Success case of an IBLC into an agroindustry of the animal feed sector

Deliverable D3.7

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	Company
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ABBREVIATIONS

APS: Agroindustrial Pascual Sanz

a.r.: as received, wet basis

d.r.: dry basis

h: hour

IBLC: Integrated Biomass Logistics Centre

LHV: Lower heating value

MSP: Maize stalk pellet

MSP-100: 100 % maize stalk pellet

MSP-10: 10 % maize stalk – 90 % forestry wood pellet

MSP-30: 30 % maize stalk – 70 % forestry wood pellet

MSP-52: 52 % maize stalk – 48 % forestry wood pellet

t: tons

vs: Versus

w-%: weight percentage

WSP: Wheat straw pellet

WP-100: 100 % forestry wood pellet

WSP-100: 100 % wheat straw pellet

WSP-35: 35 % wheat straw – 65 % forestry wood pellet

WSP-60: 60 % wheat straw – 40 % forestry wood pellet

WSP-72: 72 % wheat straw – 28 % forestry wood pellet

yr: year

Partners Short Names

CIRCE: Fundación CIRCE

WFBR: Stichting Wageningen Research

ZLC: Fundación Zaragoza Logistics Centre

CERTH: Ethniko Kentro Erevnas Kai Technologikis Anaptyxis

RISE: RISE Research Institutes of Sweden

CREA: Consiglio per la Ricerca in Agricoltura e L'analisi dell' Economia Agraria

APS: Agroindustrial Pascual Sanz S.L

NUTRIA: Anonymi Biomichaniki Etairia Typopiisis Kai Emporias Agrotikon

LANTMÄNNEN: Lantmännen Ekonomisk Forening

PROCESSUM: RISE Processum AB

Spanish CO-OPS: Cooperativas Agro-Alimentarias de España. Sociedad Cooperativa

INASO: Institouto Agrotikis Kai Synetairistikis Oikonomias INASO PASEGES

AESA: Agriconsulting Europe S.A

UCAB: Association Ukrainian Agribusinessclub

UBFME: University of Belgrade. Faculty of Mechanical Engineer

EXECUTIVE SUMMARY

AGROinLOG is based on the idea of Integrated Biomass Logistic Centres (IBLC) which implies to diversify the activity of the agro-industries through alternative business taking advantage of the synergies related to the current activity (as for instance, equipment, contact network, staff capacity, etc.).

This deliverable is focused on the fodder sector, which was studied through the collaboration during the project of Agroindustrial Pascual Sanz (APS) as agro-industry demo partner and Fundación CIRCE (CIRCE) as main technological centre providing support to this demo.

Agro-industries in the fodder sector normally account with a dehydrated business line to produce high compression bales of lucerne for instance, and a pelletization line to produce pellets for the animal feed market. This activity is mainly taking place between the months from April to November, since the arrival of the loose raw material is what mainly defines the timeframe of the production. In the case of the pellet production this line operates the whole year according to customers' needs and electrical tariffs, although the production capacity is reduced from December to March. In APS´s case, it was estimated that they can work in an alternative business line between 615 to 2050 hours/year depending on the year, without interfering their current activity.

Taking into consideration the available time to operate the new business line, the current machinery availability and their contact network, it was proposed to develop energy blends pellets based on herbaceous materials and forestry woodchips. In this sense, the use of herbaceous material implies to carefully consider some properties (ash, chlorine, …), which have a huge variability associated to the area where these crops are cultivated, and also to other parameters like the management of the crop or climate conditions. For this reason, a traceability assessment should be performed by the agro-industries, in order to identify the best raw materials considering the quality that should be reached in the end product; the aim is to guarantee the production of a blend pellet with the maximum amount of herbaceous material without compromising the quality of the final product. The less wood is used in the blend, the lower the operation cost will be, since working with wood normally implies extra steps, like the reduction the moisture content and the pre-milling of the material, steps than can be avoided using wheat straw and maize stalk.

Along the project different blends were produced by APS and monitored by CIRCE, cost operation was obtained and validation activities were carried out. As a result, the blend 60 % straw – 40 % wood was selected as the best blend developed according to the quality criteria and cost operations optimization for APS, being competitive with the industrial pellet under the current market conditions which is the main competitor of the blend pellet produced.

The IBLC model demonstrated to be profitable in the case of APS and probably in agro-industries of the fodder sector with similar conditions having a pelletization line already, even though there are two main risks in order to fulfil this goal:

- Securing the selling of a new product in the energy market at the targeted price could be challenging depending on the market conditions, mainly in the first years, since the agro-industry needs to identify, attract and retain its clients.
- Raw material cost could increase depending on the year, which could compromise the project economic feasibility.

Outside the energy market, other studies were performed in order to assess the possible use of pure herbaceous material to produce thermoplastic reinforced with natural fibres, activated carbon, adsorbent for hydrocarbons spills, bio-composites, and furfural and levulinic acid. The results obtained were very promising, although in the short-term the commercialization of this product for these purposes is difficult since the market is not yet well developed.

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1 INTRODUCTION

AGROInLOG is a project based on the demonstration of Integrated Biomass Logistics Centre (IBLC), which is defined as a business strategy for agro-industries to take advantage of unexploited synergies in terms of facilities, equipment and staff capacities, to diversify regular activity both on the input (food, feed, and biomass feedstock) and output side (food, feed, biocommodities & intermediate biobased feedstocks), thereby enhancing the strength of agro-industries and increasing the added value delivered by those companies.

Three different demo cases were studied in different agro-industries sector (fodder, olive oil, and grain sector) along the project in order to assess the feasibility of developing new business lines outside of the currently one, Figure 1.

Figure 1: Sector of the three demo cases deeply studied in AGROInLOG project.

This deliverable was focused on the fodder sector, which was studied through the collaboration during the project of Agroindustrial Pascual Sanz (APS) as agro-industry demo partner and Fundación CIRCE (CIRCE) as main technological centre providing support to this demo.

The deliverable is structured as follows:

- Previous study to evaluate the integration of an IBLC: the current situation of the agro-industry is briefly described but also the feasibility to implement a new business line and the market potential of the new product.
- Considerations to assess the technical and economic feasibility of an IBLC in the fodder sector: firstly an introduction describing the importance of this action is included, then the methodology followed to carry out the study, the main results obtained in the agro-industry studied and the conclusion for the fodder sector.
- Finally, the advantages and drawbacks are mentioned, as well as the lessons learned and the conclusions obtained for the fodder sector.

2 Previous study to evaluate the integration of an IBLC

The first point to assess if an agro-industry can become an IBLC, it is to determine the current situation of the agro-industry, the range of hours that the company could work in other activities different from the regular business line and the months when this period would take place. Secondly, the already existing equipment should be studied as well as their contact network in order to assess its possible utilisation by the new business line. As a result, the new biocommodities that could be produced can be assessed.

2.1 Current situation of the agro-industry

Agroindustrial Pascual Sanz (APS) is an agro-industry dedicated to the production of dehydrated forage (alfalfa/lucerne) for the animal feed market (producing bales and pellets). In order to manufacture these products they have two different lines inside the facility, a dehydrated line and a pelletization line, as described in Figure 2.

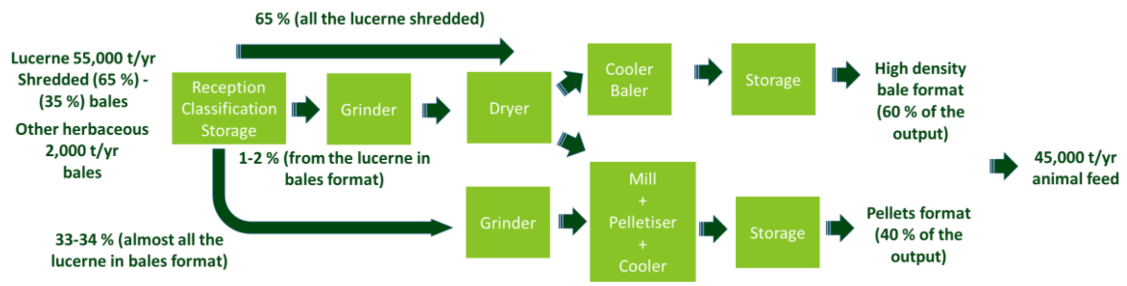

Figure 2: General diagram of the animal feeding from APS production

Regarding this production process some considerations should be taken into account:

- There is one rotatory dryer that is common to the two production lines (bales and pellets). The outlet of the cyclone (located between the dryer and the cooler baler) is the only point in the facility where the line is open.
  Even when producing bales, there is always a small quantity of material (5-10 % of the dryer outlet) that exits the line due to leak problem and this material is used for pellet production.
- The thermal consumption of the facility comes exclusively from the rotatory dryer (natural gas burner). The pelletisers do not work with steam.
- The two coolers work with ambient air recirculated by fans (no cold is produced to be used in this process).
- The higher electrical consumption comes from the pelletization line, mainly the mill and the pelletisers (there are two).

As any other company from the agro-industrial fodder sector, APS business is highly dependent on the market demand and prices which considerably fluctuates every year according to the availability of the raw materials and its corresponding prices. APS' customers are both national and international (around 50 % of the sales are international being EAU and China the main international markets). To provide an overview of the production within the last years, the following figures are provided:

- Production of 27,000 t/year of lucerne in a high density bales format, being around 22-24,000 t/year of 100 % lucerne (65-80 % of these bales are for international market) and 3-5,000 t/year of the animal feeding blend (100 % for international market).
- Production of 18,000 t/year of lucerne pellets format for animal feed market (10 % for international market).

The lucerne campaign generally starts in April and finishes in November, as can be seen in the Figure 3. The main gas consumption, which totally correspond to the dehydrated line used to produce bales, takes place from May to October in 2018, and the electrical consumption which mainly corresponds to the production of pellets occurs from April to November in 2018.

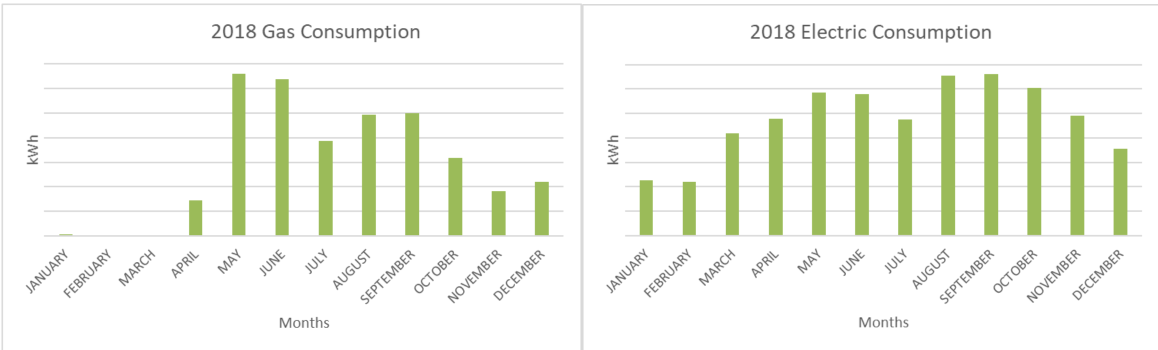

Figure 3: Gas consumption (left) and electrical consumption (right) in APS through 2018

It can be concluded that APS´s case, and as general rule for the agro-industries in the fodder sector, has a seasonal activity mainly working in the months from April to November. This fact is clearly significant in the production of bales (dehydrated line), since the arrival of the loose raw material is what mainly determines the timeframe of the production. In the case of the pellet production, this line operates the whole year according to the customers' needs and electrical tariffs (even though from December to March the production decreases comparing to the other months, from April to November).

2.2 Feasibility to implement a new business line

Before defining the optimal biocommodity for the new business line, it is important to determine the available time that the agro-industry can invest in the new business line. As previously mentioned, in APS´s case (and generally in agro-industries from the fodder sector) their current activity mainly takes place between April to November. For this reason the idle period established to implement the new line was proposed between the months from December to March, although unlike what happens with bale production, feed pellets are manufactured during the whole year.

2.2.1 Methodology

In order to assess the available time for the new line during the idle period, some considerations must be taken into account:

- The operation in each hour does not have the same effect on the production cost since APS has six different types of electric tariffs as a function of the month and daily hour. P6 is the cheapest and P1 the most expensive. The cost ratio between P1 and P6 is 1.807 (regarding the part of the cost referred to the variable power).
- Despite the variable cost, there is a fixed cost related to the power contracted in each tariff, being as well as for the variable cost, considerably more expensive for P1 tariff than P6.
- Additionally, there is an extra cost when the power contracted in each tariff is exceeded.

Taking into account these considerations, the number of hours available during the idle period and the production capacity were assessed considering two scenarios: (1) without interrupting the current activity of APS during these months and (2) considering that APS would interrupt their animal feed production during these months, therefore the agro-industry would be entirely dedicated to produce the new product. In order to evaluate these scenarios, the following aspects were taken into account:

- The assessment was performed in order to determine the hours that were available to work in the new line considering the hours that the installation was not working during these months and 50 % of the hours in which only the dehydrated line was working. Also, considering the excess restriction, which during these months implies not working in electric tariff P1 since the cost associated to the excess will imply more than 25 €/t (the power contracted in this tariff is 250 kW). For this reason, from December to February it was considered that the line could work 90 % of the time from 21 to 10 (5 hours in P2 and 8 hours in P6), and in March 90 % of the total hours.
- The optimal configurations selected to produce energy pellet during the time range considered, were the Tub grinder + hammer mill + peletizer 1 (P+M+ GR1) in the electric period of P2 to P5 (the average production is 2.11 t/h and the average power 430 kW), and the Tub grinder + hammer mill + peletizer 1 + peletizer 2 (P+M+ GR1+GR2) in P6 (the average production is 3.70 t/h and the average power 560 kW).
- Electric cost was assessed (variable and excess cost).

2.2.2 Results

Taking into account the previous methodology, the results obtained for APS case are showed in Table 1 and Table 2.

Table 1: Production capacity and electric cost of the new line without interrupt the current activity of APS from December to March.

Production capacity of APS in the new business line without interrupt the current acivity						
	Total time available to produce energy pellet (h)	Available time considering excess restriction (h)	Available time considered (90 % of total time) (h)	Energy pellet production (tonnes per month or year accordingly)	Variable cost (€)	Cost associated to the excess electricity consumption (€)
2016						
Dec	574	375	337	1124	11302	740
Jan	494	317	285	955	9528	682
Feb	457	253	228	729	7781	597
March	310	310	279	860	9122	653
Idle period total 2016	1834	1254	1128	3747	37733	3027
2017						
Dec	499	321	289	962	9708	767
Jan	403	226	203	651	6937	644
Feb	366	185	167	508	5806	574
March	268	274	246	766	7987	695
Idle period total 2017	1536	1006	905	2887	39438	2680
2018						
Dec	320	220	198	663	6608	711
Jan	453	278	250	815	8492	778
Feb	218	129	116	388	3867	566
March	243	267	240	725	7864	738
Idle period total 2018	1234	893	804	2591	26831	2793
2019						
Dec	222	139	125	385	4363	568
Jan	264	184	166	562	5505	696
Feb	218	145	131	446	4329	626
March	165	214	192	611	6257	724
Idle period total 2019	869	682	614	2004	20454	2613

Based on these considerations and input data, the number of available hours to produce energy pellet without interrupting the current activity of APS ranges from 1128 to 614 hours a year, which implies around 3750 to 2000 tonnes of energy pellet annually, assuming a cost per month lower than 1000 € associated to the excess on the electricity consumed.

Table 2: Production capacity and electric cost of the new line interrupting the current activity of APS from December to March.

Production capacity of APS in the new business line interrupting the current activity						
	Total time available to produce energy pellet (h)	Available time considering excess restriction (h)	Available time considered (90 % of total time) (h)	Energy pellet production (t/year)	Variable cost (€)	Cost associated to the excess electricity consumption (€)
Dec	744	538	484	1923	16024	894
Jan	744	527	474	1613	15743	883
Feb	696	467	421	1408	14079	828
March	744	744	670	2008	21848	991
Idle period total 2016	2928	2276	2048	6685	67695	3596

On the other side, the available hours to produce energy pellet considering interrupting the current activity of APS during these months is 2048 hours, which imply 6685 tonnes of energy pellet annually, with an excess electricity cost per month lower than 1000 €.

2.2.3 Conclusions

Both scenarios reflect the feasibility for agro-industries of the fodder sector to manufacture a new product, in terms of available time, production capacity and how the values considered for these aspects vary during the idle period studied. This information is certainly useful for the agroindustry in order to adapt the new production line since it should be highlighted that the lucerne market is highly variable from year to year. Because of this, APS and other agro-industries can explore the possibility to implement an alternative activity in those years in which their main activity as dehydrated lucerne producers decreases and their free time during the idle period increases.

This study should be carried out by any agro-industry interested in becoming an IBLC, since it can slightly or strongly change depending on the power electricity contracted, the variable cost and fixed cost and the power consumption of the specific agro-industry. As a result, this study can provide the company with a first number about the production capacity that can be achieved as an IBLC.

2.3 Market potential of the new products

The opportunity for APS or any agro-industry to become an IBLC lays on the synergies with their current activity in terms of facilities and man-force in order to explore new markets and reduce their investment pay-back period. As a result of the current facilities and the huge contact network of suppliers of herbaceous material, also being the more abundant feedstock in the surrounding area, these raw materials were considered as the input material to be considered to produce agro-pellets.

One of the main drawbacks of the herbaceous material is the high content of chlorine and ash which are linked to undesirable combustion properties. For this reason, from the beginning it was considered necessary to do some research about the design and production of blended pellets, and not just pellets 100 % made with herbaceous material. As a result, the raw material considered to produce bio-commodities were wheat straw, corn stalk and forestry wood. Sudan grass was initially considered but finally discarded as raw material for energy uses due to the high purchasing price of this material (60 €/t) and its current interest as product for animal feed.

The reasons behind of the production of pellets are mainly four:

- APS already has a pelletization process, so the investment required to adapt the line to produce blend pellet is minimal.
- Pellet format allows higher bulk density and therefore lower transport costs to the final consumer.
- It is a usual format for solid biomass due to its facility to flow (boiler feeding system) and reduced storage needs comparing to other biofuels such as almond shells per energy unit.
- The particle size of the material composing the pellets (less than 6 mm) makes easier their processing as feedstock for other products (like bioplastics, biochar, extraction of chemicals, etc.) avoiding extra costs for grinding and milling compared to a supply in bale format.

In general terms, even when using blends with woody resources, agro-pellets could not satisfy the requirements of the average domestic boilers according to the national standards (usually designed for high quality woody pellets) mainly due to their ash behavior. But they can guarantee a sufficiently satisfactory performance on medium or large-scale boilers with automatic cleaning system of ashes placed for example in the cattle or food sector facilities or in rural areas. Generally speaking, these installations include more robust devices prepared to deal with lower quality fuels as well as ruled by final users more accustomed to performing O&M maneuvers in the boiler and looking for minimizing energy costs. In order to be competitive in price, the agro-industry strategy should be focused towards targeting the proper installations that are currently using industrial pellet instead of the installations that are using agro-residues without mechanical transformation.

3 CONSIDERATIONS TO ASSESS THE TECHNICAL AN ECONOMIC FEASIBILITY OF AN IBLC IN THE ANIMAL FEED SECTOR

3.1 Selection of raw materials

As previously mentioned in section 2.3, working with herbaceous material for energy purposes involves several restrictions to be taking into account. For this reason the following study was proposed.

3.1.1 Methodology

The Chlorine content (and other elements) has a huge variability associated to the area where these crops are cultivated and to other parameters like the management of the crop or climate conditions. For this reason, and in order to optimize the percentage of wood needed, a traceability assessment of the wheat straw and corn stalk was carried out. To this aim APS' main suppliers were identified, and the corresponding main storage areas studied. Additionally, representative samples were taken from these different areas in order to analyse the quality of these raw materials (proximate analysis, ultimate analysis and ash composition).

Since the more appropriated raw materials are purchased by APS and until the final product is manufactured in their facilities, it needs to be stored at the plant in open air conditions during a period of time. As result, there could be dry matter losses and possible degradation of the material in the storage area that needs to be quantified and considered.

These losses were evaluated for wheat straw and maize stalk under normal conditions (always open air storage at APS's facility and stack of bales with a height of 8 bales). The study assessed the weight of the same 24 bales, the evolution of the weight of ten bales associated with the position they had within the pile, the moisture, ash and low heating value content associated with the position of the bale within of the pile. In all the cases samples were analysed every month along the 6 months of the study (from July to December in the case of wheat straw and from October to March in the case of maize stalk).

Figure 4: Procedure to monitor the degradation degree during the storage of wheat straw and maize stalk.

3.1.2 Results

As a result of the traceability assessment carried out, concerning the wheat straw (Table 3) nine areas were considered in the assessment labelled from A to I in the regions of Zaragoza, Huesca and Soria. As a result, two areas (E and F) were selected in which the material had better properties for energy uses than the others. In the case of maize stalk (Table 4), the work carried out was not as intensive as with wheat straw due to rainfalls during the campaign of 2018, for this reason the study was limited to two areas in Zaragoza, picking up the material from the area B.

Table 3: Results of the traceability assessment carried out for the wheat straw in 2018

Traceability assessment for the wheat straw, 2018										
Parameter	Unit	A	B	C	D	E	F	G	H	I
Moisture	% a.r.	5.80	8.20	8.10	9.60	9.70	9.10	7.70	10.00	8.70
Ash	**% d.b.**	**11.10**	**10.9**	**10.7**	**5.80**	**6.00**	**6.50**	**6.70**	**6.40**	**6.60**
	Ultimate analysis									
C	% d.b.	42.20	42.3	42.5	45.29	45.23	44.69	44.51	43.98	44.91
H	% d.b.	5.70	5.70	5.70	5.90	6.00	5.90	6.00	6.00	6.00
N	% d.b.	0.46	0.56	0.53	0.47	0.30	0.33	0.78	0.47	0.61
S	% d.b.	0.10	0.14	0.14	0.08	0.13	0.08	0.13	0.13	0.14
Cl	**% d.b.**	**0.77**	**0.68**	**1.02**	**0.52**	**0.27**	**0.27**	**0.44**	**0.60**	**0.64**
O	% d.b.	39.70	39.7	39.4	42.00	42.10	42.20	41.50	42.50	41.00

Table 4: Results of the traceability assessment carried out for the maize stalk in 2018

Traceability assessment for the maize stalk, 2018			
Parameter	Unit	A	B
Moisture	% a.r.	6.70	14.70
Ash	**% d.b.**	**10.60**	**9.00**
	Ultimate análisis		
C	% d.b.	42.80	43.70
H	% d.b	5.60	5.50
N	% d.b	0.80	0.90
S	% d.b	0.12	0.10
Cl	**% d.b.**	**0.75**	**0.57**
O	% d.b.	39.33	40.23

According to the study carried out to monitor the degradation of the material during the storage throughout the project, it can be stated that the wheat straw increased 5 % its moisture content during the storage period (from 7 to 12 %-w/w) in contrast to corn stalk which decreased it 2 % (from 13 to 11 %-w/w). In the case of wheat straw, the dry matter losses is just 0.5 % but for the corn stalk is almost 4 %. In both cases, the conditions of the bales located on the top are strongly dependant on the rainfall. LHV presents some variability along the months but in both cases the values were quite constant. Ash content evolution showed behaviours not only related to loss of dry matter during the storage, which would have implied obtaining increasing ash content values in all the cases. Looking for other explanations, the influence of other variables as the own variability of this characteristic, the exogenous material added in the harvesting stage and rainfall washing effects could have affected more the results attained.

3.1.3 Conclusions

Carrying out an initial traceability assessment study is very important since it will allow to reduce the amount of forestry wood used while obtaining an energy product with good quality. Additionally, it will contribute to reduce the production cost of this pellet since the more forestry wood is used to produce the blend, the higher the production cost (see section 3.7 for more details).

Therefore, before beginning the supply of the raw material each season, it is highly recommended that the agro-industry carries out an analysis to determine if the quality of this raw material from the best area identified during the project has changed. This action was performed jointly with APS for the wheat straw in 2018 and 2019 for the two areas selected, and based on the results obtained it was concluded that although the chlorine content slightly increased and the ash content slightly decreased comparing to the values obtained in 2018, these values were still appropriate to minimize the percentage of wood in the blend while fulfilling the standard ISO 17225-6 (see section 3.3 for more details about this standard).

Regarding the degradation of the material in open air storage, it can be concluded that it mainly affects to the bales located on the top and the bottom of the pile, being mainly affected the months with a significant rainfall.

3.2 Harvesting and supply chain

The harvesting operation of the new raw materials was studied. Additionally the main possible suppliers that will be contacted in order to purchase these raw materials were identified and ranked.

3.2.1 Methodology

Firstly, a study was carried out to assess the optimal distance in which the harvesting operation with the current machinery used by the agro-industry (self-loading harvesting operations) is more profitable versus the harvesting with a baling system (normally carried out by suppliers, since APS does not have such machinery).

These tests were performed in Zaragoza (Spain) in July 2017 for the wheat straw harvesting, and in October 2017 for the maize stalks harvesting. During each trial, two harvesting systems were tested and compared, the baling and the self-loading wagon systems (Figure 5). The machines used during the tests are common tractors and equipment used by APS suppliers to harvest lucerne.

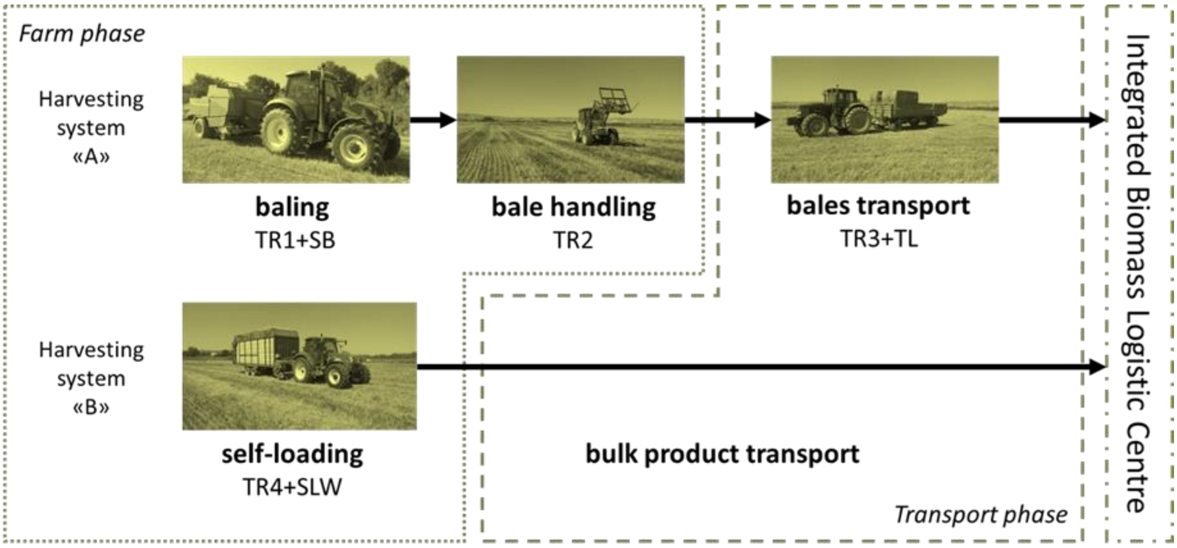

Figure 5: Scheme of the harvesting systems compared during the tests

The methodology followed was based on a split plot experimental design for each harvesting test. The fields were divided in three blocks (statistical replications) for each treatment (baling and self-loading tests). The performance analysis was carried out using primary data collected during the tests: these were the working times of the machines used, the bulk densities of the product transported, fuel consumption of the tractors, biomass losses during the harvesting stage and the moisture content of the biomass at the IBLC. The secondary data collected were all the economic parameters necessary to carry out the cost analysis of both logistic chains. The cost investments (€), service life (y), resale percentages (%), annual usages (h/y), interest rate (%), the repair factors (%) and insurance (%) of the machines, as well as the labour costs were assessed.

Simultaneously, other different study was performed aiming to rank the best suppliers to produce energy and animal feed product. In order to carry out this study different criteria were identified for each sector and it was evaluated based on the weight assigned by nine different experts to each criteria according to their experience. The results were assessed through Analytic Hierarchy Process (AHP), which is a multicriteria decision making methodology to transfer human perceptions into numerical values. Afterwards, all the suppliers were evaluated and a score was assigned to each criteria according to the previous experience of the agro-industry with this supplier, this analysis was developed to assess the quality of the material and other aspects. As a result, a simulation model was done with all this input in order to rank the supplier for energy and animal feed uses.

3.2.2 Results

As a result of the first study carried out, the maximum distance to the IBLC from which it is more economically convenient to gather the biomass in bales (normally provided by the suppliers) instead of using a self-loading wagon per each residue type (normally done by the agro-industry) was obtained. According to the results, regarding wheat straw, distances up to 11.4 km are more profitable to be harvested in bales. In the case of maize stalk it was up to 16.0 km, this higher distance was due to the higher bulk density of loose maize stalks compared to straw (89.3 kg/m^3 and 18.6

kg/m³, respectively), which has a significant influence on the results achieved for straw and corn stalk.

Regarding the second study, the criteria to be considered for each market were assessed (Figure 6) and the weighting factor of each one assigned. In both sectors, the purchasing price and the quality criteria were the most important. Even though, the quality criteria considered were different for each sector, in the case of the energy sector it was based on the moisture content and the ash and chlorine content. In the case of the animal feed it was based on the moisture content, the ash and protein content and the colour of the material. The other criteria in both markets were not as important as the previously mentioned.

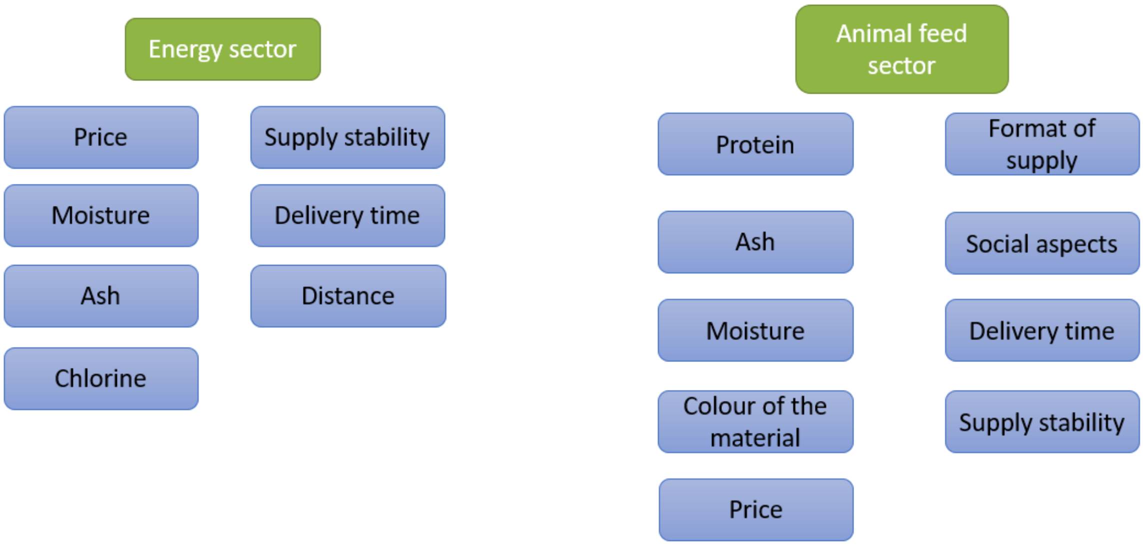

Figure 6: Criteria to be considered for the purchasing of raw material in the energy and fodder sector.

As a result, it was possible to identify the most appropriate suppliers to purchase the material in order to produce energy pellet and to produce animal feed product.

3.2.3 Conclusions

There are several factors that will contribute to improve the profitability of the business line. Among them, the selection of most adequate machinery, taking into account not only the quality of the raw material obtained but also the operational cost associated to this phase of the value chain. The raw material used should fulfil not only quality criteria but also other requirements, among them for instance price, stability, on time delivery, etc. Therefore, the selection of the suppliers that better suit the criteria established is key. It is highly recommended when implementing an IBLC concept in an agro-industry to perform this kind of study since it will provide an easy decision-making tool for the raw material purchasing. The criteria selection and weight assigned will of course be different depending on the end-product manufactured, but the model can be also useful for other sectors.

3.3 Definition of blends

Once the raw materials were selected, the definition of the blends for energy purposes was done according to the following methodology.

3.3.1 Methodology

The considerations taken into account to define the blends were:

- Initially, the 3 first fuels considered were the 100 % herbaceous materials selected (straw and corn stalk) -therefore no blend needed in this case- to determine the range of the operational costs and to evaluate their behaviour in CIRCE's combustion facilities (see section 3.6 for more details). Additionally, the 100 % forestry wood pellet was produced and tested as reference fuel in order to compare the results obtained with the blends pellets.
- In terms of quality, the consideration taken into account was to satisfy ISO-17225-6 class A and B (Table 5) and ash-behaviour indexes criteria (sintering, fouling and slagging). At least, 2 blends of wheat straw and 2 of maize stalk were designed to satisfy some of these criteria.

Table 5: Properties of non-woody pellets (mixed pellets included) according to ISO 17225-6

Quality limits for non-woody pellets ISO-17225-6		
Property	Class A	Class B
Moisture content (w-% $_{ar}$)	≤ 12	≤ 15
Ash content (w-% $_{db}$)	≤ 6	≤ 10
Net calorific value (kWh/kg $_{ar}$)	≥ 4.0	≥ 4.0
Cl (w-% $_{db}$)	≤ 0.10	≤ 0.30

- To satisfy economic and quality criteria so that the blend produced could be currently competitive in the market of the industrial pellet. In this case, a market study was carried out (see section 3.8) in order to evaluate the biofuel against the blend pellet which will be competing considering the differences in terms of price and quality.

3.3.2 Results

Table 6 shows the criteria achieved by the energy pellet blends produced by APS during the project.

Table 6: Criteria achieved by the blends produced by APS

Code	Blend	Quality B (ISO 17225-6)	Quality A (ISO 17225-6)	Ash-behaviour Indexes criteria	Competitive (economically and quality) respect the other biomass
WSP-100	100 % Straw - 0 % Wood	Yes	No	No	Yes
MSP-100	100 % Stalk - 0 % Wood	No	No	No	No
WP-100	100 % Wood	Yes	Yes	No	Yes

WSP-60	60 % Straw - 40 % Wood	Yes	Yes	No	Yes
MSP-52	52 % Stalk - 48 % Wood	Yes	No	No	No
WSP-35	35 % Straw – 65 % Wood	Yes	Yes	No	No
MSP-30	30 % Stalk – 70 % Wood	Yes	No	No	No
WSP-72	72 % Straw – 28 % Wood	Yes	Yes	No	Yes
MSP-10	10 % Stalk – 90 % Wood	Yes	Yes	No	No

Based on these results, regarding the production cost and the analysis of the quality parameters obtained for the different blends, the final blends showing the best economical/quality ratio are:

- Pellets 100 % wheat straw: it could be competitive with agro-biomass with lower quality and prices, as for instance almond shells, olive pits, grape marc, etc.
- Pellets 60 % wheat straw – 40 % wood and 72 % straw – 28 % wood: they could be competitive with the industrial pellet using forestry wood.

3.3.3 Conclusions

After the definition of the blends, the analysis carried out and the validation tests, it can be concluded that in order to define energy blends by the agro-industries, the standard ISO-17225-6 can be considered as a possible standard for quality criteria, even though it is the real combustion test performed in the facilities the one that will provide the outputs to define and evaluate the behavior of the fuel. Regarding the current ash-behavior indexes considered, the conclusion that can be drawn is that the indices present contradictory results for sintering and deposition, for this reason it might not be advisable to consider them in first instance to define the quality of energy blends. The contradictory results obtained might be due to the fact that ash-behavior indexes were designed for fossil fuel, not biomass.

3.4 Production test

Production tests are important since they will allow to define the cost related to the production of the new blends, the new equipment required in order to optimize the line, the people involved in the production of the new line, adjustments required on the operational mode, etc. As result, this information will help to define the cost structure and evaluate the feasibility of the IBLC (see section 3.7).

3.4.1 Methodology

In order to optimize and assess the production cost of the blends previously defined, the whole pelletising line of APS was subject of study as it is the potential part of the facility to be used for the production of biocommodities based on biomass feedstock. Also, the dehydrated line was monitored since it is used to dry the wood in the rotary dryer and an independent tub grinder which it is used as pre-milling process to reduce the size of the wood.

In each test (a total of 66 were performed along the project) the following information was studied:

- Production and losses obtained in all main equipment of the pelletization line (tub grinder, hammer mill, and pelletizers G1 and G2) but also in the dryer and in the tub grinder with each blend.
- Electric and thermal consumption of the previous lines mentioned with each blend.
- Electric consumption exceeding the electric power contracted in all the tests carried out.
- Die used in each test.
- Degree of use of consumables with each test carried out (for instance the hammer in the hammer mill, the die in the pelletizer, …).

Test with just one pelletizer operating and tests in which two pelletizers were working at the same time were monitored in order analyse the most profitable configuration.

3.4.2 Results

Table 7 summarizes the main results obtained from the production tests carried out by APS and monitored by CIRCE.

Table 7: Production, consumption and yield obtained in the test of the nine final blends produced by APS

Production (output tonnes/h), consumption (kWh/kg) and yield (%) of the final energy blends pellets					
Blends	Pellet production (t/h)	Dryer production (t/h)	Tub grinder production for wood (t/h)	Energy consumption (kWh/kg)	Mass yield (%)
100 % straw	2.0-2.5	-	-	0.13-0.17	91.5
100 % straw (G1+G2)	2.5-3.0	-	-	0.10-0.14	91.5
100 % stalk	1.7-2.2	-	-	0.16-0.20	80.0
100 % wood	1.9-2.4	6	2.5	0.51-0.55	72.0
60 % straw	2.0-2.5	6	2.5	0.28-0.32	82.6
60 % straw (G1+G2)	3.5-4.0	6	2.5	0.25-0.29	82.6
52 % stalk	1.2-1.7	6	2.5	0.36-0.40	75.7
52 % stalk (G1+G2)	3.0-3.5	6	2.5	0.32-0.36	75.7
35 % straw	1.5-2.0	6	2.5	0.42-0.46	77.8
30 % stalk	1.5-2.0	6	2.5	0.46-0.50	74.0
30 % stalk (G1+G2)	3.2-3.7	6	2.5	0.39-0.43	74.0
72 % straw	1.8-2.3	6	2.5	0.22-0.26	85.1
72 % straw (G1+G2)	2.5-3.0	6	2.5	0.20-0.24	85.1
10 % stalk	2.0-2.5	6	2.5	0.47-0.51	72.6

Focusing on the pellet production, in general the production with wheat straw material is higher than with corn stalk, even though in the case of wheat straw (using one granulator) it is on average around

2.1 t/h and did not change with the different percentages of the blends tested (just in the case of the blend WSP-35 a variation was recorded). However, in the case of the maize stalk the line performed on average 1.8 t/h but presented more variation between the different blends. Regarding the use of two pelletizers instead of one, it clearly helped to increase the pellets production per hour, on average 1.7 more than with one pelletizer.

As was previously mentioned, dryer and pre-milling in the tub grinder are not necessary for wheat straw and corn stalk, just for woody resources, that it is the reason why the value of the production (t/h) was constant for all the blends considering that APS operates this line with at least more than 24 tonnes of woodchips (average amount that is coming in one truck), in order to be more profitable.

Regarding the energy consumption and yield achieved, these parameters were clearly affected by the use of the wood in the blend, due to the thermal energy required to reduce the moisture content before feeding it into the pelletization line.

3.4.3 Conclusions

The production obtained for energy blends pellets is acceptable compared with the production of energy blends achieved in other facilities, but in all the cases lower than for lucerne pellets, which usually ranges between 4 t/h with one pelletizer to 6.5 t/h with the two pelletizer. This could be explained due to the dies used for energy pellet have a smaller pellet track and therefore suffer much more wear and tear over time than dies used to produce pellet for animal market. Agro-industries interested in producing energy blends, can take as reference that the production capacity will be reduced at least 1/3 respect to the current production of lucerne pellet.

Finally and as a general rule for agro-industries willing to integrate a new business line to produce energy blend pellets, it should be considered that when blends are produced, the die of the pelletizer should have a compression rate more similar to the compression rate required by woody resources than to the one required by herbaceous resources, even if the blend has more than 50 % of herbaceous material.

3.5 Product quality

The quality of the final product will define the energy market space (domestic or small-medium industrial sector, and large industrial sector) and consequently their competitors (fossil fuels, other biomasses, …) according to the parameters obtained.

3.5.1 Methodology

In order to assess the quality of the energy blend produced the following analysis were performed to each blend:

- Proximate analysis (moisture, volatile matter, fixed carbon, ash content).
- Ultimate analysis (percentage of C, H, N, S, Cl and O).
- Bulk density, durability, and fines percentage.

- Heating value.
- Ash analysis.
- Ash fusibility temperatures.

Despite the analysis of the final energy blend pellet, it should be taken into account there is a risk of the contamination of the blends produced as a result of using the same equipment utilized to produce animal feed pellets (since the characteristics of the products are quite different). This contamination can occur in both directions. A study was carried out in this regard during the project.

The methodology followed was based on the analysis of samples collected during the production process at different times. Samples were taken after the production of pellet for energy purposes every 30 minutes when producing again pellet with lucerne for the animal feeding market. These samples were sent to a laboratory in order to evaluate the parameters determining the quality of the animal feed product (moisture, protein, ash and fiber) and to ensure that there was no contamination of heavy metals, dioxins and salmonella, which will imply the impossibility to commercialize this product. The same samples were analyzed at APS with the NIR equipment in order to evaluate if the results matched and in case the results would have differed a calibration of the NIR equipment would have been performed. The same methodology was followed when energy pellets were produced after the production of animal feed pellets.

3.5.2 Results

Table 8 shows the main results of the energy blends produced in AGROinLOG´s project with herbaceous material and Figure 7 shows the blends produced and the quality criteria achieved for each blend according section 3.3.

Table 8: Main results of the analysis carried out for the final blend produced

Analysis of the blend produced										
Parameter	Units	WP-100 Wood pellet 100 %	WSP-100 Wheat straw pellet 100 %	MSP-100 Maize talk pellet 100 %	WSP-60 Wheat straw pellet 60 %	MSP-52 Maize stalk pellet 52 %	WSP-35 Wheat straw pellet 35 %	MSP-30 Maize stalk pellet 30 %	WSP-72 Wheat straw pellet 72 %	MSP-10 Maize stalk pellet 10 %
Moisture	% a.r.	7.6	4.8	5.5	6.7	5.5	10.2	6.0	6.4	7.6
Ash	% d.b.	1.0	6.1	12.5	3.1	6.2	4.1	4.9	3.9	3.2
Cl	% d.b.	0.02	0.19	0.53	0.05	0.20	0.05	0.16	0.06	0.06
Durability	% a.r.	91.3	97.7	96.1	95.9	97.4	92.6	97.5	96.6	-
Fines percentage	< 3.15 mm	3.07	1.76	2.44	1.52	0.98	4.41	0.86	3.10	1.27
	Heating value									
Low heating value (LHV)	kWh/kg, a.r.	4.90	4.43	4.00	4.67	4.61	4.50	4.69	4.59	4.70
	Main components of the ash analysis									
SiO_2	% m/m d.b.c.	16.55	55.81	38.94	34.57	38.38	35.00	37.26	38.11	22.71
P_2O_5	% m/m d.b.c.	3.89	2.62	3.61	3.84	4.17	2.96	2.88	4.36	3.65

K_2O	% m/m d.b.c.	13.27	21.71	11.05	28.48	11.75	23.87	11.81	27.52	11.29
CaO	% m/m d.b.c.	41.02	9.88	21.95	20.27	24.97	21.6	26.90	17.50	35.06

On the one hand, pure herbaceous pellets clearly have worst quality than the reference fuel (WP-100), ash, chlorin and silica content (important parameter for achieving a good performance in combustion test) are higher and the LHV lower, even though the pure wheat straw pellet shows better results than the pure maize stalk pellet. On the other hand, the production of blends considerably contributes to increase the quality of the blends, reducing the ash, chlorine and silica content and increasing the value of the LHV, just as previously mentioned the blends based on wheat straw showed better results than the blends based on maize stalk.

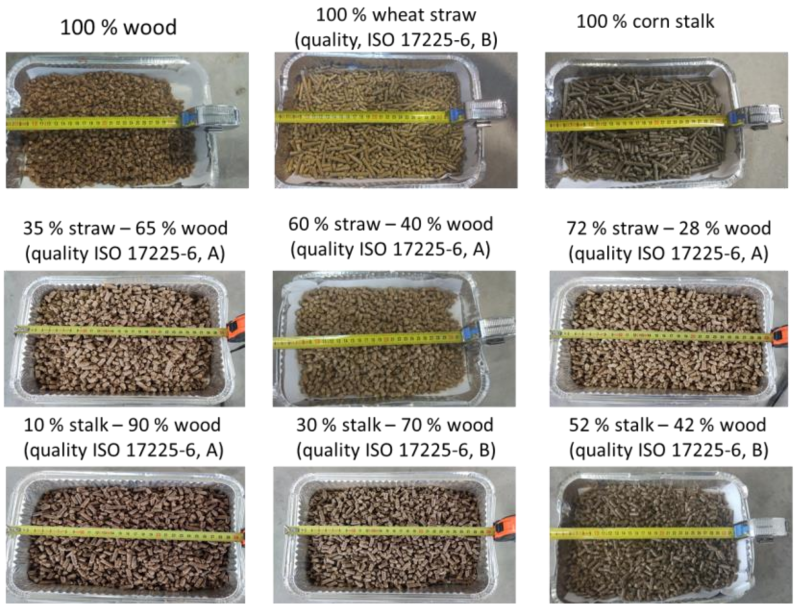

Figure 7: Final blends produced by APS and the quality criteria fulfilled for each f them

As result of the monitoring study regarding the possible contamination of the product it was concluded that the first 2.5 hours from the moment the production changes from one product to the other, the material obtained offers variations in quality that will be corrected in the following way by implementing a risk prevention protocol.

- In the case of animal feed pellet, during the first 2-2.5 hours, the pellet obtained does not present a first quality but can be released equally, so there is no loss of final commercial product for APS. To get back to a first quality product (average of 14-15% of protein) APS will use during these hours lucerne with high protein content (around 17-18%).
- In the case of energy pellet, during the first 2.5 hours the pellet is obtained just at the limit of what would be considered a minimum quality for marketing, so APS will use in these first hours a higher amount of forestry wood in order to guarantee at least a minimum quality.

3.5.3 Conclusions

The analysis of the pellet produced can give to the agro-industries a very valuable information about how the behavior of this product in combustion boilers could be, for this reason it is important to carefully design and carry out this step. Comparing the results obtained, the blends based on wheat straw showed better results so this reinforces the importance of the traceability assessment mentioned in section 3.1 in order to select the best raw materials. Also, it was established that a higher content of wood in the blend does not imply a higher quality in the final blend. For instance, the blend 60 % straw – 40 % wood, in terms of quality is almost equal that the blend 35 % straw – 65 % wood, but notably better than 100 % straw.

Finally, it should be indicated that products targeting different sectors can be manufactured in the same agro-industry without risky problems of contamination, even though the first hours after changing from one product to another some preventive measures should be taken in order to avoid problems with the quality of the final product.

3.6 Validation activities

Although the analysis of the blends developed is quite representative and allows to predict the future behavior in combustion facilities, it is based on the combustion test results when the advantages and drawbacks of the blends can be clearly identified when comparing with the reference fuel (WP-100). Therefore, the real validation of these blends was done during the combustion tests carried out in CIRCE´s laboratories (fixed bed reactor and industrial-scale boiler based on a grill burner. In both cases deposition probes, bottom ash composition and behaviour were evaluated associated to the combustion tests performed, together with SEM and XRD analysis of the bottom and flying ashes generated) and the validation activities that took place at the facilities of different end users (industrial stakeholders).

3.6.1 Methodology

The methodology followed to carried out the test was firstly to test the blend in the fixed bed reactor, analyse de data and afterwards provide this information to carried out the long run test in the industrial scale boiler of 430 kW_{th}, although due to some malfunctions in the closed water cooling circuit (actually, in one of the aero-refrigerators), the output of the plant was set at 300 kW_{th} instead of at its nominal working features.

Regarding the fixed bed reactor (installation described in Figure 8) CIRCE has compared the properties of the blend fuels through 10 tests programmed for each studied fuel (91 test were carried out), five primary air conditions were tested (in order to cover the range of lambda from 0.6 to 1.9) and one repetition each to ensure replicability. All the tests were monitored and analysed according to the following parameters: ignition time (s), velocity of the ignition front (m/s), ignition rate (kg/m^{2}s), flame propagation front temperature (ºC), bed temperature (ºC), bottom residue (g) (classified in three fractions: S1, S2 and S3 as function of the sintered fraction and the facility of the sintered fraction to disaggregate), unburnt material, deposition rate (g/m^{2}h), air excess ratio. In addition, fly ash deposition samples and bottom ash samples collected in the combustion tests were characterized. To achieve this, scanning electron microscopy (SEM) with energy dispersive X-ray spectrometry (EDS) and Powder X-ray diffractometry (XRD) methods were employed.

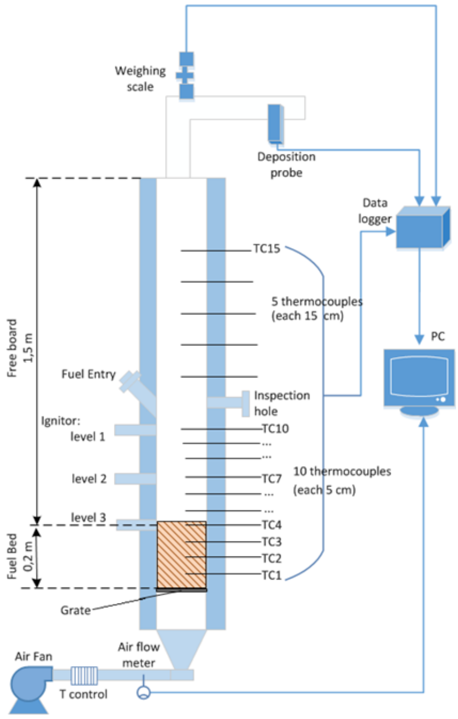

Figure 8: Scheme of the experimental test facility.

Regarding, the 430 kW_{th} biomass grate-fired unit (installation described in Figure 9), before performing each test, the operating parameters were adjusted to achieve the expected output (300 kW_{th}) attaining a high quality combustion (low CO emissions). The operating parameters considered were the screw feeding frequency, the working period of the ash pusher, λ and the primary/secondary air distribution. Long run combustion tests implied running the boiler for at least 6 hours at steady-state conditions, trying to simulate of the use of these fuels in a real domestic or industrial application. Also, gas emissions were monitored with a portable analyser (VARIO plus Industrial/SE model, MRU · Measuring instruments for flue gases and environmental protection GmbH) that combines infrared (NDIR) technology (CO, CO_2 and CH_4) and electrochemical sensors (SO_2, NO, NO_2 and O_2).

After each experiment, the residual ash placed on the grate and the one scraped by the pusher onto the ash pit were assessed by visual inspection in terms of colour and hardness. Sintering degree in the collected bottom ash samples was assessed both through visual inspection and by means of categorizing them into three ash fractions, S1, S2 y S3, being analyzed also with SEM and XRD.

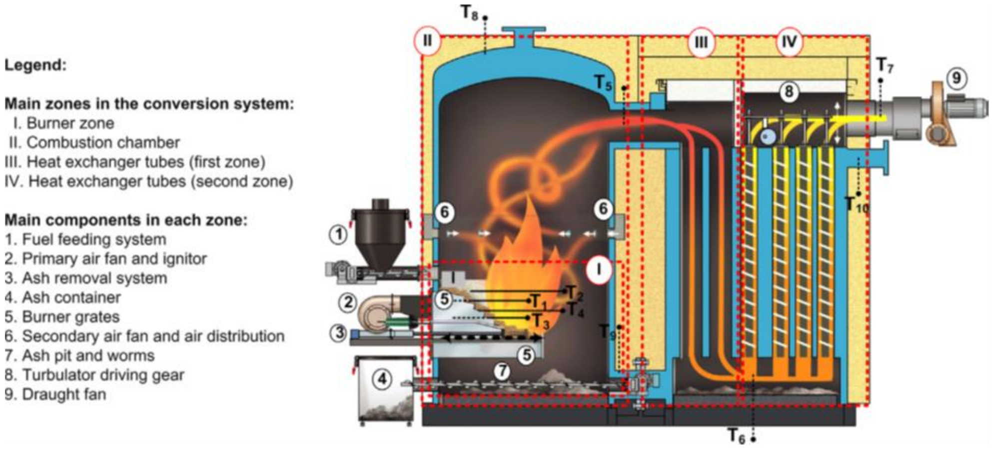

Figure 9: Main components of the grate fired conversion system.

3.6.2 Results

Table 9 and Table 10 summarize the main results achieved during the test carried out:

Table 9: Main results attained during the test in the lab scale grate reactor

Main results attained in the lab-scale grate reactor										
Parameter		WP-100	WSP-100	WSP-72	WSP-60	WSP-35	MSP-100	MSP-52	MSP-30	MSP-10
Air excess (λ)	Min	0.66	0.85	0.75	0.74	0.62	0.81	0.64	0.68	0.64
	Max	1.91	1.67	1.35	1.41	1.48	1.18	1.27	1.45	1.51
Mean T_if,max [ºC]	Min	934.9	1134.7	1103.3	1009.2	1099.6	1234.1	1202.6	1240.0	1151.6
	Max	1179.5	1262.0	1168.9	1136.1	1239.4	1267.6	1281.9	1293.2	1267.6
Ignition rate (kg/m^2s)	Min	0.049	0.055	0.058	0.059	0.063	0.058	0.067	0.067	0.063
	Max	0.066	0.074	0.066	0.064	0.071	0.063	0.071	0.071	0.069
Fed fuel (kg)	-	3.73	4.79	4.26	4.01	3.36	4.32	4.54	4.51	4.11

Table 10: Main results attained during the test at steady-state conditions regarding operation, emissions, deposition and yield.

Main results attained in the grate fire boiler test										
Parameter	Units	WP-100	WSP-100	WSP-72	WSP-60	WSP-35	MSP-100	MSP-52	MSP-30	MSP-10
Test duration at steady state	h	8.38	6.05	6.23	7.05	7.52	7.75	6.75	6.13	6.02
	Boiler working conditions									
Flow of biomass	Kg/h	76.6	83.1	78.0	79.2	82.6	97.2	83.4	81.2	86.0
Average output	kW	304	303	293	303	300	270	265	276	281
Total air	m^3/h	551	581	538	504	516	507	508	480	546
Average EA	%	66	80	68	53	54	60	50	50	46*
Time between ash scrapping manoeuvres	s	170	140	170	170	185	140	140	155	170

Average emissions results										
T-Amb	ºC	26	21	22	30	26	28	25	27	18
T-Gas	ºC	791	762	810	852	835	803	759	783	749
O_2	% d.b.	8.52	8.37	8.58	6.48	7.25	7.72	9.90	8.67	10.29
CO_2	% d.b.	12.44	12.38	12.38	14.48	13.71	13.24	11.63	13.03	11.03
CO	ppm d.b.	120	244	249	132	143	236	113	105	181
NO	ppm d.b.	99	162	150	146	140	206	171	163	126
NO_2	ppm d.b.	6	0	1	1	3	0	0	0	8
Average deposition										
Amount of ashes generated	FS1 (kg)	5.65	9.20	5.19	3.44	6.05	27.01	9.17	10.07	6.65
	FS2 (kg)	0.61	4.10	2.00	1.36	3.17	8.73	2.76	2.65	1.51
	FS3 (kg)	0.18	22.50	12.20	9.59	9.22	33.03	12.82	13.56	5.32
	Total (kg)	6.44	35.80	19.39	14.39	18.44	68.77	24.75	26.68	13.48
Deposition rate	g/m^2h	18.8	67.3	44.8	38.3	43.2	154.5	58.0	42.2	38.3
Yield Compared to WP-100**	%	100	102	101	97	100	86	84	90	84

*Average excess of air for MSP-10 was lower than expected in order to guarantee a good performance as a consequence of the problems faced with the air distribution of the installation.
**The yield mentioned in the table is not the combustion yield, it corresponds to the yield referred to the reference fuel, WP-100.

Based on the results obtained from these tests it was possible to draw several conclusions:

- The higher the amount of herbaceous material incorporated in the blend, the lower the optimal range of operation (does not admit to work with a wide range of air excess), and in general the air excess required is also lower. For this reason, if in the short or mid-term other tests are performed to validate the product on a client boiler, it would be important to take the time to adapt the operational parameters of the boiler to the specific blend used. When this adjustments are not carried out, if the performance achieved during the test is not as good as expected, it is in general associated to the new raw material characteristics; however in some cases the problem might be related to an inappropriate configuration of the operational parameters for the specific biofuel and not to the fuel itself.
- It is worth highlighting that the results achieved regarding the CO emissions were in all cases lower than 500 mg/m^3 N d.b. which was one of the targets established in order to fulfil the standard considered for boilers (ranging from 150 to 500 kW).
- When comparing these biofuels with the reference fuel WP-100, the main drawback was related to the sintering and deposition phenomena associated to the ash. As a result, it can be concluded that in order to avoid sintering problems, the fuels should have a low ash content, low Si content and high Ca+Mg content. Regarding the deposition, in order to avoid problems the fuels should have a low percentage of ash, few fines and a low content of S and Cl. APS, and in general any agro-industry interested in becoming an IBLC focusing on energy applications, should have in mind these considerations when evaluating the composition of the raw materials selected in order to develop a proper blend. If new raw

materials were used in the future to produce other blends, this analysis will be crucial to design the most adequate blends.

- If the two families of agropellets are compared, the WSP pellets have a slightly lower fraction S2/3 and lower ash percentage than the MSP pellets. The effect regarding the corrosion and the mechanical durability of the boiler using this blend versus other biomasses should be evaluated in the middle-long term.
- In terms of combustion performance, the WSP family presented better results that the MSP family, as a result the blend selected for industrial validation was the one with 60 % wheat straw-40 % forestry wood, since it achieved a good behaviour compared to the reference fuel WP-100, in terms of emissions, yield, sintering and deposition phenomena. Compared with the other WSP blends in terms of quality, it is almost equal to the blend WSP-35, but notably better than WSP-100 and WSP72. However, the production price (around 120-130 €/t) is more competitive than the blend WSP-35 (around 150-160 €/t) and at the same time quite competitive with the industrial pellets, which is the main competitor of these blends.

Additionally, with the final blend selected (WP-60) four industrial validation tests were carried out in real stakeholders' facilities: 2 agro-industries, one manufacturer of boilers and one domestic user. All the validators qualified the test performed as "satisfactory" or "very satisfactory", as they did not face problems with the operation of the boiler during the test, being the main inconvenient pointed out the quantity of ashes generated (as expected according the results obtained in the laboratory trials). However, it is worth mentioning that this disadvantage did not cause problems during the operation, since the automatic cleaning was able to remove the ashes produced. All the validators indicated that they would be interested in the product if the purchasing price was more competitive than their current biofuel in terms of €/kWh.

3.6.3 Conclusions

Validation test were quite satisfactory and proved that the blends developed offer good results with the right operational parameters, especially with the blends based on wheat straw, even though in other areas, for instance in which the corn stalk would present difference regarding the composition, this fact can change and the pellets based on corn stalk might achieve better results than the straw blend pellet, which points out the importance to perform a traceability assessment of the raw material used to produce the blend.

Finally, it is important to remark that before commercializing the product it should be validated in different installations in order to optimize the operational parameters and allow to analyse the results obtained. This fact is quite important taking into account that herbaceous materials are not very well seen in the energy sector, so probably if a future client offers the opportunity to test the new product, it will be advisable to confirm in advance he can adapt the operation parameters and boiler accounts with the systems required to achieve a successful operation with this biofuel, otherwise probably this client will refuse to use this product and others similar in the future.

3.7 Cost structure and investment necessary in the new business line

The cost structure and the investment necessary to implement the new business line define the profitability of an agro-industry to become an IBLC.

3.7.1 Methodology

Aiming to define the agro-industry's cost structure for each blend the following parameters were studied:

- Production and yield for each blend (assessed in section 3.4).
- Energy consumption (electrical and thermal) for each blend (assessed in section 3.4), taking into account the variable cost and the exceed cost.
- Raw material cost (wheat straw, maize stalk and forestry wood).
- Personnel cost (for instance the production of blends required more people that the production of pure biofuels).
- Losses in the process (since the raw materials are purchased by APS and until the final product is commercialized there are losses along the process that need to be quantified and considered).
- Fixed cost, including in this point the investment necessary in the new business line.
- Selling price for the ago-industry and assess if a retailer is necessary considering the commercialization strategy designed for the product.

3.7.2 Results

Although APS already accounted with a pelletization line and a dehydration line (with a rotary dryer), some investment was required in order to adapt its facility to integrate the new business line, the corresponding figures are summarized in Table 11. Although these equipment was bought for the new IBLC, some were also used for the main activity line dedicated to animal feed products; for instance the NIRS analyser (which assess the quality of the raw material and the final product) and the moisture control device (a sensor attached in the mixer previous to the pelletizer in order to guarantee the right moisture in the final product). In these cases the investment associated with the new line or the animal feed line were considered taking into account the sales invoice. Other equipment necessary in the new business line such as the dies, were considered in the assessment as variable cost since it depends on the number of hours they are being utilised. As a result, the total investment associated with the new line was 50,000 €, the rest of the equipment is associated to the lucerne business line.

Table 11: APS equipment financing costs for the new business line

Investment for APS IBLC			
Investment APS	TOTAL	New line	Lucerne
DS 2500 NIRS Analyzer	40,000 €	4,000 €	34,000 €

Screening machine "Zaranda" (to avoid fines in the final pellet)	21,000 €	21,000 €	-
Dies to carry out production tests	56,000 €	Indirect costs	-
New line for operating with blends (a hopper for feeding the forestry wood)	24,000 €	24,000 €	-
Moisture control device for the mixer	3,000 €	700 €	2,600 €
TOTAL	144,000 €	**49,700 €**	36,600 €

Taking into consideration this investment, the cost structure of the different blends produced are showed in Table 12:

Table 12: Selling cost structure (€/$t_{wb\ at\ 9\ \%}$) for the nine blends manufactured by APS.

Selling cost structure (€/$t_{wb\ at\ 9\ \%}$) of the energy blends pellets									
Cost breakdown	100 % straw	100 % stalk	100 % wood	60 % straw	52 % stalk	35 % straw	30 % stalk	72 % straw	10 % stalk
	Cost distribution (€/$_{twb\ at\ 9\ \%}$)								
Total raw materials	42	39	80	59	61	69	70	54	77
Total production cost	21-29	29-37	68-76	53-61	71-79	73-81	77-85	43-51	70-78
Fixed cost	7-9	7-9	7-9	8-10	8-10	8-10	8-10	8-10	8-10
Total cost	70-80	75-85	155-165	120-130	140-150	150-160	155-165	105-115	155-165
	Selling price (€/$_{twb\ at\ 9\ \%}$)								
Selling price at plant	85-95	90-100	170-180	135-145	155-165	165-174	170-180	120-130	170-180
Selling price at destination	95-105	100-110	180-190	145-155	165-175	175-185	180-190	130-140	180-190
Selling price at retailer	107-117	112-122	192-202	157-167	177-187	187-197	192-202	142-152	192-202
	Selling price (€/kWh)								
Selling price at plant	0.019-0.021	0.023-0.025	0.035-0.037	0.029-0.031	0.034-0.036	0.037-0.039	0.036-0.038	0.026-0.028	0.036-0.038
Selling price at destination	0.021-0.024	0.025-0.028	0.037-0.039	0.031-0.033	0.036-0.038	0.039-0.041	0.038-0.041	0.028-0.031	0.038-0.040
Selling price at retailer	0.024-0.026	0.028-0.031	0.039-0.041	0.034-0.036	0.038-0.041	0.042-0.044	0.041-0.043	0.031-0.033	0.041-0.043

Taking into account the market analysis (see section 3.8), the blend developed within AGROinLOG project should be competitive with the industrial pellet (selling price at client around 165-190 €/t, around 0.038 €/kWh) with the current market conditions, being the WSP-100, MSP-100, WSP-60, WSP-72 and MSP-52 similar or highly competitive with this reference fuel, even though quality criteria should be considered. Therefore, according to the results obtained from the validation activities carried out (see section 3.6) the best blend considering economic and quality criteria it is the 60 % of wheat straw and 40 % of forestry wood.

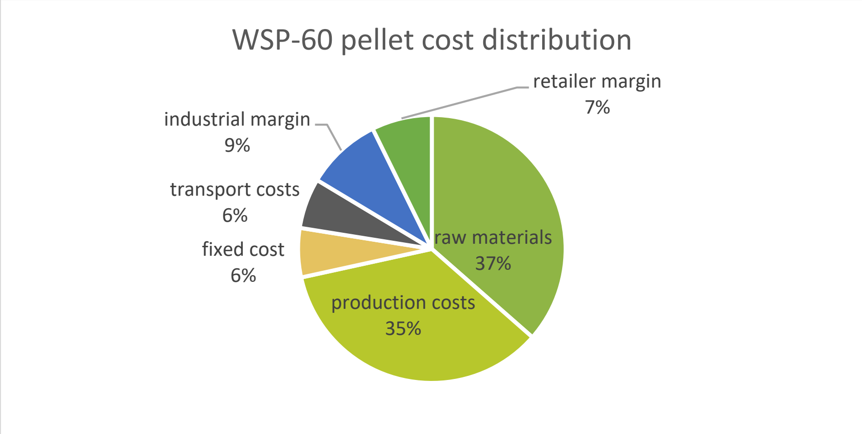

Figure 10: Cost distribution of the final energy blend selected

Taking into consideration the cost distribution of the blend selected, the selling price considered a retailer for the commercialization of the product and the commercialization of 4,500 tonnes/year of WSP-60 (according number of hours available for APS, see section 2.2). A study was carried out considering 10-year cost-benefit analysis with an average cost increase of 2 % and a similar selling price increase. As a result, the payback period is less than one year and the total net profit value at the end of year 10 is around 600,000 € discounted at a 2 % ratio.

3.7.3 Conclusions

The IBLC model is economically profitable in the case of APS and probably in agro-industries of the fodder sector with similar conditions having a pelletization line already, even though there are two main risks that should be taken into account in order to fulfil this goal:

- Securing the selling of a new product in the energy market at the targeted price could be challenging depending on the market conditions, mainly in the first years, since the agro-industry needs to identify attract and retain its clients.
- Raw material cost could increase depending on the year, which could compromise the project economic feasibility (the increase of the raw material purchasing price will for instance strongly affect the selling price of the pellet produced, as it is the main parameter that affects to the final price, Figure 10).

3.8 Market analysis

The blends pellet defined and tested in combustion facilities were performed aiming to be competitive in the energy market, the main competitors of this agro-pellets are:

1. Fuel from fossil sources: diesel and natural gas.
2. Higher quality standard biomass pellets: ENplus A1, ENplus A2, DINplus, etc.

3. Other agro-residues of similar quality as a fuel (mainly in terms of ash content and heating value) that are being used in many agro-industries due to their low price in the market: olive pomace, olive pits, almond shells or grape marc, for example.

Comparing to the use of fossil-based fuels, the final client willing to use agro-pellet must do an investment in a new boiler and a new feeding system. Normally, the use of biomasses in the middle term usually allows to recover the investment carried out, even though each case should be studied in concrete according to the energy demands to be covered and the kind of energy to be produced (thermal or electrical).

Regarding the other biomasses mentioned, a market study in the surrounding area of the APS ´s facility was done (Table 13) in order to assess the biomass competitors, these prices can be also extrapolated at national level applying a range of ± 10 €/$t_{w.b.}$.

Table 13: Market of the biomass near APS facility.

Market of the biomass near of APS facility				
Fuel	Moisture (%)	LHV (a.r.), kWh/kg	Price (€/t_{wb})	Price at client (€/$kWh_{a.r.}$)
Forestry pellet (EN Plus A1)	8	4.67	210	0.045
Industrial forestry pellet	10	4.43	170	0.038
Forestry wood chips, G-40	30	3.33	85	0.026
Agro-biomass wood shredded, G-30	25	3.85	70	0.018
Grape marc	8	4.80	110	0.023
Olive Pit	10	4.70	120	0.026
Almond shells shredded	7	4.78	100	0.021
Almond shells	15	4.31	65	0.015
WSP-100	9	**4.43**	**115**	**0.023-0.026**
WSP-60	9	**4.67**	**165**	**0.032-0.035**

Taking into account the ratio €/$kWh_{a.r.}$ showed in the Table 13, on the one hand it can be highlighted that processing the biomass increases considerably the price, for example when forestry wood chips are compared with forestry pellet or almond shells vs almond shells shredded. On the other hand, processing the biomass has some advantages as avoiding problems in the feeding systems since the product is more homogeneous, reducing degradation and dry matter losses of the material, higher energy density which implies less space needed to store the same energy content, logistics advantages compared to loose material, etc.

In addition to the wide range of prices, also the quality is quite different among them. It is important to mention that although the forestry wood pellet with A1 EN Plus certified is included in the list, the blends pellet will not be competitive with this pellet in terms of quality. Based on this consideration, the domestic boiler segment is not initially considered as a potential customer for this business, since although there are some boilers accounting with the appropriate technology to burn the blend pellet, the majority of the boilers used in the domestic market are based on underfeed burner without automatic cleaning system (technology not appropriated for pellet with higher amount of ashes and some tendency to sinterization).

Thus, according to the quality and the selling price, the WSP-60 can successfully compete in the industrial market with industrial wooden pellet with no specific regulatory demands by end users. In the case of WSP-100, it could be competitive with other agro-industrial biomasses as grape marc, olive pit and almond shells shredded.

It is important to remark, that the percentage of the blends and therefore the production can change according to the quality of the raw materials and the cost of processing these raw materials. It is highly recommended for the agro-industries in the fodder sector to define the blends and the production cost according to the considerations and methodology reported in section 3.3. and 3.4.

Regarding the distribution of the new product, the agro-industry could take over the distribution of the new products to the final users (main option in order to be more economically competitive in the market) or might decide to sell all the new production to intermediaries, distributors, Energy Service Companies (ESCOs) or other logistics companies. By taking the latter strategy, no direct relationship with final users should have to be established and commercial efforts will be avoided for the agro-industry.

Outside of the energy market, AGROinLOG has explored the production of other bio-commodities with pure herbaceous pellets (WSP-100 and MSP-100): the production of innovative bio-composites boards, thermoplastic reinforced with natural fibres, adsorbent for hydrocarbons spills, production of activated carbon for supercapacitors and the production of furfural and levulinic acid.

As a result, in all the markets studied outside the energy market the results were very promising, demonstrating the huge potential of these resources as alternative raw materials for different applications. Nevertheless, in the short-term the commercialization of the 100 % herbaceous pellets for these alternative applications is risky since the market is not well developed yet and therefore a higher effort will need to be allocated to the commercialization. But it is foreseen that in the mid or long term, market conditions together with the potential growth of these applications could set an adequate and economically feasible framework.

4 IBLC IMPLEMENTATION ADVANTAGES AND DRAWBACKS

4.1 Advantages

Agro-industries inside of the fodder sector that produce dehydrated bales and animal feed pellet, already accounts with functional production lines to produce other products and become an IBLC, with low investment needed to adapt the existent lines to the new raw materials and final product. Therefore, the risk associated to the new activity in terms of investment is low, also the risk associated with the problem of contamination due to the products will sharing the same production line was discarded (see section 3.5).

Furthermore, the staff already accounts with the knowledge and experience needed for the operations of both lines, for that reason in case of malfunctioning the personnel is able to quickly understand where it might come from and to identify possible solutions. Just a training should be done only on new equipment operation or changes regarding the operation of the existing equipment.

At the same time, agro-industries usually accounts with an established network of contacts that can be very useful for the supply of the new raw materials, since normally intermediate-big suppliers of lucerne are also suppliers of other herbaceous raw materials such as wheat straw or corn stalk. This synergy of contacts does not only apply to raw materials, but also the suppliers of the machinery of the different lines can provide valuable information about the new business line operation and how to optimize the existent equipment at the agro-industry, since they typically supply machinery to the energy sector.

Regarding the final consumers, agro-industries usually have a good relationship with other agro-industries that consume biomass for their dehydration process. If these agro-indsutries account with a boiler that is able to work with this type of biofuel, they could be possible consumers of blend pellet, even though normally they consume biomass without transforming operations (for instance almons shell, olive pits, …) so the blend pellet could be not be competitive in price, but each case should be studied independently.

Finally, and the most important advantage is that the IBLC concept implementation allows to diversify the business line by moving away from the sector in which the agro-industry currently operates, offers to the company more stability and at the same time the possibility to avoid seasonality, therefore contributing to create full time jobs and reduce the pay-back of the currently machinery. In addition, the diversification of the agro-industry activity by manufacturing products for two different sectors allows the company to be more prepared to face and adapt to possible fluctuations in one of the markets.

4.2 Drawbacks

The production process associated to the blends pellets, is more complex, mainly because it involves the use of different raw material that should be blended appropriately during the manufacturing process in order to achieve the blend's design (percentage of each raw material) and fulfil the quality criteria requested.

In addition, different dies should be used, which requires technical changes in the pellet line, which in turn implies time and if not carried out properly, can lead to breakdowns during the production activity and affect the regular activity. Also, the replacement of these dies is carried out more frequently when producing energy pellets than animal feed pellets.

Based on the agro-industry's experience accumulated during the project, the higher wear and tear regarding dies can be also extended to the rest of the consumables such as the rollers, threads and the entire transport system given the hardness of the raw material. Therefore agro-industries would have to take into account the possible wear and tear or increase in maintenance costs of the production lines - due to pelletizing chips or drying them. In this regard, a study should be carried out in the future to find out what the risk is and to quantify it.

The main drawbacks for agro-industries is related to identify the final consumers willing to purchase the new product at the targeted selling price and achieve the customers' loyalty. Especially considering that the market range of blend pellet based on herbaceous materials is narrow (see section 3.8. for more details), which means that the possibilities are limited, even though an intermediate with experience in the energy sector can be in charge of the commercialization of the new product.

5 LESSONS LEARNT

Regarding the raw materials studied along the project, the wheat straw shows better characteristics to be used for energy purposes (blend pellet production) than the maize stalk, even though this fact cannot be considered as a general rule.

In this sense, it was demonstrated through the work performed in the project that carrying out a traceability assessment in the initial phases was key to ensure the quality of the final product. In turn it will help to define the best supplier and reduce the amount of wood in the blend while obtaining a product with a good quality for the industrial energy market. As result of reducing the amount of wood in the blend, the productivity achieved in the production lines is higher, being the consumption and the cost operation lower, as well as the cost associated with the maintenance of the line, therefore the selling price of the product is quite competitive.

It is important to remark that although the percentage of wood in the blend can be lower than the herbaceous material, the dies that should be used in the pelletizer should have a compression rate more similar to the dies of wood than the dies used for pure herbaceous material.

The investment that an agro-industry from the fodder sector would require to become an IBLC was reduced in the demo case considered due to the current existing equipment that can be used for the new activity. As a result, the cost structure reported demonstrates that this new business line can be profitable if the price of the raw material is stable and the commercialization of the product at the selling price targeted is achieved.

Also, it should be mentioned that sharing the same line for the production of different products does not imply a contamination of the line, just some protocols have to be considered during the first 2.5 hours to guarantee that the a product is manufactured with the same quality as usual.

The targeted end user for the commercialization of the blend pellet is the medium industrial consumers which is currently using industrial pellets accounting with boilers which have efficient cleaning systems for ashes removal. Right now, this market is narrow despite in the last years the tendency of some boilers manufacturers has been to build more robust devices allowing the consumption of alternative biomasses and not just based of forestry wood. Another client could be the big consumers, but they probably will rather opt for products whose price is lower than the one offered by the IBLC. Lastly, the small consumers are not prepared for the consumption of this type of pellet in general since the boilers installed are very basic with underfed burners.

Regarding the other markets studied, the results obtained were very promising, although in the short-term the commercialization of this products is difficult since the market is not yet well developed.

In conclusion, regarding the IBLC model potential implementation, agro-industries from the fodder sector can consider this line of business as an alternative if profitability and the market conditions allow it, or if their own market (the animal) would suffer from a problematic season.

6 CONCLUSIONS

It has been demonstrated that the integration of a Biomass Logistics Centre based on the production of blend pellets inside the fodder sector is possible and profitable with a low initial investment for the agro-industries, since they already account the majority of equipment necessary for carrying out the new activity.

Therefore, it can be a business line to be considered by the agro-industries during the period of lower activity which takes place usually from December to March, in order to avoid seasonality and to create full time work. The results highlight that one of the main advantages of the IBLC model is its flexibility to adapt their secondary business line to the market conditions in order to optimize the profitability of the agroindustry while contributing to diversify the business.

The main risk associated to the profitability of this alternative business line, is the commercialization of the product, since normally agro-industries do not know the energy market. For this reason it could be interesting to consider the option of establishing relationships with other intermediates (as energy services companies, biomass suppliers, ….) to facilitate the penetration of the new product in the market.

Finally, regarding the other applications studied for pure herbaceous pellets (bio-composites boards, thermoplastic reinforced with natural fibers, adsorbent for hydrocarbons, activated carbon for supercapacitors, furfural and levulinic acid), the results obtained were very promising, although in the short-term the commercialization of this products is difficult since the market is not yet well developed.

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