BIOREFINERIES, BIO-OIL, AND SOCIETY: A BIBLIOGRAPHICAL SURVEY

Biorefinarias, bio-óleo e sociedade: um levantamento bibliográfico

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RESUMO: A sociedade atual pode viver uma crise devido ao aumento do consumo. Juntamente com este aumento de consumo, aumenta-se a utilização e a busca por recursos energéticos. Grande parte dos recursos energéticos utilizados nos dias de hoje é proveniente de fontes fósseis, ou seja, fontes não renováveis de energia, principalmente derivados de petróleo e carvão. Desta maneira para diminuir o consumo destas fontes finitas, busca-se nas fontes renováveis de energia uma solução. Dentre as várias fontes renováveis, a biomassa é uma das opções, sendo esta, a principal candidata a suprir de maneira sustentável a uso de hidrocarbonetos tanto como fonte de energia quanto como fonte de matéria prima para as indústrias químicas. O uso da biomassa, assim como as demais fontes renováveis, ainda possui muitos gargalos. Por exemplo, a biomassa possui uma baixa densidade que dificulta seu transporte e consequentemente sua utilização. Uma maneira de vencer este obstáculo é densificar a biomassa. A densificação deste material pode ser feita através da rota termoquímica produzindo um composto chamado de bio-óleo. O bio-óleo poderia ser produzido em pequenas unidades ainda no campo e depois ser enviado a uma grande central chamada de biorrefinaria. O bio-óleo pode se tornar então um intermediário no conceito das biorrefinarias. Onde nestas unidades, seria produzida parte dos insumos químicos e dos combustíveis para a sociedade. Mas para que haja essas mudanças, medidas politicas devem ser adotas. Na COP 21 realizada em Paris em 2015 um passo foi dado nesta direção. Desta maneira este trabalho faz uma breve analise bibliográfica das consequências que a utilização do bio-óleo como intermediário nas biorrefinarias pode trazer tanto no âmbito social, quanto tecnológico, além de relacionar possíveis impactos políticos decorrentes da utilização da biomassa como fonte firme de energia numa matriz energética renovável.
Palavras-chave: Bio-óleo, Biorrefinaria, Sociedade

ABSTRACT: Current society might undergo a crisis due to increased consumption. Along with this increase in consumption, utilization also rises, as well as the search for energy resources. A large part of the energy resources used today comes from fossil sources, i.e., non-renewable sources of energy, especially oil and coal. Therefore, to decrease the consumption of these finite sources, renewable energy sources are regarded as a solution. Biomass is one of the options among the various renewable energy sources and it is the main candidate to supply in a sustainable way the use of hydrocarbons both as a source of energy and a source of raw material for the chemical industry. The use of biomass, as well as other renewable sources, still has many challenges. For example, biomass has low density, which hinders its transportation and, consequently, its use. One way to overcome this obstacle is to densify biomass. The densification of this material can be made thermochemically, producing a compound called bio-oil. Bio-oil could be produced in small units in the field and then be sent to a large central unit called a biorefinery. Bio-oil can thus become an intermediary to the concept of biorefineries. These units would, then, produce part of the chemical raw materials and fuels for society. But for these changes to occur, political measures must be adopted. At COP 21, held in Paris in 2015, a step was taken in this direction. Thus, this study makes a brief literature review of the consequences that the use of bio-oil as an intermediary in biorefineries can bring both socially and technologicaly, as well as to relate possible political impacts resulting from the use of biomass as a steady source of renewable energy.

Keywords: Bio-oil, Biorefinery, Society

INTRODUCTION

Society has reached a stage of development in which it is necessary to study its environment to be able to continue the process of development, since the current consumption level is not sustainable (GELLER, 2003).

There is an impasse between development and use of the environment. And within this impasse, social issues such as income distribution, energy matrix, and especially sustainability are discussed.

According to the Greenpeace report of February 2007, the replacement of energy sources must be made by 2050 to avoid a large increase in the planet's temperature. Geller (2003) argues that an energy revolution is possible and desirable. This revolution will bring technological and social impacts.

Technologically, energy matrix must be rethought due to new technologies (as solar, wind and biomass energy sources) and mainly to the integration between them. This integration will need a very well designed control, nowadays, smart grid is the major tool studied (GREENPEACE, 2016).

Socially, work force will be required in these sectors. As many of the process will be new, new jobs will open up, others can decrease and even disappear according to technology used, thinking just in renewable energy sector (SOUZA et al., 2016).

Thinking in other sectors, for example, those related to fossil fuels. The jobs going to decrease or going to be shifted to renewable sector. Transport of oil by trucks and by ships going to be affected. Ships transport many of oil used in the world. So, what about these jobs? Society need to be prepared to live this new paradigm, the low carbon society (SHARMINA *et al.* 2017).

Studies concerning the interaction between technological and social impacts of these revolutions must be done. It is important to analyze, plan and understand the possible impacts of these changes.

One of possible changes will be the creation of biorefineries. Food and nergy going to be processed at these units. Sugar mills are an actual example, because they are able to process sugar and ethanol but using just one part of the sugar cane. In the future, sugar mills going to be able to produce more and possibly different products through different process, using other parts of the sugar cane, like straw and bagasse (SOUZA *et al.,* 2016).

Therefore, this study will make a brief literature review addressing social and technological issues of the use of renewable energy sources, in particular biomass. Specifically, we will analyze the use of bio-oil, a product derived from biomass, as an intermediary in the concept of biorefineries and possible impacts to the use of this energy source (PEREZ; DAS; ADAMS, 2013).

METHODOLOGY

This study was developed by searching scientific articles, master degree dissertation, doctorate thesis and books from the last 20 years with national and international relevance, in order to evaluate the state of art of the theme: biorefineries, bio-oil and society.

Most of the papers read were obtained from Science Direct, Scopus, SciELO and Google Scholar.

Furthermore, reports from non-governmental organizations were also analysed. These institutions organize reports predicting possible consequences from climate change, and suggest mitigating actions.

Results and challenges found by the authors in the selected papers are going to be shown at this study.

RESULTS AND DISCUSSION

Results from the bibliographical review will be shown at this topic. It is organized in four sub items:

– Social Aspects

– Energy Aspects

– Bio-oil

– Biorefineries, society and the Thermochemical Route

At the three first sub items, each aspect are studied separately. After, interaction among them are analyzed and a proposal of how bio-oil can be used in a possible biorefinery is done.

SOCIAL ASPECT

Discussions about the social and environmental impacts related to consumer society occur globally since the 1970s with the publication of the report: *The Limits to Growth*, by the Club of Rome and the creation of the United Nations Environment Programme (UNEP) in Stockholm, in 1972. In addition, Brazil outstood in discussions for hosting ECO 92 in 1992 and Rio+20 in 2012, both held in Rio de Janeiro. The most talked-about recent event was the COP 21, held in Paris, in 2015. (ALTVATER, 1995; MELLO; HOGAN, 2007).

In a regional level for Brazil, these effects are seen by the poor income distribution and increase of *favelas*, as noted by Mueller (1997). Another regional problem is deforestation, mainly in the Amazon region, to expand the agricultural area.

Poor income distribution can be seen by the disparities between rich and poor, however, this consequence is not unique to Brazil, as shows Altvater (1995), who states that: "The united world is a divided world", whose division is between rich and poor.

According to Melo and Hogan (2007), this model of consumer society was strengthened after World War II, to recover the economies of the countries most involved in the battle. The increase in consumption boosts the industry, which consequently generates jobs and money for people to spend. The system in this loop moves the economy.

This loop of consumption requires raw materials and energy, having environmental degradation as a side effect that impacts society in different ways according to the social level (GELLER, 2003; MUELLER, 1997; SEROA DA MOTA, 2002).

A study on environmental impacts concerning the social level in Brazil is shown by Seroa da Mota (2002). This study argues that degradation is greater as income increase, but the impacts are more noticeable in the poorest populations.

This degradation has consequences, such as increased air pollution, global warming, ecosystem degradation, sea level rise, bad use of land/soil, imbalance in fishing activity, and access to drinking water (GARNER, ASSADOURIAN; SARIN, 2004; GELLER, 2003).

Another factor to be considered when it comes to consumption of goods and its impact on the environment and on society is the energy aspect.

ENERGY ASPECT

Energy is the source of society's development. However, the use of energy resources for conversion into electrical energy and for the production of goods is increasing year by year, due to the consumer society (GELLER, 2003; SAWIN, 2004).

Energy consumption is present throughout the entire production chain. Thus, with population increase, reduction in the size of households, and increase of purchasing power, there are more houses, with more home appliances, cars, and consequently greater energy consumption to produce these goods (SAWIN, 2004).

A positive factor is that the processes and goods such as home appliances and cars are becoming more efficient over the years. However, consumption is increasing at a rate greater than the increase in efficiency. Thus, global energy consumption continues to increase (GELLER, 2003; SAWIN, 2004).

According to Goldenberg (1998), this increase in efficiency is higher in countries that are already industrialized. The poorest and developing countries consume energy less efficiently, and these are the places where there has been a rise in energy and goods consumption, as point data provided by Garner, Assadourian and Sarin (2004).

Regarding the conversion of energy, it is necessary to decrease the use of petroleum derivatives such as fuel. According to the Greenpeace report of February 2007, electric power conversion systems must be decentralized and sustainable. This way, the use of fossil fuels and carbon for conversion into electrical energy is reduced.

After a few years of this study from Greenpeace, these measures have a good chance of being implemented. During COP 21, the most important political agreement related to international climate change and sustainable development was signed. Named Paris Agreement, it obliges signatory countries to adopt measures and programs to combat climate change. (FRAMEWORK CONVENTION ON CLIMATE CHANGE, 2015).

For this goal to be achieved, many of the actions are aimed at reducing the use of fossil fuels, whose burning is responsible for the emission of greenhouse effect gases, the main cause of climate change. It is worth pointing out that these emissions are generated mainly by anthropic activities and the increase in emissions has been continuous since the beginning of the industrial revolution (IPCC 2014).

This agreement, signed in Paris, as well as positive concerning the environmental aspect, is also very good in the political perspective, as Geller (2003) had already stated that a possible energy revolution would only be achieved with political engagement.

An example of this assertion by Geller (2003) was the Growth Acceleration Program (PAC), a public policy adopted by the Brazilian Federal Government in the early 2000s for the development of national infrastructure, whose projects did not have the participation of the Ministry of the Environment and did not consider environmental and sustainable issues, showing the disregard with which the theme was treated until then (VILLANI, 2008).

With a promising future, but for not so noble reasons, for the energy revolution to be consolidated, it must go through a period of transition from a non-renewable energy matrix to one based on renewable sources. Geller (2003) and the Greenpeace report of 2016 cite natural gas as the fuel responsible for stabilizing this transition. Because this fuel, even though being from fossil origin, is less polluting than the other non-renewable sources.

The main renewable energy sources are wind, solar, hydraulic, geothermal, and biomass. Despite the potential of these sources, they present a dispersed character compared with fossil energy sources, because the latter ones are scattered on the surface of the planet and often depend on climatic factors to be used (BRUCKNER *et al.,* 2014).

To compose a renewable energy matrix diversity is necessary. Each region should analyze which are the best ways to use its renewable sources and integrate these sources to the energy system (BRUCKNER et al., 2014).

In this regard, biomass offers an advantage over other sources, because even with the scattered character of biomass, it can be concentrated in power generation units. A Greenpeace report of 2016 on energy points out biomass as a steady source of energy, one that can be considered constant, considering renewable sources.

Biomass is any organic product, both of vegetable (formed through the process of photosynthesis, in which CO_2 and H_2O are converted into organic matter by solar energy) and animal waste origin. Therefore, plants, wood, silviculture waste, agriculture and livestock waste are considered biomass (ADEBANJO, 2005; BONDUKI; GONÇALVES, 2011).

The importance of biomass goes beyond the energy aspect. As previously mentioned, in the process of photosynthesis CO_2 is absorbed, therefore, this raw material will be able to absorb CO_2 from the atmosphere under certain conditions, as for example, in the process of reforestation of devastated areas (BRUCKNER *et al.,* 2014).

With energy use, biomass can be burned directly for conversion into thermal and/or electrical energy, this being the traditional use of this renewable source and most used in poor and developing countries (GELLER, 2003).

New technologies, however, are being created to use biomass fully, with improvements in planting and new methods to transform biomass into other fuels or hydrogen (GELLER, 2003).

BIO-OIL

The problem of using biomass for energy generation is its low density, which hinders its transportation and makes its use expensive. A way to use this raw material is to densify it, increasing its mass per unit volume to facilitate transportation (RENNARD et al., 2010; ROSSUM *et al.,* 2007).

One way to densify biomass is to turn it into liquid. There is already an entire logistics prepared to meet the demand with this raw material in liquid state, due to the petrochemical industry. Another advantage is better accommodation, not requiring large spaces to store it, due to the increase in density (RENNARD et al., 2010; ROSSUM *et al.,* 2007; PÉREZ, 2010).

Biomass (density between 80-240 kg/m^3) can be converted into liquid by fast pyrolysis, a process that consists in the thermal degradation of the material between 400-650°C with residence time of less than 2 s and a rapid cooling of vapors, which condense and form the bio-oil. This product has an average density of 1,200 kg/m^3 and the process has an average yield of 60% in mass regarding the dry biomass used for its production (PÉREZ, 2010; ROCHA *et al.,* 2009).

According to Pérez (2010), fast pyrolysis is an available technology, but not on a large scale due to technical and economic factors. Geller (2003) argues that the technologies to process biomass are expensive at first, but with R&D and market expansion, these values tend to decrease, making technology competitive. The cost of bio-oil is 10% to 100% higher than the fossil fuel (CZERNIK; BRIDGWATER, 2004).

Bio-oil is a complex mixture of chemicals of various molecule sizes, has dark brown color, and has a strong odor of smoke. It has a great presence of water, mainly because its raw materials are humid (SÁNCHEZ, 2010; SCHLITTLER et al., 2009; CZERNIK; BRIDGWATER, 2004; OASMAA; CZERNIK, 1999).

Nowadays, studies show that bio-oil can be used as a substitute for fossil oils in some applications, like diesel engines, gas turbines, boilers and furnaces for heat and power (ZHENG, 2016; OASMAA; CZERNIK, 1999).

This feedstock can be classified as a modern use of biomass, since the raw material passes by a treatment that improves its end use. There are still many obstacles to be overcome for the effective use of bio-oil (CZERNIK; BRIDGWATER, 2004; OASMAA; CZERNIK, 1999).

The most critical one is the acid character of the material, which hinders its storage in non-metallic reservoirs. Another point to be improved for the use of bio-oil is its stability when stored. During storage, the aging process of bio-oil starts to occur, which consists of polymerization reactions and changes in physical and chemical properties with the increase in water content and viscosity of the material (SÁNCHEZ, 2010; CZERNIK; BRIDGWATER, 2004).

This last case it is not so bad, a recent study showed among other things that a blend of aged bio-oil with glycerin, a byproduct from biodiesel, was able to produce a more stable emulsion when compared with blend made with new bio-oil (ZHANG; WU, 2017).

Other point also difficult use of bio-oil is wide variety of it, because it is related to the feedstock used to prepare. Standardization need to be done even as norms for producers and users (CZERNIK; BRIDGWATER, 2004).

More information as well need to be researched, environmental health and safety issues are not completely resolved besides that bio-oil is still unknown by the public, so some resistance in its use can be found (CZERNIK; BRIDGWATER, 2004).

Only studies and information for people going to solve the challenges related to bio-oil. Thus, many possibilities and applications will be opened to diversify the use of bio-oil.

BIOREFINERIES, SOCIETY AND THE THERMOCHEMICAL ROUTE

By possessing several compounds (around 300 different ones already identified), bio-oil can be used as an intermediate in biorefineries. The biorefineries are integrated complexes that produce different products from different raw materials of organic origin, aiming at more efficient processes from the thermodynamic, economic, and environmental point of view (SÁNCHEZ, 2010; OASMAA; CZERNIK, 1999).

Economic feasibility studies show that bio-oil can be used as input in a biorefinery provided that should be produced in small and medium-sized decentralized pyrolysis units (PEREZ; DAS; ADAMS, 2009).

These decentralized units going to be responsible to densify biomass and would have the capacity to generate jobs and infrastructure for the communities around it, improving the quality of life, the same as what happens with workforce employed in the production of ethanol in Brazil (SOUZA et al., 2016; GREENPEACE, 2016; SMITH et al., 2014)

As the production of bio-oil will be decentralized, this production will be strongly linked to the rural population, which will settle in these regions, decreasing rural exodus and developing these areas.

In developing countries, this process can bring similar benefits, especially because they are in the process of being included in the consumer society. These populations may consume more efficient products, regarding both energy and production, concerning what is consumed today (SMITH et al., 2014)

Another important point related to the production of energy through the communities is that the population will be able to be present and have more participation in the process of energy generation, with a more democratic control of production (SWEENEY, 2014).

The State of the World 2014 report provided by The Worldwatch Institute (WWI) states that in addition to democratic control, a social property and community control of energy policies should exist, and these actions, when deployed, should become politically irreversible (SWEENEY, 2014).

From a technical point of view, the bio-oil produced in the countryside would be brought to a large and centralized unit (a biorefinery). In this unit, the bio-oil can undergo chemical, biological, and thermal processes for obtaining derivatives. This happens because the composition of the bio-oil contain carbon, hydrogen, and oxygen, being a sustainable source for the production of fuels and chemical inputs (ADEBANJO, 2005; ROSSUM *et al*., 2007; ROCHA *et al.,* 2009; PEREZ; DAS; ADAMS, 2009; PANIGRAHI *et al.,* 2003; OLIVEIRA, 2011; ROCHA, 2012; SCHULTZ; TRICHES, 2012; JUNIOR, 2012).

In Figure 1 is an example of the structure of a biorefinery run by bio-oil. From the social point of view, each site used for the production of biomass, production of bio-oil, and, finally, in biorefineries, would generate new jobs, both formal and informal, and consequently it would allow improvement in the living conditions of the population of these regions.

At field, work force probably going to be similar to what is found in sugar cane first generation jobs, which are related to planting and harvesting. At densification step and at biorefinery more specialized jobs going to be needed (SOUZA *et al.,* 2016).

The more specialized is work force the higher is education, as well as fees and the participation of female workers. However, the number of jobs are lower if compared to those open in the field (SOUZA *et al*., 2016).

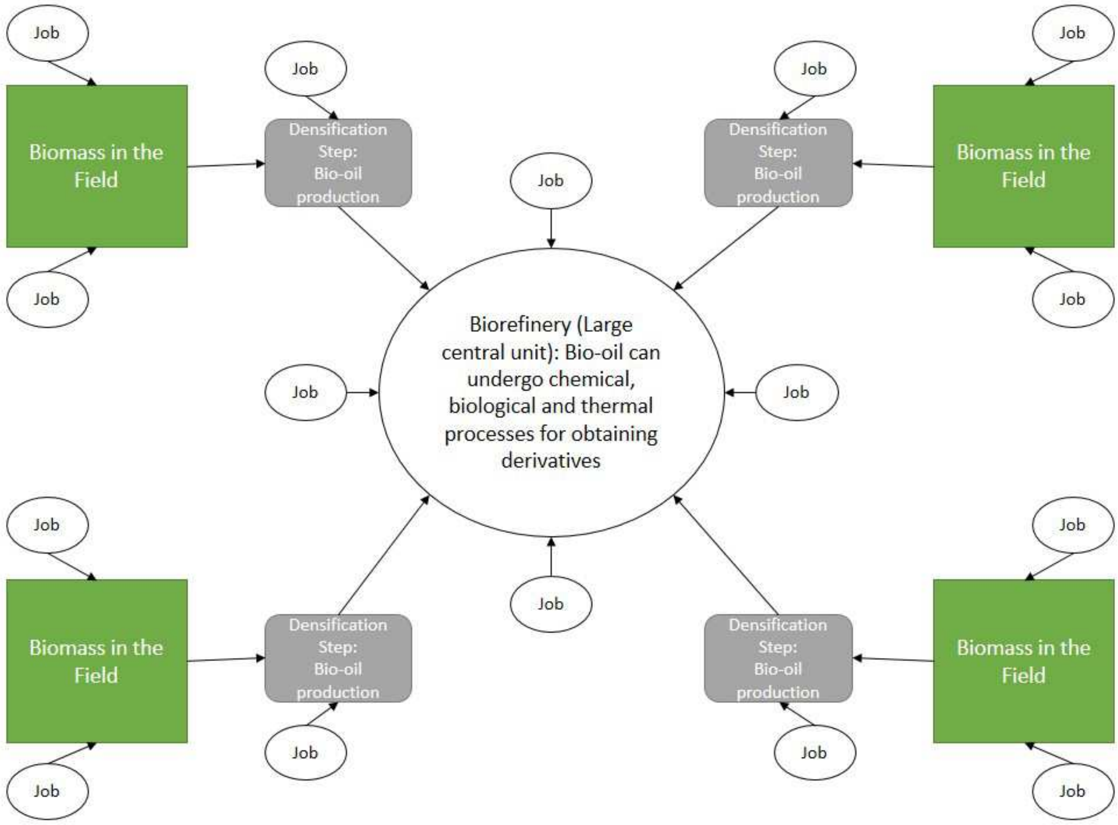

Figure 8 – Organization of a Biorefinery

Figure 2 presents a summary of some of the processes by which bio-oil can pass and their respective products.

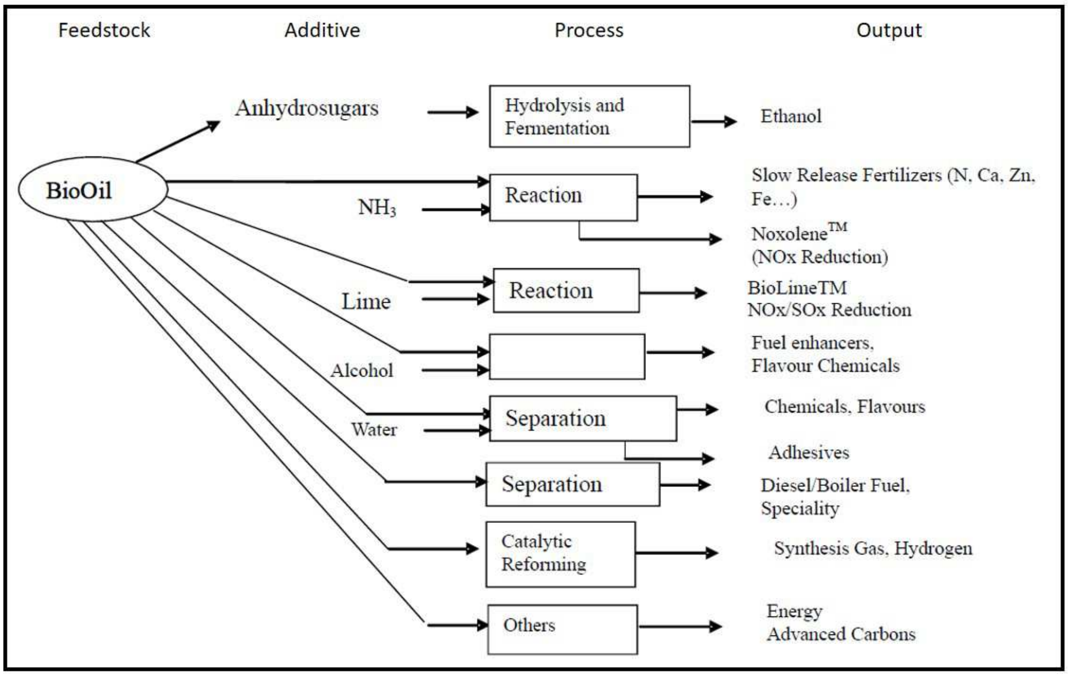

Figure 2 – Utilization route of Bio-oil, adapted from Perez, Das, and Adams (2009).

To have an idea of the available energy potential, a survey on the amount of organic waste produced in Brazil was made by Bonduki and Gonçalves (2011). They estimated about 290 million tons of agricultural waste in the year of 2009. The fate of this waste is usually simple burning (not for energy purposes).

In this study, the authors estimated that silviculture generated around 85 million m^3 of forest residues, and paper and cellulose industries generated almost 11 million tons of waste. These wastes have a similar fate to that of agricultural waste (BONDUKI; GONÇALVES, 2011).

In a hypothetical situation, if all agricultural waste from 2009 were dried and only a quarter of its mass lasted (around 75 million tons of dry waste) and this material could be harnessed and transformed into bio-oil (with 60% yield) to be used as feedstock for a biorefinery. The estimated energy potential (considering the inferior heat of combustion of bio-oil as 15 MJ/kg), if you only burn the bio-oil, is of 6.75×10^5 TJ/year, which converting to TWh would be 187.5 TWh. For comparison, this energy would be the equivalent of almost twice the energy produced at the Itaipu power plant in its best year (in 2016, the plant generated 103.09 TWh) (ITAIPU, 2017).

In this hypothetical situation, it is possible to see the energy potential that is dispersed and being poorly exploited in Brazil. If the burning of this material occurs in a controlled location, it can reduce the occurrence of respiratory problems of the population living close to the locations where current burnings take place, and it is also possible to avoid the expansion of the agricultural frontier for planting dedicated to energy, leaving these areas available for reforestation.

The Brazilian agricultural production tends to increase, and, consequently, its waste will also increase. Therefore, it is important to proper dispose of this material.

Conceptually, a biorefinery run by bio-oil is an interesting project, because bio-oil can be produced from various biomasses and can even be produced using waste as raw material.

In the biorefinery, value would be added to the material, being produced inputs to society, as well as fuel options that can be used in industry for the production of electricity and for transport.

One of the routes used to add value to bio-oil is the thermochemical route, which seeks, by thermal processes, to obtain greater efficiency from the raw material.

Gasification is one of the main technologies applied in this route, being studied primarily by the catalytic or non-catalytic conversion of the bio-oil.

Catalytic gasification is widely studied, since it can achieve a composition of synthesis gas (H_2 + CO) with low levels of impurities, also achieving, in some cases, the elimination of the presence of CH_4 and light carbon chains (C_{2+}). The problem is the life cycle of catalysts, which is saturated with coke, disabling the catalytic sites (ROSSUM et al., 2007; CHHITI et al., 2011; ROSSUM et al, 2009).

For the non-catalytic gasification, there is less work, usually with the influence of temperature, atmosphere, residence time, and the reaction with presence or absence of water vapor being studied (steam reforming) (CHHITI et al., 2011).

Costa and Sánchez (2015) studied a non-catalytic gasification in inert atmosphere to try to avoid coke formation inside reactor. It was seem that the heavier fraction of the bio-oil could be the responsible for the coke formation and for the increase of CO_2 and CO yields.

Zheng el al. (2016) concluded bio-oil is an ideal material for gasification, easier to put into mass production and economically more profitable than steam reforming.

The thermal conversion of bio-oil has the following systematic: the bio-oil is atomized, forming small drops. The drops undergo an initial warming, increasing in size and then micro explosions occur. In this process, there are two regions with constant temperatures: one at 100°C, in which evaporation of the light volatile components occur; and another at 450°C, in which the thermal cracking of unstable components occur. Cracking process forms char, tar and gases. During this step occur the formation of gases from gasification, if this process occurs with lack of an oxidizing agent. From 600°C, the ignition of the drop begins, starting combustion. (WORNAT; PORTER; YANG, 1994).

The resulting gas can be burned to generate energy, or, if it reaches the ideal ratio of H_2/CO, it can be used for the production of fuel and certain synthetic materials by the Fisher Trosph process.

Wastes from the thermochemical route can be used in other stages of the biorefinery, or can serve as agricultural fertilizers.

FINAL CONSIDERATIONS

The need to change the energy matrix is a fact. It needs to become renewable and diversified, to assist the world temperature to stay in an acceptable level, with the least possible amount of side effects. The Paris agreement is an important step toward this change, especially for putting politics as an agent of change.

The renewable matrix will have biomass as a steady source of energy. Studies indicate that it will be responsible for at least 25% of global energy. Because of this, it is necessary to analyze the impacts that a change like this can bring to society.

Due to the scattered character of biomass, energy production through this source will require large areas and maximization of the utilization of biomass, as it is not recommended to increase the existing production area, due to deforestation and competition for space with food production.

For production in large areas, a workforce is necessary, therefore, one of the positive points of biomass will be the creation of jobs and the consequent appreciation of this work, as it occurs with sugarcane workers, who, compared with other rural workers, are better paid.

Therefore, if people are better paid, there will be more consumption, which will encourage the productive chain. This point is critical, since this better paid population should be consuming more sustainable products, produced within the renewable energy matrix to prevent major environmental imbalances.

In developing countries, the use of biomass needs to be enhanced to achieve better use of raw material, making the process of energy generation more efficient. In addition to the generation of jobs, there is the possibility of the population settling in nearby locations for the production of biomass and energy, decreasing the flow of people to the cities.

Also in favor of biomass being a scattered source, there is the fact that the population might be closer to the production and might also make the use and control of the energy more democratic, passing the decision-making power of energy policies to the population.

As for the maximization of the utilization of biomass, it is directly related to the biorefineries, which will be responsible for converting the energy and producing chemical inputs to society. Since biomass has low density, for greater logistics efficiency, it must be densified, and bio-oil is a good solution for this problem.

Bio-oil still needs to be further studied to improve its physical and chemical properties, but when this challenge is overcome, it will be possible to submit it to biological and chemical processes at biorefineries to produce raw materials and energy. One of the solutions that will need to be employed to the diversification of the energy matrix.

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