Systematic analysis of innovation opportunities for woody biomass exploitation

SYSTEMATIC ANALYSIS OF INNOVATION OPPORTUNTIES FOR WOODY BIOMASS EXPLOITATION

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ABSTRACT: In this paper the authors present a roadmap aimed at the identification of business opportunities, technical requirements and opportunities of innovation in the woody biofuel production process on the base of a survey of the available biomass resources and the state of the art of the available technologies. The method has been applied to define the optimal exploitation of the biomass resources available in the Appennino Tosco-Emiliano according to the market demand. The analysis performed has shown that logistics, transportation and drying costs of the woody biomass having an high level of moisture, strongly affect the production costs of chips and pellets in the Appennino Tosco-Emiliano. A possible solution requires to remove the water content during the forest operations. Nevertheless, this task is very hard to accomplish, since grinding technologies are still not able to separate water from woody biomass. Moreover, drying technologies are still based mainly on heat: this process is very power consuming, strongly inefficient and very expensive. Starting from these results the authors have studied some possible solutions to drastically decrease the moisture content in the woody biomass using mechanical energy to separate water and biomass instead of thermal energy to make water evaporate. These conceptual solutions are at the embodiment stage, but the simulations performed so far demonstrated a relevant decrease of production costs for woody chips and pellets and an improvement of their quality.
Keyword: biomass conversion, biomass drying, biomass resources, pellets, solid biofuels, wood chips.

1 INTRODUCTION

The woody solid biofuels can represent a relevant complementary way to petroleum and its derivatives for several Italian regions, both for heating and power generation, since it has a large area of the national territory covered by forests. In the last two years the market demand of pellets and chips has grown dramatically and the woody biofuel production can represent a business opportunity for a lot of rural areas. Beside the distribution of the woody biomass in the national territory is not uniform in terms of essences and their characteristics. As a consequence, it is necessary to design treatment and conversion processes according to the local availability of the woody biomass, in order to optimize its rational exploitation. In the last years a lot of methods have been proposed in order to address the assessment and the optimal exploitation of different kinds of biomass resources according to their availability in a territory.

In [1] a method for estimating potential woody resources for solid biofuel production from forest larger than 5000 m^2 based on national forest data, is presented. The locality data are extracted from the biomass assessment and they are coupled with data on location of conversion facilities. These data are used to set up an economic model based on GIS (Geographic Information System) to form industrial marginal cost-of-supply curves from an optimization of the allocation of the wood.

A decision support system for the systematic exploitation of the forest biomass is presented in [2]. In the proposed approach an optimization algorithm is used to identify the optimal size of the plants and their location according to the biomass resources that are available in the area and the supply costs. The method allows to define which kind of energy is convenient to produce in the area, taking into account multidisciplinary aspects such as economic, social, technical and regulatory factors.

In [3] a methodology based on the earth observation data is introduced aimed at the estimation of the biofuel potential on a territory. Spatial data are used to assess land potential availability and to identify potentially available areas for energy plantations.

In [4] the biomass potential assessment and the analysis of biofuel trade chains are evaluated under different scenarios in order to obtain an estimation of the biofuel potential in the Central and Eastern European Countries.

A software approach that, on the basis of a preliminary evaluation of the biomass resources in the Italian provinces, allows to identify the biomass availability and the characteristics of the plants that could be realized, is described in [5].

All these methods are rather effective in order to assess the biomass availability on large areas of the national territory, however they are not suitable to identify the functional requirements that the biofuel production process should have in order to fulfill the market demand on the basis of the rational exploitation of the biomass resources. In such a context the authors have developed a road-map to support the analysis of a biofuel production process from both functional and economical point of view in order to identify still not exploited business opportunities on the basis of the available technologies and the biofuel market demand. Moreover, a systematic approach to link the analysis of the system with the identification of the technical solutions able to overcome these functional needs is also proposed. Section 2 reports the proposed road-map, the selected tools and a detailed description of their integration. In Section 3 the application of the road-map to improve the production process of solid biofuel in the region of the Appennino Tosco-Emiliano is described. Eventually in Section 4 the results of this approach are discussed.

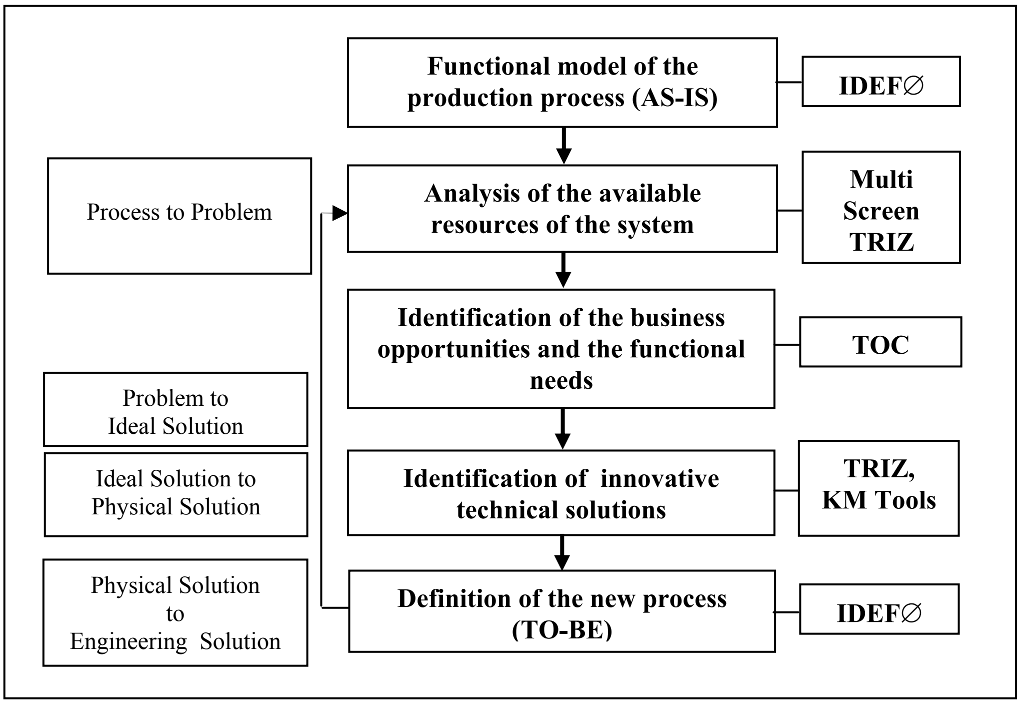

Figure 1: proposed roadmap for the identification of technology innovation opportunities in a biofuel production process and related tools.

2 TOOLS AND METHOD

In order to fulfill the objectives presented in the previous section, a roadmap based on the integration of complementary techniques supporting process analysis and development here is presented. This road-map is able to support the systematic analysis of a biofuel production process in order to identify business opportunities that are not exploited due to poor performance and/or lacks of functionality of the system, according to the available biomass resources and the market demand. The identification of the functional needs is the key step to define innovation tasks aimed removing the business limits. The road-map and the related tools are shown in figure 1, it is constituted by 5 main steps.

1 - State of the art analysis of the solid biofuels production process.

In this first step of the road-map, an analysis of the available technologies used for the treatment of the woody biomasses and their transformation in solid biofuels (such as pellets, chips, etc.) is performed in order to evaluate costs and expected plant efficiency.

Such a kind of task requires to define the functional model of the biomass transformation process (AS-IS model) in order to characterize each phase according to the functions that it performs. The flows of materials, information and energy in input and output to each phase are represented. The functional parameters such as the efficiency in terms of energy consumption and the input/output physical parameters (such as temperature, pressure, etc.) of the materials involved in the process are also detailed for each phase. The IDEF∅ technique is adopted to perform the functional analysis of the process in order to represent a process according to the E.M.S.(Energy, Material and Signal) flows, by specifying control mechanisms and tools.

2 – Analysis of the available resources of the system.

This step is aimed to identify all kinds of resource, available outside and inside the production process, that may be exploited to improve the production process itself. The tasks of this phase are:

- To analyze each phase of the process and its flows in order to discover if there are resources inside the system that are not exploited. These resources may be used in order to improve the overall efficiency of the system (i.e. the energy lost due to the friction in a phase may be used as thermal heating for other phases of the process, etc.).
- To identify the availability of external achievable resources in terms of market opportunities and available materials (demand of pellets, chips, availability of woody, etc.).

In order to accomplish the above described tasks, an investigation of the woody biomass volumes that are obtained and that could be collected by the local sustainable exploitation of the forests and others human activities, is performed. A woody biomass classification in terms of essences, their moisture content, location and distribution in the area and a cost analysis is done in order to make a characterization of the starting material both from a quality and budget point of view.

According to the results of the previous step, once each phase of the transformation process has been described in terms of the functions that should be performed and the physical input and output parameters have been identified, the analysis of the available resources within the production process is performed. According to the TRIZ concept of "resources", each substance, field, interaction, characteristic, property, time/space availability within the system not used at its maximum potentialities is an opportunity to improve the system itself. An useful tool to support this task is the so-called (by the TRIZ community) Multi-Screen approach, consisting in a multi-scale analysis to be focused on each time-step/phase of the process and on the cause-effect relationships existing between its functional interactions.

3 - Identification of the business opportunities and the functional needs.

Once the system has been characterized in terms of functional parameters, the analysis of the requests the process is able to satisfy is made according to the results of the previous step. As a consequence, it is possible to identify business opportunities still unexploited in the current reality of the system due to technological and functional needs that the system is not able to supply at present.

Such a complex task requires modeling both the functional architecture of the process and the value of the flows involved within and outside it. Such a technical-economical model can be suitably built according to the tools provided by the Theory of Constraint (TOC). According to the TOC, the production process is represented as a technical system constituted by chains of operations, where each ring represents a phase. The flows taken into account in this kind of model are the monetary flows generated by the system that are defined as follows [6]:

- **Troughput (T)**: "The rate of which the entire system generates value through sales (product or service)": these flows represents the money coming in the system.
- **Inventory (I)**: "All the money the system invests in things it intends to sell": this is the flow of money that are spent in order to buy the raw materials.
- **Operating Expenses (OE)**: "All the money the system spends turning Inventory into Throughput" this flow of money going out the system to buy labor, utilities, consumable supplies, energy, etc.

According to TOC principles, to improve the system the first priority is increasing T, since it has the greatest potential impact on the bottom line, while decreasing OE and/or I is secondary and in any case should not jeopardize future throughput.

The problem is to know "what to change" in the current reality of the system in order to improve its Throughput: this represents the functional need or the so called "constraint" to be removed. TOC problem-analysis tools, the Current Reality Tree (CRT) is helpful to accomplish this task. By CRT the cause-effect relationships behind the current situation can be highlighted going back from one or more tangible or not tangible undesirable effects produced by system. The root cause represents the core problem that originates all the undesirable effects: this represents the Constraint of the system to be removed in order to increase the T/OE ratio of the entire process.

4 - Identification of innovative technical solutions.

The aim of this step is to analyze the constraint in order to identify the innovation demand to remove it. Once the expected improvement in terms of performance and/or functionality related to the constraint have been identified, they are translated into new specifications of the innovative process.

Focusing the process requirements on the constraint limits brings sometimes to unexpected specifications due to the clearer vision of the process obtained through the model of the system. It may happen that these specifications don't require any inventive step, but just the application of solutions already known by the design team.

Besides, if the previous analysis points to the necessity to overcome a trade-off due to conflicting requirements or to a physical limit of an internal resource, the "injection" can be conceived by applying TRIZ tools for the identification and solution of physical contradictions.

As a result, a conceptual solution is generated in terms of physical properties of the system that allows to improve the Throughput of the Constraint or to reduce its Operating Expenses/Inventory.

Due to the nature of the TRIZ inventive process, the conceptual solution could be derived from any field of application, thus its embodiment into an engineering solution may involve multidisciplinary competences, even external to the design team experience.

This task can be suitably supported by Knowledge Management (KM) tools, in order to retrieve and analyze relevant technical contents from patents, scientific journals etc. even with limited resources.

5 - Definition of the new process (TO – BE).

The solutions developed in the previous phase are then evaluated to establish the opportunities of implementation in the process. A simulation of the TO-BE process is performed in order to verify the impact of the proposed innovations on its functional parameters and to compare the updated Troughput/Operating Expenses with the old process. Once again IDEF□ and TOC tools are used in this step.

The first iteration stops with the definition of the TO – BE process; of course, the latter may be further analyzed in order to check whether the Constraint of the process is still the same or another phase/function of the process has become the most critical.

According to the needs of the whole process the above described steps can be iterated: as depicted in figure 1, the new iteration starts from the analysis of the resources available for the TO - BE process, since it represents the current reality of the improved system.

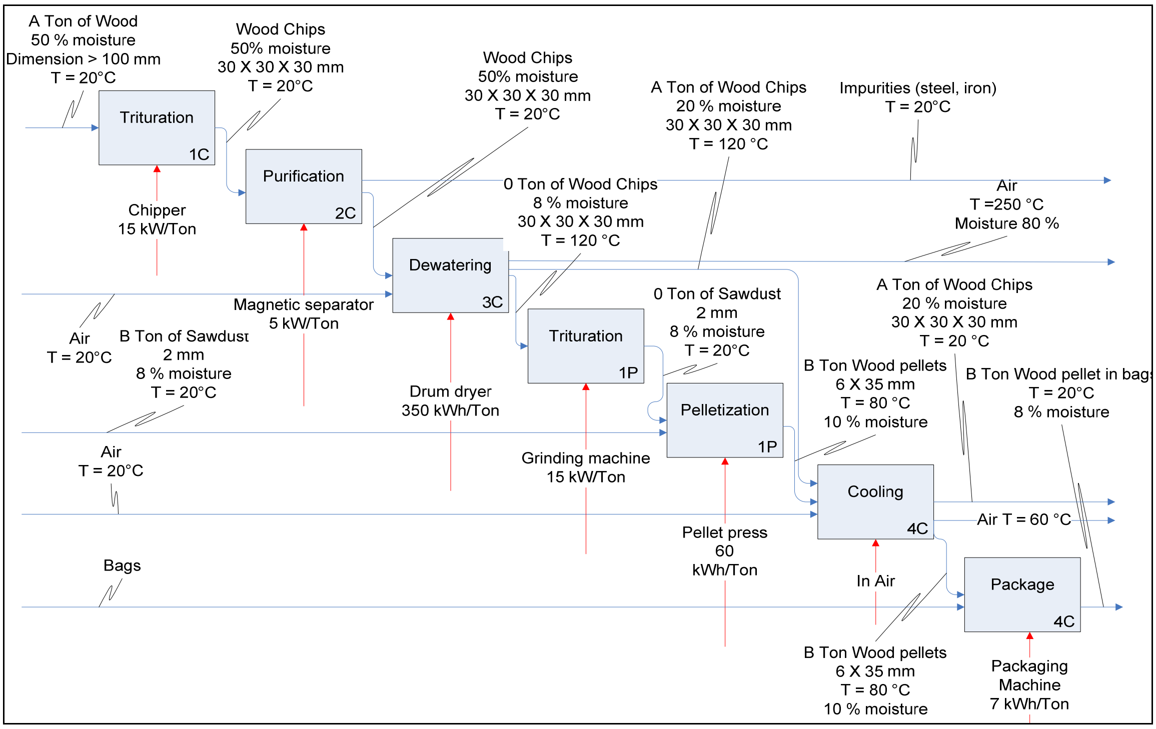

Figure 2: IDEFØ of the solid biofuel production process (AS-IS) with flows of materials and energy consumption involved in the process.

3 WOODY BIOMASS EXPLOITATION IN THE APPENNINO TOSCO-EMILIANO

In the last two years the market demand of solid biofuels in Italy is dramatically grown and it represents a business opportunity for a lot of rural areas: one of these is the Appennino Tosco-Emiliano. Besides the installation of stoves for domestic usage, able to burn this kind of biofuel is grown in the last years in Italy so that the market demand of wood chips and pellets is much higher than the market supply.

Two different kinds of solid biofuel are obtained by the exploitation of the forestry resources and sawdust available in the area: woody chips and pellets having the following characteristics:

- Wood chips: overall dimensions of 30 X 30 X 30 mm, maximum moisture content of 20% in weight, market price 70 €/Ton;
- Pellets: cylinders of pressed sawdust having a diameter of 6 or 8 mm, height of about 35 mm, moisture content of 10% in weight, market price 220 €/Ton;

The application of the above described road-map has been performed in order to identify the functional needs of the production process allowing the rational exploitation of the biomass resources according to the market demand. The results of each step of the road-map are, here, presented.

1 - State of the art analysis of the solid biofuels production process.

The IDEFØ of the process by which solid biofuel are manufactured, is shown in figure 2.

According to this figure, the process used to produce the wood chips starts with the trituration (called "chipping") of the woody biomass in order to obtain chips having overall sizes of about 30 X 30 X 30 mm. Typically the chipping of the wood is performed during the forestry operations, the chips should be dried in order to avoid the starting of the fermentation or burned as soon as possible. Different kinds of chipping machine are available in the market, however the power required to obtain one ton of wood chips may be evaluated in about 15 kW per hour. However this estimation depends on the biomass moisture content: the power consumption during the chipping of the wood increases with the moisture content.

The next phase is aimed at purifying the obtained wood chips by removing any kind of impurities (such as solid particles, glass, iron, etc.). The required power can be neglected with respect to other phases of the process.

In order to avoid fermentation, the moisture content is reduced to 20% in weight, a dewatering is performed using thermal heating and at the end of the process the wood chips are cooled in air. Obtaining an exact estimation of the energy involved in the drying process is a quite difficult task since it depends on the size of the plant. However some data available in the literature [7,8] indicate a power consumption to evaporate one ton of water of about 1 MWh. The temperatures involved in the drying process should not exceed 200 °C in order to avoid the loss of the volatile substances enclosed in the woody biomass having high heat power. An alternative way to dry the biomass without supply heat power is represented by the natural dehumidification performed in air. Such a method requires buildings having large waterproof volumes where to store the biomass in a way to avoid the fermentation hence this drying system has two main drawbacks: it is very expensive in terms of logistic costs and a long time is needed in order to reduce the moisture up to the value required for the wood chips and pellets.

Due to moisture and dimensions requirements only sawdust is, actually, used to produce pellet while most of the woody biomass is used to produce chips. The power consumption to produce one ton of pellet is estimated in 60 kW per hour. Besides, the pellettization of the sawdust produces a not negligible heat due to the high friction of the extrusion die, thus the pellets require to be cooled at the end of the process before the packaging.

2 – Analysis of the available resources of the system.

The availability of the wood biomass resources in the Appennino Tosco-Emiliano and their costs are summarized in table 1. In table 2, the costs of each phase of the process are surveyed (the cooling phase is omitted since it does not generate costs) [9].

The volume of the raw material is estimated to be 30.000 tons per year divided as in the following:

- 5.000 tons coming from the wood industry;
- 25.000 tons coming from the sustainable exploitation of the forests covering the Appennino Tosco-Emiliano mountains.

Table 1: biomass resources availability

	Wood	**Sawdust**
% Moisture	40-60	10-15
Dimensions (mm)	> 100	2-3
Availability(ton/year)	25.000	5.000
Cost (€/ton)	25.00	5.00

Table 2: production costs (€/Ton) of solid biofuel

	Wood chips	**Pellets**
Trituration	3.00	-
Purification	2.00	-
Dewatering	8.00	-
Pelletization	-	11.00
Packaging	-	1.50

The costs summarized in table 2 don't take into account the transportation of the biomass from the forest to the biomass transformation plant and from this one to the customers. Quantifying such a kind of costs is a very difficult task since they are strongly affected by the moisture content of the woody biomass. At present it is not convenient to use biomass that are located over 50 km from the woody chips production plants.

As shown in the IDEFØ diagram (figure 2) there are flows of energy discharged from some phases of the process that constitute unexploited internal resources of the system (such as the heat content discharged by the cooling phases, the heat content in the air discharged from the dewatering phase, etc.) as well as the materials extracted by the purification process and the water obtained during the dewatering phase. While the materials extracted by the purification phase may constitute market opportunities, the thermal flows discharged during the process have temperatures that don't allow their reuse for other tasks of the process.

3 - Identification of the business opportunities and the functional needs.

According to TOC paradigm the T, I and OE flows generated by the Current Reality of the system have been evaluated. At present, while the market demand of wood chips is entirely covered by the production, the pellets demand is not satisfied at all. Under these boundary conditions the monetary flows that may be generated by the process are those reported in table 3.

The required investments for the plant assessment are also summarized and the productivity, Net Profit and ROI are evaluated for each product.

The analysis of the system performed on the basis of the ROI criterion, suggests to focus the production just on pellets from sawdust, without taking into account the use of the wood; in other words, according to the ROI criterion, the usage of wood to produce pellets is not worthwhile.

On the contrary, the analysis of the monetary flows according to TOC principles shows that selling one ton of pellets more (that means one ton of wood chips less, according to the available resources) produces an increment of the Throughput of the whole system. In other words TOC suggests to refuse the ROI criterion and to adopt an opposite strategy between pellets and wood chips production.

Thus the main problem of the current reality is that while the process is able to satisfy the market demand of the wood chips, it is not able to produce more pellets to be sold. The negative effect is that the market demand of pellets cannot be satisfied.

Table 3: T, I, OE and Investment (M€) generated by the system in a year

	Wood chips from wood	**Pellets from Sawdust**	**Pellets from wood**
T	2.10	1.10	6.60
OE	1.14	0.067	1.67
I	0.75	0.03	0.75
Investment	1.30	0.05	1.35
Productivity (T/OE)	1.84	16.50	3.95
Net Profit (T-OE-I)	0.21	1.01	4.18
ROI (NetProfit/Investment)	0.16	20.20	3.10

As described in the previous section, the CRT tool allows to point to the causes of the undesired situation. As shown in figure 3, the Constraints limiting the Throughput of the system are the moisture content and the dimensions of the wood chips that does not allow their pelletization so that only sawdust is used. These constraints are related to the limited performance of the system that requires too much energy to dewater the chips and it is not able to reduce their dimensions up to those required for the pelletization phase.

Thus, the analysis of the process brings to well defined technical problems:

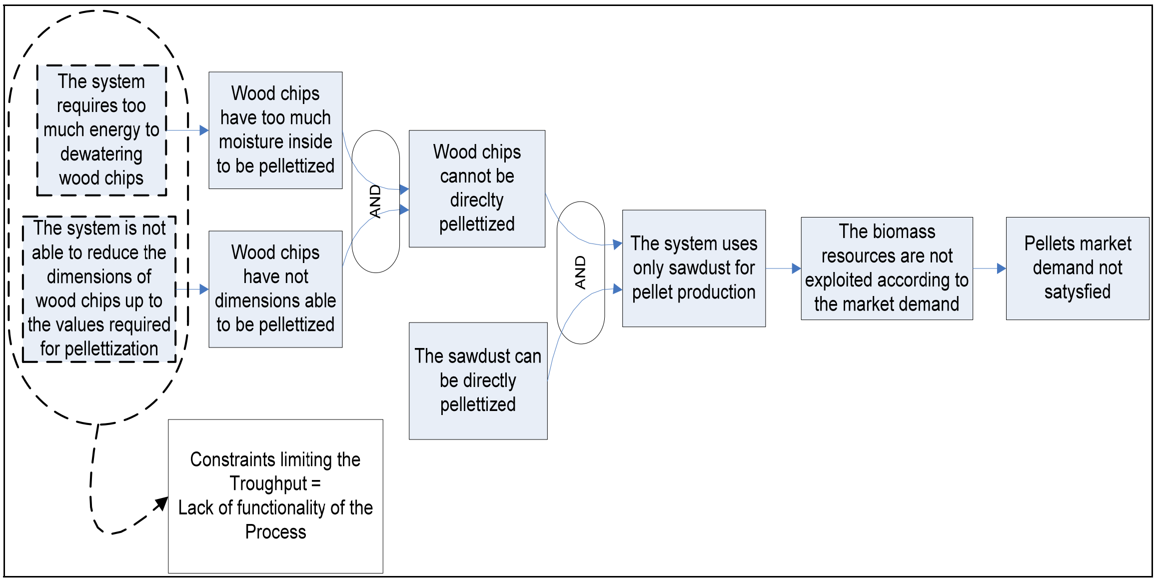

Figure 3: Current Reality Tree of the AS-IS process: from the negative effect (dx) to the core problem(s) (sx).

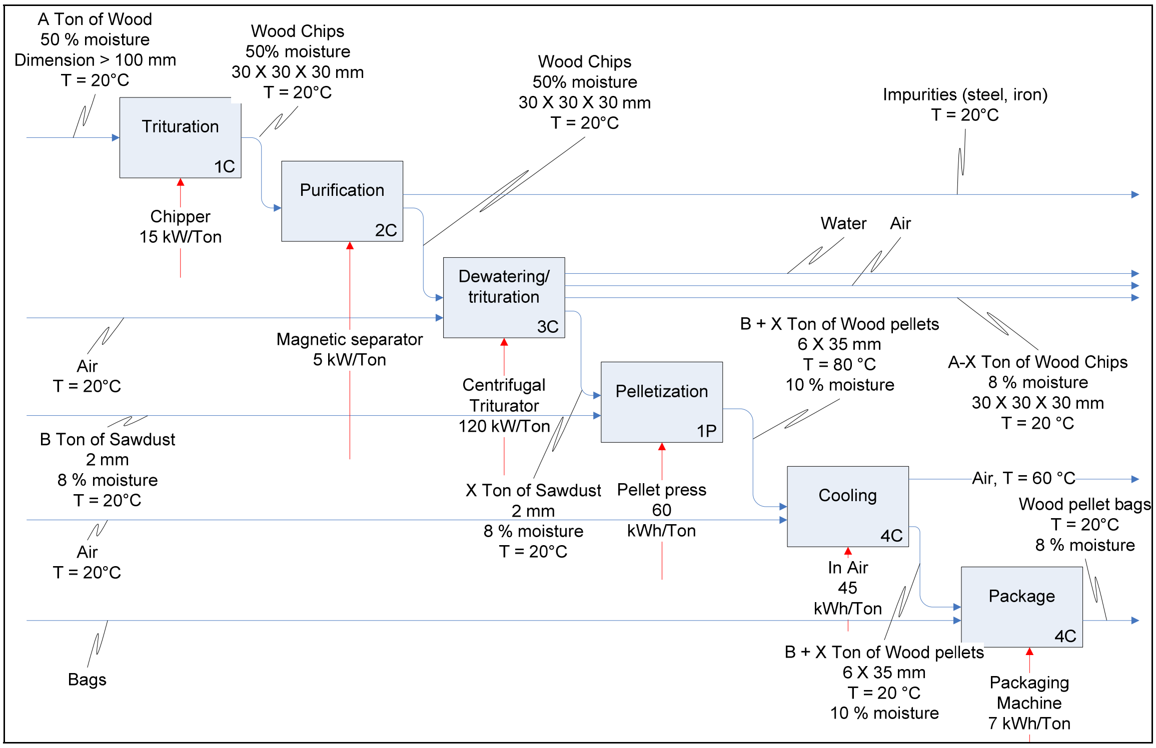

Figure 4: TO-BE process.

- How to dewater chips from 50% to 8-12% of moisture with minimum energy consumption?
- How to triturate the chips into 2.5 mm diameter particles, in order to allow the pelletization?

While the second task is somehow achievable with already well established technologies, dewatering is actually demanded to thermal dehumidification that is a high energy consumption, poor efficiency process (indeed it has the highest OE of the process).

The efficiency depends on the dimensions of the processed material: dewatering sawdust requires less energy than dewatering wood chips. So the problem is that actual technologies for trituration are not able to work properly with wet materials, while thermal dewatering is more efficient with small size materials.

4 - Identification of innovative technical solutions.

A deeper analysis of the problem has revealed a number of concurrent contradictions both in heat dehumidifiers and in triturating machines. Among them, the latter have

a relevant evolutionary potential in terms of contributing to moisture reduction: high speed mechanical energy is a powerful resource to separate water from wood particles during the milling process. If ultrasonic waves are generated by means of high speed shocks, they can further contribute to moisture reduction as claimed also in [10, 11, 12]. A specific patent search to validate such a conceptual solution has revealed three patents [13, 14, 15] adopting the same physical principle to pulverize and dry raw material. At least one of these patents has been converted into a real product by First American Scientific Corp.: a rotor equipped with chains or knifes operates the trituration of the material, by shooting the particles towards the walls of the machine. The impact transforms the kinetic energy of the particle into impact energy that makes the particles and the water vibrate: this allows the separation of the different materials. According to the datasheet supplied by the producer, such a system is able to reduce the moisture content from 60% to 10% and the particle size up to 1 mm. The most relevant property of this technology is the energy consumption three times less of a traditional heat based dehumidification.

5 - Definition of the new process (TO – BE).

A novel TO-BE process has been simulated under the assumption to integrate this technology and the IDEFØ diagram presented in figure 4 has been developed. This process allows to exploit the available biomass resources according to the actual market demand so that the T of the system can be maximized. Moreover the OE of the dewatering/trituration phase has been strongly reduced (22 vs 38 €/Ton). A further advantage is that the final product has a moisture content of 8 % (pellets) instead of 20 % (wood chips) compared with the old process, thus improving the heating power supplied to the customers. Moreover if the milling and dewatering of the biomass is performed during the forestry operations a strongly reduction of the biomass transportation costs may be obtained. This allows the rational exploitation of the forestry resources by removing any kind of location constraint. According to these tasks a new low cost milling and dewatering system implementing the same physical principle used in the machine produced by First American Scientific Corp. is under development in the framework of this project.

Nevertheless, the TO-BE process is still under investigation by the authors in order to check further opportunities for improvements. A new iteration according to the proposed road-map has been performed and the results shown that the pelletization will be the new critical phase limiting the performance of the system.

4 CONCLUSION

A road-map to support the analysis of a production process in order to find functional limits and business opportunities has been presented. The procedure is based on the integration of different methods and tools in order to perform, technical-economical analysis according to the multidisciplinary nature of the task. The main aspects of the proposed integration have been investigated and described.

The application of the road-map to the production of solid biofuel has demonstrated its validity with relevant opportunities of improvement and innovation.

The focus on the Constraint of the process, identified according to the TOC philosophy allows to manage even complex situations with affordable efforts; by improving the Throughput of the Constraint the whole process gains the maximum benefit.

Moreover by simulating the development of the Constraint performance and the shift of the Throughput bottleneck to another phase of the process, it is possible to anticipate technological and know-how needs in the field.

The research work will be further developed in order to extend the applicability of the roadmap not only to production processes, but also to other kinds of technical systems and to decision processes in general. The integration of process simulation tools will be performed in order to speed-up the application of the procedure and in order to support the decision phases.

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