomass co-firing are covered in Table-4.

Table 4: Comparison of Decentralized Biomass Plant versus Biomass Co-firing

Attributes	**Biomass firing in decentralized and small biomass power plant**	**Biomass co-firing in large coal fired power plant**
Asset Utilization	Separate Biomass Plant Installation	Existing coal-fired plant utilization
Net Efficiency, CO2 Saving and Energy Yield	~X	~2X
Scale of Generation	12-20 MW	10% biomass co-firing in 500 MW generates 50 MW
Biomass use form	Raw Biomass can be used. Less transport required	Palletization and long transportation required
Operational issue	Frequent shutdown due to slagging and fouling	No issue of slagging or fouling
Separate PPA and Resources, Clearance	Requirement of separate PPA, infrastructure, land, statutory clearance, manpower	Not required
Electricity cost	**Fixed Cost**-More due to high per unit fixed cost. **Variable Cost**-Comparable even with less costly raw biomass due to more specific fuel consumption.	**Fixed Cost**-Less due to less per unit fixed cost. **Variable Cost**-Comparable even with costly biomass pellets due to less specific fuel consumption.
Salability of power	Low as DISCOMs find it costlier	High as DISCOMs are already paying fixed cost and only differential variable cost is needed to be paid extra.
Fuel security risk	Fuel Security Risk due to complete dependence on biomass feedstock as primary fuel.	Less concern about reliability of biomass feedstock being secondary fuel

2.9 Coal power plants are often not located in areas having surplus biomass in near surrounding. In such a case, is biomass co-firing advisable?

If we analyze surplus biomass on given map which is marked in blue and green in picture 5, it may be found that there is no dearth of surplus biomass within 500-1000 km distance for power plants located in northern, western, southern parts of country. Supply chain and vendor base are the major constraints which need to be resolved. Plants located in the eastern part may get surplus biomass from another states or regions. Transportation of biomass pellet is no longer a constraint because biomass is pelletized to enable long distance transportation and ease of handling. Further, CO2 emission in palletization and transportation is far lesser than CO2 saving by coal substitution with carbon neutral biomass pellet.

2.10 Can loose and bigger size chopped biomass or biomass briquette be used instead of biomass pellet for co-milling in power plants?

Loose and bigger size chopped biomass cannot be fed directly to the milling system. Whereas biomass briquette has diameter higher than 25 mm as well as higher constituent particle size which is not suitable to be fed in the coal mills as large fibrous constituents cannot be pulverized in coal mills. This may choke mill and cause fire. Biomass pellet has pre-pulverized constituent particles (using hammer mills). During co-milling of pellets, it gets broken into constituent particle size and easily passes the classifier due to low particle density. That is why pellets are used for co-milling.

2.11 Can pulverized biomass in powder form directly be used for co-firing instead converting it into pellets?

Storage, handling and conveying of pulverized biomass involves lots of dust which causes health & fire hazard, loss of material as well as messy vicinity. Due to lower density in powder form, transportation of such material shall also be costly. That is why it is always advisable to use biomass pellet instead of biomass powder.

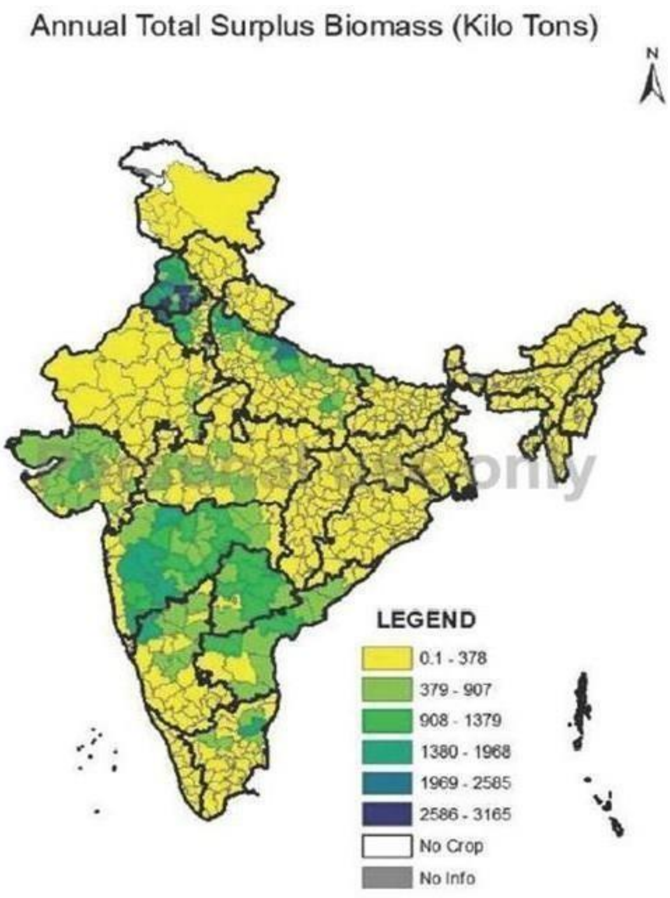
2.12 What is the impact of biomass co-firing on ash utilization in cement plants?

Initially, European EN 450 standards specified that only fly ash from pure coal or anthracite combustion was allowed as an aggregate in the cement or concrete industry. After co-firing experience in Europe and analysis of ash generated from co-firing, original European EN 450 standard was revised and now European EN 450-2 standard specified that fly ash from co-combustion of specific secondary fuels such as wood chips, straw, olive pit and other vegetable fibers, green wood and cultivated biomass, etc. can now be used for concrete provided the percentage of secondary fuel does not exceed 20% by mass and if the derived amount of ash from the co-combustion material is not greater than 10%. There are additional limits on the static chemical properties of the ash such as the chloride content must be less than 0.1% and the total alkali content (normalized as Na_2O) less than 5%. Even in the worst case due to high level of chloride in grass and straw, co-firing up to 10% may be done without any concern of ash utilization. After analysis of ash generated from co-firing, Indian standard for ash may be revised accordingly.

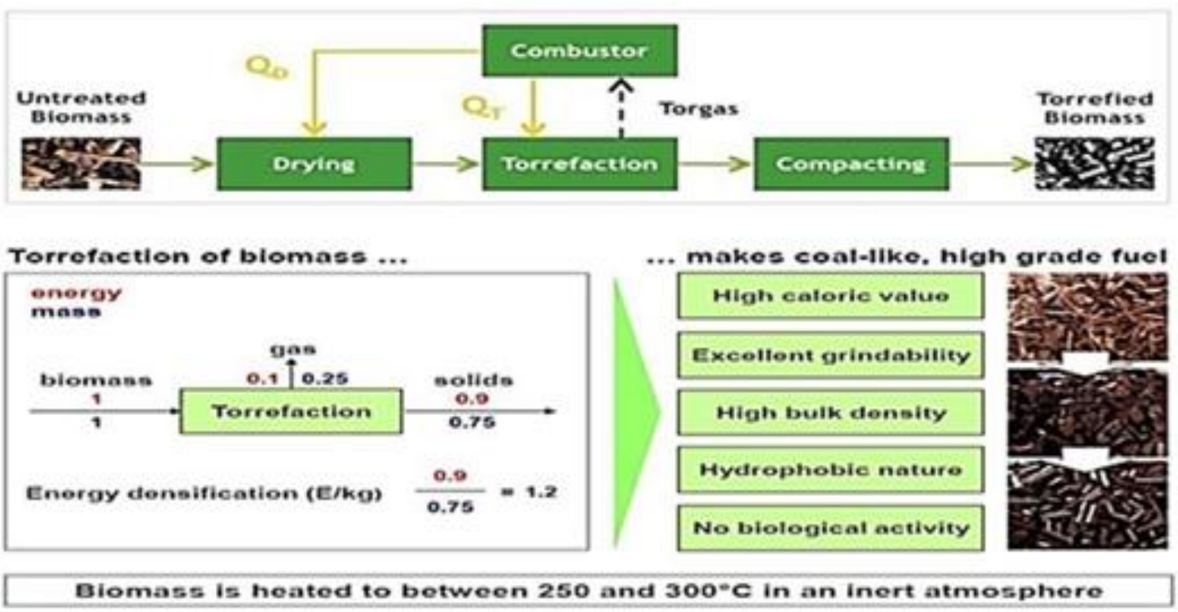
2.13 What is biomass torrefaction?

Torrefaction is a process in which biomass is heated between 250^0 C to 300^0 C in lack of oxygen to convert it into coal like material. This improves properties of biomass and makes it suitable to be co-fired in higher ratio [7] [8]. Following changes happen in biomass after torrefaction-

- GCV is improved roughly by 20%.
- It becomes brittle to be grinded in mill.
- It becomes hydrophobic.
- Volatile and chlorine content get reduced.
- Ignition temperature gets increased slightly.



Picture 5: Surplus Biomass, Report of TIFAC & IARI, 2018 [6]



Picture-6: Biomass Torrefaction Mass and Energy Balance

2.14 Which is better option-torrefied or non-torrefied biomass pellet?

Picture 7: Different forms of biomass

Advantage of Torrefaction-

- 20% higher GCV than parent material offers advantage in transport cost per kCal.
- Easy pulverization and less power consumption in pellet manufacturing due to brittleness.
- Less wear & tear in pellet manufacturing.
- Co-firing above 10% can be achieved.
- Less volatile content allows high mill inlet air temperature leading to less HR/APC loss.
- Hydrophobic nature allows open storage.

Disadvantage of Torrefaction-

- The yield is typically 75% of input parent material quantity. Less yield results in less CO2 saving per ton of biomass used for torrefaction to replace coal.
- Costly than non-torrefied pellet if raw biomass cost is high.

In view of above, an optimal business case for torrefaction arrives with raw material having low GCV, high silica content which is available at comparatively cheaper cost in abundant quantity such as paddy straw. High silica content in such raw material leads to more wear and tear in pellet manufacturing and makes it tough to pulverize without torrefaction. Thus, torrefaction makes palletization of such raw material technically feasible and financially viable. It also enables a higher percentage of co-firing in plants located nearby to torrefaction unit.

2.15 Why GENCOs should co-fire biomass pellet which is 2-4 times costlier than coal? Why DISCOMs should give priority to biomass power over RTC solar/ wind power as a business case other than social cause?

Solar and wind power may appear cheaper but when combined with energy storage to make it RTC, it becomes costlier than biomass power. As the world is heading towards a less carbon economy, biomass co-firing gets significance as business case due to better techno-economics. GENCOs as well as DISCOMs should give priority to power from biomass co-firing as a business case because of following associated benefits-

Benefit to GENCO	Benefit to DISCOM
• Cheapest Method of CO2 mitigation in power plant. • Incremental cost due to biomass co-firing is pass through in tariff without any impact on merit order. • It improves ESG rating as well as make GENCO future ready to compete in carbon market without major capex investment. • In future, penal provision for not meeting mandated co-firing % may come like that of plant located in NCR. • Mechanism for incentivizing biomass co-firing in power plants may come in future. • Less requirement of flexibility and energy storage while increasing RE share with biomass. It will help increasing PLF of power plant.	• DISCOMs are already paying fixed cost of existing power plant and they get RTC RE (biomass power) just by paying differential cost of coal and biomass. • RPO is available to DISCOM for purchase of biomass power from co-firing plants. • On RTC basis, biomass power is cheaper than RTC solar and wind power combined with energy storage. • It is firm and dispatchable power without seasonal variability unlike RTC solar and wind power. No associated cost for handling such variability. • It reduces back up and balancing requirement even at high share thus reduces associated cost loading.

3. Conclusion

To discourage stubble burning by large scale utilization of surplus agricultural residue, biomass co-firing is the most efficient, cost competitive, environment friendly method. Existing thermal assets can be made ready for RTC RE power generation within small time frame and without any major capex investment. It has multifaced socio-economic benefits. Apart from this, biomass co-firing makes a sound business case in energy transition for all associated stakeholders. It helps in mitigating air pollution and carbon footprint of coal fired power plant while increasing farmer's income and generation of employment having significant potential contribution in GDP. CO_2 emission in palletization, transportation and utilization of biomass pellet is far less than the CO_2 saving through replacement of coal in power plant. Thus, long distance transportation is also not a constraint as far as carbon footprint is concerned. India is rich in surplus agricultural residue which is available within 500-2000 km distance from majority of coal fired power plant. The only constraint is that supply chain, pellet manufacturing capacity and logistics are still at infancy stage which is expected to proliferate exponentially in coming time with the development of clarity and confidence among stakeholders.

References

[1] WorldData. info 2021, World Data website, eglitis-media, Oldenburg, Germany, accessed 20 February 2023, <https://www.worlddata.info/asia/india/populationgrowth.php#:~:text=From%201960%20to%202021%20the,in%202021%20with%2%2000.80%20percent.>

[2] National Dairy Development Board 2019, National Dairy Development Board website, NDDB, Anand, Gujarat, accessed 20 February 2023 <https://www.nddb.coop/information/stats/pop. >

[3] Guardian News & Media Limited 2023, The Guardian Website, The Guardian, London, UK, accessed February 2023<www.theguardian.com/environment/2021/may/18/sales-of-peat-compost-to-gardeners-to-be-banned-from-2024>

[4] Administrative staff collage of India, 2019-2020, "Evaluation Study for Assessment of Biomass Power and Bagasse Co-generation Power Potential in the Country" Edited by Administrative staff collage of India based on District wise data compiled from the Directorate of Economics and Statistics of year 2018.

[5] Directorate of Economics and Statistics 2022, Directorate of Economics and Statistics website, Ministry of Agriculture and Farmers Welfare, Government of India, accessed 20 February 2023< https://desagri.gov.in/document-report/plot-wise-summary-data-for-the-years-2018-19/>

[6] Indian Council of Agriculture Research, 2018, ICAR Website, ICAR, Krishi Bhavan, New Delhi, assessed on 20 Feb 2023 "Estimation of Surplus crop residues in India for biofuel production, Joint Report of TIFAC & IARI, October 2018https://krishi.icar.gov.in/jspui/bitstream/123456789/34455/2/TIFAC_IARI_report_2018.pdf

[7] Jaap Koppejan, Marcel Cremers, Michel Wild, IEA Bioenergy, 2016, IEA Bioenergy website, assessed on 20 Feb2023https://www.ieabioenergy.com/wpcontent/uploads/2016/01/IEA-Bioenergy-torrefaction webinar.pdf

[8] European Pellet Conference, 2019, pellets19. eu website, Wels Austria, assessed on 20 Feb 2023 <https://content.yudu.com/libraryHtml/A43aoq/ForestBioenergyRevie/reader.html?page=8&origin=reader>

Author Profile

Pankaj Kumar Gupta
General Manager, Energy Transition and Policy Research, NTPC Engineering Office Complex, Noida. He has more than 30 years' experience in thermal power plants in engineering and Operation & maintenance of Steam Generator. Out of which, more than 24 years of experience in Engineering and design of subcritical and supercritical Steam generator & its auxiliaries, Electrostatic Precipitator (ESP) and other Environmental systems like FGD & De-NOx system.

Dipankar Halder
Addl. General Manager, Energy Transition and Policy Research, NTPC Engineering Office Complex, Noida.
He has more than 21 years' experience in thermal power plants in all areas of plant in engineering, engineering services and operation & maintenance. Out of which he worked 15 + years in engineering and design of CHP, Turbine, Ash handling, FGD, Boiler, system engineering, ACC, FOH and Layout. He was key engineering member of NTPC team for NTPC's only international project in Bangladesh where widened his experience in all the area of engineering. In O&M, he headed mechanical maintenance team and has experience in O&M of CHP.

Ashwini Kumar Verma
Sr. Manager, Energy Transition and Policy Research, NTPC Engineering Office Complex, Hyderabad. He has more than 15 years of diversified experience in the area of power plant operation & commissioning, Power Plant System Design, Engineering of Turbine & Auxiliaries. He is the leading team member pioneered biomass co-firing from concept to commercialization and working further to enhance ratio of biomass co-firing and resolving technical, commercial, policy and several other issues associated with biomass co-firing. His other portfolios are coal to 100% biomass conversion and long duration energy storage.

TYPE: Correction

PUBLISHED: 06.06.2023

DOI: 10.21275/SR23503003135

Corrigendum: Frequently Asked Questions on Biomass Co-Firing

Pankaj Kumar Gupta[1], Dipankar Halder[2], Ashwini Kumar Verma[3]

Energy Transition and Policy Research, Engineering Division, NTPC Limited

Abstract: ***NTPC took blue sky initiative of biomass co-firing in coal fired power plant in year 2017 to solve the issue of stubble burning by farmers while mitigating CO2 emission from coal fired power plant by partial substitution of coal with carbon neutral biomass pellets. This will create a large-scale market for agricultural residue in the power sector to enable farmers to start selling it rather than burning. In May 2021, Govt. of India launched National Biomass Mission for expansion of biomass co-firing across country. Nevertheless, many myths are still associated with biomass co-firing which kept on hovering in the minds of masses which remains an inhibiting factor so far. This paper aims at bringing clarity among different stakeholders and instilling a sense of confidence among them for nationwide promotion and adoption of biomass co-firing.***

Keywords: biomass co-firing; carbon neutral; pellet; torrefied; stubble burning; ex-situ; air pollution; energy transition; renewable; smog; biomass; agricultural residue; paddy straw, FAQ on biomass co-firing NTPC, biomass NTPC.

In the published article, there was a typographical error in the paragraph no. 2.8 with respect to carbon footprinttransport by road, and CO2 saving by substitution of coal by biomass pellet which was displayed as "36 kg per km per ton" and "almost 1329000 kg CO2 is saved if a ton of coal is substituted by biomass pellet."

The correct paragraph appears below.

"Typically, pelletization, transport by road, utilization has carbon footprint of 86 kg per ton, 36 kg per 1000 km per ton, 126 kg per ton of biomass pellet, respectively. Whereas almost 1329 kg CO2 is saved if a ton of coal is substituted by biomass pellet."

The authors apologize for this error and state that this does not change the scientific conclusions of the article in any way. The original article has been updated.

Publisher's note