# CARBOVAL COMO UM VETOR PARA INTENSIFICAR O CONCEITO DA ECONOMIA CIRCULAR NO INDÚSTRIA SIDERÚRGICA *

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**Resumo**
Em um mundo de recursos naturais decrescentes, com a intensificação das indústrias automatizadas de todos os tipos (I4) e contínuo aumento da população, é necessário desenvolver melhores caminhos para a geração e distribuição de riquezas. Uma das alternativas para este objetivo é o conceito da Economia Circular. Este artigo apresenta um exemplo focado na intensificação do uso de resíduos de biomassa na produção integrada de aço exclusivamente baseada na combinação de reatores industriais existentes em um layout que favorece o conceito da economia circular. O ferro também é obtido do processamento tradicional de sucata, reprocessamento de resíduos de ferro e óxidos de ferro, como a escória, pequenos óxidos de ferro, reversos metálicos, resíduos da indústria siderúrgica integrada tradicional. Os resíduos de biomassa são provenientes da demolição de casas de madeira, e outros resíduos de biomassa, como limpeza florestal para evitar-se incêndios, resíduos de moinhos, paletes usados e qualquer outra fonte de biomassa. As combinações dos reatores tornaram-se possíveis devido à nova versão do processo de Carbonização Contínua, Carboval, um reator especialmente projetado da tecnologia Lambiotte tradicional, para produzir, de preferência, o carvão vegetal que possui as mesmas características necessárias para alimentar o Mini Alto Forno tradicional a base de carvão.
**Palavras-chave**: Economia Circular; Resíduos de Biomassa de Madeira; Micro-mill; Gases Industriais.

## CARBOVAL AS A VECTOR TO INTENSIFY THE CIRCULAR ECONOMY CONCEPT IN THE STEEL INDUSTRY

**Abstract**
In a world with decreasing natural resources, intensifying fully automated industries of all kinds (i4) and continuous population increase, it is necessary to devise new ways to look for wealth creation and distribution in a human including manner. One of many alternatives towards this goal is through the concept of Circular Economy. This paper presents an example focused in intensifying the biomass wastes use in the integrated production of steel units exclusively based on existing industrial reactors combined in a layout favoring Circular Economy concept. The iron units are also from the traditional scrap processing along with the reprocessing waste iron and iron oxides sources such as scale, small iron oxides and metallic reverts, residues from the traditional integrated steel industry and biomass wastes coming from wood house demolition and other biomass residues such as forest cleaning to avoid forest fires, saw mill residues, used pallet and any other wood based residues. The existing reactors combinations became possible due to the new version of the Continuous Carbonization process, Carboval, a reactor specially reengineered from the traditional Lambiotte technology; to produce preferably lump charcoal that has the same characteristics necessary to feed in the traditional Charcoal based Mini Blast Furnace.
**Keywords:** Circular Economy; Wood Biomass Residues; Micro-mill; Industrial Gases.

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# 1 INTRODUCTION

The growth of the world population results in the necessity of more natural resources. This is possibly an unsustainable scenario in the current economic model, given the finitude of those resources. This model is based in the extractive, transformation and production activities, use and discard and its limitation isn't associated only the scarcity of raw material, but also the spatial matter. The generation of waste, often not reused, is increasing, as well as the lack for disposal areas, greater every day [1].
The circular economy is an economic model of production that aims environment protection, pollution reduction and sustainable development. Thus, resources used with the highest possible efficiency, reusing and recycling or seizing a main process sub product as an input in other processes, decreasing the formation of residues. This economy requires practices as organized industrial allocation, urban infrastructure, environment protection, technological paradigms and social welfare distribution [2].
Circular model intends to minimize the necessity of raw material, since the components stands for a reuse flow, so that when its life cycle finishes in a process, it can get a new function and be used in another process. Many processes generate secondary products, for example, the gases produced in the processes in steel sector. The use of this waste in other processes is a fundamental concept of the circular industry; thus the concept residue is discarded and the term sub product is used. Figure 1 shows the schematic relation of circular economy.

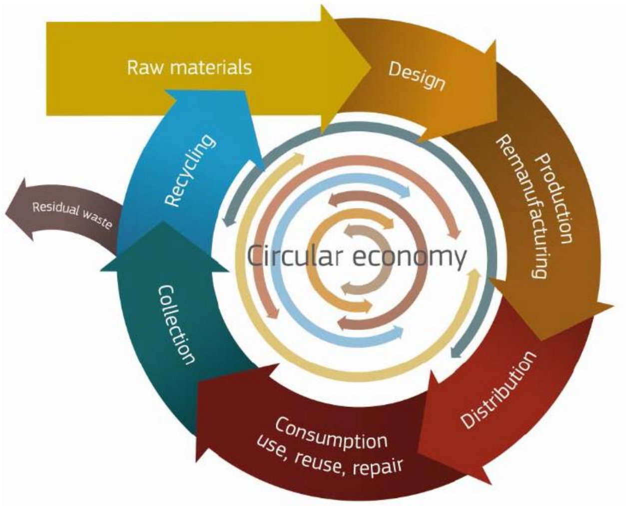


**Figure 1**. Circular Economy[1].

Circular economy happens by means of synergy between industry process that presents potential to feed or to be fed by secondary products of other processes. The Electric Arc Furnace (EAF) is a traditional reactor used in the mini-mill, resulting in steel production, considered a recycler of iron and steel, since its input is traditional iron scrap. The most consuming electric energy process is the electric steelworks, the oxygen converters and the hot rolling mill. In Brazil, 14% of the production costs in a micro-mill that use EAF is to electric energy, while in a coke based integrated plant this percentage is 3% [3]. With Figure 2 is possible to check two scenarios about the steel production in a micro-mill. The first case is the normal flow in an EAF. Iron scrap and external electric energy are inputs.

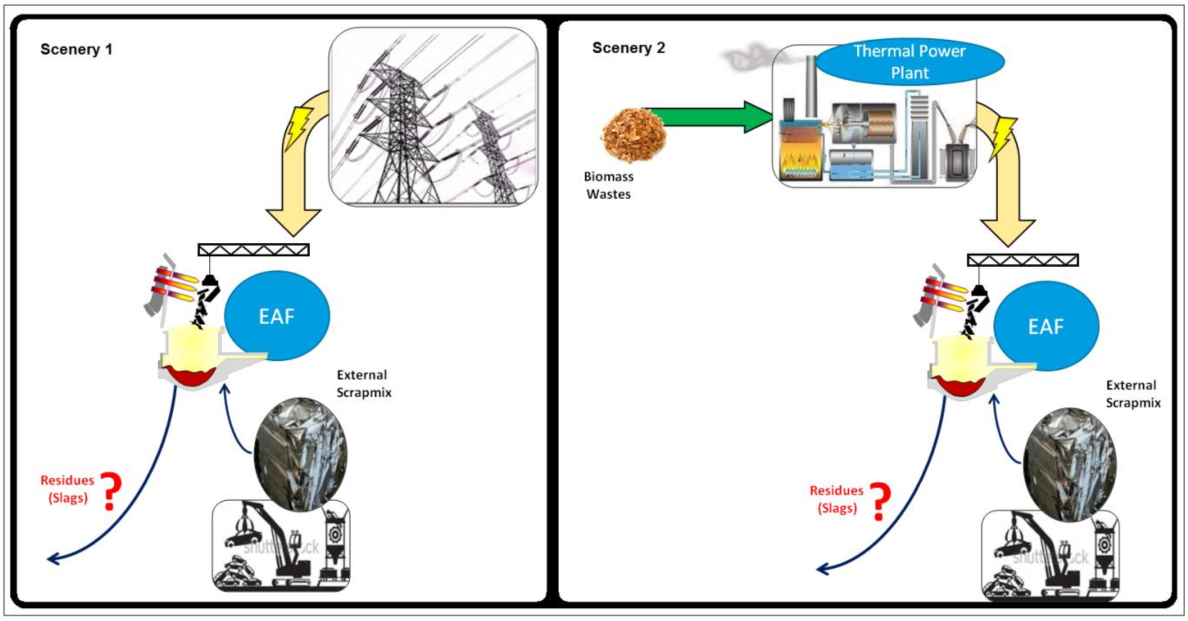


**Figure 2**. EAF Flow.

Looking for an alternative to reduce the costs in the steel production, the second scenario presents an option that includes a thermal power plant based in biomass waste. Thus, the energy necessity can be supplied by a low cost energy source. There is one problem in the exposed cases. The residues generated during the process, as slag and dust, must be discarded, since there is no use for these residues in the process.

Figure 3, with scenario three, shows an alternative that enables the highest resources circularity.

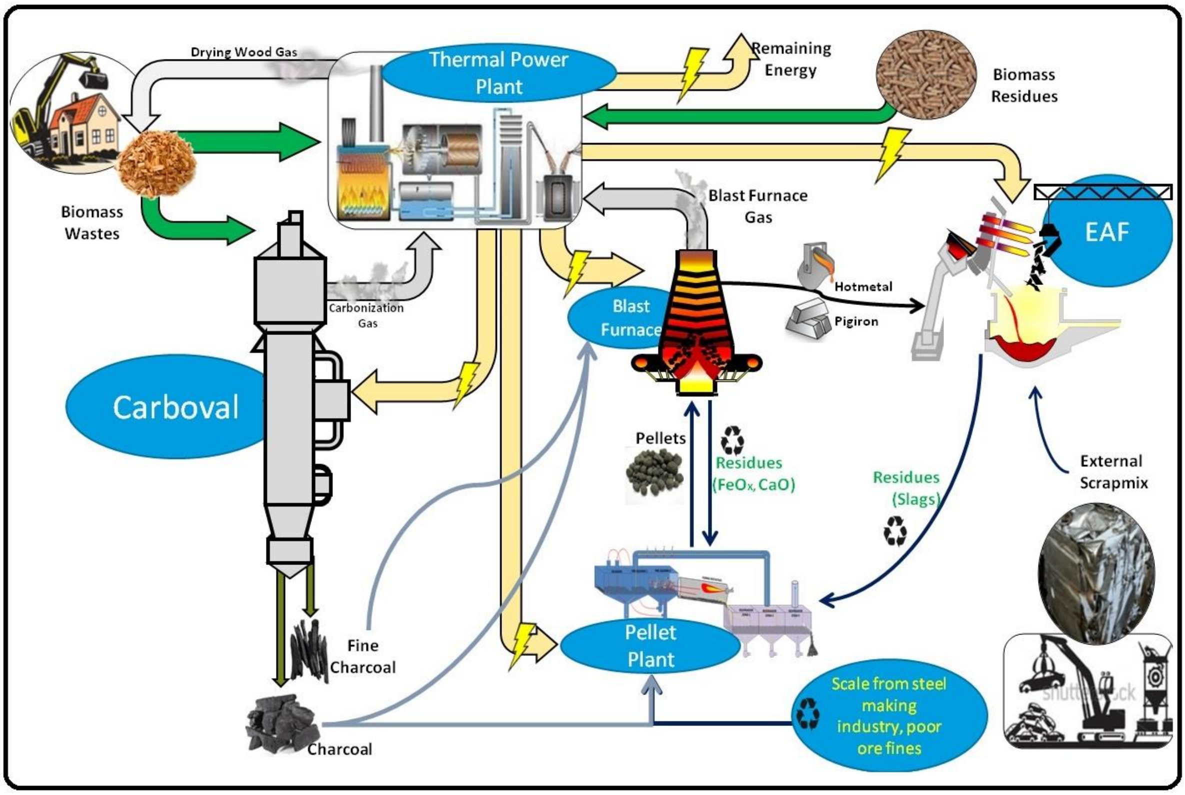


**Figure 3**. Scenario 3.

In this scenario, larger opportunities of recycling were included, the wood biomass wastes are used to generate energy and as input in a main process. Other biomass types are still worn in the thermal power plant, but now the residues generated during the processes, as slag and dust, can be used inside the system. There are also process gases generation, which contribute to major overall energy efficiency.
In addition to the proposed in scenario 2, three other reactors were included: a Continuous Carbonization reactor, a blast furnace and a pellet plant. Wood is an environmental resource used in a global scale; therefore the generation of wood waste is also large. Possible examples could be urban wood wastes, construction and demolition wastes and primary and second mill wastes. Thus, to include wood biomass wastes in the steel process is a great idea, because there are large quantities available of the resource at a low cost.
The synergy presented is only possible due the inclusion of Carboval Continuous Carbonization Reactor, responsible to provide charcoal to MBF and pellet plant, recycle wood biomass wastes and generate carbonization gas, which will be used in the thermal plant.
Scenario 3 is the last studied possibility, granting optimal circularity in the system. The pellet plant feeds the MBF and the blast furnace gas is directed to the thermal power plant. Also, every solid residue, from the EAF and MBF, as well as any others steel industry wastes, is an input in the pellet plant. Concluding the circular economy, the power plant provides the electrical energy to all these reactors and enables the energy to be also exported, possibly being sold.
This paper has the objective to present the situation with 300 thousand tons produced steel per year, based on the economy circular concept, in a mini mill, comparing the possible scenarios.

## 2 METHODOLOGY

The procedures consisted in developing a calculus spreadsheet that permitted the simulation of a steel production of 300 kt/y in a micro mill, considering the data in Table 1.

**Table 1.** Data Input

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| Steel Production (kt/y) | 300 | 300 | 300 |
| %Fe in steel | 99,5 | 99,5 | 99,5 |
| EAF slag (kt/y) | 30 | 30 | 30 |
| %Fe in slag | 25 | 25 | 25 |
| EAF dust (kt/y) | 7,5 | 7,5 | 7,5 |
| %Fe in dust | 40 | 40 | 40 |
| Iron Scrap Use (kt/y) | 319 | 319 | 184 |
| %Fe in Scrap | 97,0 | 97,0 | 97,0 |
| Hot Metal Use (kt/y) | - | - | 107 |
| %Fe in Hot Metal | - | - | 94,0 |
| Solid Pig Iron Use | - | - | 92 |
| %Fe in Solid Pig Iron | - | - | 94,0 |
| Total Metallics(kt/y) | 319 | 319 | 323 |
| Thermal Power Plant Capacity | - | 30 | 30 |

| | | | |
|---|---|---|---|
| Thermal Power Plant Efficiency | - | 27 | 27 |
| Fixed Carbon | 71 | 71 | 71 |

The inputs and outputs of each reactor and their relations with other reactors were treated as shown hereafter.

## 2.1 Carboval Continuous Carbonization Reactor

In the carbonization process two important concepts are Fixed Carbon (%FC) and Gravimetric Yield (%GY). The relation between this two concepts and temperature can be view in Figure 4.

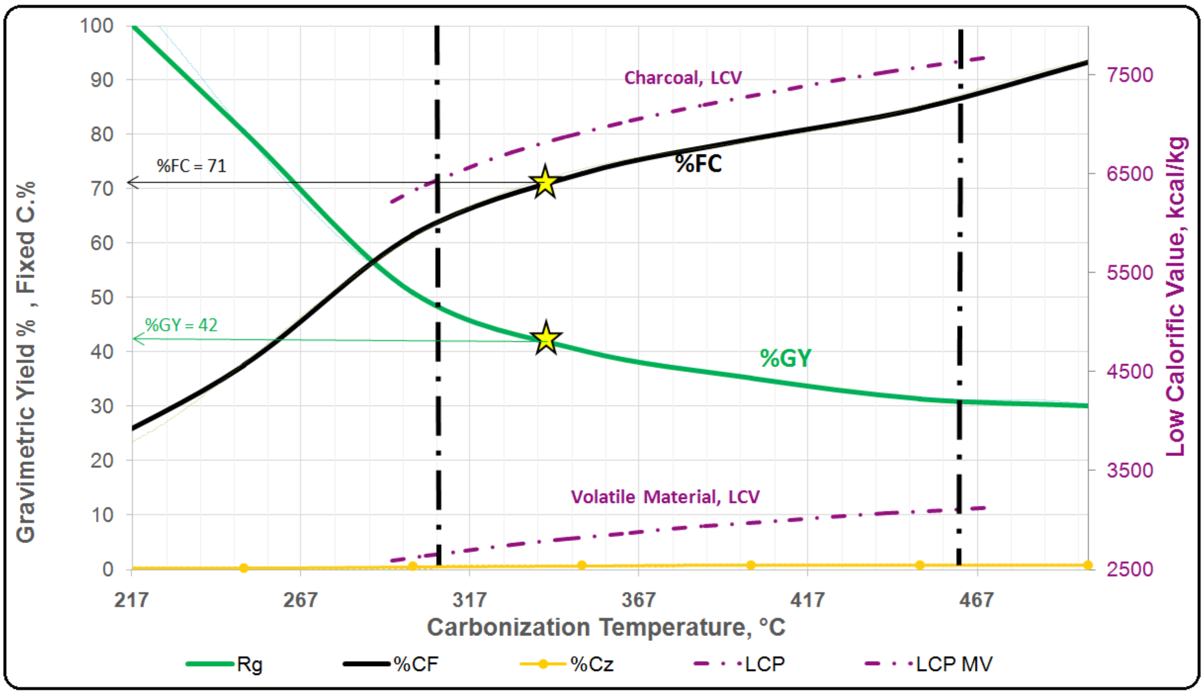


**Figure 4**. Fixed Carbon, Gravimetric Yield and Temperature.

The graphic is hypothetical [4], based on laboratory data, with both curves adjusted for the pilot plant. Also, the chart shows that higher carbonization temperature produces charcoal of better energetic quality due higher percentage of fixed carbon. But, the energetic gain is given with the decrease of gravimetric yield. This means that highest fixed carbon results in a charcoal with elevated low calorific value, but with less efficiency in mass. During carbonization the wood volatile fraction is converted in gases and the energy contained in this volatile material is higher as much as the fixed carbon.

The stars in the graph show the results obtained during a continuous and permanent operation period of Carboval Reactor of Vallourec Soluções Tubulares do Brasil. This reactor operated between 2013 e 2015 producing the charcoal that supplied the blast furnace of the company. A previous energy balance found 71% FC and 42% GY.

Thus, the simulator was prepared to vary the percentage of fixed carbon in the charcoal and consequently the energy flow.

## 2.2 Blast Furnace – MBF

The blast furnace is the main charcoal consumer and its energy necessity is directly connected with charcoal energetic quality. It was developed a base scenario, presented in Figure 5, with the goal to determine energy quantity required to produce one ton of liquid pig iron.

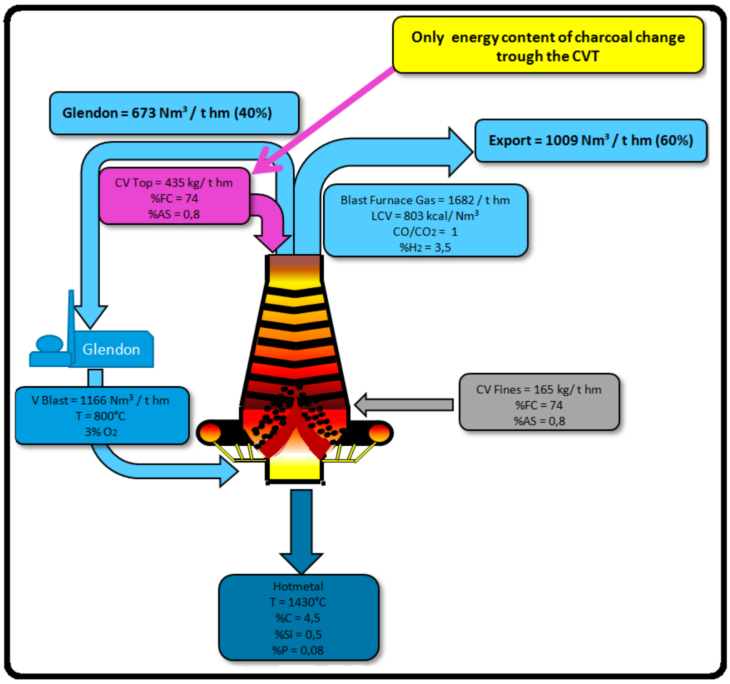


**Figure 5**. Blast Furnace Base Scenario.

It was considered in the base scenario the input of charcoal with 74%CF, thus, it was defined the input of 435 kg of top charcoal and 165 fine charcoal. These are typical values, relating the charcoal demand and fixed carbon, considered in the blast furnace. The ash percentage considered was 0.8%. Blast Furnace Gas generation also is fixed carbon function, and it is as low as higher the fixed carbon. From base scenario values, the blast furnace generation is 1682 $Nm^3$ by ton of pig iron, with low calorific value 803 kcal/$Nm^3$. Forty percent is used in the glandon and the remaining is sent to the thermal power plant.
Other values about the process in blast furnace were considered constant, as the relation $CO/CO_2$ and $H_2$ percentage in the blast furnace gas values 1 and 3.5, respectively. About air injection, was considered an input of 1166 $Nm^3$ by ton of pig iron, with 3% $O_2$.
From the base scenario we can calculate the amount of energy needed in the blast furnace. For the simulation this value and the value of the low calorific value were used to calculate the amount of top charcoal needed and the amount of charcoal fines was considered constant.

## 2.3 Mini Pellet Plant – Grate Kiln Type

The mini pellet plant, Figure 6, Grate Kiln Type, is general recycler for metal wastes and low quality ore fines. It is possible to reuse processed steel scale, small metal and iron ore fines as a complement. From the EAF and de MBF, ferrous content and slag are also inputted. The energy source is the charcoal fines, after the Carbonization Continuous Reactor. Pellet is the final desired product.

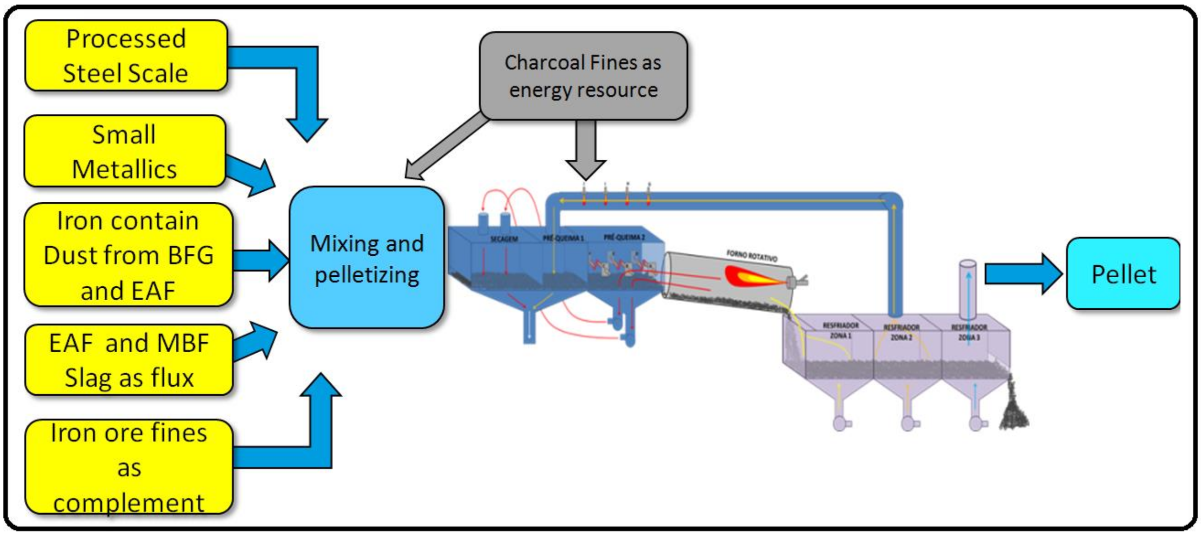


**Figure 6**. Pellet Plant.

## 2.4 Multitype Fuel Rankine Thermal Power Plant

The thermal power plant has the function of supplying the energy need of other reactors: the blast furnace, pellet plant, Carboval Reactor and electric arc furnace. Besides it can export energy to extern market. Its conception is the cycle Rankine and can be fed with many kinds of fuel. To contribute to the system circularity, it works with carbonization gas, blast furnace gas, wood wastes that can't be used in Carboval, and any other biomass waste.
In the simulation, the energy need of each reactor is calculated based in the steel production, as well as the carbonization gas and blast furnace gas production. Then, it's calculated the wasted biomass need, if necessary. Figure 7 presents all input and output in the thermal power plant.

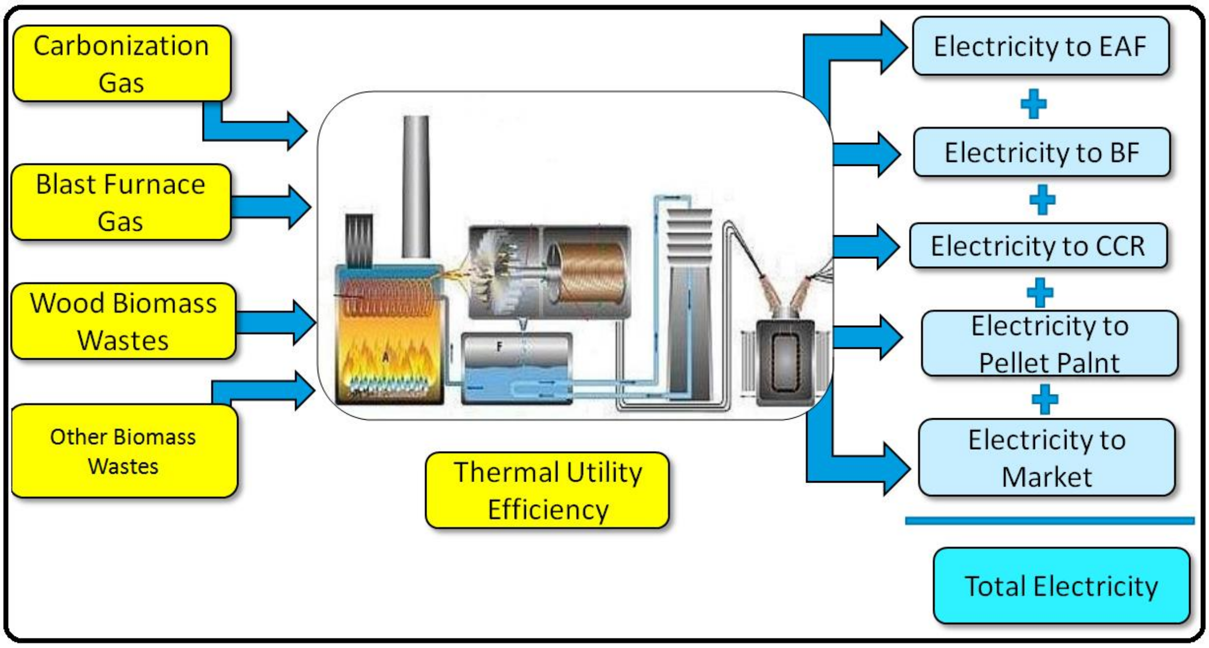


**Figure 7**. Thermal Power Plant.

## 3 RESULTS AND DISCUSSION

The scenarios presented before were simulated, as followed.
Scenario 1: normal flow in the EAF with iron scrap and external electric energy as inputs.
Scenario 2: normal flow in the EAF with iron scrap and external electric energy as inputs and inclusion of a thermal power plant based in biomass waste.
Scenario 3: alternative that enables the highest resources circularity. With inclusion of three other reactors: Carboval Continuous Carbonization Reactor, blast furnace and pellet plant.
Table 2 presents the main results.

**Table 2.** Main Results

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| Energy Required in reactors (MVA) | 27 | 27 | 20 |
| External Energy (MVA) | 27 | - | - |
| Energy Generated (MVA) | - | 30 | 30 |
| Energy to Market (MVA) | - | 3 | 10 |
| Biomass Waste to Thermal Power Plant (kt/y) | - | 230 | 101 |
| Biomass to Caboval Reactor (kt/y) | - | - | 215 |
| Total Biomass (kt/y) | - | 230 | 316 |

The results prove that Scenario 3 is the best option. The use of other residues beyond iron scrap provides major circularity and thus, the best energy distribution.
In Scenario 1, the electric need in the reactors, 27 MVA, is supplied by an external source. This way, it's necessary to buy electrical energy, by a high cost.
In the Scenario 2, one improvement is realized in the previous scenario, the inclusion of thermal power plant powered by waste biomass. In this situation the thermal power plant provides energy to reactors, and is also possible to export 3 MVA, of electric energy. For this it is necessary an input in the system of 230 kt/y of biomass residues. Given the big availability of this resource and its low price, this scenario is more attractive than the previous one.
The proposal to include other reactors, in Scenario 3, presents the best results, provoking an iron scrap input fall from 319 to 184 kt/y. Consequently, the energy required in the other reactors decreased, total of 20 MVA. Considering the thermal power plant capacity of 30 MVA, there are 10 MVA available to market and would be necessary 316 kt/y of biomass wastes, 37% more than Scenario 2. But, as the cost of the biomass waste is low, Scenario 3 stills the most viable option.
Integrate wood biomass and other biomass in the steelmaking process made it possible to recycle waste steel, supply energetically the reactors and to generate energy to external market.
Looking for the best context to produce 300 ton/y of steel, according to a circular economy, the United States presents a big potential, attending the requisites for a efficient synergy between the technologies in the process, given the wood waste, mineral resource and high quality iron scrap availability. The chosen zone is the State of Minnesota.
This state counts with wood residues availability, from urban wastes, as the ones from the construction and demolition of the traditional American houses, which are made with wood, pellets and crop residues.
It is important to emphasize the American government incentive to somehow use the forest residues, as a way to prevent catastrophic fires. One example is the Healthy

Forest Initiative, which authorizes the expense of federal money to forest restoration and high priority thinning.

Figure 8 express the availability of Urban Wood Waste in 2012. Minnesota State has 25 to 50 thousand tons of dry wood per year. Figure 9 shows now the Forest Residues in the US for the same year. The same state, also, has more than 100 thousand ton of dry per year of that residue.

In Figure 10, it is shown the crop residues, which Minnesota State presents more than 300 thousand ton per year. This survey was accomplished by the National Renewable Energy Laboratory (NREL).

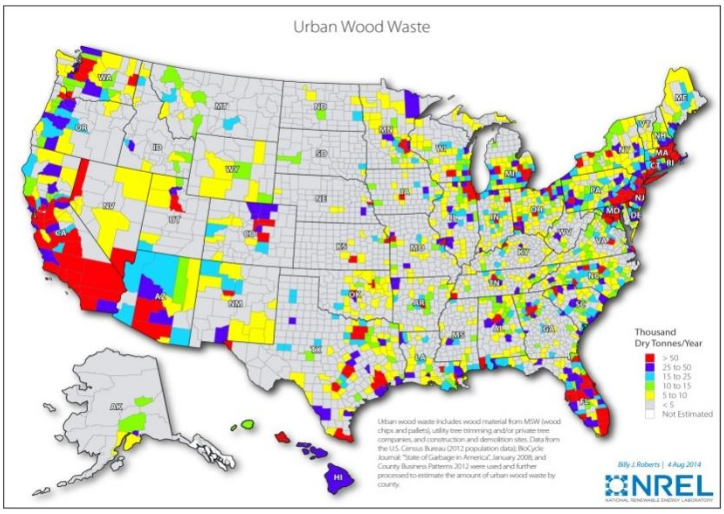


**Figure 8**. Urban Wood Waste [5].

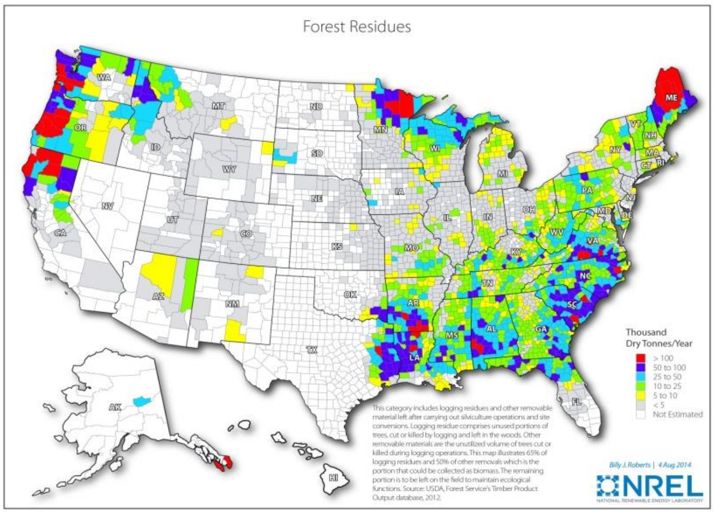


**Figure 9**. Forest Residues [6].

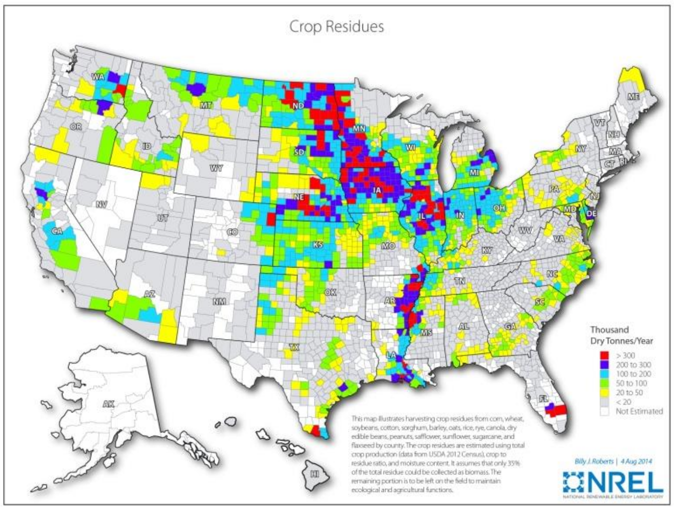


**Figure 10**. Crop Residues [7].

In Minnesota State are also located iron mines, contributing to the choice of the state as a promising region for the suggested integrated steel industry. Figure 11 highlights the main minerals ate the given state.

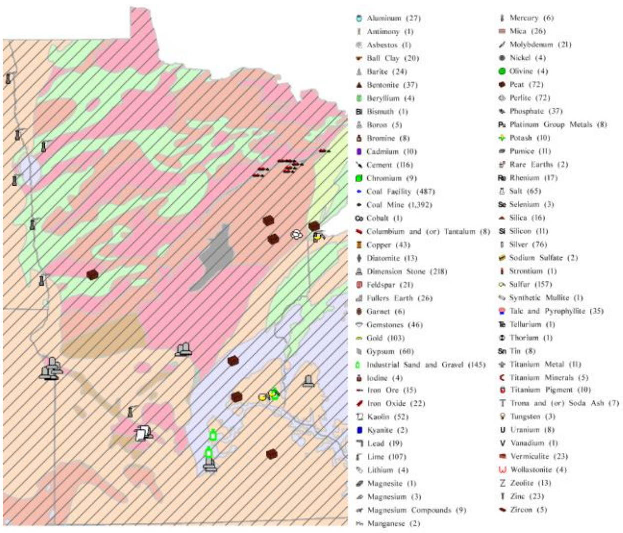


**Figure 11**. Mineral Resources In The State Of Minnesota [8].

Finally, it is worth to lay emphasis on the good quality of the American mini mills, thanks to organization and efficiency policies in the collecting stages, processing and distribution of the iron scrap. These policies are fruits of the cooperative work between government and enterprises. Such measure boosted the semi integrated plants development in the American territory.

## 4 CONCLUSION

The Carboval Carbonization Reactor opens the opportunity to integrate the steel making process with any residues types, with wood or biomass. For this, it's necessary to include the Carboval Reactor, a blast furnace and a pellet plant in a micro-mill. This system will be more circular, and the residues keep in the production route.

Carboval is a great opportunity to increase the circularity within the steel making productive environment, conciliating the consolidated iron recycling technology with recycling of biomass residues, enabling the generation of electric energy in a thermal power plant based in biomass and process gases, which grants the conversion of low energy sources in high quality energy.
Through this study, it was verified that the state of Minnesota, in the United States of America, presents potential for the installation of a plant integrated with FEA for the production of 300 kt/y of steel. The state of Minnesota has mineral sources of iron and also wood, urban, forestry and harvesting wastes sources. In addition, the policies of the American government attached with private companies, contributing to reach the good quality metal scrap is another essential factor which the State could achieve steel production in a circular concept. All of it, aiming the optimal use of raw materials and secondary products generated during the processes.

## ACKNOWLEGDMENTS

To Vallourec Soluções Tubulares do Brasil S.A. (VSB) company for supporting researches and development projects.
To Lis Nunes Soares, Ph. D, specialist engineer in terminal processes, for the orientation in the project.
To Ronaldo Sampaio, Ph. D, metallurgy specialist engineer, for the orientation in the project.

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