

India Biomethanation of Crop Residues for Stubble Burning

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Contributor: Preseela Satpathy ,

Stubble burning in India continues despite the severe consequences on the environment and the massive health crisis in the country. Farmers resort to such practices as a cheap and hasty solution post-harvest, which helps them prepare for their next crops. Converting the agricultural leftovers to biomethane energy is recommended as an effective mitigation method, which handles the large volumes of stubble and protects the environment from further air and soil pollution, generating a green biofuel that could be converted to heat and electricity.

biogas

crop residue

stubble burning

1. Introduction

The practice of crop residue burning in India, its impact on deteriorating the air quality and the ecosystem as well as the damage on human health, requires no introduction. India, being one of the largest agricultural lands in the world, holds 157.35 million hectares of land for cultivation ^[1]. Obviously, along with the several million tons of agricultural produce each year, there remains a huge volume of agricultural leftovers on the fields. An estimated 500–550 million tons of crop residues are produced every year in the country ^[2] primarily from rice, wheat and millet (forming nearly 70% of the total stubble) while the rest are from sugarcane, cotton, maize, ground nut etc. ^[3].

While a considerable share of this finds application as animal feed, animal bedding, in thatched roofs etc., a larger portion (nearly 3/4th) remains as waste on the farmlands. Collecting agricultural residues, transporting and storing them becomes labour intensive, expensive and inconvenient especially for the small-scale farmers due to a short window of less than a month to prepare for the next crop ^[4]. A quick fix solution to manage these huge volumes of agricultural residue is to directly set them on fire. Reports indicate that as much as 23 million tons of stubble alone from rice straw are burnt in North India each year ^[5]. Such on-farm burning remains a cost-effective approach for the farmers, clears the farm for re-use along with providing pest control.

2. Consequences of Stubble Burning

The consequence of this broadly favoured practice undeniably is dangerously high levels of air pollution that has even contributed in declaring a public health emergency situation in Delhi ^{[6][7]}. Increase in the particulate matter, PM10 and PM2.5 concentrations, when the crop leftovers are burnt on the farm, is also of particular concern to human health ^{[8][9]}. Reports show an increase in the particulate matter by 86.7% after the rice harvest, and by 53.2% after the wheat harvest, when the stubble burning occurs in Punjab ^[8]. The air is then termed anything from

toxic to poisonous, with PM_{2.5} concentrations reaching up to more than 10 times above the WHO air quality guidelines [10]. The northern Indian states, especially the urban areas, even if hundreds of kilometers away, suffer the severe impact of such on-farm burning, especially in winter, due to the already accumulated industrial and vehicular pollutants [7]. Poor visibility is yet another aftermath of such open-fire practices in the NCR (National Capital Region), which has further been linked to numerous road accidents. Along with the serious pollution, it has, also, been connected to a drop in tourism by nearly 25–30% [11].

Recent studies by Venkatamanan et al. [12] calculated the generation of nearly 313.9 Gg of methane, a powerful greenhouse gas, along with heavy quantities of CO₂, CO, NH₃ and N₂O as well as several million tons of PM_{2.5} and PM₁₀ from stubble burning over northwestern India. Emissions of CO and NO₂ have also been recorded to increase by 7–25% and 22–80%, respectively, across India during crop burning [13]. The release of short-lived climate pollutants, aerosols and soot particles, due to stubble burning, has also been extensively studied and reported [14]. Furthermore, the disturbance in atmospheric chemistry and radiation balance, due to the organic components, such as benzene and polycyclic aromatic hydrocarbons added into the ambient air during stubble burning, have also been confirmed [15][16].

When air quality deteriorates to such an extent, its severe impact on the public health is inevitable, and various studies confirm the same by linking stubble burning to human health deterioration. A study by the Health Effects Institute has attributed about 66,000 deaths in India, due to the PM released as a result of stubble burning [17]. The population faces severe risks of lung complications such as bronchitis, asthma, Chronic Obstructive Pulmonary Disease (COPD), cancer, etc. [18]. Such air quality not only poses a threat to the ones with pre-existing respiratory conditions but also to healthy adults, and has been linked to cardiovascular, neurological and dermatological issues [7]. Current studies, also, indicate poor air quality directly proportional to increasing COVID-19 cases and are associated with high mortality rates [19][20].

The practice of stubble burning does not limit its damaging effects to air, but has also been linked with deteriorating the soil fertility, damaging the microbial population and ecosystem and unbalancing the nutrient budget (resulting in severe nutrient loss), which naturally induce economic losses. The National Academy of Agricultural Sciences reports that the result of open burning only in northwest India accounts for the loss of carbon and nitrogen accounting, roughly, to nearly a loss of INR 2 billion each year [21]. Studies by IFPR (International Food Policy Research) estimated in North India alone, air pollution co-related to stubble burning contributed to a loss of approximately USD 30 billion per year [22]. Scientists and the government are trying to address the stubble menace, but the challenge seems to keep increasing, as more and more farmers choose this option. There is an urgent need for a solution that converts the perspective of considering the agricultural leftovers as a resource and not a waste-product, one that brings additional income and improves soil quality, which further helps the farmers. Due to the absence of an economic or meaningful benefit, farmers continue to choose to set their farms on fire, lacking a useful alternative.

3. Biogas/Biomethane from Stubble

Utilising and consuming the enormous quantities of low-cost crop residues can enable effective crop residue management, agreeing with the principles of the circular economy. In India, rice and wheat comprise a major share of the total stubble burnt, 34% and 22%, respectively [11]. While gasifiers have been widely recommended to generate energy from agricultural leftovers [23], biogas, a renewable, carbon-neutral source of energy, has an added advantage of requiring lesser investments in comparison, plus the digester maintenance and operation are relatively simple [24]. During the process of anaerobic digestion, organic matter is converted to a mixture of energy-rich methane (that constitute 50–70% of the total gas), along with carbon dioxide and other gases in traces, thus extracting the energy potential of the substrates. Biogas is a generic term for the gases produced during anaerobic digestion, and the main gases contained are methane and carbon dioxide. The designation biomethane is used to describe the methane part derived from biomass [25]. Biogas can be upgraded to increase the methane content (between 75–99%), by a process of biomethanation, also called biomethane production [26][27]. Different upgrading and scrubbing methods are utilised to enrich the gas to natural-gas quality, which could be used as a vehicle fuel or fed into grids. Since the supply of such bioenergy usually exceeds the on-site demand, they can, also, be stored in the form of liquified biomethane (LBM) or compressed biomethane (CBM). These could be utilised in LNG- and CNG-run vehicles, respectively. In recent years, 'sector coupling' has been, also, gaining momentum, by coupling electricity and gas sectors, where excess electricity stored as H₂ (from water electrolysis usually) is coupled with CO₂ (from biogas plants, landfills etc.) to produce CH₄ [28], also known as power-to-gas (P2G) technology. P2G enables efficient energy storage and enables a bidirectional coupling of electricity (preferably generated from renewable sources) with natural gas grids [29]. With the various advancements in technologies that are available, biogas or the upgraded biomethane formed from the agricultural wastes could benefit small-, medium- and large-scale farmers or industries, based on their individual requirements and capacities. Additionally, the digestate produced in biogas digesters are excellent soil conditioners, recycling and retaining the nutrients such as nitrogen (N), phosphorous (P), and potassium (K), maintaining a healthy humus content in soil. Such an approach can, thus, provide economic benefits to the farmers along with offering environmental protection and effective stubble management [30].

Despite being a sustainable and cost-effective method, the biogas sector in India remains with a large untapped potential. While the rural sector accommodates the maximum number of biogas plants, awareness regarding substrate utilization remains limited to only cattle dung, and the output remains limited to a cooking fuel substitute [31]. Biogas digesters throughout the country suffer reactor failures due to inadequate knowledge, lack of attention paid to regular maintenance and poor dissemination of information and technology [32]. This study intends to broaden the scope of substrate utilization, especially for the small-scale/individual farmers in India, who could co-ferment their animal manures along with the carbohydrate-rich crop leftovers, and the research goal enquired if stubble could be a favorable biogas substrate. Numerous researchers have attempted to determine the biomethane potential of the lignocellulosic crop residues, and the results have been encouraging with polysaccharide-rich substrates. Considering the two major crops subjected to stubble burning, rice and wheat, studies report a methane potential of nearly 390 L/kg vs. [33] and 240 L/kg vs. [34], respectively. These values are comparable to energy crops utilised in large-scale industrial biogas plants for generating energy [35].

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