SUGARCANE STRAW RECOVERY ROUTES

SUCRE PROJECT

APRIL 2020

UNDP

gef
GLOBAL ENVIRONMENT FACILITY
INVESTING IN OUR PLANET

SUCRE

lnbr
brazilian biorenewables national laboratory

CNPEM
Brazilian Center for Research in Energy and Materials

ABOUT SUCRE PROJECT

The SUCRE (Sugarcane Renewable Electricity) Project is primarily designed to **increase the production of electricity with low greenhouse gases (GHG) emission using the sugarcane straw** made available during the crop harvest. SUCRE team has been working on identifying and solving issues that hinder partner mills from fully and systematically generating electricity. Beginning in June 2015, it is a total five years of Project, with funding of around US$ 7.5 million from Global Environment Facility (GEF) and a counterpart from the Brazilian Center for Research in Energy and Materials (CNPEM) of over US$ 3 million. The recovery and use of straw for electricity production in the private sector triggered an investment of approximately US$ 160 million by partner plants (a major part of which has already been done through the installation of dry cleaning systems, refurbishment or purchase of boilers, turbogenerators, balers and other pieces of equipment). The initiative is managed through a partnership with the United Nations Development Programme (UNDP) and is carried out by the Brazilian Biorenewables National Laboratory (LNBR), which is part of CNPEM.

ABOUT LNBR

The Brazilian Biorenewables National Laboratory (LNBR) is part of the Brazilian Center for Research in Energy and Materials (CNPEM), a non-profit private organization that operates under Contract Management with the Brazilian Ministry of Science, Technology, Innovations and Communications (MCTIC). LNBR uses Brazilian biomass and biodiversity to solve key scientific and technological challenges by employing high-performance biological platforms of industrial relevance for the sustainable development of advanced biofuels, biochemicals and biomaterials. The Laboratory has a history of technology development in partnership with companies, including start-ups. Among LNBR open-access facilities one finds a Pilot Plant for Process Development, a unique facility for scaling up of technologies.

ABOUT CNPEM

The Brazilian Center for Research in Energy and Materials (CNPEM) is a non-profit private organization under supervision of the Brazilian Ministry of Science, Technology, Innovation and Communications (MCTIC). Located in Campinas, São Paulo, the Center is comprised of four laboratories, worldwide references in their fields, which are open to the scientific and business communities. The Brazilian Synchrotron Light Laboratory (LNLS) is currently assembling Sirius, the new Brazilian electron accelerator. The Brazilian Biosciences National Laboratory (LNBio) is dedicated to solving challenges in the areas of health. The Brazilian Biorenewables National Laboratory (LNBR) is focused on biotechnological solutions for the sustainable development of advanced biofuels, biochemicals and biomaterials, using biomass and the Brazilian biodiversity. Finally, the Brazilian Nanotechnology National Laboratory (LNNano) conducts scientific research and technologic development into solutions based on nanotechnology. The four Laboratories also have their own research projects and participate in the transversal research agenda coordinated by CNPEM, which articulates scientific facilities and capabilities around strategic themes.

TABLE OF CONTENTS

EDITORIAL BOARD AND STAFF

CNPEM DIRECTOR-GENERAL
Antonio José Roque da Silva

LNBR DIRECTOR
Eduardo do Couto e Silva

SUCRE PROJECT MANAGEMENT
Manoel Regis Lima Verde Leal | National Director
Thayse Dourado Hernandes | Coodinator

PRODUCTION
Douglas Forchezatto
Jorge Neves

GRAPHIC DESIGN
Viviane Celente

PHOTOGRAPHY
Projeto SUCRE

INTRODUCTION

With the advance of the prohibition of burning sugarcane in almost all mechanizable areas, straw appears as a residue that can be used as a fuel to generate energy, through direct burning in boilers, since this harvesting practice results in a large amount of biomass remaining in the field.

This brochure describes the sugarcane straw recovery routes, considered before as vegetal impurities and currently seen as a co-product of sugarcane. The processing of shredded straw, although it is a technology not yet in a commercial stage, is also included to show the improvements introduced by SUCRE through virtual prototyping techniques, with biomass modeling, a specialty of SUCRE's team.

During the SUCRE Project, as field trials were carried out under specific circumstances of a few mills, such as: cane field conditions, sugarcane variety, soil texture, implements and agricultural machinery, the data collected in this work cannot be used as a general rule as they may not represent other production environments for mills in the national sugar-energy sector.

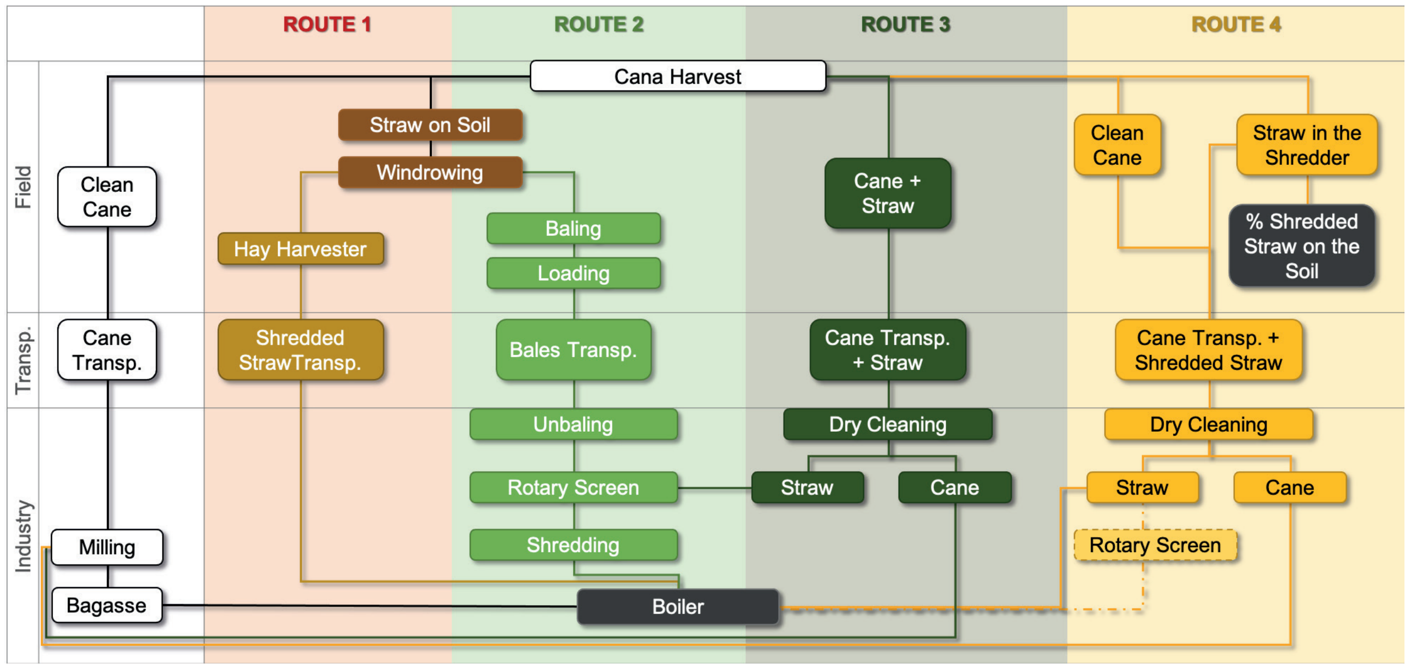
SCAN THE QRCODE
ABOVE OR ENTER THE LINK
HTTP://BIT.LY/SUCREPROJECT
TO READ MORE ABOUT
SUCRE PROJECT

Straw windrowing operations in the field

STRAW COLLECTION ROUTES PERFORMANCE

The four straw recovery routes from the field shown bellow were tested and evaluated during SUCRE Project.

STRAW RECOVERY ROUTES



BEGGINING OF OPERATIONS: STRAW WINDROWING

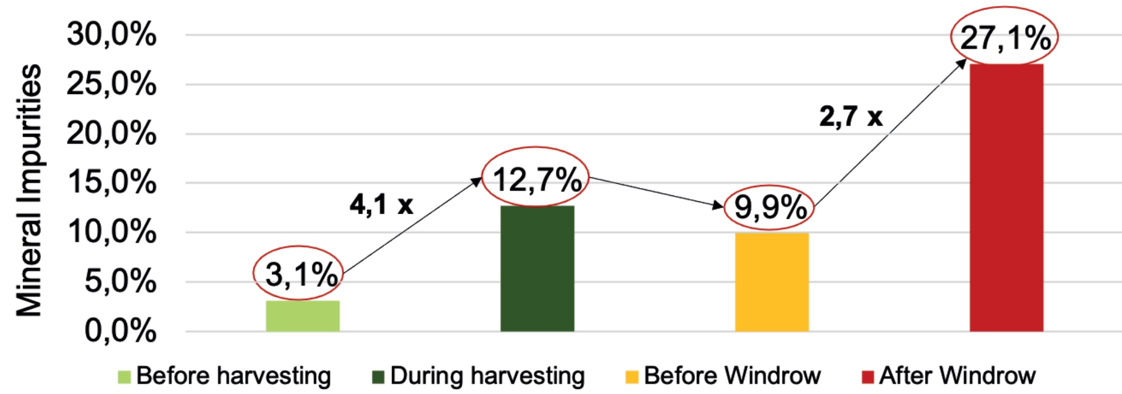
After the cane harvesting and before the windrowing operation, the straw is kept in the field between 4 and 10 days for drying. Before that, the straw has a very high moisture content for the proper operation of the baling machines and after the tenth day, the tillage operations after harvesting are prioritized, competing with the straw recovery.

The windrowing is normally of the triple type, which has three passes of the rake to form a single windrow. With two passes, two adjacent rows are formed, and the third pass joins the two rows, forming a single row.

However, the process incorporates mineral impurities (soil) to the biomass, which causes serious maintenance problems in the industry. In order to better understand this phenomenon, the SUCRE Project evaluated the path of mineral impurity and determined that a large part of it that is incorporated in the biomass does not come only from the windrowing, but that the harvester also contributes to this inclusion.

As the figure below illustrates, in the conventional harvesting of chopped cane, the amount of soil (mineral impurities) increases by up to 4 times, and then there is an increase of almost 3 times in the straw windrowing operation in the field, in the experiments carried on the Project.

INCREASE OF MINERAL IMPURITIES IN THE OPERATIONS OF CANE HARVESTING AND STRAW WINDROWING



ROUTE 1: HAY HARVESTER

After the straw is heaped, in Route 1, the hay harvester machine travels over the rows of straw, and performs the straw collection, chopping and transfer operations to the trucks or transloader trailers, which move alongside the hay harvester. The trucks unload this straw directly into the mill's bagasse stock yard, forming a mixture of bulk straw and bagasse, as shown in the next figures.

This Route 1 has presented in the test a field capacity of 16.8 t / h; fuel consumption of 3.3 l / t; load density of 93 kg / m³; in addition to a collection efficiency of 31%, and a mineral impurity index of 25% in the loaded straw.

Hay harvester operation in the field

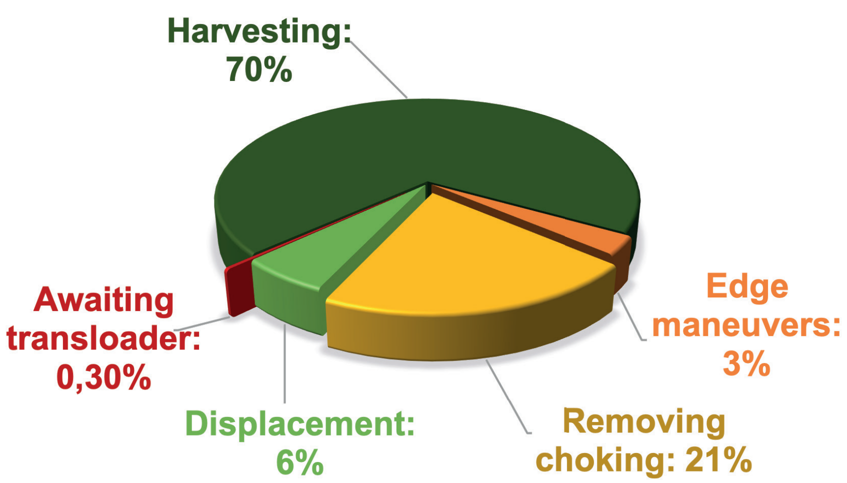
Operation of mixing straw with sugarcane bagasse

Mixing straw with the sugarcane bagasse

The hay harvester operating in the field spends 70% of the time harvesting straw, but is stopped by choking 21% of the day working hours, as this machine was originally developed to work harvesting hay, a much less aggressive crop than sugarcane straw; so this equipment must be adapted by the manufacturers to improve its performance in the field with straw.

The Route 1 of collecting straw in bulk, by hay harvester machines, has as main characteristic the low need for investments in the industrial area. As the straw is shredded in the field, the straw that arrives at the mill does not need to pass through a shredder to reduce the size of the particles to be used in the boilers.

CHART WITH TIME (%) OF THE HAY HARVESTER SPENT IN DIFFERENT OPERATIONS DURING THE WORKING DAY



ROUTE 2: BALING

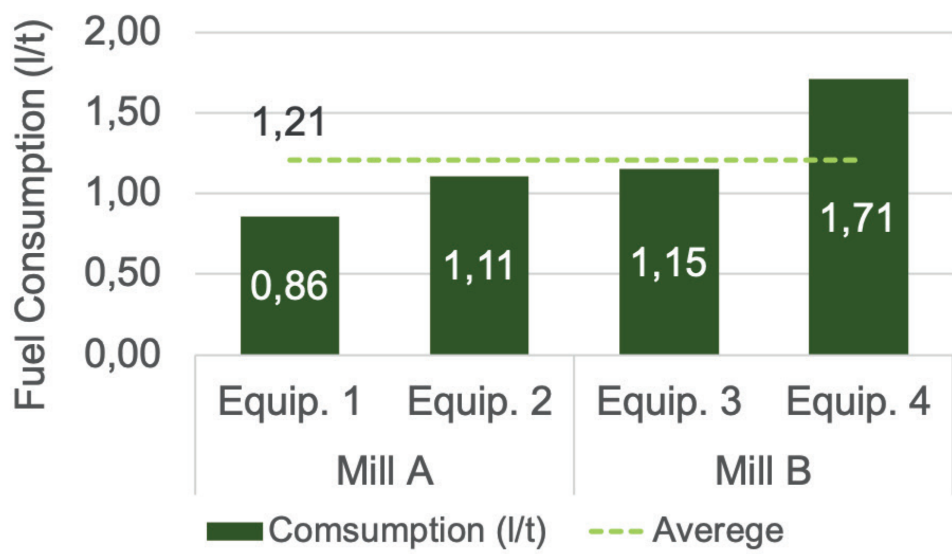
In the Route 2, the baling operation begins also after the windrowing, when the baler collects the straw contained in the windrows, compresses it and ties it with longitudinal twines to transform it into prismatic bales.

The next operation consists of collecting the baled material, which is carried out by the bale-collecting cart. The cart groups the bales into piles and transfers them to the edge of the sugarcane field, from where the bales are loaded onto the semitrailer with the support of a forklift, to be delivered to the reception of the bales processing plant in the industry.

Field tests have shown that the balers have an average field capacity of around 40 t / h, with a straw of around 10% moisture content, with a fuel consumption of 1.21 l / t, incorporating in the straw close to18% of soil, for a maximum collection efficiency of 46%.

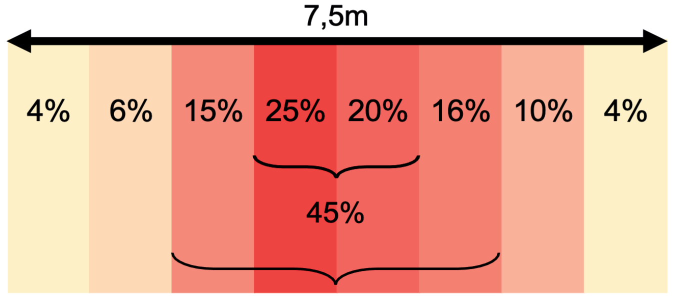
BALERS PERFORMANCE

Mill/ Baler	Weight of bales (kg in bs)	Potential capacity(t/h)	Straw moisture(%)	Mineral impurities(%)
A / Equipment 1	492	43.1	7.4%	12.22
A / Equipment 2	504	45.5	6.6%	9.72
B / Equipment 3	538	44.0	11.0%	24.59
B / Equipment 4	481	34.0	10.4%	24.95
Average	**503**	**41.7**	**8.9%**	**17.87**



COLLECTION EFFICIENCY AND LOCATION OF RESIDUAL STRAW IN THE FIELD AFTER BALING

	Potencial straw (t/ha)	Baled straw (t/ha)	Residual straw (t/ha)	Straw collection efficiency(%)
Mill A (sandy)	14.58	6.73	7.85	**46.17**
Mill B (clay)	13.11	4.51	8.59	**34.42**



Another point to note is the profile of straw distribution in the field, after the collection operation, for both bales and hay harvester. The lack of homogeneity in the straw distribution, which compromises the agronomic benefits of its maintenance in the field, is clearly a result of the collection process, as it concentrates the biomass in the windrow (around ¾ of the remaining straw), because the front fingers of the baler are not able to collect all the material, recovering only part of the straw remaining in the field after cane harvesting.

ROUTE 3 - INTEGRAL HARVESTING (CANE + STRAW)

Route 3, integral harvesting, does not require the windrowing process because it does not collect straw from the ground. Instead, during the harvesting operation, the straw is not separated from the cane, or only partially removed, by the harvester extractor fans, but is directed to the transloader along with the cane.. The advantages are the elimination of all subsequent straw harvesting operations, whether by bales or bulk (hay harvester), the reduction of mineral impurities due to the fact that the straw no longer has contact with the soil, and the immediate release of the harvested area for the subsequent tillage operations, in addition to independence from the climate, not requiring anymore the 4 -10 days of sunshine to dry the straw.

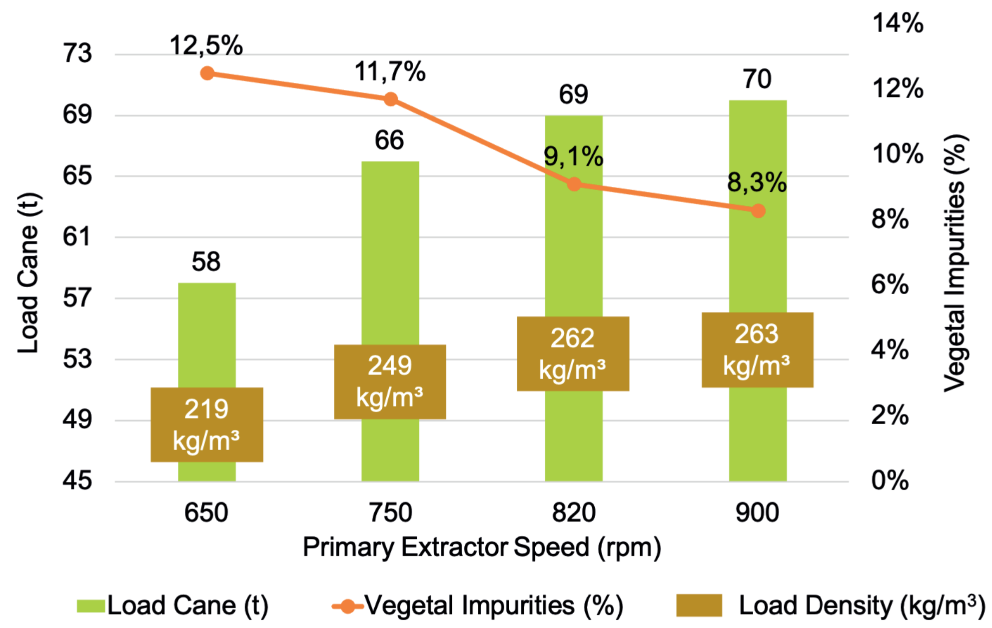
However, its critical points are the low density (Figure below) of the cargo transported to the mill, greater need for equipment in the harvesting fleet, especially transloaders, with the consequent higher cost per ton transported.

Cane + straw load on the integral harvest route

In order to assess the impacts of collecting straw with integral harvesting, Route 3, on the technical indicators of harvesting, transloading and transport, tests were carried out to assess the influence of the rotation speed of the primary extractor of the chopped sugarcane harvester, on the amount of vegetal and mineral impurities in the load, the sugarcane visible losses, the fuel consumption and the potential field capacity of the harvester.

The figure below shows 4 % lower vegetal impurity index in the load between extreme fan speeds, 20% increase in load density, resulting in an additional 12 t in the transported weight.

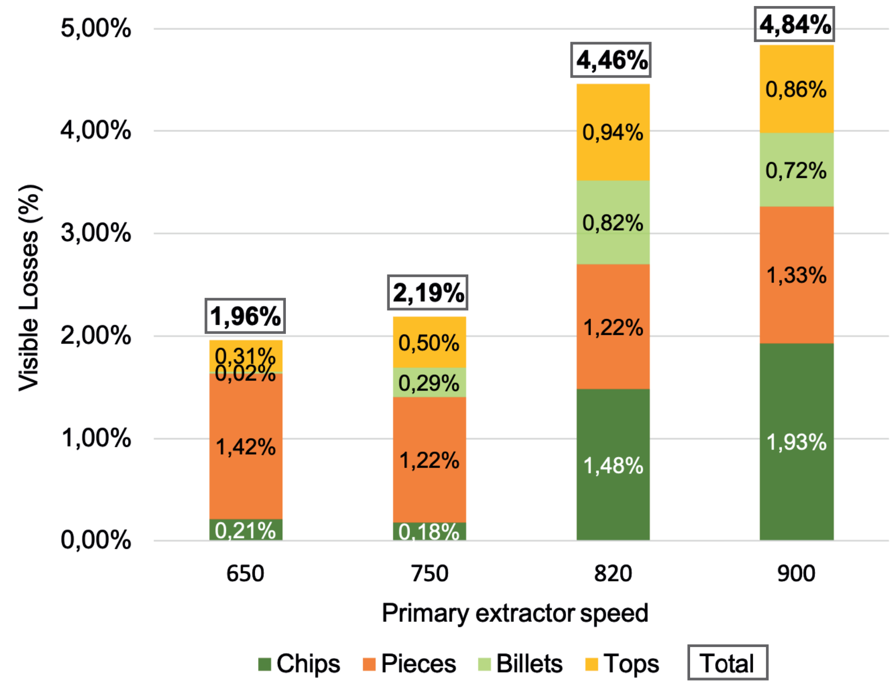
CANE TRANSPORTED VERSUS VEGETAL IMPURITIES



CANE VISIBLE LOSSES

The figure below illustrates that higher extractor speeds resulted in 2.5 times more visible losses in the field than with lower speeds.

VISIBLE LOSSES FOR DIFFERENT RPM OF THE PRIMARY EXTRACTOR



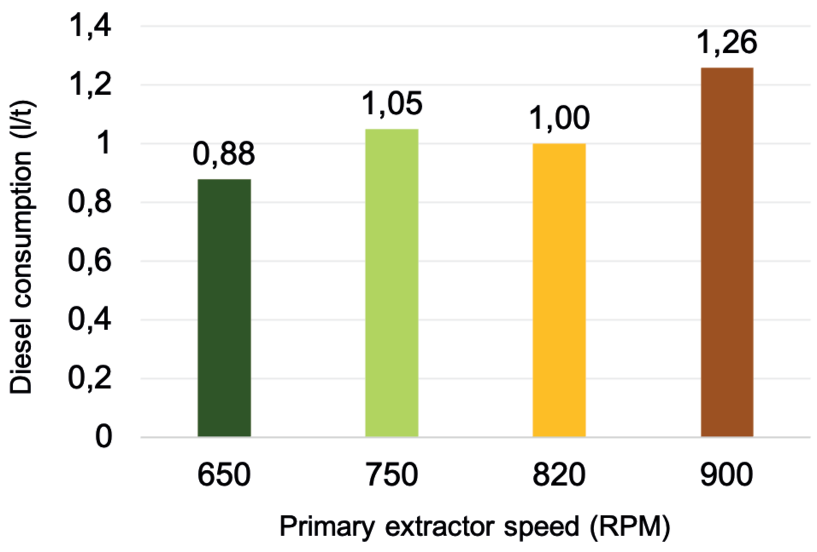
FUEL CONSUMPTION

The primary extractor at 650 RPM reduces the fuel consumption (Figure beside) by 30%, when compared to the 900 RPM rotation.

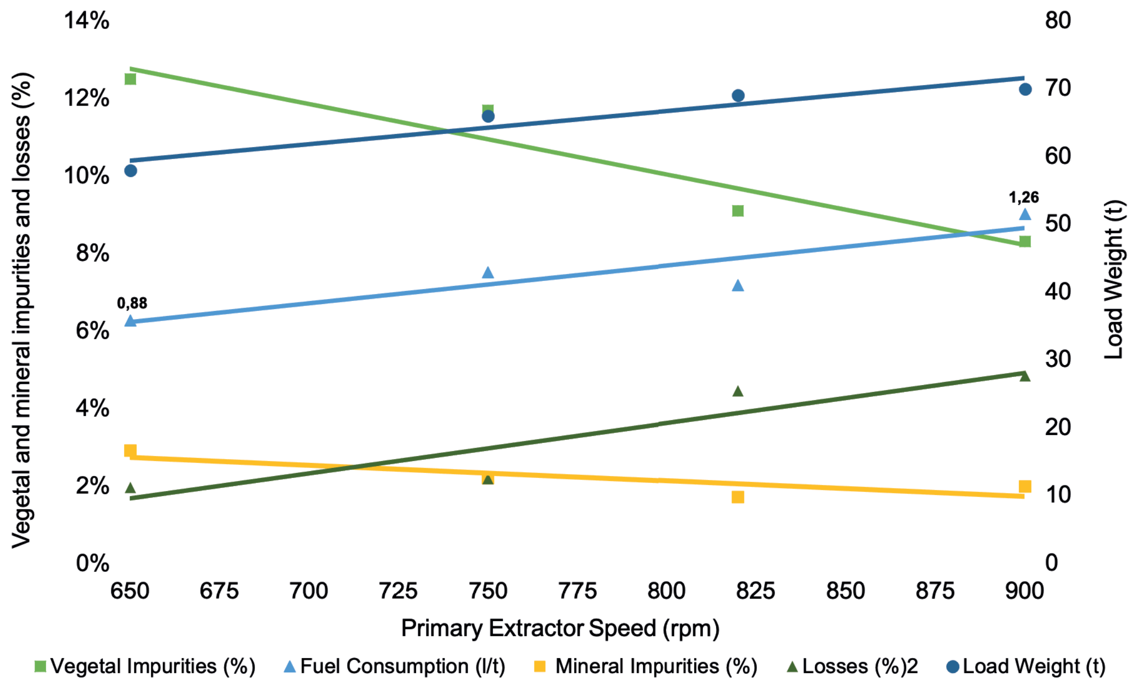
Figure shows a summary of the test with all variables evaluated in the field associated with each speed of the primary extractor.

The reduction of the speed of the primary extractor to 650 RPM in the cane harvester allows a greater amount of straw to be transported with the cane billets, but this strategy increases the transport cost due to the reduction in density. On the other hand, this configuration reduces the visible losses of sugarcane billets by 2.8 percent points.

DIESEL CONSUMPTION VARYING THE RPM OF THE PRIMARY EXTRACTOR



EFFECT OF THE VARIATION OF THE PRIMARY EXTRACTOR RPM ON EACH FIELD VARIABLE



WHAT IS THE BEST ROUTE?

In the case study of the following Figure, performed with the CanaSoft / BVC tool, it was considered:

- Milling of 3Mi t (average mill);
- Recovery of 2.6 t/ha of straw (26%);
- Average straw transport distance to the mill of 27 km;
- Yield of 80 TCH (tons of cane per hectare);
- 10t of straw/ha (dry basis) remaining in the field after harvest;
- In the comparison of the recovery routes, route 3 of integral harvesting (cane + straw) has shown a 39% lower cost than route 1 with bulk straw (Hay harvester) and 47% lower than route 2 (Baling).

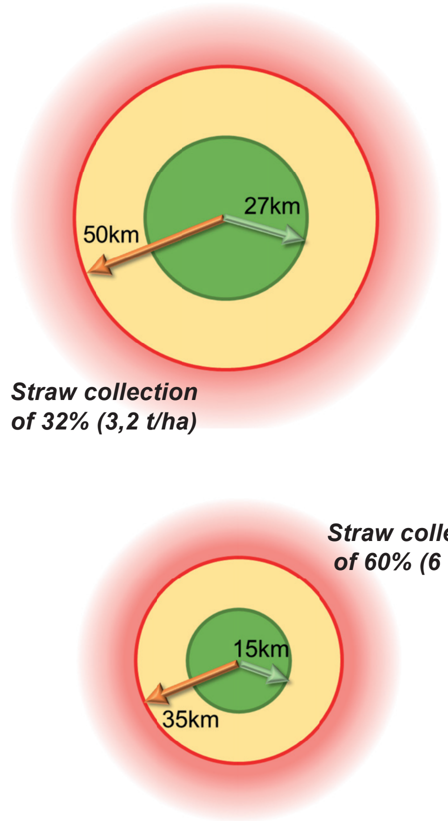
COMPARATIVE COSTS OF STRAW RECOVERY

A sensitivity analysis (figures below) was performed at the same mill in relation to the distance from the industry, assuming a collection of 32% (3.2 t/ha) and 60% (6.0 t/ha) of straw.

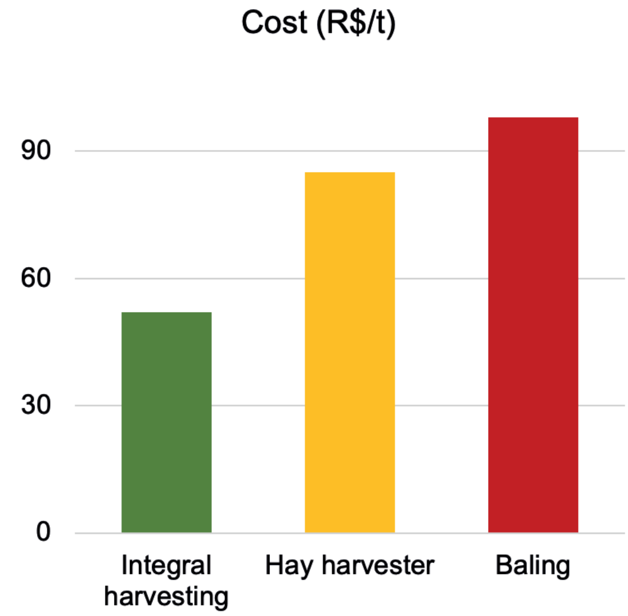
Given that there are pros and cons in all routes, the only way to assess the most advantageous route is through economic viability analysis, and for that there was a need to include the distance factor in the analysis because transport costs, which are the most impacted, respond directly to this variable.

With this being said, it is each mill´s responsibility to analyze its own straw collection plan and choose the solution that best suits it.

SENSITIVITY ANALYSIS OF THE ROUTES IN RELATION TO THE DISTANCE OF THE INDUSTRY



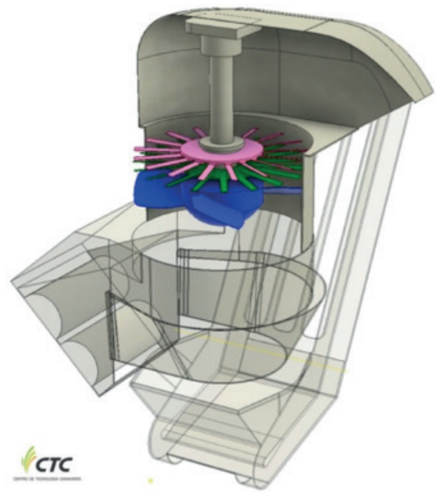
COMPARISON BETWEEN THE STRAW RECOVERY ROUTES



SHREDDED STRAW RECOVERY IN THE FIELD: A NEW WAY

SUCRE Project established Route 4 of shredded straw recovery, aiming to improve the critical items present in Route 3 (Integral Harvest), that are the low density of the load transported to the mill, greater need for equipment in the harvesting fleet, especially transloaders, and low efficiency of the Dry Cleaning System (DCS) in the industry.

Route 4 foresees the implementation of a straw shredder (figure beside), which is mounted on the primary extractor of a commercial chopped cane harvester, which chops all cane straw material that is blown by the primary extractor, through one set of rotary knives / counter-knives.



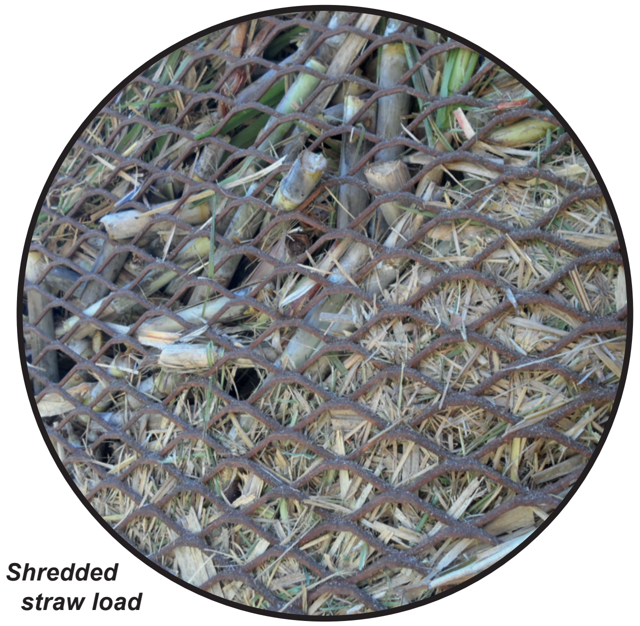
Straw shredder, set of rotary knives / counter-knives, (green and pink), mounted on the primary extractor of the commercial chopped cane harvester

LNBR/CNPEM, with the permission of the Sugarcane Technology Center (CTC), built a prototype of the Straw Shredder/CTC set, with the objective of evaluating the effect of the straw shredding on the load density, on transport cost and, mainly, on efficiency of the dry cleaning system in the industry, currently at a maximum of 38%, according to tests carried out by the SUCRE Project.

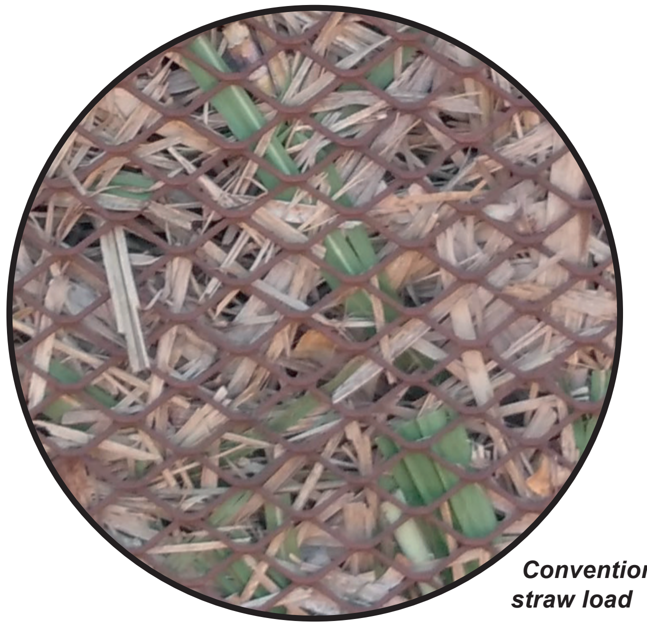
The new component was assembled on the primary extractor of a Case A7700 commercial chopped cane harvester (figure below from a SUCRE Project partner mill).

With the straw shredded, directing 50% of the biomass into the load and 50% to the ground (figures below), more straw is transported per load, with a higher load density, reducing transport costs.

Assembly of the straw shredder/CTC in a commercial harvester from a mill partner, and operating in the field



Shredded straw load



Conventional straw load

RESULTS: LOAD DENSITY

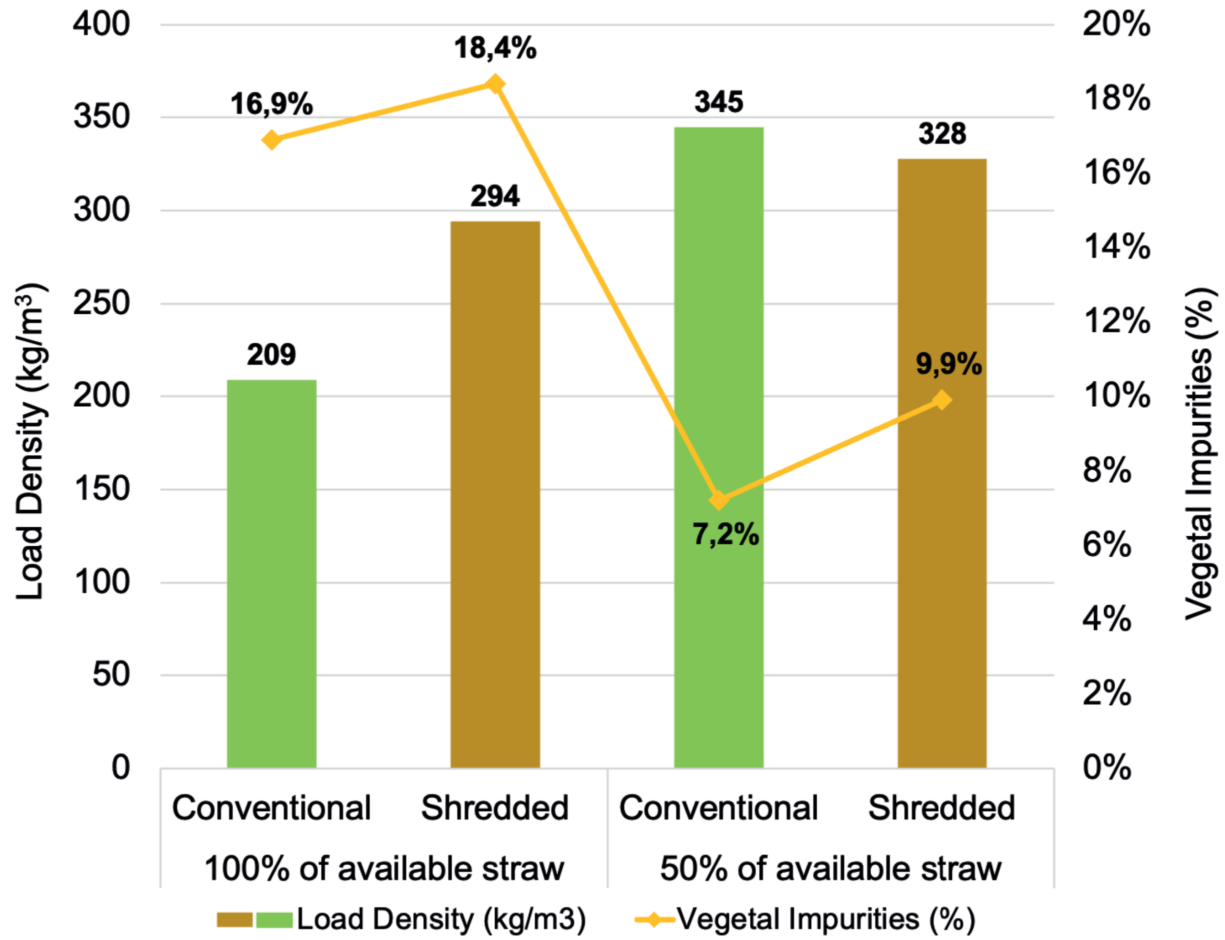
During the first tests, when was transported to the mill all the straw available in the sugarcane field (100% of the amount of straw into the cargo), there was an increase of 41% in the density of the load, from 209 to 294 kg/m³, with a difference of 2 percentage points in the vegetal impurity, from 16.9 to 18.4%, as shown in the Figure below.

In the case of the collection of 50% of the straw available in the sugarcane field, that is, when the amount of straw in the load was reduced by 50%, although the load density has been reduced by 5%, from 345 to 328 kg/m³, it was found that the vegetal impurities increased by 38.8%, from 7.2 to 9.9%.

It is possible to note in the graph below:

- 100% Shredded Straw: + 9% straw (1.5 %) with 41% more weight, in the same volume (m³) transported;
- 50% Shredded Straw: + 37% straw (2.7 %) with 5% less weight, in the same volume (m³) transported;

LOAD DENSITIES WITH DIFFERENT PERCENTAGES (%) OF SHREDDED AND CONVENTIONAL STRAW
(PATTERN STRAW PROCESSED BY CONVENTIONAL CHOPPED CANE HARVESTER)



RECEPTION AND PROCESSING IN THE INDUSTRY

According to each route, on arrival of biomass at the mill, there is a pre-processing to be carried out before the material is adequate to be mixed with bagasse and fed to the boiler.

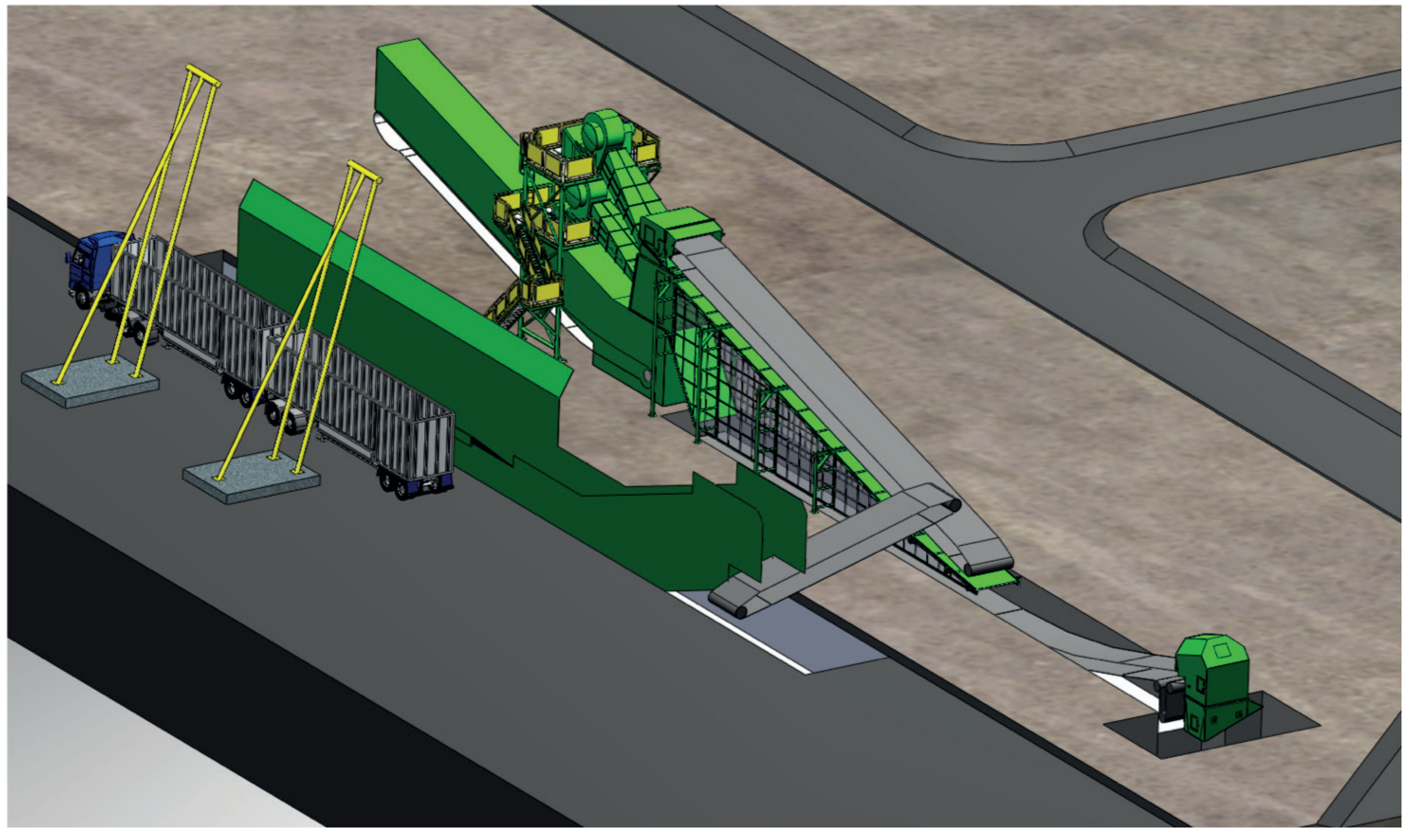
If the biomass is collected by Route 1 – hay harvester -, it is already in a particle size distribution close to that of the bagasse and in condition to continue to storage or use in the boiler. Coming from Route 2 - baling - there is a need for processing consisting, normally, of unbaling, screening and shredding, in a specific plant. Finally, if it comes from Route 3 – integral harvesting – or from Route 4 – integral harvesting with shredded straw –, there is a need to separate the straw from the sugarcane + straw load, which occurs in the Dry Cleaning System (DCS). After separation, the conventional straw, if it came from Route 3, goes through screening and shredding.

The SUCRE Project conducted a field evaluation of the efficiencies of the some existing DCS, as shown in the table below, which indicates that the highest efficiency of the tested DCS was 38%.

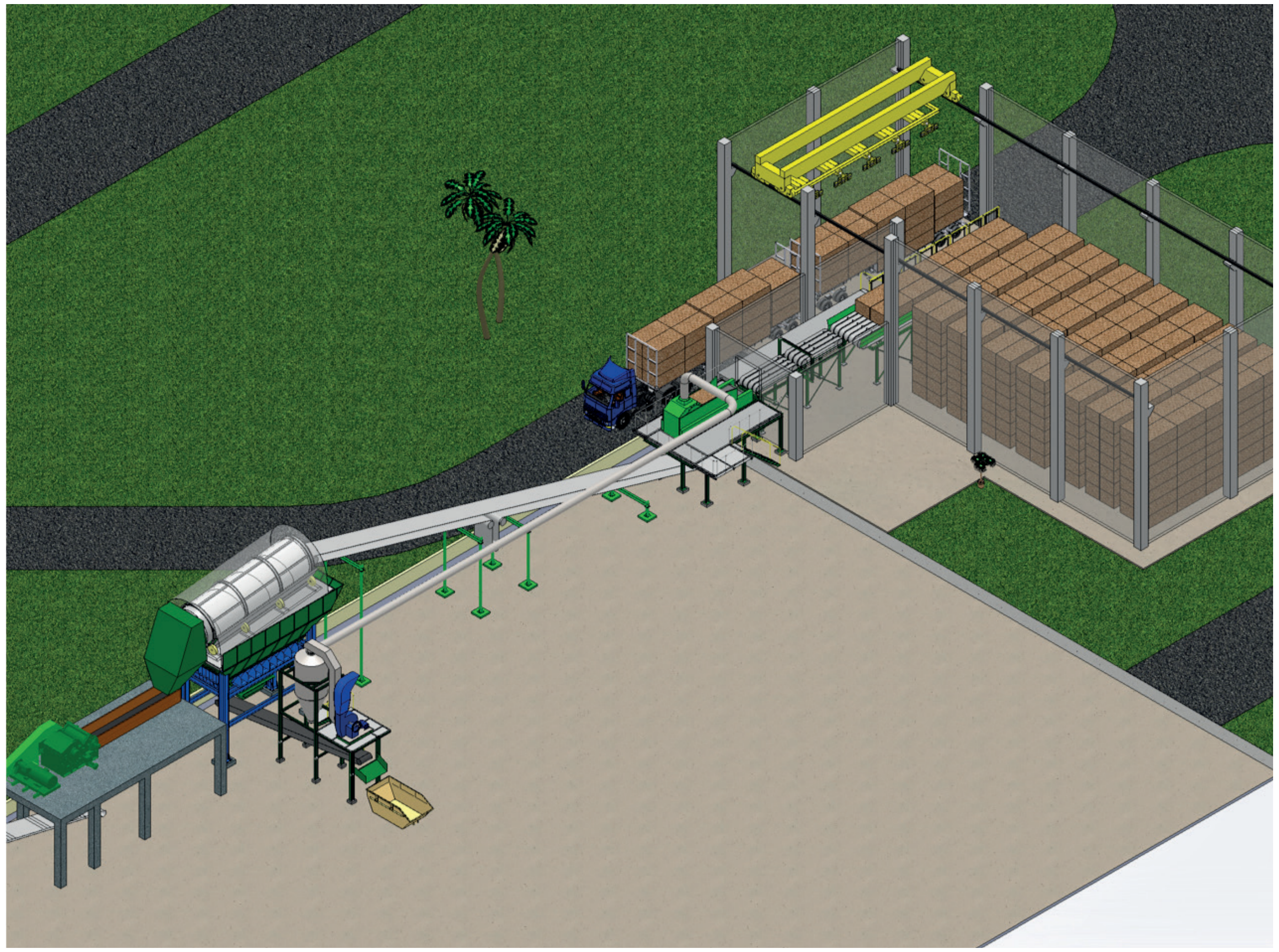
The layouts show the pre-processing systems and include a flexible plant, which allows operation with both systems, bales and integral harvesting.

DCS EFFICIENCY WITH CONVENTIONAL CHOPPED STRAW

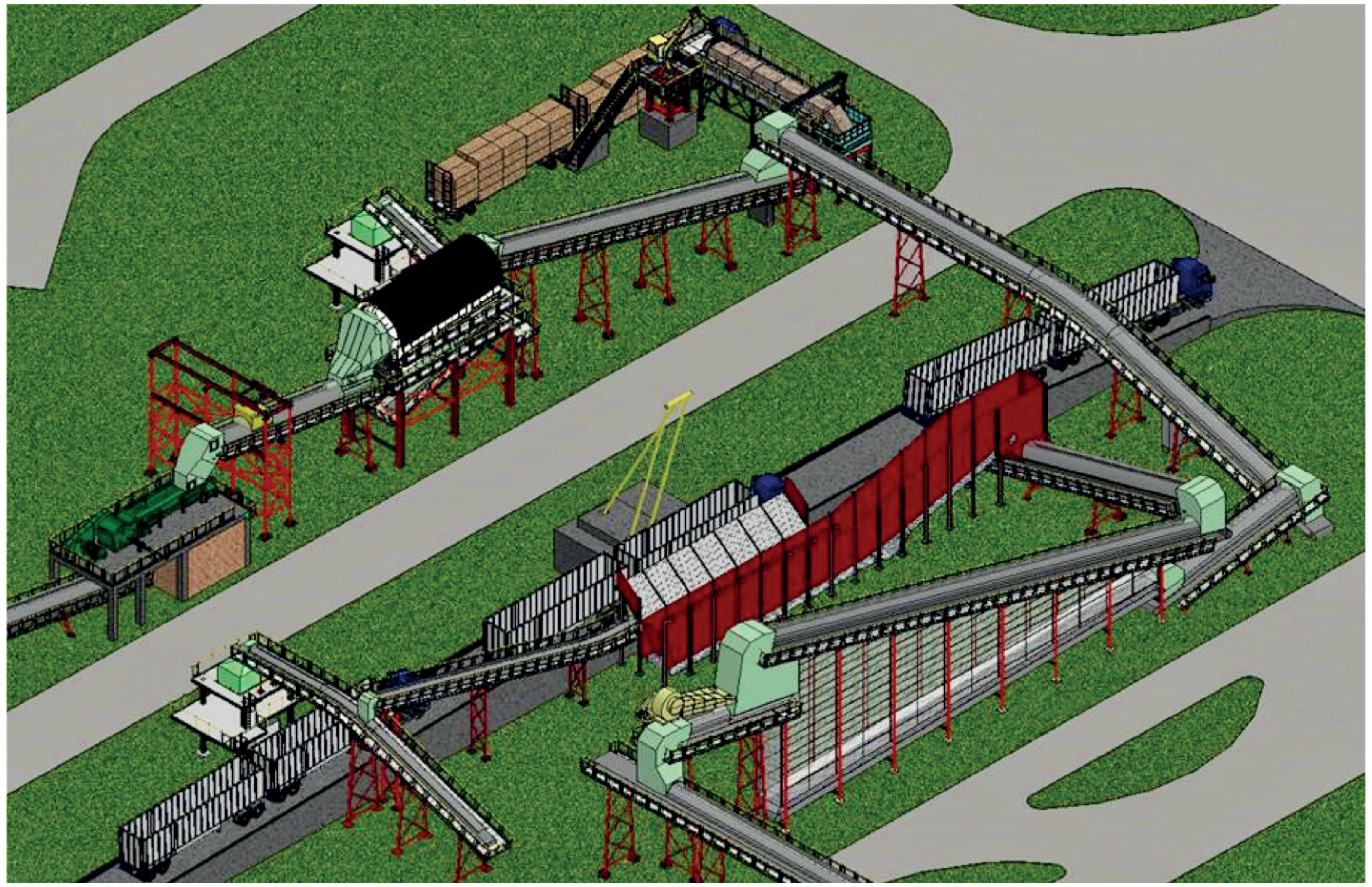
Mill	Processing of sugarcane during the test (t/h)	Input straw (%w.b.)	Straw separated during the test (t/h)	Straw separation efficiency (% w.u.)
1	706	5.5	6.9	18
2	555	12.0	17.6	24
3	740	13.0	23.5	25
4	380	12.4	14.4	31
5	157	7.9	2.9	32
6	1051	4.0	14.2	38



Dry Cleaning System (DCS) industrial plant



Bale Processing System for industrial plants



Mixed industrial Plant, Dry Cleaning System and/or Bale Processing System

EFFICIENCY OF THE DCS WITH SHREDDED STRAW

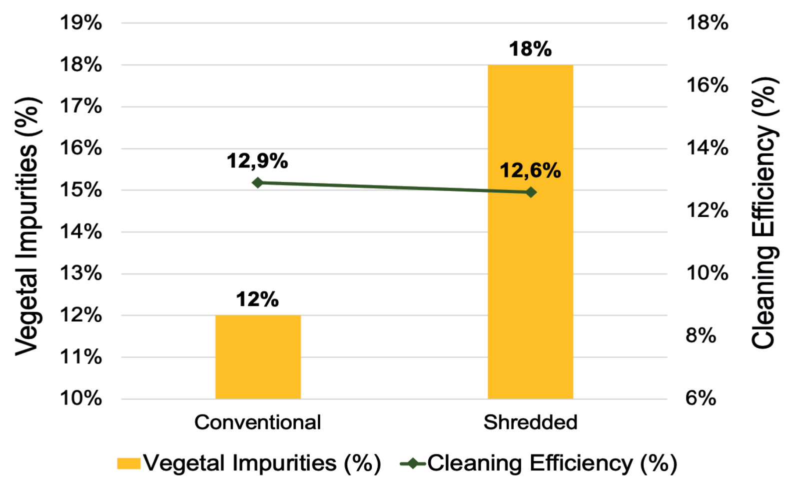
The assessment of the impact on the efficiency of the Dry Cleaning System (DCS) was done by comparing two conditions. The first with the collection of 100% of the available straw in the field and the second with the collection of 50% of the available straw. In both treatments, comparisons were made between shredded straw and conventional straw (straw processed by chopped cane harvester in the conventional way)

The following Figure shows the efficiency results as well as the amount of vegetal impurities measured at the inlet, before going through the DCS.

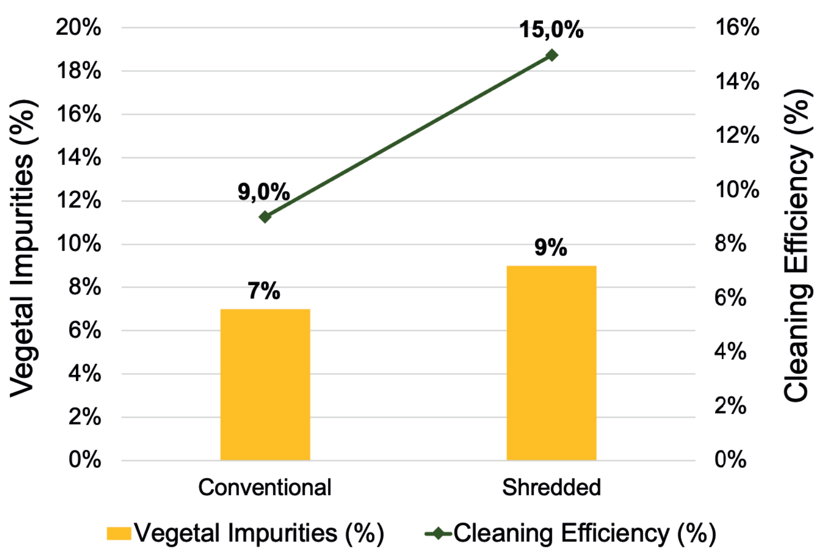
In the configuration for removing 50% of the straw available in the sugarcane field, the preliminary results of the test at the partner mill demonstrated that the DCS had an increase in cleaning efficiency of about 67% operating with shredded straw(from 9 to 15%). It should be pointed out that the percentage of straw in the load was 27% higher, from 7% to 9% vegetal impurity, in conventional and shredded straw, respectively. Due to the low efficiency of the tested DCS, this result shall only be considered as indication of trend and not as a representative value.

In turn, for removing 100% of the straw available in the sugarcane field, the preliminary results of the test at the partner mill demonstrated that the DCS had the same cleaning efficiency of about 13%. However, it should be mentioned that the percentage of straw in the load was 50% higher, from 11.8% to 17.6% vegetal impurity.

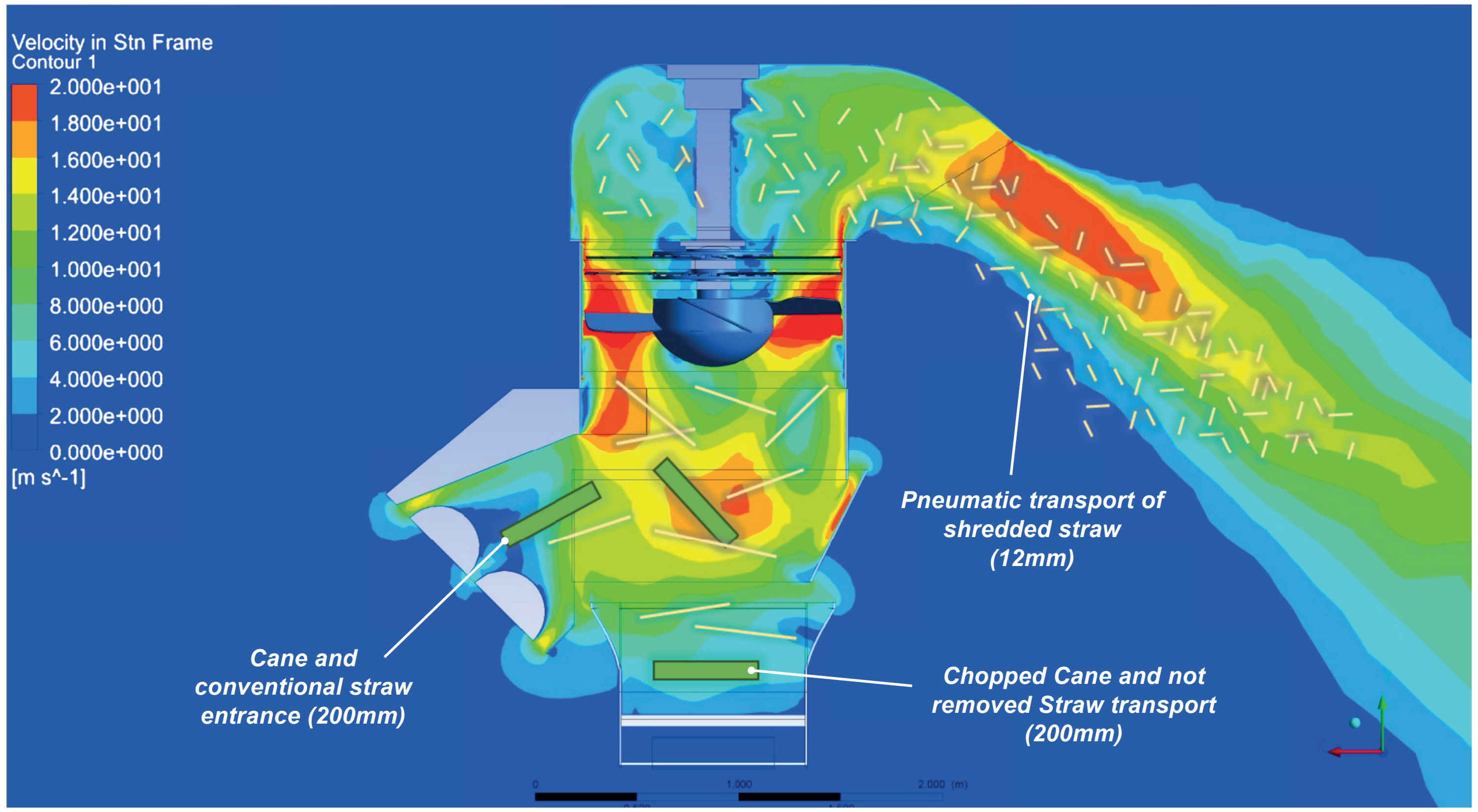
EFFICIENCY OF THE DCS AND PERCENTAGES (%) OF STRAW IN THE CARGO IN THE HARVESTING OF APPROXIMATELY 100% OF THE STRAW AVAILABLE IN THE SUGARCANE FIELD



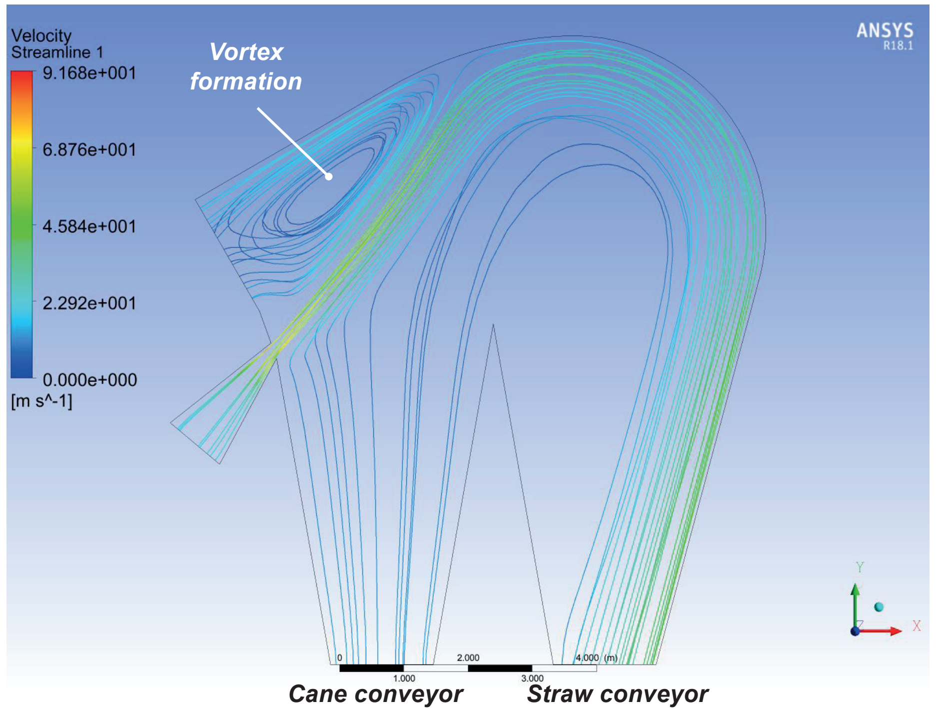
EFFICIENCY OF THE DCS AND PERCENTAGES (%) OF STRAW IN THE CARGO IN THE HARVESTING OF 50% OF THE STRAW AVAILABLE IN THE SUGARCANE FIELD



COMPUTATIONAL SIMULATIONS TO SUPPORT INNOVATION



Another legacy of the SUCRE Project is the indication of the necessary improvements in the straw processing equipment, aiming to increase the performance of this component in the future, with the development by the manufacturers, indicated by the virtual prototyping, the computer simulation, prepared by LNBR/CNPEM specialists.



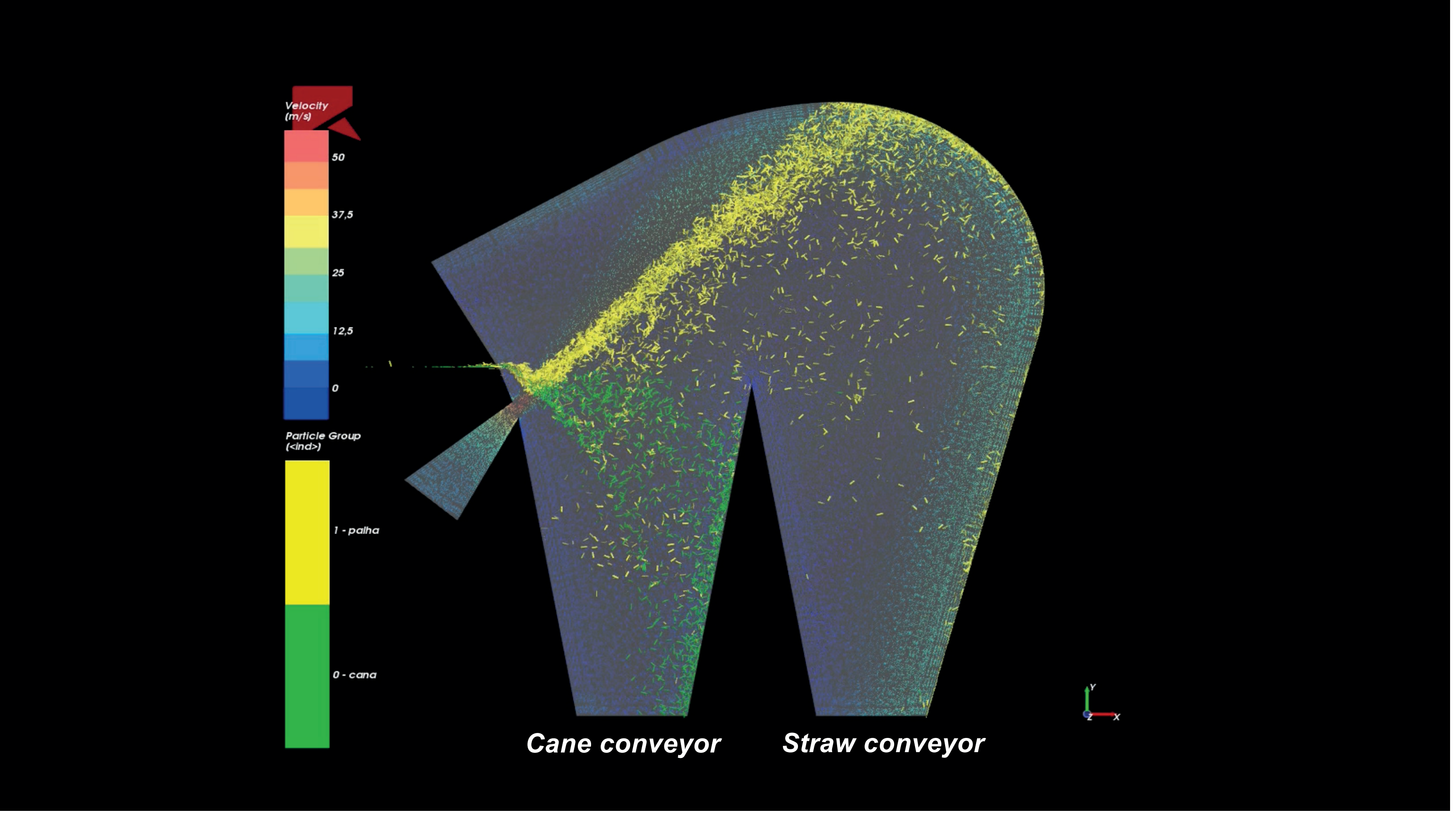
STRAW SHREDDER (FIGURE ABOVE)

Improvement of the Project, removing vortex and increasing the efficiency of the equipment operation. Straw Shredder in CFD (Computational Fluid Dynamics), with a Simulation of the recommended operating condition – 1000-1000-1000 Rotations, that is, primary extractor at 1000 rpm, shredder rotor No. 1 at 1000 rpm and shredder rotator No. 2 at 1000 rpm.

DCS - STANDARD MODEL

Improvement of the Project, by removing vortex and increasing the efficiency of the equipment operation. DCS in CFD (Computational Fluid Dynamics). (Figure beside)

Separation of the straw in the DCS, coupling CFD and DEM (Discrete Element Method): Standard model DCS, computer simulation, average air velocity ~ 30 m/s. (Figure in the next page)



VIRTUAL PROTOTYPING: DCS - OF CFD + DEM ANALYSIS, SCENARIO 1

An analysis of the separation of straw (yellow color) and cane billets (green color), under the influence of an extractor with an air speed of 50m/s.

A second scenario was done with the extractor positioned at 90° in relation to the center of the Octagonal Cylinder ("big drum"), since objective is that the straw be separated and transported to the second conveyor.

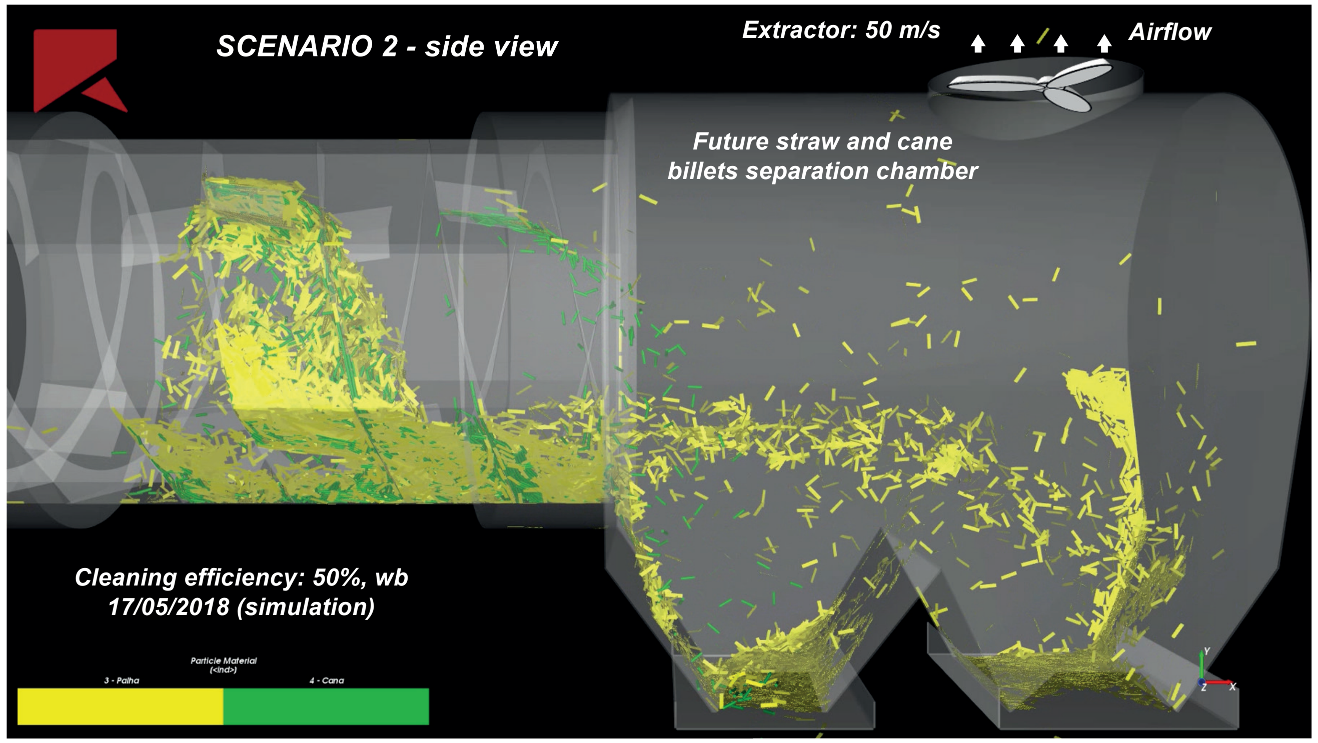
VIRTUAL PROTOTYPING: DCS - OF CFD + DEM ANALYSIS, SCENARIO 2

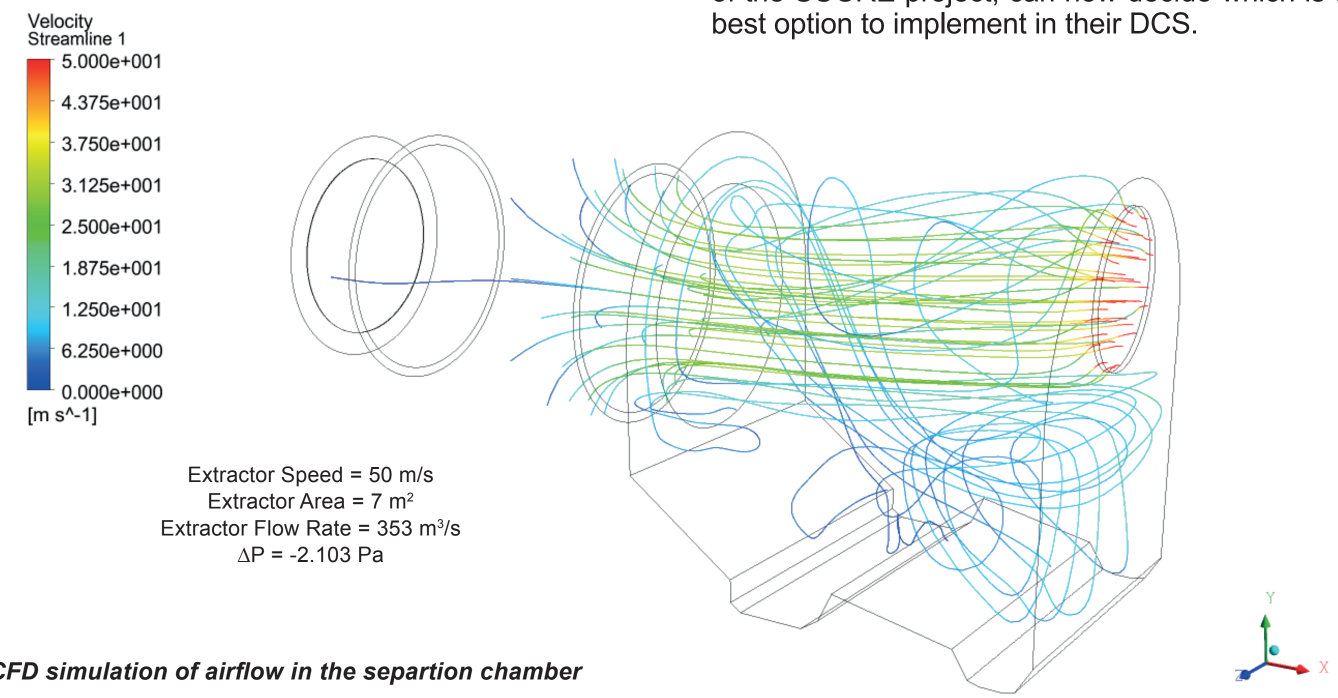
In order to complete the study with the intention of improving the cleaning efficiency of the alternative DCS, another scenario was simulated, with the extractor aligned with the flow of the mass of sugarcane + straw (biomass) and an air speed of 50m/s.

Observing the diagonal / longitudinal view of the equipment, it is noticed that there is an accumulation of straw on the straw conveyor, and it is also noted that the cane is directed to the dedicated conveyor.

The use of virtual prototyping with the aid of CFD (Computational Fluid Dynamics) and DEM (Discrete Element Method) techniques, improved the performance of the straw shredder, mounted on a chopped sugarcane harvester, and increased the efficiency of the Dry Cleaning System (DCS) equipment, in its conventional and alternative versions.

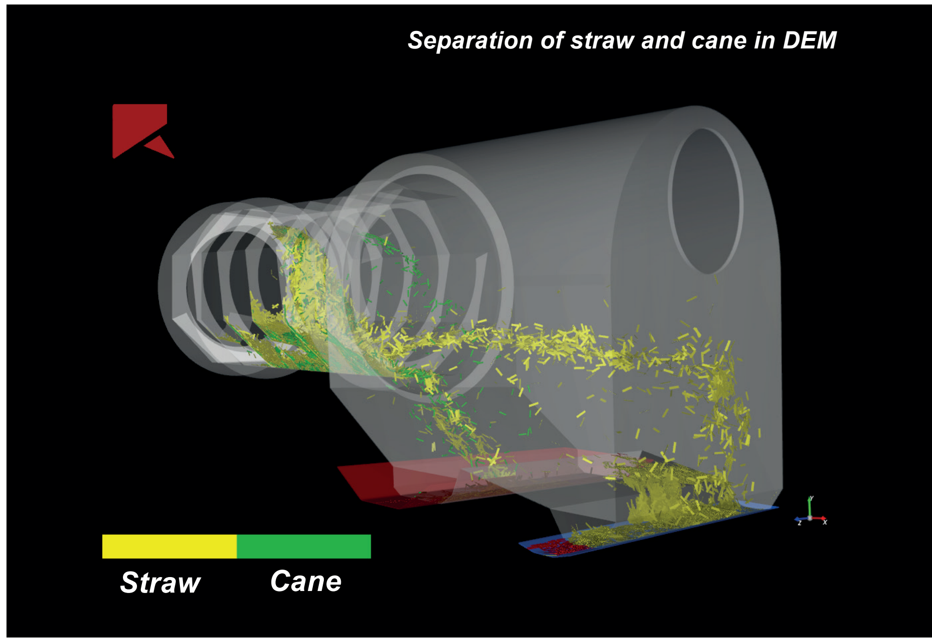
With these simulations, models and scenarios, of the DCSs, the manufacturers of this type of equipment on the market, in partnership with the mills that own these DCS models, taking advantage of this legacy of the SUCRE project, can now decide which is the best option to implement in their DCS.





CFD simulation of airflow in the separtion chamber

FINAL COMMENTS



Based on the results obtained during the trials of the SUCRE Project at the partner mills, it was concluded that the increase in the mineral impurity content in the straw comes firstly from the sugarcane harvesting, but the windrowing operation also has a major contribution to final straw mineral impurities

Field tests have shown that reducing the speed of the harvester extractor makes it possible to increase the amount of biomass that can be transported along with sugarcane billets. In addition, the lower speed favors the reduction of visible losses during the harvesting, reduces fuel consumption and increases the operational capacity of the harvester.

The straw shredder system, CTC model, proved to be promising in straw shredding, since the characteristics of the straw indicated a particle size smaller than the conventional straw processed by chopped cane harvester without shredding.

Shredded straw increased the load density, reducing the cane + straw transport costs, and the impact on efficiency (%) of the Dry Cleaning System (DCS) was positive. However, it is important to highlight that only one trial was done in the agricultural and industrial conditions specific of that particular sugarcane producer.

It is suggested that the mills interested in use the straw as boiler´s fuel, to carry out the agricultural and industrial tests in their own field conditions and, mainly, follow the trials methodology of the SUCRE Project reported in this Brochure.

CNPEM
Brazilian Center for Research in Energy and Materials

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA, INOVAÇÕES E COMUNICAÇÕES

PÁTRIA AMADA BRASIL
GOVERNO FEDERAL

DISCLAIMER

Although the information in this publication is obtained from credible sources and the authors, reviewers and editors of this material have taken comprehensive steps to ensure the compilation and processing of this information in commonly accepted standards, the Brazilian Center for Research in Energy and Materials - CNPEM, its representatives, employees, directors, agents, suppliers or third parties mentioned in this publication do not make any statement or guarantee, expressly or implied, as to the veracity, accuracy, adequacy or compliance of the information for a particular purpose (commercial or otherwise) or absence of infringement of intellectual property or copyright. In no event shall CNPEM, its representatives, employees, directors, agents, suppliers or third parties be liable for direct, indirect, incidental, punitive, special or consequential damages of any kind (including, without limitation, material and moral damages coming out of the use, inability to use or results of use) whether based on warranty, contract, liability or any other legal or equitable theory. The contents of this publication are protected by copyright laws, international treaties and other treaties and intellectual property laws. Except as expressly provided otherwise, the data generated by CNPEM under the auspice of the SUCRE Project can be reproduced provided that the authorship is cited as being from the SUCRE/ LNBR/ CNPEM Project and fidelity is maintained in reference to the official content of the published documents.