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CLEAN AND GREEN ECONOMY FOR AIR POLLUTION

ACTIONABLE SOLUTIONS FOR WASTE-TO-WEALTH FROM CROP RESIDUE

CII-ITC Centre of Excellence for Sustainable Development

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Cleaner Air Better Life

Clean and Green Economy for Air Pollution

Actionable Solutions for Waste-to-Wealth from Crop Residue

Mohit Sharma, Aditya Bhuyan, Ishan Sahajpal

Technology Assessment Report
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EXECUTIVE SUMMARY

In the absence of a large momentum for change required to move away from dominant rice-wheat monoculture in the breadbasket of India, management of rice straw inside the field (in-situ) through direct reuse by farmers and management outside the field (ex-situ) are the only practical choices for addressing the burning issue which causes peak pollution across severely polluted cities of the Indo-Gangetic plains. While in September 2020, we produced evidence of the change taking place in the heart of Punjab and Haryana across 102 villages intervened by CII, this report further focusses on ex-situ management solutions. These set of solutions need to be scaled for addressing 1/3rd of the rice straw or approximately 13 million tonne rice straw, while the remaining 2/3rd is filled by in-situ management solutions. We target ex-situ use cases that are not only actionable and environmentally sound but also make an economic sense to all stakeholders. Some of these perhaps, make more economic sense than others due to higher value addition in the process. But market situations are equally responsible for what works on the field and what does not. These include prices of raw materials or final products and market/consumer awareness levels which are key factors that determine the project's success. The aggregation model, once scaled, can address a host of such challenges and unlock all other delivery models along with the supply chain of biomass management. The aggregation model, detailed and evaluated here, can add significant economic value to farmers as well as rural entrepreneurs, creating increased income and livelihood opportunities in rural areas. It is estimated from field data that the straw aggregation model can bring down the cost of ex-situ operations at the farmer's end by 34%, bringing it at par with other methods. This is a significant finding and government may immediately prioritise this activity by-

1. Bringing the this activity (akin to bio-CNG) under the priority lending schemes of national banks
2. Ensuring an insurance cover to rural straw banks set up by the aggregators for insulating them from risk of fire hazards

The SATAT initiative is an encouraging step from the Government to ensure offtake and a minimum guaranteed price for bio-CNG. But ensuring the offtake of bio-fertilisers which make up for 43% revenues from bio-CNG model {Internal Rate of Return (IRR) at 29%} will be crucial for its viability. Analysis shows that even with a 50% offtake of bio-fertiliser from bio-CNG plant, the net worth of project goes down by 72% and payback period nearly doubles. Also, one composting pit of 30x10 ft can support small-marginal farmers with an additional income of INR 30,000 per year at zero capital cost and even without a microbial solution. Therefore, marketing support for bio-fertilisers is crucial and needs the following support-

1. Schemes for promotion and market development assitance to bio-fertilisers from crop residue akin to the City Compost Policy by Government of India
2. National Agricultural Co-operative Marketing Federation of India Ltd. (NAFED) and similar agencies can be roped in for their Pan-India network to propagate and distribute green-manure through nation-wide network of outlets.

Total Mixed Ration (TMR) feed pellets are found to be highly profitable (IRR at 36%), albeit requiring very careful planning by rural entrepreneurs for local availability of filler material. Scaling this model will require-

1. Scheme from NDDB for knowledge support to rural entrepreneurs willing to set up TMR feed pellet units based on rice straw
2. Mass awareness creation for dairy farmers across Punjab and Haryana to remove their misconceptions about nutritional value of rice straw (non-basmati varieties)

Three key material uses of rice straw are evaluated in this study - construction panels, blocks and pulp. All three are found to have excellent returns with IRR greater than 100%. Efforts are still underway to develop bio-char reactors for improving environmental performance of the bio-char making process, which can arrest more than 90% emissions. With these specific material uses of rice straw, which are rapidly evolving on the field, new standards/certifications are proposed for the following products and processes-

1. Use of crop residue or lingo-cellulosic materials in construction bricks and blocks
2. Standards and certification for torrefaction reactors to produce bio-char and bio-coal in consultation with technology developers
3. Certification for green manure and liquid bio-fertilisers from Ministry of Agriculture akin to the successful German model
4. Separate route for testing procedures to certify green building materials will be desirable

In addition, the following step is also proposed for marketing and promoting already existing products from rice straw-

1. Public-cum-private procurement of construction materials from rice straw which already have a demonstrated track record of working on the ground and are evaluated in this study, including construction blocks, panels, and other such products

Finally, the Solid-fuel Pellets (SFP) model is demonstrated to work from operator and end-use market perspectives i.e. co-firing in industrial boilers (55% IRR) and thermal power plants (TPP) (73% IRR). Key difference from all other models is that the SFP model is highly sensitive to market prices and operation becomes unviable beyond landed price of rice straw greater than INR 2/kg and pellet prices lower than INR 4.5 /kg. Given the fact that necessary guidance has already been provided on co-firing by concerned authorities and regulatory agencies, Government may consider -

1. Mandating all TPP units to start consuming at least 5% rice straw-based SF pellets using competitive bidding
2. A new policy mandate, akin to Government of India's fly ash directive, can be issued for use of straw-based SF pellets within a certain radius
3. Industrial boilers can be given a choice to co-fire SF pellets as well as directly the rice straw as long as adequate emission control systems are in place

1. BACKGROUND: AIR POLLUTION AND BIOMASS MANAGEMENT ECOSYSTEM

Smoke from agricultural burning in the breadbasket of India leads to peak pollution episodes across Northern India as a result of huge quantum of rice straw burnt across agrarian states in a relatively short period in the winter months of October and November. Agricultural burning has risen to dominance with intensification of agriculture across agrarian states dominated by rice-wheat monoculture (Badarinath et al 2006), narrowing of time window[1] from groundwater conservation policies (Singh et al 2020a) and lack of an adequate biomass management ecosystem to handle surplus agricultural waste (CII-NITI 2018).

Atmospheric brown clouds from open agricultural burning coupled with unfavourable weather conditions (temperature inversion during winters and blocking effect of Himalayas) exacerbate air quality situation across the already polluted National Capital Region and surrounding areas which are highly urbanised (Saikawa et al 2019). Living in areas with intense crop residue burning is associated with three-fold increase in acute respiratory infection and averting crop residue burning across North Western States can save India INR 10,500 Crore over 5 years (Chakrabarti et al 2019). The problem of crop residue burning in the year 2020 was also compounded by labour shortage due to the COVID-19 crisis. As a result, second highest active fire detections were observed[2] across the four rice-growing states in the region—Punjab, Haryana, Madhya Pradesh, and Uttar Pradesh (See Figure 1) for the post-monsoon period since Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on the Suomi NPP satellite collected data for the first time in 2012 (NASA Earth Observatory 2020).

Reducing surplus rice straw by moving away from rice to more sustainable cropping systems, in favour of more diverse agriculture, is the first choice to address crop residue burning but this requires system-wide changes in agriculture and has not yielded results despite years of efforts. We are, therefore, only left with a practical choice to add economic value to this agricultural waste through direct reuse at the field (in-situ management) and recycling outside field (ex-situ management). In-situ management is a part of the broad conservation tillage techniques defined as any form of tillage that minimises the number of tillage passes, where soil aggregate disruption is reduced, and a minimum of 30% of the soil surface covered with residues (Carter 2005). It can provide several benefits such as soil conservation, economic advantages associated with reductions in crop establishment time and energy use, reduction in soil sheet erosion and nonpoint pollution, and enhanced storage or retention of soil organic matter and improvement of soil quality at the soil surface (Singh et al 2018). Most of these benefits are established through field data in our study (Sharma et al 2020) of CII Crop Residue Management Programme across 105 villages of Punjab and Haryana where more than 87% farmers practiced improved crop residue management practices in 2019 based on their economic advantages. But in-situ has its own limitations and based on our learnings, about one-third of farmers find it difficult to rely fully on in-situ methods. This is the case with-

- Fields with hard soils where feasibility of in-situ management techniques remains limited
- Fields with sandy or sand-loamy soils and alternate crop rotation (e.g. rice-potato-sunflower) where in-situ management is either not cost-effective or it compromises the productivity for subsequent crop
- Farmers who want to provide a gap between application of rice straw to field

Ex-situ is an essential component of the biomass management system in addition to in-situ management by farmers and needs to be developed as a back-up option. Therefore, scaling ex-situ solutions and accompanying supply chains and creating market awareness on these solutions is highly desirable.

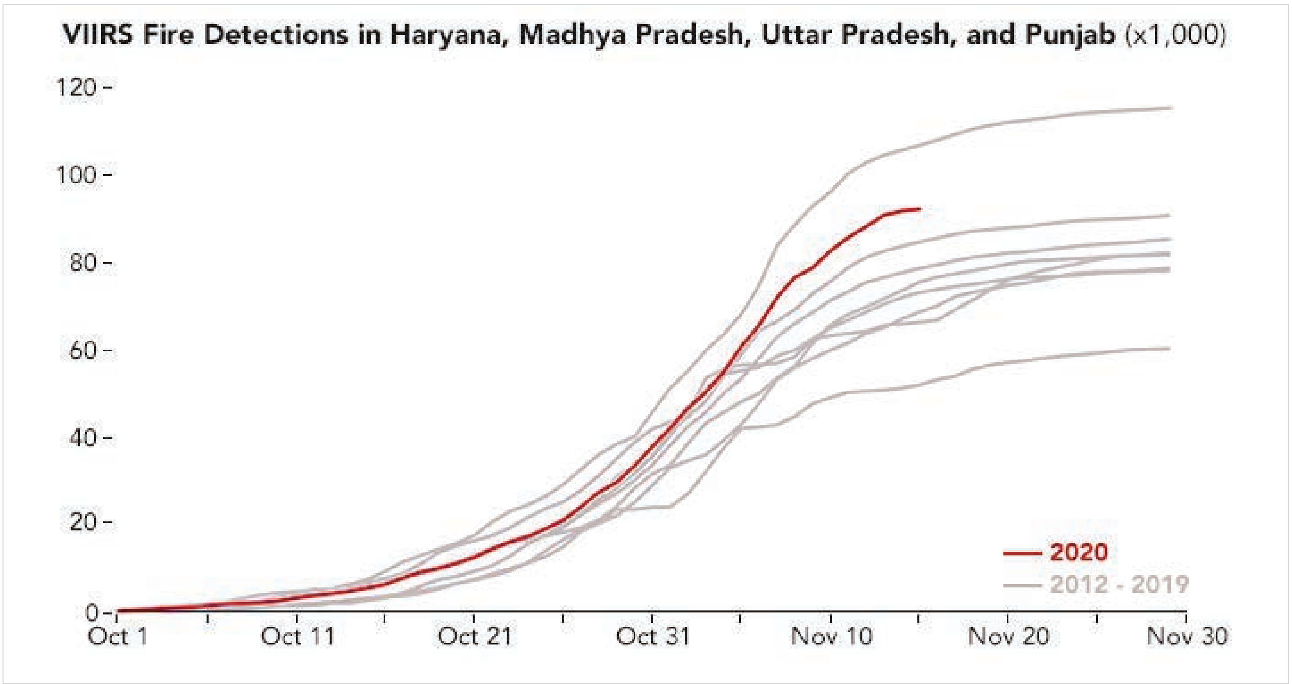
[1] 25% increase in the post-monsoon rice crop production in Punjab during 2002-2016

[2] Despite good adoption rate of in-situ management practice in the last few years

Challenges for ex-situ are compounded by the fact that rice straw is one of the most difficult types of biomass to be processed owing to its inherent characteristics such as high silica and lignin content. This limits its economic viability in many applications as compared to other types of biomass or crop residue such as wheat, cotton, sugarcane etc.

Prime motivation for this study is therefore to understand the economic viability of these solutions. Also, most of these solutions are still at a nascent stage of development. Long-term support to these solutions is therefore necessary through dedicated policy and financial measures.

Figure 1. Active fire counts observed by Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on the Suomi NPP satellite in October-November for years 2012-2020.



Source: NASA Earth Observatory (2020)

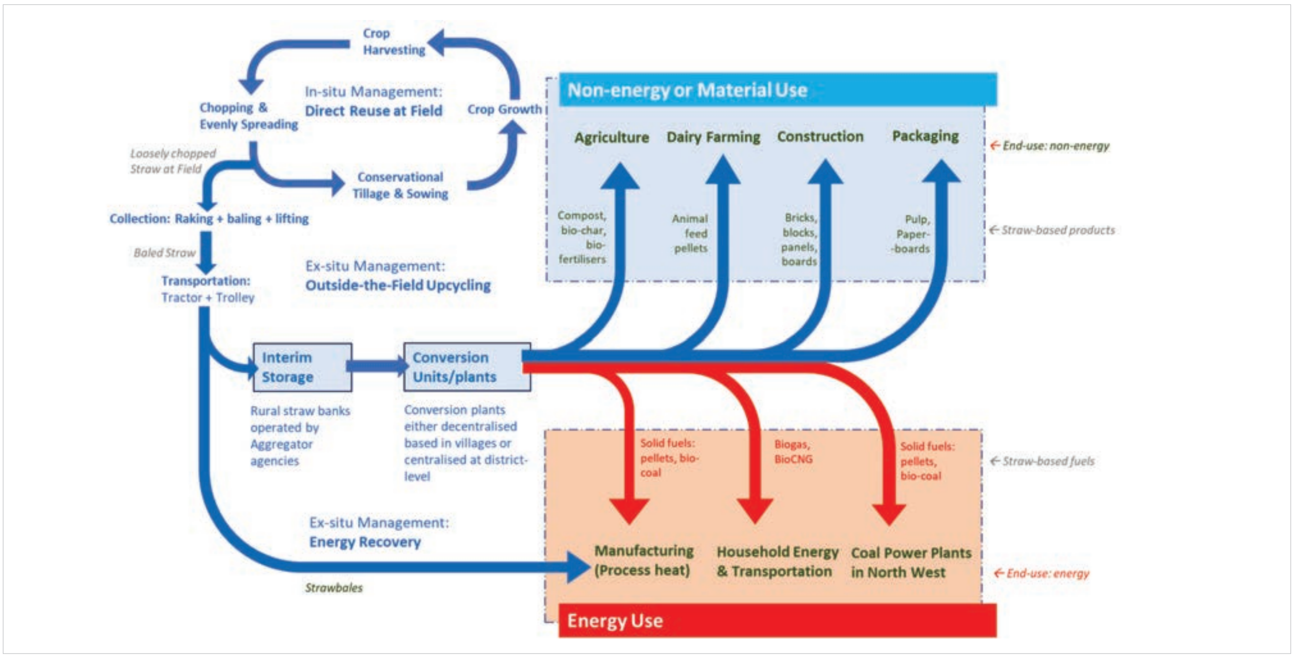
2. INTRODUCTION: ASSESSMENT OF EX-SITU MANAGEMENT SOLUTIONS

As most ex-situ management solutions for rice straw were either under development or trials on field, their economic viability was questionable. Solutions were screened based on their environmental merits and technology readiness level and a detailed assessment of shortlisted solutions was undertaken. The key research question for the team was to understand whether the shortlisted solutions are economically viable? Detailed cost analysis helps to shed light on the critical aspect of these business models i.e. economic viability with respect to the market situation. The price fluctuations and unsteady supply hampered new technologies and delivery models from gaining momentum. Figure 2 provides an overview of biomass management system and various solutions as part of this system which are being assessed under this study. Section 3 provides a brief summary of the methodology and key strategies used to assess actionable ex-situ solutions. Key lessons from the field on how these solutions are being tried by various entrepreneurs and assessment of the respective delivery models are captured in section 4 under relevant subsections. These subsections are focussed on-

- Straw aggregation for delivering biomass to the user facility
- Agriculture and rural energy for specific applications of rice straw within the rural economy i.e. compost, bio-char, animal feed and bio-CNG
- Construction elements for use of rice straw in building/construction
- Pulping and packaging solutions from pulping of rice straw which also opens up possibilities for use of rice straw in various packaging solutions
- Solid fuels and energy recovery focussed on pelletisation of rice straw to solid fuels and energy recovery in industrial boilers and thermal power plants

Finally, the findings are concluded along with actionable recommendations in Section 5.

Figure 2. Process diagram of biomass management system with specific elements under scope of this study.



Source: Cleaner Air - Better Life (2021) Analysis

3. METHODOLOGY FOR ASSESSING ACTIONABLE SOLUTIONS

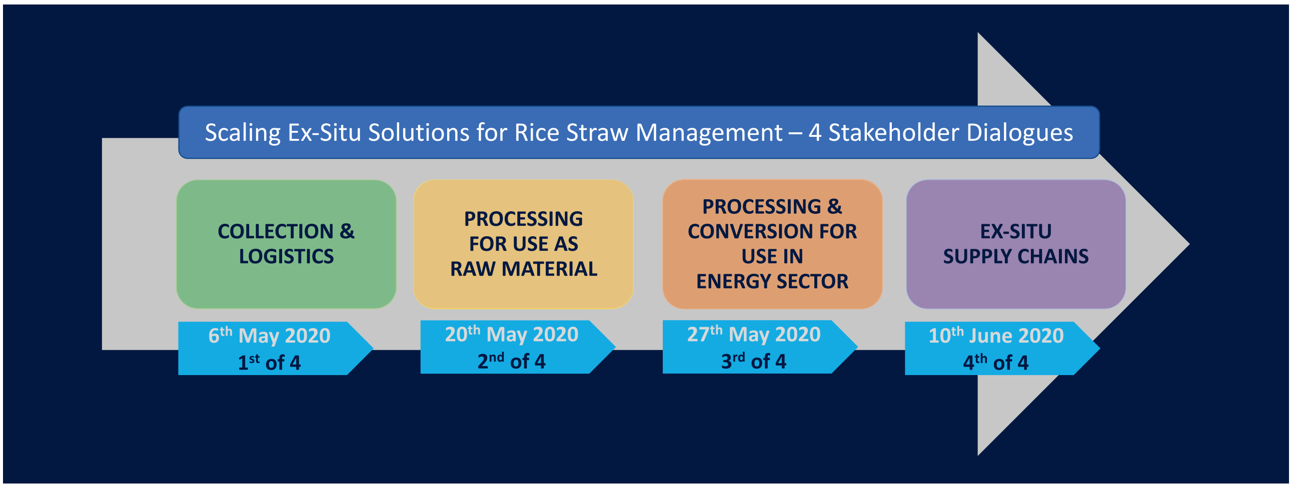
The methodology for this study followed a combination of approaches. These included-

1. Field visits and interactions with rural entrepreneurs working to develop delivery models on the ground across Punjab and Haryana
2. Stakeholder dialogue series (See Figure 3) was organised virtually in May-June 2020 to understand the challenges being faced for scaling up delivery models and get inputs from a wider group of stakeholders including industry experts
3. Data collection from select enterprises and a detailed cost-benefit assessment in order to understand economic viability or market readiness of these solutions

Field visits were undertaken by the research team across multiple locations in Punjab and Haryana in the winter of 2019 to build an understanding of multiple solutions being tried out by rural entrepreneurs on the ground. These entrepreneurs were then further invited to present their ideas for scaling delivery models to manage rice straw at the dialogues series focusing on specific components of the biomass management ecosystem.

Key indicators such as Pay Back Period (PBP), Net Present Value (NPV) and Internal Rate of Return (IRR) have been used to assess economic viability of various delivery models along the biomass management supply chains. PBP is computed from annual cashflows and initial investments of these delivery models but does not reflect the time value of money. Therefore, Discounted Cash Flows (DCFs) of these delivery models were modelled for a realistic scenario to understand the project's viability from an investment perspective. DCF and NPV values have been used to integrate time value of money[3] into the annual cash flows and are useful tools which aide financial decisions. Due to limitation of the NPV method to compare projects with similar initial investment outlays, project IRRs were computed to compare economic viability of different delivery models. IRR is essentially the discount rate at which NPV of the project reaches zero value or DCF of the project equals initial investment. Sensitivity analyses are subsequently performed on discounted cash flows and NPV to understand impact of key assumptions or market situations such as prices of raw material and final products. All cost components e.g. labour, land, energy, chemical inputs, transportation, equipment/plant, storage, packaging, raw materials etc. have been considered for building these investment models.

Figure 3. Timeline of stakeholder dialogue series undertaken to undertsand challenges faced by enterprises to scale various technologies and delivery models for rice straw management in North West Region.



Source: Cleaner Air - Better Life (2021)

[3]standard discount rate of 8% is utilised across assessed delivery models.

4. DELIVERY MODELS FOR WASTE TO WEALTH FROM AGRICULTURAL WASTE

Figure 4. Round Strawbales stacked in pyramid shaped rows at rural straw bank in Ludhiana, Punjab

4.1 Straw Aggregation

Straw aggregation is a specialised business that is yet to be scaled as a lucrative business model across rural North West. It is the backbone of biomass management ecosystem and is a very specialised business as it requires experiential knowledge of best practices to collect/bale, stack, store and transport biomass in order to meet requirements of the user. These best practices include-

- Optimal moisture level[4] before baling chopped straw
- Compression force applied on different layers of bale
- Proper stacking (See Figure 4) with criss-cross layers and pyramid forms for stacking round bales
- Safe distance between rows for proper access and shielding from the risk of fire

The above considerations[5] are important so that biomass degradation (from rainwater seepage, microbial activity etc.) and risk of fire are minimal during storage. There are a few credible enterprises, such as Farm2Energy, who have successfully demonstrated the aggregation model across Punjab and Haryana. Rural straw banks typically store 1000-100,000 tonnes of biomass in the form of bales. Baling of biomass is necessary to ensure efficient supply chains. As the rice harvesting period lasts only for 15-20 days, interim storage at rural

[4] 20-25% requiring drying of straw for two sunny days
[5] above list is not exhaustive for scope of this study

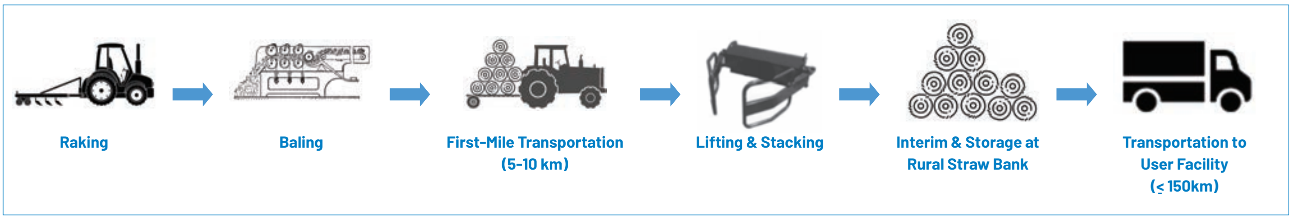
locations is crucial for the uninterrupted supply of biomass to user entities including industrial boilers, conversion facilities for solid fuel pellets, bio-CNG plants etc. (See figure 2). As per our estimate, 100-1000 straw banks will be needed across the two states if ex-situ is to fill the gap for an estimated one third of surplus rice straw which needs to be planned for ex-situ management.

Cost data for study has been acquired from Farm-to-Energy which is active across Punjab and Haryana. Cost data was then modelled from the operator's perspective. As depicted in Figure 5, key steps involved in the process include-

1. Collection from the field (raking and baling)
2. Transportation from the field using tractor-pulled trolleys
3. Stacking and interim storage at the rural straw banks which are set up by aggregator agencies in proximity of their catchment area (within 5-10 kilometres of central location)
4. Final transportation of baled straw to user facilities using trucks

For building the biomass aggregation case, capacity of the rural straw bank was assumed to be 60,000 tonnes rice straw in a season or year requiring capital investment of INR 4.5 Crore. Investment included hardware for all the steps outlined in figure 5 e.g. rakers, balers, fork lifters etc. The catchment area for this particular size of rural straw bank was spread roughly over 100 square kilometres. Due to efficiency considerations, final transportation to user facility was limited to a distance of 150 kilometers and an average transportation charge of INR 525 per tonne of baled straw has been used.

Figure 5. Process flow for straw aggregation model for collection and uninterrupted supply of rice straw by aggregation agency.

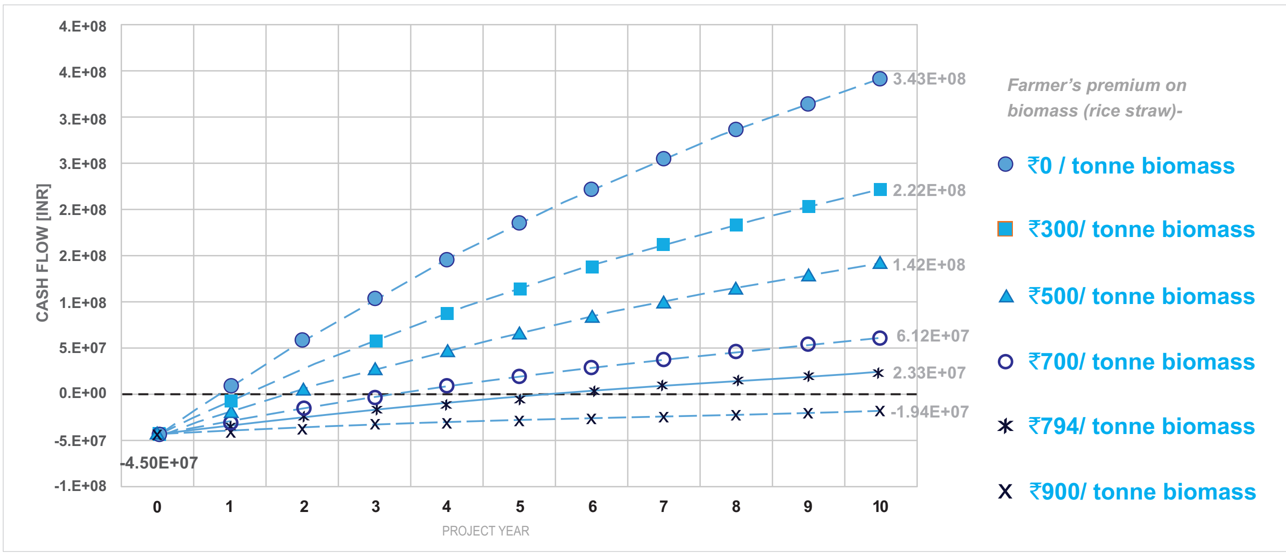


Source: Cleaner Air - Better Life (2021) Analysis

Based on learnings from 102 villages across Punjab and Haryana, as detailed in our study (Sharma et al 2020) published in September 2020, it costs the farmer INR 1985 per acre or using a standard factor of 2.5 tonne per acre - INR 794 per tonne rice straw. This is the typical amount charged by a service provider for evacuating agricultural waste from the field but under the aggregator model used by Farm2Energy, the operator of straw bank or aggregator does not charge any money from farmers for this service. Hence the inherent assumption for modelling this process was that while cost to farmer for availing baling and evacuation service is fixed at INR 794 per tonne rice straw, a premium of a similar amount is being paid to the farmer by aggregator (Farm2Energy here). Project cash flows were further analysed for different scenarios as depicted in Figure 6 where the farmer is being paid a premium which is either lower or more than this value. It is worth noting that it costs the aggregator approximately INR 650 per tonne of biomass for operations ranging from collection from field till stacking of bales at the site of interim storage or rural straw bank.

As depicted in Figure 6, the project is viable (or cummulative net prsent value of inventment over a 10 year period is postive), if farmer premium is limited to a threshold value of approx. INR 850 per tonne of biomass. For the standard assumption of farmer's premium at INR 795 per tonne, net present worth of the project is postive (INR 2.3 Crore) and the project is found to be viable.

Figure 6. Investment model for aggregation unit or rural straw bank with scenarios for different levels of farmer's premium on the rice straw.



Source: Cleaner Air - Better Life (2021) Analysis

Although the simple payback period is 4.4 years, discounted cash flow analysis indicates that the project yields postive returns in 5.5 years (at 8% discount rate) which is a more realistic timeline for its break-even point from an investment perspective. The internal rate of return for the project is 18% which is a useful indicator of its economic vialbilty for comparison with other models whose initial investment outlay and cash flows are very different from the aggregator model.

Evidently, for scenarios where the farmer's premium is lower than INR 795 per tonne, the project is viable throughout and its value increases with a decrease in this premium. If the aggregator charges farmer the same rate as a private service provider of farm machinery (full amount of INR 795 per tonne for their services or in other words, zero premium), project value at the end of 10 years is found to be 7.6 times the initial investment (INR 34.4 Crores).

In addition to the above insights from cost analysis, there is a significant risk of a fire hazard which exists at rural straw banks maintained by enterprises for collection and aggregation of biomass in rural areas.

Subsequent sub-sections of the report dwell on various conversion and use cases including energy as well as material applications. Although generated in a relateively short time window, straw is typically stored year-round either at rural straw banks or onsite storage attached to user facilities. Longer storage periods inevitably accrue losses due to degradation of paddy straw and 20% decrease in the Calorific Value (Singh et al 2020b) within a year of storage, which has been documented. While this is a significant loss for energy applications, it is worth noting that even lower grade biomass can be utilised in selected material applications e.g. manufacturing building/construction elements which are also covered in the subsequent subsections.

4.2 Agriculture and Rural Energy

There are several possible applications for rice straw within the agricultural sector and rural economy besides its direct reuse at field by the farmer (formally, in-situ management). These methods are preferable over other methods discussed in subsequent subsections as they do not require transportation of straw or final products to longer distances outside the rural areas. However, these methods have their own limitations for scaling to the entire region and given the huge quantum of straw generation, role of other methods cannot be denied in the overall biomass management ecosystem.

Key methods for this include-

1. Composting for conversion to green manure
2. Pyrolysis for conversion to bio-char
3. Chopping/shredding for dry animal fodder and mixing (with supplements) for Total Mixed Ration (TMR) to animals (with further option of pelletisation)
4. Biomethanation for conversion to biogas and further purification of biogas and subsequently compression to bio-CNG

Composting is possible in multiple forms or configurations. These key methods can be classified as-

1. In-situ composting: This form of composting is undertaken simultaneously along with in-situ management. Inoculum with microbial culture is sprayed onto the field to accelerate composting but this requires chopped and evenly spread straw on the field which is either retained as a mulch layer or incorporated into the soil.
2. Ex-situ pit composting: Manually outside the field in small pits with or without microbial inoculum and vermicultures
3. Ex-situ windrow composting: Composting outside the field at scale with tractor-pulled farm implements with or without microbial inoculum and vermicultures

Different composting techniques and microbial solutions are currently under trial with farmers. While all techniques have their own limitations and benefits, focus of this study is on the ex-situ techniques. Pit composting requires near-zero capital, but it is labour intensive for operations such as- digging the pit, turning the compost bed etc. For a composting pit of 30x10 square feet size, farmers can compost roughly about 30-45 tonne of rice straw in a year (assuming 4-6 batches in a year). Assuming a conservative price of manure at INR 3/kg and four batches in a year, net benefit to the farmer from setting up one such compost pit is estimated around INR 29,881[6]. This model can further be scaled using larger areas for composting and mechanised means for turning the compost beds (windrow composting).

Composting has significant potential for treating rice straw and generating value for farmers but there are barriers such as limited land availability with farmers for composting and limited use of green manure by farmers who are into intensive agriculture with heavy dependence on chemical inputs. Some of these challenges for popularising and scaling bio-fertilisers have been revisited under biomethanation where bio-fertiliser is a key by-product along with biogas or bio-CNG and significantly impacts cash flow of this delivery model.

Bio-char, which is the main product of pyrolysis process, is used as a soil conditioner on agricultural land for a standalone application or application along with fertilisers and green manure. It has high potential as a soil conditioner in areas of North West where soil is deficient in organic Carbon. Secondary literature mentions that if residues are converted into bio-char, 50% of initial biomass Carbon can be recovered as compared to only 3% during open burning (Venkatesh et al 2018). Although a crude form of bio-char kilns which can control 40-60% emissions as compared to open burning exists, technology development for more efficient reactors which can further reduce it to 95% are in progress. The proposed reactor from Takachar, once fully developed, will be able to consume 2-5 tonnes of rice straw per day. Lack of standards and certifications for such reactors (as it is neither a boiler nor gasifier) and marketing barriers for organic inputs are key challenges speculated by technology developers.

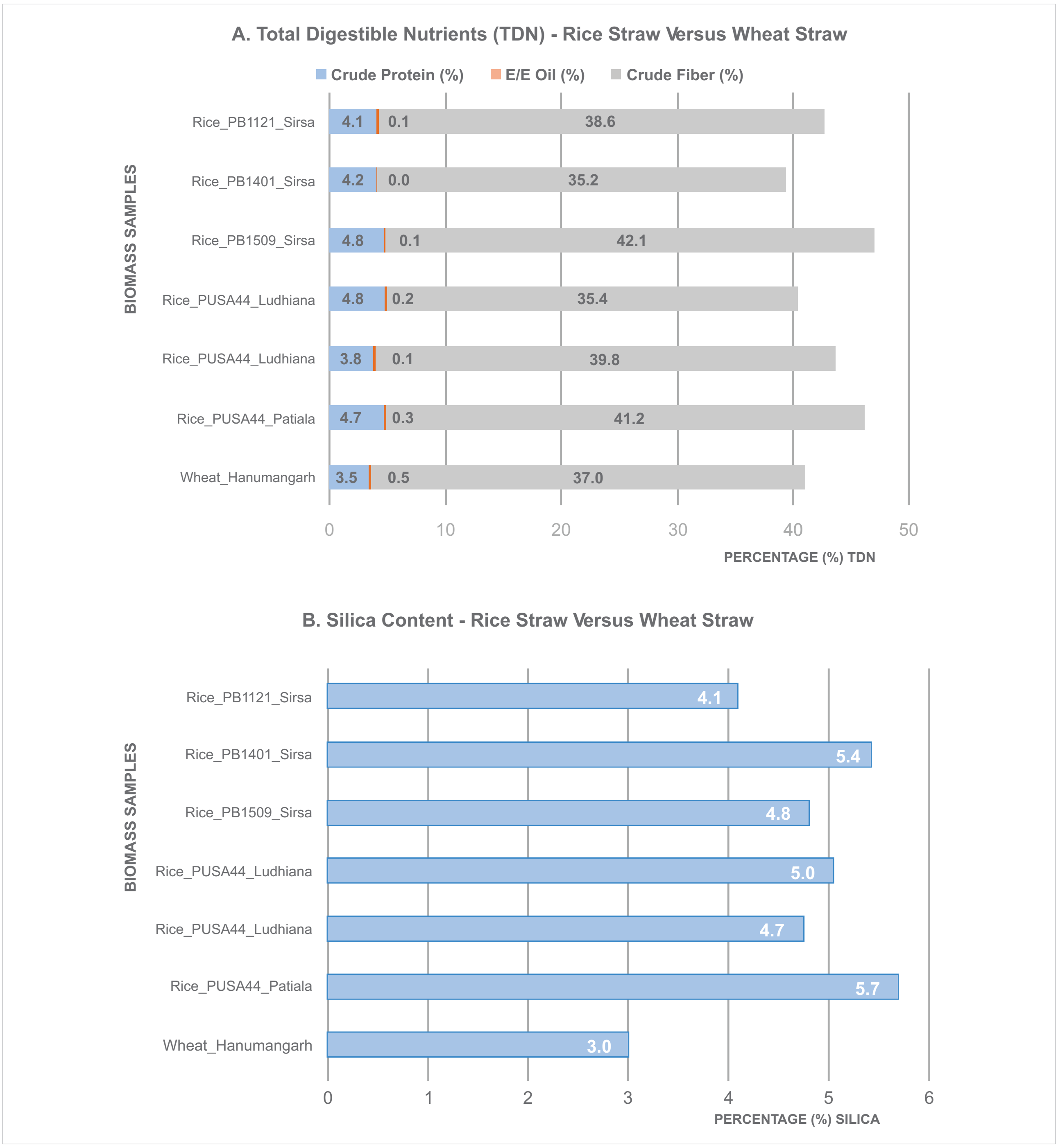
Animal feed in the forms of - (1) dry fodder and (2) balanced animal diets with addition of nutrients, formally known as Total Mixed Ration (TMR), are two major routes through which rice straw can add value to the rural economy in North West and revive decentralised dairy farming. Presently, India faces a net deficit of 35.60 % green fodder, 10.95 % dry fodder and 44.00 % concentrate feed ingredients (IGFRI 2015). Surplus paddy straw can be used directly or by treating the straw with protein or nitrogenous compounds (Kumar et al 2014).

In Punjab and Haryana, farmers have traditionally been feeding the cattle with wheat straw and their preference for wheat straw over rice straw is based

[6] Total revenues and operational expenditure in a year is estimated at INR 63,840 and INR 33,959 respectively.

on a flawed perception of poor nutrient value associated with non-basmati rice straw. We analysed the samples of rice straw from the two states in the laboratory at Saras Dairy Plant in Hanumangarh, Rajasthan[7] for their nutrient[8] values and preliminary analysis of these findings, summarised in Figure 7, show us that these nutrient values are quite comparable[9]. This helps in busting the myth associated with lower nutrient value of rice straw. Also, silica content of both biomass types is compared in Figure 7 and although Silica content is higher for rice straw (average 5% compared to 2% in wheat straw), it is manageable for this application.

Figure 7. Comparison of total digestible nutrients (A) and silica content (B) of rice straw vis-a-vis wheat straw across North Western Region.



Source: Cleaner Air - Better Life (2021) Analysis

[7] Close to Haryana border

[8] Protein, fats and fibre

[9] Reference nutrient values of wheat straw from Hanumangarh are used for comparison.

Rice straw bales are already being transported by local entrepreneurs from Haryana and Punjab to the bordering and straw scarce state of Rajasthan as they are able to fetch good prices there and dairy farmers have absolutely no problem feeding rice straw to their animals. But transporting bulky straw bales to far away distances is not very efficient as the shelf life of straw bales is low. Also, treated rice straw feed enhances milk and meat yield when compared with untreated rice straw (Wanapat et al, 2009).

Therefore, converted rice straw TMR pellets as a balanced diet with the addition of other required nutrients or filler materials is seen as an emerging delivery model. SARAS Dairy's plant in Hanumangarh (see Figure 8) has in fact been producing TMR from wheat straw and piloted use of rice straw with support from National Dairy Development Board (NDDB), India. Our research team visited this plant located in Hanumangarh in the winter of 2019. Capacity of this plant is 50 tonnes per day (tpd) TMR. TMR based animal feed produced from this plant is supplied across Rajasthan in the form of pellets or briquettes and has been beneficial to dairy farmers whose access to green fodder is limited and helps them in maintaining the pH of cattle stomach and increase the quality and yield of milk. Key challenges faced by plant engineers during the piloting phase with rice straw and learnings from this are summarised below-

- Due to silica and fibre content of rice (See figure 7), grinding and feeder units face frequent jams causing the entire plant to breakdown. Wide and large feeders can solve the jamming problem.
- Metallurgy for grinding units was adjusted with specialised blades for rice straw and additional mechanical supports were added to conveyer feed systems.
- Optimal moisture is crucial and high moisture in rice straw can also lead to similar challenges.
- Moreover, there are widespread misconceptions in the dairy industry regarding particle size at which straw should be grinded. Rather than grinding rice straw down to 1-3 mm size, a particle size of 6-12 mm is suitable for animal digestion.
- The above consideration also reduces chances of mechanical wear and damage in grinding and feeding units

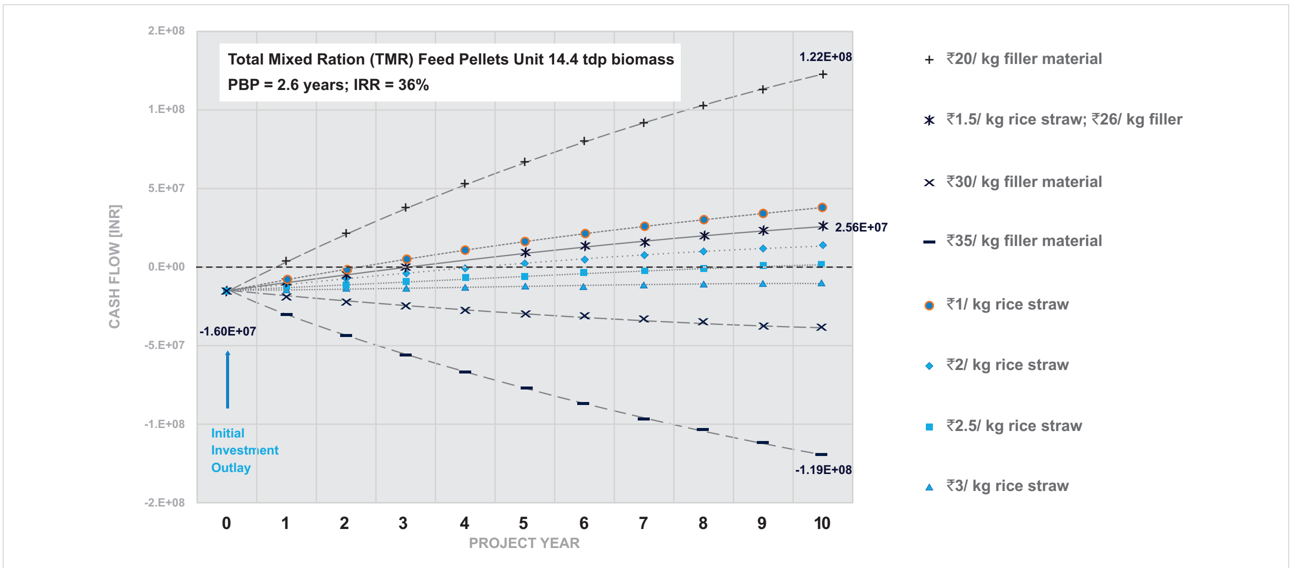
Figure 8. Total Mixed Ration (TMR) plant at SARAS Dairy in Hanumangarh, Rajasthan.

These summarised learnings are also applicable to entrepreneurs setting up units at smaller scales. TMR mixer can be set up by the rural entrepreneur for making the formulated TMR with addition of proteins, mineral mixture, molasses etc. TMR mixture produced can be in the loose form or can be densified into pellets for increasing shelf life of the product, easier handling and efficient transportation to longer distances. Appropriate design of onsite storage and location criteria are important considerations for cost-effective transportation and access to market/consumers. TMR mixers are available in the market in varying sizes (2-8 m^3) and can even be mounted to tractors (>50HP tractor). There are, in fact, 208 small TMR mixers (mainly based on wheat straw) which have been operating in Punjab as of 2019 and the capital cost for these is 3-5 lakh with 50% capital subsidy[10].

For this study, a medium sized (24 tpd TMR) plant was considered for developing the investment model. As shown in Figure 9, the capital investment needed for this scale is INR 1.6 Crore. Three key steps in the process include-

1. Grinding of rice straw to fine particles
2. Batch mixing with filler materials as per a predesigned formulation
3. Processing mixer in Roll-type extrusion pellet mill

Figure 9. Total Mixed Ration (TMR) feed pellet investment model with scenarios for different prices of raw materials: rice straw and filler materials.



Source: Cleaner Air - Better Life (2021) Analysis

The proposed plant, which is under development, will consume about 14.4 tonne rice straw in a day which is 60%[11] of the overall TMR formulation and 40% filler materials are added. Annual cash flows from the unit have been estimated at INR 62 lakh based on detailed data from the project developer at GBDSGNS Foundation based in Raikot block (Ludhiana, Punjab). Given the fact that, prices of filler materials and rice straw are prone to market situations, further sensitivity on these has been carried out. For an average price of filler materials at INR 26 per kg (refer the TMR formulation in Table 1.) and rice straw at INR 1.5/ kg, the project PBP is estimated at 2.6 years while based on discounted cash flow analysis, actual break-even is achieved in 3.5 years' time period (with net present worth of INR 2.56 Crore). It can be seen from Figure 8 that the TMR pelletisation investment model is highly sensitive to the market price of filler materials. With the average price going up from INR 26 /kg to INR 30/ kg the project becomes completely unviable[12]. Project viability is good for rice straw prices ranging from INR 1-2 /kg.

[10]based on inputs at CII stakeholder dialogue series in May-June 2020
[11]By weight
[12]Negative NPV

Feed constituents and their prices vary from place to place depending on specific nutritional requirements of dairy animals as well as local availability of filler materials.

Table 1. Filler materials with prices for considered formulation of TMR pellets

S.N.	Filler Material	Composition [Percentage by Weight]	Price [INR/Kg]
1	Corn	2-5%	40-60
2	Maize	10-15%	12-20
3	Millets	2-5%	50-80
4	Mustard	10-15%	20-30
5	Barley	3-5%	50-60
6	De - oiled Cake	5-8%	29
7	Urea	1%	10-15
8	Salt	1%	15-20

Source: Data collected from GBDSGNS Foundation

Biomethanation is a key route for decentralised delivery models in an agrarian state to meet the future needs of energy most sustainably. The team visited the fully commercialised plant by Sampurn Agri Ventures in Fazilka, Punjab (40 tpd capacity) which is a zero-liquid discharge plant and has been in operation for last the 5 years (See Figure 11). Green manure produced by the plant approved by Punjab Agriculture University has shown significant benefits for improving crop yield and soil health in the field. Based on the same technology (dry digestor technology based on dual phase biomethanation process) and data collected from the technology provider, investment model for bio-CNG was developed. The analysed model processes rice straw at 70 tpd and has a catchment area of 100 km. For delivering purified and compressed bio-CNG, the capital requirement is INR 38 crore. Bio-methanation of rice straw can save significant amount of import duties from avoided crude oil and gas imports. It is therefore also part of Government of India's SATAT Initiative. Biofuels have the potential to reduce our fuel import bill by Rs. 1 lakh crore (GoI 2020). But it is a rather less known fact that bio-fertilisers (liquid bio-fertiliser and green manure combined) produced from biomethanation can potentially substitute 40% of the total fertiliser consumption[13], reducing a burden of INR 20,000-30,000 crore spent by Government of India on fertiliser subsidies. Both need to be seen in light of the fact that bio-fertilisers contribute to 43% of all the revenues. Therefore, they play a crucial role in the plant's economic viability. Yearly cash flows from the assessed Bio-CNG model are as follows-

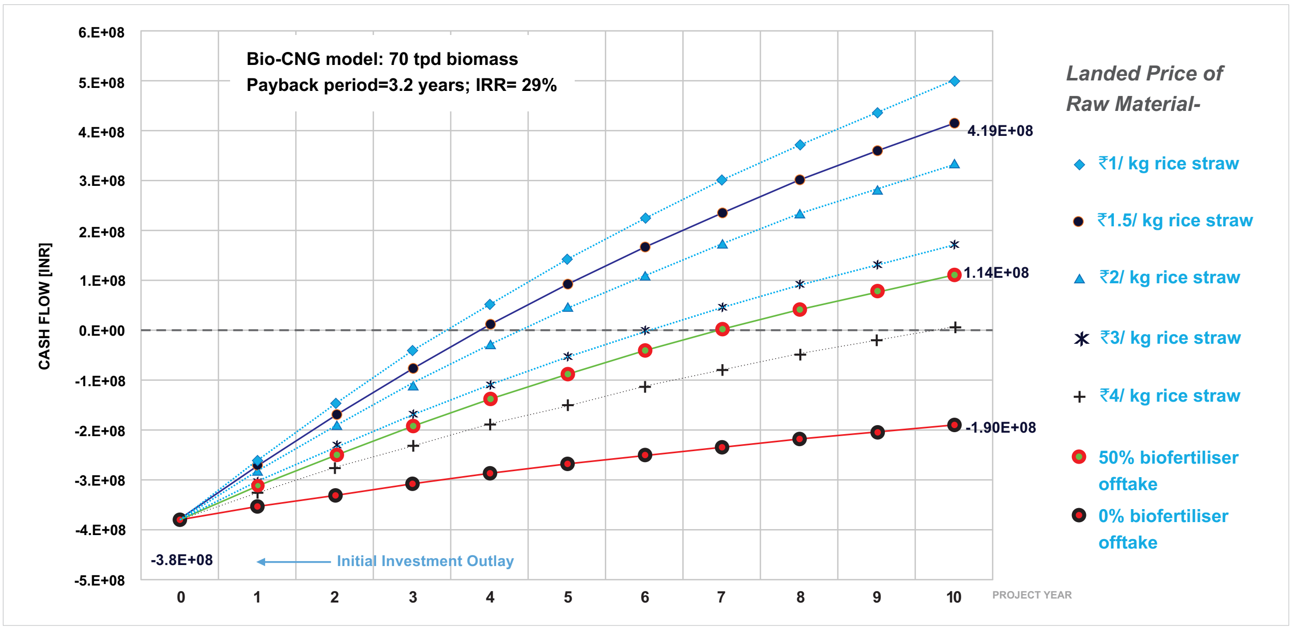
1. Bio-CNG: INR 12.2 crore for 2.6 kilo tonne Bio-CNG per year (57% of all revenues)
2. Manure: INR 5.6 crore for 14 kilo tonne manure per year (26% of all revenues)
3. Liquid fertiliser: INR 3.5 crore per year for 3500 kilo litre fertilisers in a year (16% of all revenues)

[13]Stakeholder inputs at CII Stakeholder dialogue series for scaling ex-situ solutions

Promoting a bio-CNG model therefore requires equal emphasis from an agricultural perspective, if not less, and equal amount of efforts from agricultural agencies in order to improve viability and scale this delivery model across the North West region.

As depicted in Figure 10, net present value of the project is INR 42 crore at an internal rate of return at 29%. As per the assured price and 100% offtake of bio-CNG guaranteed by GoI under its SATAT initiative and assuming 100% bio-fertiliser offtake, it takes the project a little less than 4 years to reach break-even point. The simple payback period is 3.2 years. But if bio-fertiliser's offtake is zero, the model becomes completely unviable and findings reveal that NPV of the project will in turn be INR -19 crore. Even if the plant is able to sell half the bio-fertilisers it generates (or fetch half the assumed[14] market prices), the project is just viable at NPV of INR 11.4 crore with break-even in 7 years. Due to high economic value created by the bio-CNG model, it is also relatively far less sensitive to fluctuations in landed prices of rice straw in comparison to solid-fuel pellets (See Section 4.5).

Figure 10. Bio-CNG investment model with scenarios for raw material price and bio-fertiliser offtake.



Source: Cleaner Air - Better Life (2021) Analysis

From the above analysis, it is clear that despite bio-CNG's good rate of return, it is very difficult to scale this delivery model due to inherent challenges in the offtake of bio-fertilisers, especially in agrarian states of Punjab and Haryana where farmers are predominantly dependent on chemical fertilisers and disproportionate subsidies on fertilisers which are the biggest stumbling block for scaling bio-CNG.

[14]Manure at INR 4/ kg and liquid fertiliser at INR 10/ litre

Figure 11. Bio-fertilser offtake is crucial for viability of Bio-CNG model: Sampurn Agri Venture's Bio-CNG plant in Fazilka, Punjab with green manure from plant being cured in open as seen in the foreground

4.3 Construction Elements

Solutions for use of agricultural residues in building/construction applications are fast emerging and are driven by demand for affordable housing as well as natural building materials with low embodied energy. As rice straw is turned into construction elements, its application becomes carbon neutral or carbon negative depending on the actual use and specific context. In this study two application of rice straw in building/construction (See Figure 12) are being assessed-

1. Agrocrete bricks or blocks from rice straw, lime sludge and other industrial waste
2. Strawboards or construction panels from rice straw and non-formaldehyde-based binder

Unlike solutions considered in previous subsections, these are at a very nascent stage of development, but they are being demonstrated on the field. They are being assessed as a part of this study because-

- They have a high potential to address the air pollution challenge at scale due to rampant demand for construction materials in future. Floor space demand in India is projected to grow as much as 7 times for urban residential buildings and 3 times for commercial buildings by 2050 (Rue Du Can 2019)
- They can reduce global warming by avoiding extraction of virgin materials in construction/buildings. Natural buildings can even lower energy demand by improving the Building Envelop Energy Efficiency (BEEE), but this varies with actual use case[15].

[15]Agrocrete claims that every 'square metre' of wall made up Agrocrete blocks amounts to 38 Kg CO2e of carbon captured, 8 Kg CO2e GHGs saved annually due to improved BEEE.

- Going a step further, they can store carbon in building walls for hundreds of years and hence have negative carbon emissions over the lifecycle of their use
- Degradation of biomass over longer storage periods does not limit its use unlike energy applications where degraded straw implies significantly lower calorific value. Also, it is possible to have wet storage (with water sprinklers) which helps reducing the risk of fire hazards at storage sites

Figure 12. Agrocrete blocks and strawboard panels from Strawcture Eco

Picture on the right courtesy - https://www.thebetterindia.com/187863/uttar-pradesh-girl-quits-us-job-sustainable-homes-stubble-burning-india/

Agrocrete blocks, being assessed for their economic viability, have been developed by Greenjam BuildTech as a patented technology. Greenjam uses rice straw along with lime sludge, steel flakes and other industrial waste streams in different proportions to manufacture Agrocrete. Agrocrete bricks have a compressive strength of 7.5 Megapascal (Mpa), lighter density (1400 kg/m^3) and thermal conductivity of 0.4 Watt per metre-Kelvin (W/m-K). Agrocrete blocks also have good water resistance with less than 10% water absorption. Traditional bricks have thermal conductivity ranging from 0.4-0.7 W/m-K. depending on size of brick (Dondi et al 2004). Compressive strength of traditional red bricks ranges from 3.5 to 35MPa with widely used bricks having a strength of 5-7.5 MPa (BIS 2017).

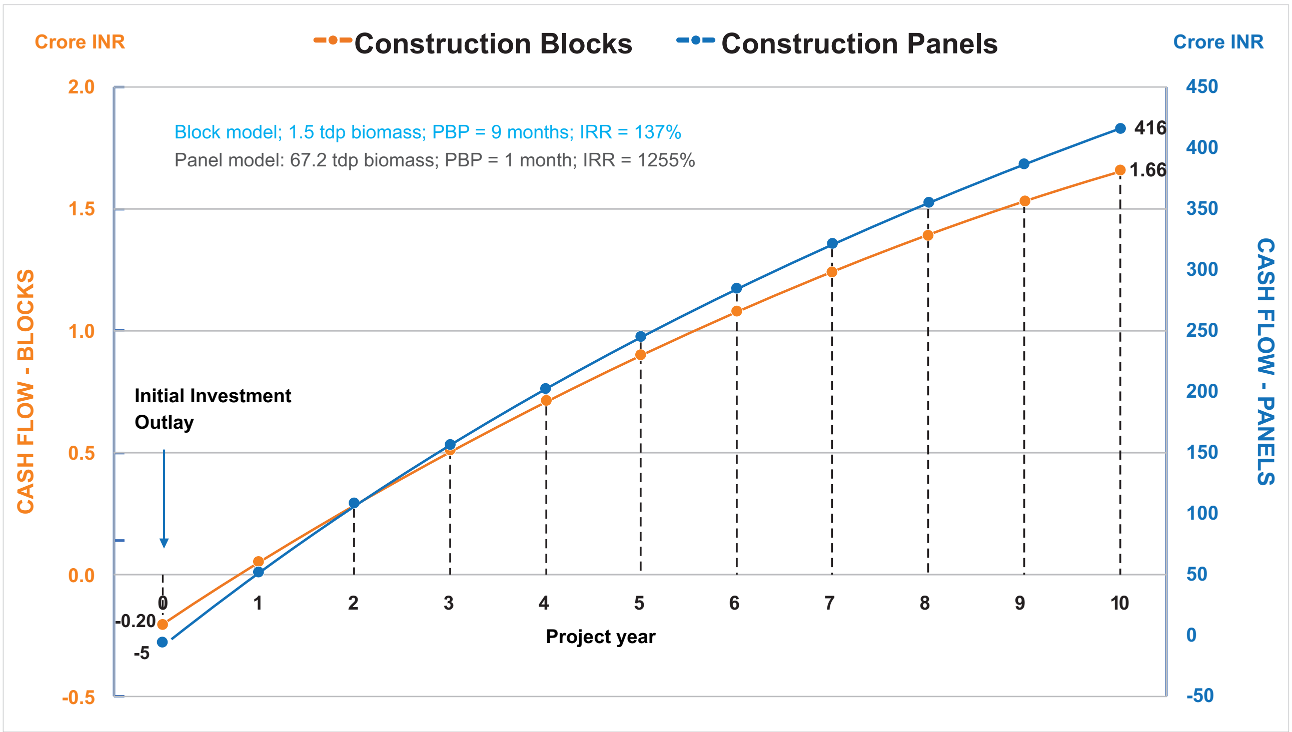
Manufacturing process of Agrocrete blocks is very simple and is similar to conventional brick making process. A small plant manufacturing 1000 blocks a day costs approximately INR 5-6 lac in capital investment. Due to the simple manufacturing process, it is possible to design a hyper-local model and engage rural entrepreneurs. Market awareness of the product is found to be a major challenge for scaling its use. Building codes also partially impact product offtake in the market. Bureau of Indian Standards (BIS)'s standard IS: 2185 which provides the guidelines for building blocks/bricks does not recognise biomass as a raw material for bricks/blocks. This also implies that use of BIS symbol for blocks is not possible despite comparable or even better characteristics as compared to red bricks.

Strawboards and construction panels from rice straw and other agricultural residues are being produced by Strawcture Eco as a replacement of wood or other concrete material. Strawcture Eco had constructed an area of 15000 square feet across six Indian cities with these panels by 2019. It has a further building capacity for manufacturing of 300,000 square meter of the panel boards in 2020-21. Strawcture Eco is building 250-300 square feet sized small houses under the Pradhan Mantri Awas Yojana, and will have a capacity to build 2300 houses from the new factory. It has targeted to sell an additional 50,000 m^2 of panels in the market directly to builders and architects. Processing of the straw into compressed boards is done with the help of a non-formaldehyde-based binding solution[16] at a certain temperature and pressure. Thermal conductivity of such panels made from wheat straw, rice straw and sugarcane bagasse is approximately 0.09 Watts per metre-kelvin (W/m-K). It is possible for the conversion unit of straw boards/panel to utilise a variety of biomass depending on location. Density of panels ranges from 750-1100 kg/m^3 depending on types-

1. Interior grade panel
2. Exterior grade panel
3. High-density flooring grade panel

While indoor panels are approved by standards, two tests were pending for exterior panels at the time of writing this report. Price of an interior 18 mm panel made from rice straw is INR 50 per square feet in comparison to a plywood material (INR 60 per square feet). Also, it is 15% lower than gypsum and cement boards. Although the panel boards are approved by the Building Material Council of India, there is no formal information to back up the fact that bio-composite panels are similar in performance to conventional building materials.

Figure 13. Investment Model for Construction Blocks and Panels

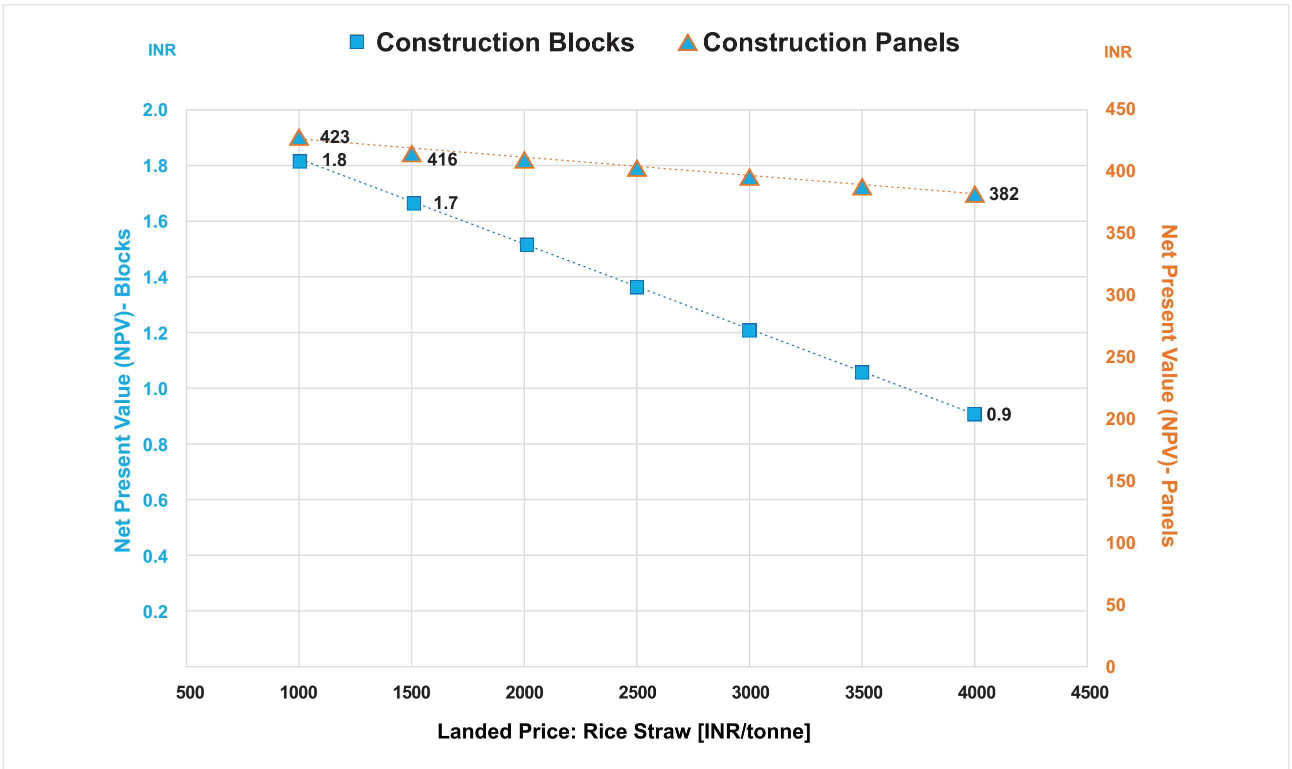


Source: Cleaner Air - Better Life (2021) Analysis

[16]outsourced from third party

For both models described, scaling is difficult due to lack of market/consumer awareness and market opportunities. Investment models (blocks consuming 1.5 tpd biomass and panels consuming 67 tpd biomass) for both were developed based on detailed data collection from both start-ups and results have been presented in Figure 13. It should be noted that although both models are shown in the same figure, discounted cash flows for the two models are not comparable, as the scale/sizes and initial investment outlays for both are very different. It is clear that both models have a very high potential for scaling and yield high returns and break even in few months, albeit, with the key assumption that both products are sold in the market immediately which is not a very realistic scenario given the current market situation. Usually, these construction elements are produced as per requirement and not as the continuous process with 300 operational days in a year as assumed in this analysis. Nonetheless, it shows that both models have very high potential if market opportunities exist. Sensitivity analysis over price of rice straw if further undertaken, in Figure 14 found that both these models, unlike other investment models presented in this study, are not very sensitive to price of straw and NPVs remain positive (INR 0.9-1.8 crore for blocks and INR 382-423 crore for panels) for the entire range of rice straw landed prices: INR 1-4 per kg used for this evaluation. Another observation can be made here is that construction panels are less sensitive to fluctuations between the two.

Figure 14. Sensitivity analysis over raw material prices



Source: Cleaner Air - Better Life (2021) Analysis

4.4 Pulping and Packaging Solutions

Once processed into pulp, rice straw can be converted to multiple products such as paperboards for packaging, disposable tableware, crafts etc. Besides addressing the air pollution problem, it can also be a solution to plastics pollution. Kriya Labs has developed the process of producing pulp from rice straw through a Chemi-thermo-mechanical process which has two crucial components-

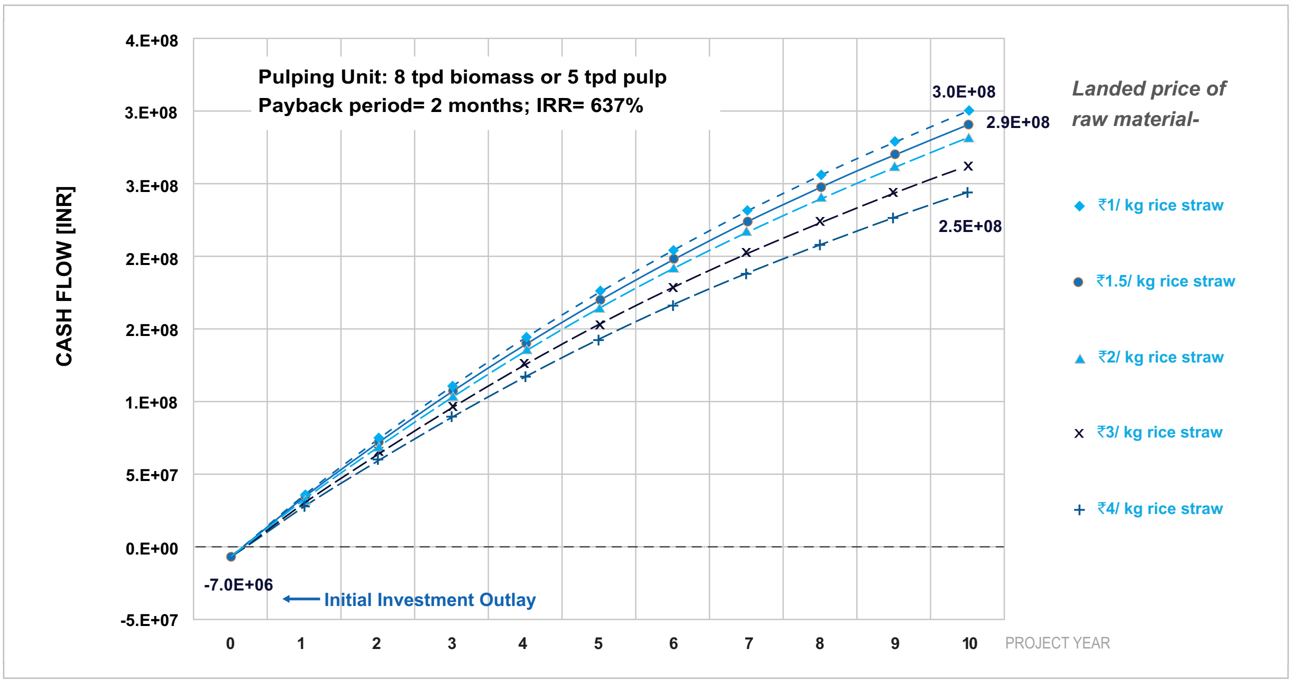
1. Pulping system
2. Water recycling system

Much like other material applications discussed in prior subsections, chipped rice straw is first prewashed to remove any dirt and silica. Softening of the chipped straw is the next step which involves treating it in a reactor with minimum doses of chemicals. The softened material goes through a mechanical refiner which applies a shear on the fibres and separates them. This step turns the cooked material into pulp which is suitable for moulding into different forms and shapes.

The conversion ratio of straw to pulp is 0.62 which means almost 625 kg of pulp is produced with every tonne of straw processed. The pulp so produced can be moulded in the form of sheets, boards, disposable tableware or other packing materials. Since the whole process of pulping involves multiple washing steps, it is quite water-intensive, so the water recycling system has a crucial role in the entire process.

The water recycling system deals with liquor generated at each step separately. All the chemicals used in the cooking step are consumed during the cooking itself and hence there is no need for any special step for their removal, leaving only organic and inorganic residues from rice straw. The system is a combination of decanting and selective filtration. Liquor is removed from the pulp in a certain proportion along with the solid in a certain proportion from this liquor. This solid is the only waste generated in the process and is an amalgamation of fine bits of lignin and silica from rice straw. It can potentially be used as a fertilizer or binding material in the construction industry. Treated water is analysed and suitable to be fed back into the process to ensure zero liquid discharge.

Figure 15. Investment model for pulping unit and scenarios for landed price of raw material



Source: Cleaner Air - Better Life (2021) Analysis

As depicted in Figure 15, the investment model and discounted cash flow analysis for pulping unit producing 5 tpd pulp has been undertaken. The project has a short payback period of 2 months, if 100% offtake of pulp is ensured at INR 40 per kg market price. The unit requires an initial investment of INR 70 lacs, consumes 8 tpd rice straw and yields a high NPV of INR 29 crore (IRR at 637 %).

4.5 Solid Fuels and Energy Recovery

There are multiple ways in which energy values of rice straw can be extracted or rather, rice straw can be converted into different energy carriers or products. Three key pathways include-

1. **Mechanical processing:** grinding straw to finer particle sizes and further densification to meet needs of the final user
2. **Thermal processing:** based on process parameters and air supply, these are further categorised into pyrolysis, torrefaction and gasification
3. **Biological processing:** biomethanation and fermentation to second generation liquid bio-fuels

Multiple energy carriers generated from the above pathways can also interlink these pathways or these energy carriers can be further used for generating electricity, but all of these excessively complex layers mean loss of energy and efficiency with each step. Also, there are inherent challenges associated with handling and processing of rice straw for energy such as-

1. Storage of biomass for year-round supply is essential but baled biomass undergoes degradation with time, causing a dip in the calorific value of rice straw. Evidence shows a 20% decrease in the calorific value over a one year period (Singh et al 2020b). As the caloric value of rice straw is already lower compared to other biomass types such as wheat, cotton, sugarcane etc., this compounds the challenges associated with energy use of rice straw.
2. The high silica and lignin content in rice straw implies that cost for processing rice straw is higher compared to other biomass types and increases with particle size requirement. This effect is already documented for the case of dedicated bio-power plants and rice straw to bio-ethanol technologies in the CII-NITI (2018).

Therefore, two delivery models i.e. 'solid fuel pellets' and 'direct firing of bales for energy recovery in industrial boilers' are considered as affordable and actionable solutions[17] in this study. For reasons mentioned under point 1, rice straw needs to be either fired directly into the boilers (wherever possible) or densified into pellets for increasing its shelf life.

Densification of biomass into Solid Fuel Pellets (SFP) also has an advantage over loose straw due to higher density and better heat conductivity. This in turn increases the efficiency of transportation and energy extraction at end-use, whether it is an industrial boiler for process heat, thermal power plant for electricity generation or in purpose-built cook stove or oven.

Crushing, mixing, drying, grinding and pelletisation are key steps involved in the process which require specialised machinery. Experiences from A2P, a bio-energy start-up active in Punjab show that-

- Use of innovative methods such as machine learning for mapping industrial boilers or use of pellets and modified equipment helped reduce cost by 12%
- Focus on different kinds of biomass may ease some of the supply chain bottlenecks for year-round availability of feedstock and address issues related to the low calorific value of rice straw.
- Wear and tear in the shredding unit (due to higher silica content of rice straw) is a significant cost factor for a pelletisation plant with greater than 1 tpd scale. Research and development for the right metallurgy and indigenous design of machinery is therefore crucial and collaboration with local entrepreneurs for customised solutions is desirable.

Calorific value of rice straw-based solid-fuel pellets is found to be 3400-3500 Kcal/Kg which his comparable to washed coal (3500-3800 Kcal/Kg). It can therefore easily substitute coal in many applications. Pellets can further be torrefied for 25-30% higher energy value (comparable to imported coal) and a higher shelf life but this entails additional cost.

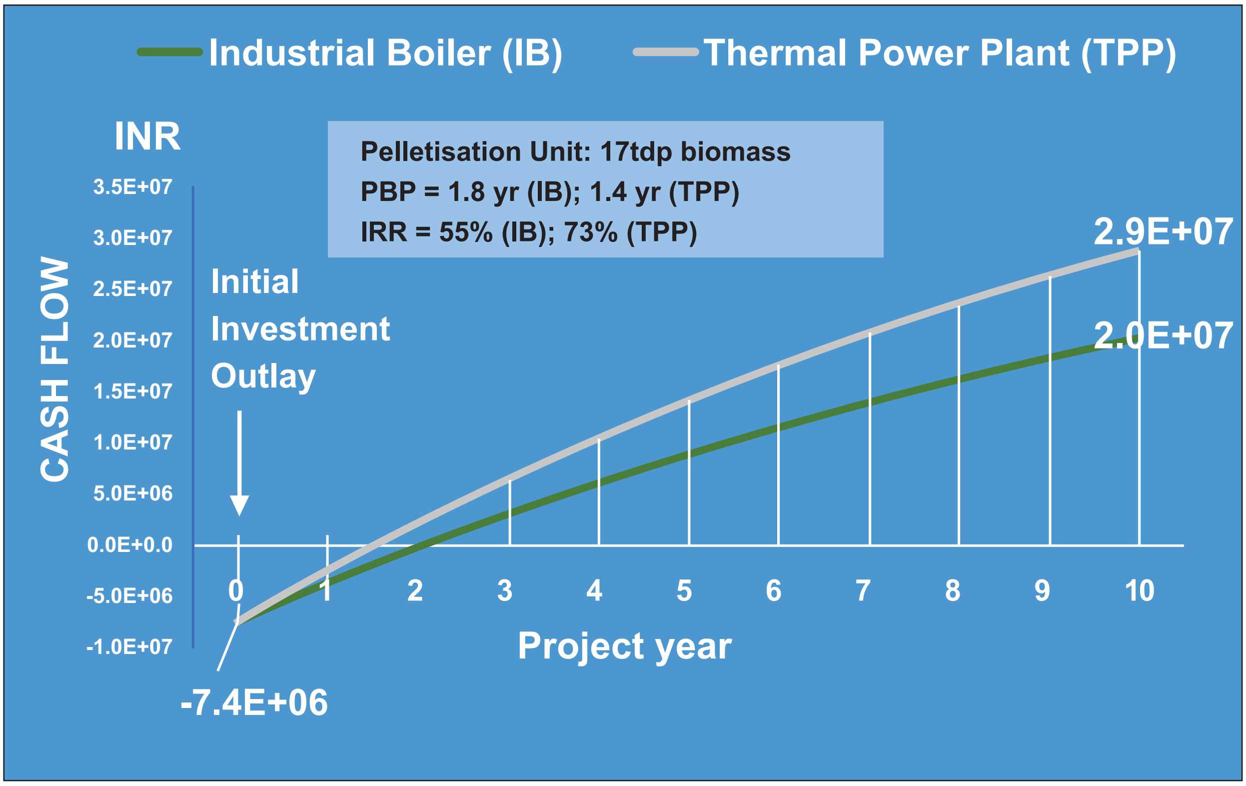
Various specific interventions have been made on this issue after Ministry of Power's advisory (MoP 2017) directed power generators to utilise 5-10% rice straw by co-firing with coal in existing thermal power plants. MoP advisory also assures generators that any

[17] Refer Subsection 4.2 biomethanation of rice straw

MoP advisory also assures generators that any increase in cost of generation will not be taken into account for the purpose of determining priority or merit order for electricity dispatch. Guidance in this regard was issued by the Central Electricity Authority (CEA) in the same year (CEA 2017). The Ministry of New and Renewable Energy (MNRE) has further clarified that generators can even avail non-solar Renewable Purchase Obligations (RPOs) (MNRE 2019). Subsequently, an order was issued by the Central Electricity Regulatory Commission (CERC) for methodology to estimate electricity generated from biomass in biomass co-fired thermal power plants (CERC 2020)

NTPC invited bids for biomass pellets for two years' supply of 1000 tpd in 2018 with a capping of price at INR 5,500/tonne for conventional pellets and INR 6,600/tonne for torrefied pellets. However, NTPC received only 240 tpd material within the capping price. Subsequent tenders have been invited without the price capping. As per NTPC, supply constraints for pellets have not led to significant co-firing so far. Total potential within NTPC plants alone is estimated to be 20 million tonne per annum at 10% co-firing. Technology readiness also exists in industrial boilers for direct firing of rice straw. Several aggregators provide ready to fire feedstock to industrial boilers. In addition, grated boilers or pulsating grate boilers have made it possible to directly fire bales in boilers without any operational challenges.

Figure 16. Investment model for pelletisation unit for use of solid-fuel pellets in industrial boilers with process energy requirement and coal-based thermal power plants



Source: Cleaner Air Better Life (2021) Analysis

The investment model has been developed to assess viability of pelletisation and as depicted in Figure 16, two different scenarios with use of pellets in industrial boilers and thermal power plants have been plotted. Essentially, the key difference between the two models is-

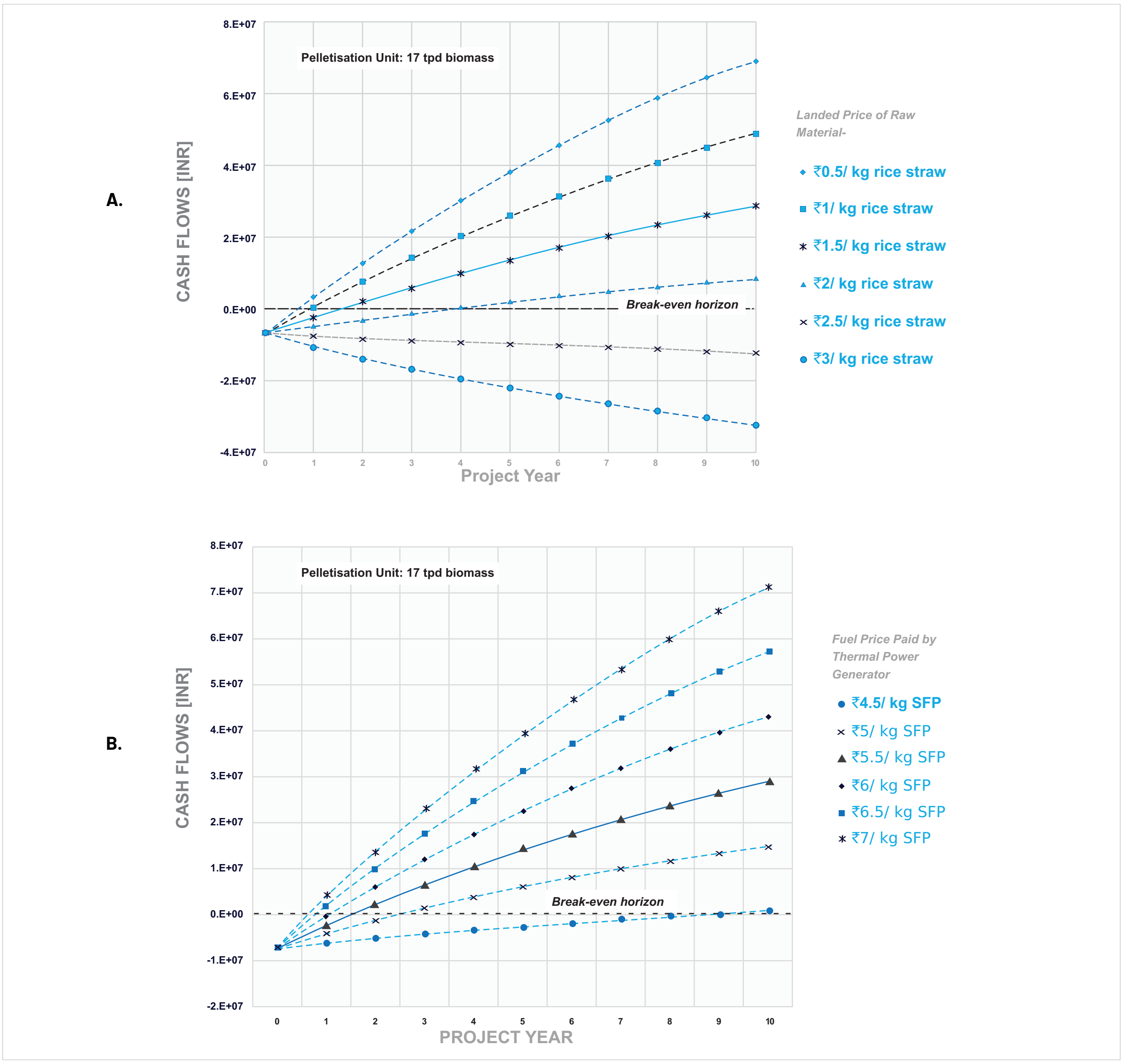
- Additional maintenance cost (assumed to 30% higher for TPP use case) to operator for meeting the particle size requirement as detailed in CEA 2019 guidance document
- The market price of SPF which is assumed to be INR 5 per kg for the use case of industrial boilers (IB) and INR 5.5 per kg for the use case of thermal power plants (TPP)

It can be seen in Figure 16 that the project payback period ranges 1.4-1.8 years depending on SFP configuration. Despite higher maintenance cost, the payback for the TPP use case is marginally higher over IB use case. The project NPV for this pelletisation unit (INR 74 lac capital investment) is INR 2 crore and 2.9 crore for industrial boiler use case and TPP use case respectively. Further, in figure 17, sensitivities have been performed for the use case of TPP over different-

1. Landed rice straw prices for operator of the pelletisation unit
2. Price of solid fuel pellets paid by thermal generators

It can be seen that discounted cash flows of the project in Figure 17 are very sensitive to both of these market prices. The project becomes completely unviable for rice straw prices over INR 2 per kg and pellet prices lower than INR 4.5 per kg.

Figure 17. Sensitivity analysis for (A) landed price of rice straw and (B) solid-fuel pellet price paid by thermal power generator



Source: Cleaner Air Better Life (2021) Analysis

5. KEY FINDINGS AND RECOMMENDATIONS FOR SCALING SOLUTIONS

Key findings with respect to various delivery models discussed throughout Section 4 point to special consideration and customization required in the design of equipment for handling and treating rice straw in North Western states due to its special characteristics: high lignin and silica content. But the biomass management infrastructure which is suited to rice straw can handle almost any crop residue. Also, there is a definite need for more entrepreneurs from diverse backgrounds to join and pool skill sets to overcome technological barriers.

Straw aggregation is a specialised business as it requires a wide array of best practices (See Section 4.1) to be integrated into the business model and needs robust quality control to be able to meet requirements of the user facility. This delivery model will be able to make an economic case for farmers as well rural entrepreneurs. Economic viability exists without even considering any capital subsidies for balers and the venture is profitable with an Internal Rate of Return (IRR) at 18% and benefits to farmers worth INR 1985 per acre. It is in fact the only actionable model which could significantly bring down the cost of ex-situ management at the farmer's end to INR 2924 per acre (from INR 4629 per acre under the conventional model) close to the cost of conventional route which involves burning (INR 2948 per acre). Serving as the very backbone of all subsequent ex-situ management operations, this activity needs to be brought under the priority lending scheme of national banks and also make sure that business risks of enterprises can be covered under insurance schemes. Depending on the size, 100-1000 rural straw banks will be required across Punjab and Haryana e.g. with the scale of delivery model considered in the analysis (which is 60,000 tonnes biomass per year), approximately 200 such units would be required across the two states.

The report presents specific cases of composting, bio-char, animal feed and bio-CNG which can add significant value to the rural economy. Scaling of composting, bio-char and Bio-CNG require promotion and mass awareness among farmers on use of bio-fertilisers for agriculture. Use of green manure remains limited to horticulture in agrarian states. The analysis shows that without using any capital or mirobial solution at all, the farmer can easily earn INR 30,000 in a year with a small composting pit of 30x10 ft. Composting is especially relevant for small-marginal farmers and can even be scaled with the help of specialised equipment on degraded lands.

Standards and certifications for reactors producing bio-char, which do not exist in the country, can affect how bio-char technologies of the future evlove and need to be carefully designed in consultation with technology developers. Also, marketing challenges are being faced in bio-char akin to green manure or bio-fertiliser due to the farmer's heavy reliance on chemical inputs in the reigon.

Non-basmati varieties of rice straw are already being used as animal fodder/feed in the Eastern states of India. Rice straw from Punjab and Haryana is even being transported to the neighbouring state of Rajasthan and sold to farmers who face scarcity of straw. There are perception issues among farmers in Punjab and Haryana which hinder them from adopting rice straw as diet for their cattle. Our rapid analysis of a few samples of rice straw from Ludhiana, Patiala and Sirsa geographies confirm these misconceptions. Values of various nutrients such as proteins, fats and fibre are found to be comparable with wheat straw. A business model (24 tpd feed pellet based on rice straw) being developed by rural entrepreneurs at the GBDSGNS Foundation in Ludhiana has been considered for evaluation of this use case. The TMR feed pellet project has good viability with IRR at 36% and achieves break even in 3 years. This model is only viable for landed price of rice straw less than or equal to approximately INR 2.5 per kg but has been found very sensitive to the prices of filler materials used in TMR pellets. Even slight fluctuations in the prices of filler materials (which depend on local availability of these) could render the TMR feed pellet project unviable and hence project viability can vary from place to place.

While standard assumption of the average price for formulation used in the model is INR 26 per kg, the project becomes unviable at the price of INR 30 per kg.

Bio-CNG can be a great source of clean energy for the rural economy and the assessed model has been found to yield good returns with an IRR at 29% assuming an assured offtake of bio-CNG as well as bio-fertilisers produced during operation. Guaranteed offtake exists only for bio-CNG (under biofuel policy by Government of India). It is found that with no offtake of bio-fertlisers produced in the process, bio-CNG model becomes completely unviable with a negative NPV (INR - 19 crore). Even with a 50% offtake of biofertilisers, net worth of the project is reduced by 72% and payback period nealry doubles.

Therefore, promotion of green manure and bio-fertiliser from agricultral waste or crop residues needs to be the focus of Government policies of unlocking the potential of three technologies: composting, bio-char as well as bio-CNG. Following recommedations are being made for this-

- Green-manure quality certification guidelines needed from Ministry of Agriculture akin to the successful German Model.
- National Agricultural Co-operative Marketing Federation of India Ltd. (NAFED) and similar agencies can be roped in for their Pan-India network to propagate and distribute green-manure through nation-wide network of outlets.

Three key and less popular cases for giving rice straw a new life or converting it into high value-added products have been presented in this study. Typically, crop residue is seen as a waste and this is perhaps why harnessing or recovering energy from rice straw seems like a logical choice. The study finds that material applications of rice straw are equally well suited when compared to energy usage. This is both as a result of inherent properties of rice straw and nature of these processes. Some of these processes, e.g. construction blocks, allow for degraded/wet biomass and are not impacted by lowering of energy value over time. With the right formulation, rice straw makes strong construction blocks and compressive strength is observed to be comparable or more than the commonly used red bricks in India.

Insulation properties of construction elements from straw are far better than conventional materials and their greenhouse gas footprint is either neutral or negative depending on the use case.

Construction and pulping models evaluated in this study have been found highly desirable from an investment perspective and can substitute virgin materials in numerous applications. Our analysis finds that construction panels, blocks and pulp from rice straw are also are found to have IRR greater than 100% albeit with assumptions that all these products (blocks, panels and pulp) are sold at fixed market prices (either lower or equal to prices of conventional products in markets). These three models are also least affected by fluctuations in prices of rice straw. Market awareness related challenges are speculated to be the key barriers when it comes to scaling the use of rice straw in manufacturing of construction elements and hence public/private procurement of these materials and other ways of promotion will be pivotal for the success of these models in future.

Although standards for construction panels or strawboard exist, standards for use of crop residues or lignocellulosic materials in construction bricks/blocks do not exist in the country as of now. As a result, blocks/bricks from crop residues are also not eligible for the eco-mark from Bureau of Indian Standard (BIS). Even if standards exist, e.g. in case of panels, it takes a long time to get green products certified and separate testing guidelines for fast tracking these procedures for green building materials are desirable.

Lastly, the solid-fuel pellets model evaluated in this study shows that despite good market feasibility, this segment has not been picking up as a result of a number of factors such as-

- The customisation required in different units, especially in grinding unit, needs specialised expertise in metallurgy and the learning curve for any start-up is very high. It is similar in the case of TMR feed pellets as well.

- The lack of backward linkages and fluctuations in straw prices are also responsible for poor viability

The latter is true especially in the case of the SF pellets model. Viability and returns have been found excellent for both use cases-

1. Industrial boilers (PBP= 1.8 years, NPV= INR 2.0 crore)
2. Thermal power plants (PBP=1.4 years, NPV= INR 2.9 crore)

Although initial investment for the SF pelletisation unit meeting requirement of the above two markets is essentially the same, a higher operation expenditure is required to produce SF pellets for TPP plants. Our assumption on a slightly higher price being paid by TPPs yielding higher returns, may not necessarily be the case. Analysis shows that the solid-fuel pellets model is most sensitive to fluctuation in straw prices and becomes unviable beyond INR 2 per kg of rice straw. Also, it becomes unviable beyond a price point of INR 4.5/kg for SF pellet. This justifies the recent lifting of capping for SF pellets by NTPC at INR 5.5/ kg. Despite this, NTPC is not able to ensure the seamless supply of pellets. Observing this in the light of the facts below, it can be said that locational criterion and competitive bidding need to be reconsidered for supply for SF pellet to thermal generators.

- SF pellet model in this study only evaluates the viability for supplying within 150 km radius of the SF plant
- Bids are being invited for supplying pellets in NTPC plants across locations in India.

A New policy mandate, akin to Government of India's fly ash directive, could be issued for use of straw-based SF pellets within a certain radius. NTPC has already set the precedent but other private generators in the North Western region and industrial boilers in Punjab and Haryana need to follow and start utilising pellets in a small amount up to 10-15%. Taking these insights into consideration and given the fact that necessary guidance has already been provided on this matter by concerned authorities and regulatory agencies (e.g. MoP, MNRE, CERC and CEA as discussed on Section 4.5); Government may consider mandating all such units to start consuming at least 5% rice straw-based SF pellets. Industrial boilers could be given a choice to co-fire SF pellets as well as rice straw directly as long as adequate emission control systems are in place and order.

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