



US 20140306386A1

(19) **United States**(12) **Patent Application Publication**
Bartol(10) **Pub. No.: US 2014/0306386 A1**(43) **Pub. Date: Oct. 16, 2014**(54) **SUSTAINABLE PROCESS FOR THE
CO-GENERATION OF PIG IRON AND
ELECTRIC ENERGY USING WOOD AS FUEL****Publication Classification**(71) Applicant: **ACTIVE LAND INTERNATIONAL
CORPORATION, Piso (PA)**(72) Inventor: **Julio R. Bartol, Montevideo (UY)**(73) Assignee: **ACTIVE LAND INTERNATIONAL
CORPORATION, Piso (PA)**(51) **Int. Cl.****C21B 5/00** (2006.01)**C21B 7/00** (2006.01)(52) **U.S. Cl.****CPC C21B 5/00** (2013.01); **C21B 7/00** (2013.01)**USPC 266/44; 266/197**(21) Appl. No.: **14/362,828**(22) PCT Filed: **Nov. 26, 2012**(86) PCT No.: **PCT/IB2012/002908**

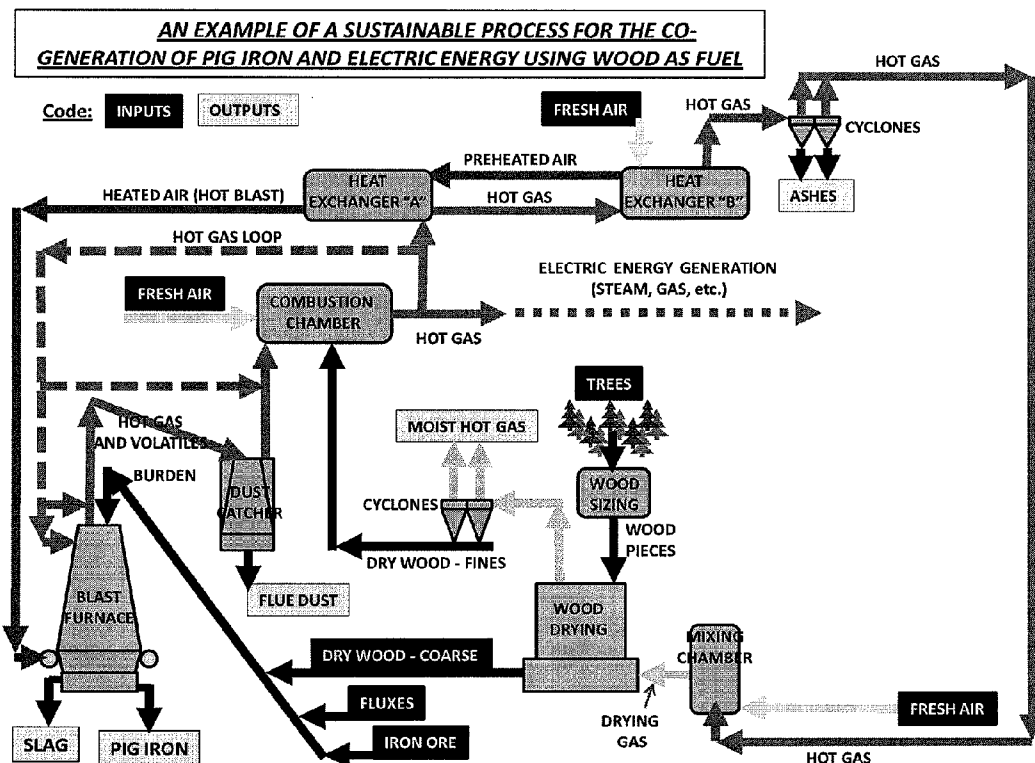
§ 371 (c)(1),

(2), (4) Date: **Jun. 4, 2014****Related U.S. Application Data**

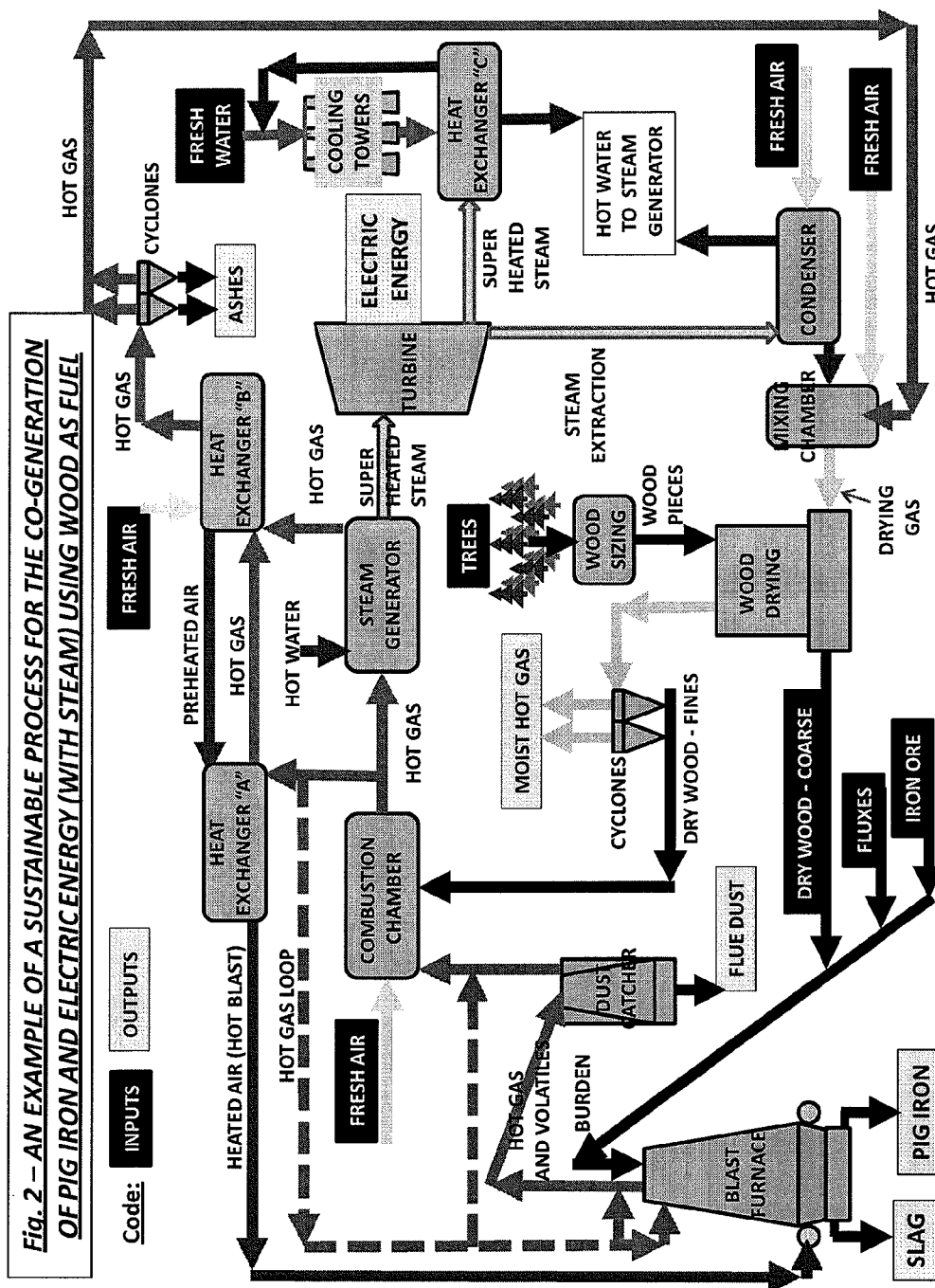
(60) Provisional application No. 61/566,874, filed on Dec. 5, 2011.

(57) **ABSTRACT**

An integrated and sustainable process is presented for the co-generation of pig iron and electric energy in a blast furnace installation in which dried wood replaces charcoal as the fuel, as the reducing and as the carburizing agent. Furthermore, this application incorporates the process—until now independent—of transforming wood into coal, inside the blast furnace.

EXAMPLE: OPERATION OF THE CO-GENERATION PROCESS (FIG.1 and FIG. 2)

EXAMPLE: OPERATION OF THE CO-GENERATION PROCESS (FIG.1 and FIG. 2)



SUSTAINABLE PROCESS FOR THE CO-GENERATION OF PIG IRON AND ELECTRIC ENERGY USING WOOD AS FUEL

[0001] This application claims priority from U.S. Provisional Patent Application No. 61/566,874, filed in the United States Patent and Trademark Office on Dec. 5, 2011, the entire disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] Pig iron is an alloy of Iron and Carbon that is used as raw material for the production of steel. Selected species of wood are transformed into pieces of uniform and predetermined size such as chips (but not only this shape) that are dried to less than 10% Moisture Content and classified by size in a wood drying and classifying line so that only dry coarse particles are charged into the blast furnace. The large amount of water evaporated in the wood drying process may be recycled to reduce the amount of fresh water used in the process. The dry wood is heated inside the furnace with hot spent gas in order to initiate the exothermic carbonization process. The greater weight of wood in the charge, that is required to compensate for the lower fixed carbon content of wood with respect to charcoal, generates a large amount of volatiles that can be burned outside the blast furnace to recuperate the energy that is normally lost in the traditional charcoal making process. The burned volatiles produce sufficient heat energy that makes possible the installation of a power generation plant to supply the power requirements of the blast furnace equipment and to produce an excess that can be used in other plant facilities and/or sold to the local power company for distribution. The invention increases the material yield of the overall process, improves the quality of the pig iron, reduces operating costs, minimizes CO and CO₂ emissions and other pollution problems associated with charcoal production, because the carbonization process takes place inside the furnace where all carbon particles are burned and exhaust gases can be managed at will. A cleaner environment reduces health risks, investments in pollution control equipment and maintenance costs. Countries that have adequate climate to develop forest products and have iron ore reserves, but no mineral coal to produce coke, would benefit from this invention by being able to produce pig iron with locally produced materials. The invention can also be applied in other fields where charcoal is the fuel of choice.

[0003] An even further step may be the installation of a downstream steel producing plant that will function not only with the pig iron supplied by the smelting plant but also, in total or in part, with the excess energy produced.

Reasons for the Invention and its Usefulness

[0004] Besides the many reasons that have been stated above, the essence of the invention is the need to recuperate the energy that is normally lost in the traditional charcoal making process and eliminate the pollution associated with charcoal production and its use. This energy, as well as many volatiles and fine charcoal particles that are pollutants, are normally vented and thus lost into the atmosphere. Here, the generated energy is sufficient to smelt iron ore and/or iron bearing materials and will produce an excess that can be sold to the grid, or to use it, in other plant activities or as stated above, in a steel producing plant. A much greater efficiency will also be obtained from the transportation point of view if the plant is sited near wood-supplying forests.

[0005] We insist, thus, in the optimization of the whole process and not only of the optimization of its parts taken separately. Our invention deals with: energy efficiency, energy production, use of a renewable source of energy, pig iron quality, materials efficiency, transportation efficiency, water recuperation, decrease of atmospheric pollutants and environment-friendliness in general (health included) among others. The present invention relates to the design of interactions among all of these parts in order to integrate them into one industrial system to obtain the most effective and efficient process for the co-generation of pig iron and electric energy. The implementation of this invention will greatly contribute to the solution of the major problems confronting the steel industry and will make viable many pig iron and steel mill projects which are presently at a standstill due to the lack of a domestic source of coal and/or electric energy. Below, under the title: "INVENTION BENEFITS", we describe these more thoroughly to better define the project, both in its uniqueness and inventive step.

[0006] Before going into the description of what is currently happening in the smelting industry, we will clearly state that we provide a chapter on the "PROOF OF THE NON-EXISTENCE OF PRIOR KNOWLEDGE", which is the failure to implement substantial pig iron projects (and as a consequence, steel mills projects) around the world, in spite of having abundant iron ore reserves as well as abundant wood in actual or potential plantations, but no other energy source in sufficient quantity.

Steel Industry

State of the Art

[0007] Even though we have found no patent describing a process even similar to ours, we will submit, as requested, a summary of the patents that could be considered closer.

[0008] Note: the Evaluator will understand that upon commenting each of the patents listed below, and so as not to render our application excessively long and our exposition tedious, we will not mention all of the differentiating factors among them. If need be, and to identify further differences and the advantages of our invention, the chapter on "INVENTION BENEFITS" should be consulted.

Current State of the Art and Main Patents on this Topic:

[0009] WO2011/052796—Method of Using Biomass in a Blast furnace. JFE Steel Corporation, Japan.

[0010] This patent shows a method of using biomass in a blast furnace, as a substitute for pulverized coal, thus increasing the flammability and heating value of the biomass to about the same level as those of the pulverized coal and capable of using conventional pulverized coal blowing equipment by enhancing the air transportability. A method for using biomass in a blast furnace is used, the method being characterized in that: biomass (A) is dried by distillation to manufacture biomass coal (D), the biomass coal (D) is pulverized together with coal (B); and the pulverized powder is blown from a tuyere (15) as an auxiliary reducing material in a blast furnace (14). It is preferably that the biomass (A) is dried by distillation at 450° C. or higher for 30 minutes or longer to manufacture the biomass coal.

[0011] Comment—as the Evaluator may appreciate, this patent, while using biomass in the blast furnace, has a completely different purpose: first it is intended to substitute pulverized coal. But regarding the wood used in the blast furnace, the purpose here seems to be to distill such wood and

turn it into biomass coal, and then the biomass coal is pulverized together with coal. Wood is either distilled to form coal, and the pulverized powder is blown from a tuyere as an auxiliary reducing material in a blast furnace. Furthermore, it establishes that it is preferable to have the biomass dried by distillation at 450° C. or higher for more than 30 minutes. All of these wood conditioning processes take place outside the blast furnace.

[0012] Our system is not similar, it only uses wood drying, it does not use coal in any way, and all our energetic, reducing and carburizing needs are obtained from burning dried wood inside the blast furnace. Furthermore, we also intend to produce a high proportion of surplus energy.

[0013] This patent is thus no antecedent.

[0014] US20100229685—Process for Producing Molten Iron (PCT No. PCT/JP08/66875). Kobe Steel Company, Japan

[0015] A process for producing molten iron where an inert gas is blown into a molten iron layer in an iron bath type melting furnace through bottom blown tuyeres provided in a hearth bottom thereof to stir the molten iron layer, a carbon material, an additive flux, and solid reduced iron obtained by heating reduction of carbon composite. Iron oxide briquettes are charged into the above mentioned furnace, and top blowing of an oxygen-containing gas is performed through a top blown lance provided for the melting furnace, so that the solid reduced iron is melted by combustion heat obtained by combusting the carbon material and/or carbon in molten iron to form iron. In addition the carbon material is charged so as to form a carbon material suspension slag layer which is formed of slag generated when the solid reduced iron on the molten iron layer is melted into molten iron and further so as to form a carbon material covering layer made of only the carbon material on the carbon material suspension slag layer, and the molten iron and the slag accumulated in the melting furnace are discharged through a tap-hole provided at a lower portion of a furnace side of the melting furnace.

[0016] Comment—this patent uses carbon and/or a “carbon material”, and is used for producing molten iron by melting solid reduced iron. It does not use wood as its only source for energy—if indeed it uses it—, reducing agent and carburizing agent, nor does it produce a great surplus energy. Furthermore, the fuel reactant is dissolved in molten salt.

[0017] It is thus not an antecedent.

[0018] U.S. Pat. No. 4,169,583—Apparatus for Reducing Ore (Clean Energy Corporation, USA)

[0019] Heat is generated by combustion of coal or like carbonaceous fuel reactant dissolved in molten salt. The generated heat is transferred to steam by an alternating sequence of direct contact heat exchangers of the salt and steam with a common heat transfer medium.

[0020] Comment—as can be readily appreciated, this patent, though conceived partially as energy producing and ore reducing, has a completely different system where the presence of molten salt is clearly a fundamental difference, as well as the use of coal instead of wood. As the text says (Column 1): “This invention has to do with apparatus for the generation and recovery of heat from highly aromatic, generally refractory carbonaceous fuel reactants, particularly from coals and residual oils.”

[0021] It is thus not an antecedent.

[0022] US2007/0209480—Production of Iron Using Environmentally Benign Renewable of Recycled Reducing Agents (Michigan Technological University, USA).

[0023] This invention relates to the smelting of ore and more particularly a composition and method for the production of metallic iron from iron ore. A mass of material formed from a mixture of iron ore particles and particles of a reductant that is either a biomass material in particulate form or a plastic resinous material in particulate form is used. The reductant can also be a mixture of biomass material and resin in any proportions. It also a new method for smelting iron from its ore which comprises subdividing the ore into particles of a selected size, mixing the subdivided ore particles with particles of a biomass material or particles of a plastic resinous material or with mixtures thereof, forming a mass of the mixture into at least one body with a shape that is suited for smelting in a furnace and exposing it to sufficient heat to bring the iron therein to smelting temperature within the furnace to thereby produce metallic iron directly from the ore.

[0024] Comment—though this patent mentions the use of a biomass material in contact with the iron ore, it does not establish such biomass material as being the only energy source, the only reduction source, and the only carburizing agent. Furthermore, it does not consider substantial energy co-production, and it considers plastic resinous materials as one of the reactants, which we don’t.

[0025] It is thus not an antecedent.

[0026] JP 2007131929—Solid Fuel for Vertical Scrap-Melting Furnace, and Method for Operating Vertical Scrap-Melting Furnace

[0027] This patent attempts to solve the problem of providing a solid fuel for a vertical scrap-melting furnace, which controls the reactivity of charcoal wood and can effectively use the burning energy for melting iron scrap, and to provide a method for operating the vertical scrap-melting furnace. The solution provided is to use solid fuel which is improved charcoal wood to be used in the vertical scrap-melting furnace 1; and is prepared by coating the surface of charcoal wood with an iron-making dust while using sodium silicate as a binder, so as to control the reactivity of the charcoal wood. The operation method includes using the above solid fuel as a main heat source, when producing molten pig iron for steel-making by charging the scrap iron as a main iron source and the charcoal wood as the main heat source into the vertical scrap-melting furnace provided with a blowing tuyere 2 in a lower part of the furnace, from the furnace top, and melting the scrap iron.

[0028] Comment—As can be appreciated, there are almost no similarities with our invention. This is a scrap melting furnace, and ours is a blast furnace. It does not need to supply any substantial reducing and carburizing agent, nor does it use only wood as its energy source. It makes use of an iron making dust and we don’t.

[0029] It is thus not an antecedent.

[0030] U.S. Pat. No. 5,588,982—Process for producing foundry iron

[0031] This patent relates to a foundry iron producing process starting from scrap and/or scrap steel. In particular, it is directed to a process of producing foundry iron in a submerged arc furnace using scrap iron or scrap steel as the primary metal sources.

[0032] A submerged arc furnace produces foundry iron from scrap iron and steel sources where little or no slag is

produced. Scrap iron or steel is fed into the submerged arc furnace with a source of silica and a carbonaceous reducing agent. The scrap iron and steel is melted while simultaneously smelting the silica in the presence of the carbonaceous reducing agent. The amount of the silica source and carbonaceous reducing agent are added in an amount to selectively control the silicon and carbon content of the resulting foundry iron.

[0033] Comment—This patent relates to a submerged arc furnace, not to a blast furnace. Its sources for metal are scrap iron and/or scrap steel. Thus, as in the previous case, it does not need a substantial proportion of reducing or carburizing agents, and its energy source is electricity. It does not consider a substantial production of electric energy.

[0034] It is thus not an antecedent.

[0035] GB191123861—Improvements in Processes and Apparatus for the Direct Production of Iron and Steel (UK)

[0036] For the direct production of iron and steel, iron ore, together with sufficient wood or peat charcoal for starting the reaction and with scrap steel or pig iron, is heated in a high-pressure gas-fired furnace which is in communication with a chamber containing carbonaceous matter heated by electricity to a temperature sufficient for the reduction of the carbon dioxide into carbon monoxide.

[0037] Comment—This old patent may use wood in the blast furnace, but it is not the goal as reducing agent, carburizing agent of energy source, nor does it consider using wood for 100% of the reducing, carburizing and energy needs, much less produce a substantial excess energy.

[0038] It is thus not an antecedent.

[0039] U.S. Pat. No. 4,160,663

[0040] A method and apparatus for the direct reduction of iron ore are disclosed. A mixture of iron ore, solid carbonaceous fuel and, if sulfur is present, calcined limestone or dolomite, are used. The carbonaceous material can be cellulosic material (wood waste, paper, particularly municipal trash, garbage, etc.), charcoal, or coal (preferably sub-bituminous coal or lignite). The above feed is continuously charged into a gasification and initial reduction zone of a shaft furnace which is partitioned partially from the remainder of the furnace. Oxygen and hot steam are introduced into the upper portion of the said zone. Partial combustion or pyrolysis of the fuel and reaction with steam take place, producing reducing gas which initiates reduction of the iron ore. Ore and gas flow downwardly through conduits into the final reduction zone. Meanwhile, hydrogen-enriched reducing gas is introduced in the middle of the final reduction zone. Top gas is withdrawn from the upper open space of the final reduction zone, drawing reducing gas downwardly from the gasification and initial reduction zone and upwardly through the final reduction zone. In addition, top gas is withdrawn from the bottom of the final reduction zone. Reduction of the iron ore to sponge iron is completed in the final reduction zone. A portion of the withdrawn top gas is cooled, purified of dust, carbon dioxide and sulfur and dehumidified, then introduced near the bottom of the shaft furnace. It ascends, cooling and carburizing the sponge iron descending from the final reduction zone and becoming heated. The cooling gas is then withdrawn from the bottom of the final reduction zone. A special form of discharge grate discharges iron successively from different areas, so as to produce agitation and mixing.

[0041] Comment—This patent uses many fuels, among them carbonaceous material which may be wood waste; it uses a shaft furnace and a steam upper injector. It does not use

wood as its only source for energy, or its only reduction and carburizing agent. Furthermore, it does not consider a surplus energy production of a previous drying of the wood.

[0042] It is thus not an antecedent.

[0043] WO1980001808

[0044] New method for the production of raw iron or so-called metalized iron ore. Biofuels i.e. preferably fuel wood and/or peat is in the final reduction brought into direct contact with the iron containing material in its solid state. Biofuels have very different properties compared to reducing agents on the basis of fossil fuels primarily coal and develop rapidly a reactive reduction gas at a comparatively low temperature. The new raw iron process is carried out with the iron containing material in its solid state of aggregation in different kinds of fluidized bed reactors in different system configurations.

[0045] Comment—similar comments to the previous ones are valid for this patent. Furthermore, it does not consider cogeneration.

[0046] It is thus not an antecedent.

[0047] GB189824749

[0048] Gas-producers combined with blast furnaces &c. The blast for a furnace A for reducing iron ores is supplied through tuyeres a from a conduit m leading from a gas producer or “furnace” B containing fuel. Wood, coal, turf, &c. are fed through a funnel E into the upper chamber of this producer above a valve d, and, when carbonized, it is dropped through this valve into the lower chamber. Distillation products of the fuel pass off by pipes g, and are used for heating purposes. Liquid fuel may be supplied by burners to the producer B. The blast from hot air chambers is directed by valves to either, or both, the producer B and a furnace D in which the iron is converted into steel. The blast leaves the furnace D and enters the lower chamber of the producer B by a port e, and, together with a direct hot-air supply from the chambers through tuyeres b, passes up through the carbonized fuel and out through the conduit m. Lime, alkalis, iron or manganese ore, and carbon are introduced into the producer B and conduit m to arrest sulphur and carbon. The producer B may have several compartments, and the upper chamber may be heated exteriorly or interiorly by the distillation products or the gases escaping from the top of the furnace.

[0049] Comment—This invention uses wood, coal, turf, carbon, and it even considers liquid fuel. It has two reaction chambers plus the blast furnace D. It does not consider the use of wood as its only fuel, reductant and carburizing agent. It does not even mention the cogeneration of electric energy.

[0050] It is thus not an antecedent.

Steel Industry

Current Situation

[0051] We have provided, as required, a synopsis of the State of the Art and the Evaluator must of course perform his own search, but the prior knowledge of the “proof of the non-existence of prior knowledge” (see chapter below) is a meaningful information of what happens in the real world, where, as an example, one among many big projects around the world, wouldn’t have floundered if it had counted with the process that we herewith describe. It is a reasonable proposition that if a 3 billion Dollars project fails due to lack of energy, where the iron ore mine would have been surrounded by nearby forests, it is almost guaranteed that the invention we herewith describe is not known to important investors,

much less when considering wood as its only fuel source and producing great amounts of excess energy.

[0052] World steel production reached some 1.4 billion tons during 2010. There are two basic processes to make steel depending on the type of raw material used. One is the blast furnace process that produces an alloy of Iron and Carbon, commonly called pig iron, by melting iron ore mixed with coal and fluxes. Pig iron is further refined in a Basic Oxygen Furnace (BOF) to produce the desired steel composition. The second process is the Electric Arc Furnace (EAF) that produces steel in one step by melting recycled steel scrap and consumes great amounts of energy per ton of steel produced.

[0053] The basic raw materials charged ("the burden") into the blast furnace for the production of Pig iron are: iron supplied by iron ore, sinter, iron ore pellets or other iron containing materials, fluxes (normally dolomite and/or limestone) to form the slag, a fuel to melt the charge, a reducing agent to remove oxygen from the iron containing material and a carburizing agent to contribute the amount of the element carbon to meet the desired composition of the pig iron. Coke is normally the preferred fuel since it is also a reducing and a carburizing agent. Coke is produced with coal from coal mines but, in countries that do not have coal mines, coke is replaced by charcoal, which is produced from wood.

[0054] This invention addresses the problems and solutions of blast furnace operations.

[0055] A blast furnace produces pig iron as part of a steel mill or it can also be an independent facility, such as a foundry. The pig iron is produced as a molten or as a solid product cast in molds. The elemental analysis of pig iron for steel production is approximately: 3.0% to 4.5% Carbon, 0.20% to 1.5% Manganese, 1.0% to 2.5% Silicon, under 0.1% Sulphur, under 1% Phosphorous and the balance is Iron.

[0056] Although steel is considered an essential product for humanity, its production causes a series of environmental problems such as carbon dioxide emissions as well as ground, water and atmospheric pollution. High energy consumption and a need to improve material efficiency are also important issues that confront the steel industry. Continuous efforts are spent in attempting to solve these major problems around the world but an effective and efficient solution has not been found.

[0057] This invention uses wood as the substitute for charcoal in the production of pig iron in order to:

[0058] a) Produce high quality pig iron with higher yields and at lower cost

[0059] b) Generate electric energy in excess of that required for the blast furnace operation, and

[0060] c) Minimize carbon monoxide and carbon dioxide emissions as well as ground, water and atmospheric pollution.

[0061] This invention resolves the main problems confronting the steel industry.

Pig Iron Production with Charcoal

[0062] Charcoal is produced by heating wood in an atmosphere low in Oxygen. Ideally, wood is supplied from renewable plantations to avoid deforestation. As an example, in Brazil, *Eucalyptus* is one of the preferred species planted to produce charcoal for the steel industry. The wood is harvested after about seven years of growth and then, it is transferred to large charcoal producing plants or distributed among hundreds of small charcoal producers that, in turn, supply the charcoal to the Blast furnace facility. The charcoal production process generates CO and CO₂ gas that, together with the fine

particles that are lost to the ground and to the atmosphere produce air and water pollution. Charcoal storage at the charcoal production facility, transportation to the blast furnace, storage and handling at the blast furnace plant create a serious ground and atmospheric pollution problem that eventually may contaminate the water. Exposure to rain degrades the quality of charcoal as a fuel and wind promotes atmospheric and ground contamination of fine charcoal particles. In addition, the heat energy generated in the charcoal production process is normally lost to the atmosphere because most producers do not recover it. Most modern charcoal facilities operate batch furnaces that require days for a production cycle that includes, charging, heating, carbonizing, cooling and discharge. Exhaust gases are rich in carbon monoxide and may be vented to the atmosphere increasing the greenhouse effect. Charcoal production facilities are normally located away from towns to avoid impact of contamination.

[0063] Charcoal is charged at room temperature into the Blast furnace and it heats up as it travels down the furnace reacting with the iron oxides of the mineral and the fluxes to remove oxygen until it is burned at the bottom of the charge. Charcoal pieces tend to be fragile and may collapse due to erosion and to the weight of the charge above them during the descending movement. This creates fine particles that may reduce the permeability of the charge and eventually are blown out of the furnace before they are burned, lowering the material yield of the process and increasing pollution.

[0064] Most of the electric energy required to operate the blast furnace facility is purchased, because the potential to generate electric energy with excess thermal energy is very low due to the low volatile content of the charcoal.

Production Strategies

[0065] Therefore, to produce pig iron inside the blast furnace, we must be concerned with four basic production systems: wood, charcoal, pig iron and electric energy. Traditionally, each of these four systems is an independent business and it is managed with the objective of optimizing its own performance.

1.—Wood.

[0066] In order to increase the process yield, wood is not debarked and is cut into logs whose length depends on the charcoal furnace dimensions. Research is focused, among other issues, in developing genetic variations that will produce straight trees in order to increase the wood density of the charge inside the charcoal producing furnaces.

2.—Charcoal.

[0067] Traditional charcoal production processes are batch and the cycle lasts several days involving the following steps: charging, heating, carbonization (pyrolysis), cooling and discharging. All the energy and the water contained in the wood are lost creating a serious contamination and efficiency problem. Its basic objective is to produce charcoal with high Fixed Carbon content and a high process yield (wood to Fixed Carbon). Fixed Carbon content of the charcoal produced depends mainly on the Fixed Carbon content of the wood specie, its particle size as well as carbonization temperature and residence time. A batch process produces a charcoal of non-uniform size and quality and with a significant process loss because all wood pieces do not have a similar heat treating history. In addition, part of the wood is burned in order to

generate the heat required for the carbonization process thus reducing the wood-to-carbon yield.

3.—Pig Iron.

[0068] Blast Furnace operation is treated as an independent process that aims, among other objectives, to obtain high energy efficiency by maintaining low temperature of the exhaust gases, at around 100° C.

4.—Electric Energy.

[0069] The small excess thermal energy contained in the blast furnace exhaust gases is often used to heat the iron bearing material, to dry the charcoal and/or to transform it into electric energy. The excess energy represents only a fraction of the plant requirements and therefore, most of the electric energy consumed in the plant is purchased energy.

We Propose a Change of Paradigm.

[0070] We approach the problem in a different way. We attempt to identify a larger industrial system that includes the four processes: wood, charcoal, pig iron and energy. Management's role is to design interactions among these four processes in order to optimize the performance of the new larger industrial system and make it sustainable from an environmental, economic and social point of view. In other words, we propose to take control of the four production processes and actively manage as many of the traditional "uncontrollable" variables as possible.

[0071] Under our systemic approach, selected and heat treated wood replaces charcoal as blast furnace fuel, reducing and carburizing agent. Wood from selected species (better with high energy density) is debarked and cut into pieces of specified size (split wood, chips, or other industrially produced shapes) with the objective of producing a uniform and an efficient fuel after carbonizing (pyrolysis). Debarking is done to minimize contamination of alkaline materials contained in the bark that deteriorate the refractory material inside the Blast Furnace causing unexpected and costly shut-downs. These cut-to-size pieces are continuously dried and heat treated with our patented process (U.S. Pat. No. 8,161, 661B2) at temperatures above the traditional 105° C. This continuous process assures that all particles will have a similar "thermal history" prior to carbonizing inside the Blast Furnace. The water from the wood may be recuperated as it is contained in the heat treating exhaust gases that may be condensed outside the drying apparatus.

[0072] The amount of wood charged in the blast furnace is calculated in direct relation to the Fixed Carbon content required by the pig iron process. Let's assume an operation requiring 600 kilos of charcoal with 75% of Fixed Carbon or 450 kilos of Fixed Carbon per ton of pig iron produced. Also assume that the Fixed Carbon content of the wood specie being used is 20% Fixed Carbon at 0% Moisture Content (M.C.). The amount of dry wood required to replace the charcoal charge will be 2,250 kilos (450/20%) per ton of pig iron produced to maintain the same amount of Fixed Carbon for the process. This value grows to 2,500 kilos per ton of pig iron produced in case the wood contains 10% M.C. Therefore, the wood charge will be almost four times heavier than the charcoal charge. But, since wood has a bulk density that is approximately twice that of charcoal, the wood charge will

occupy a volume twice the volume of the charcoal charge, thus diminishing the working volume of the furnace in that amount.

[0073] We aim for a continuous carbonization (pyrolysis) process inside the Blast Furnace at a constant and ideal temperature that will produce charcoal in tens of minutes, rather than days, using spent gases from the combustion chamber. The process optimizes charcoal production efficiency, materials yield and charcoal quality, with minimum contamination. The charcoal produced is of homogeneous size and quality and will perform in an optimum way as a fuel as well as a high quality reducing and carburizing agent. The process may be carried out at a relatively high temperature (from 150° C. to 700° C. approximately). This higher temperature is supplied by the "hot gas loop" indicated in the flow sheet and accelerates the reduction reactions taking place inside the upper part of the furnace thus compensating for the temporary reduction of working volume caused by the heavier wood charge. The operator can now decide the optimum level of Fixed Carbon content based on the cost of energy, wood and pig iron instead of always aiming at the highest level of Fixed Carbon content of the charcoal. In effect, the operator can adjust the particle size, the carbonizing temperature and the duration of the pyrolysis process to affect the Fixed Carbon content of the charcoal produced inside the furnace. See Tables below.

[0074] Furthermore, the process recuperates the energy contained in the wood volatiles which are burnt in a combustion chamber to generate heat for all the processes related to the blast furnace and the excess can be converted into electric energy, as examples, in a standard steam generating plant, or in a gas driven motor facility. The thermal energy generated from the combustion of the recuperated wood volatiles is sufficient to heat the "hot blast" at the desired temperature and to create a "hot gas loop" of burnt exhaust gases that is fed at the top of the blast furnace to carbonize the wood at the optimum pre-determined temperature. In this way, the furnace operates with a "hot top" rather than the traditional "cold top" in order to optimize the larger system of which it is an essential part. This is a distinct feature of our proposal. Besides optimizing the carbonization process, the "hot loop" may be designed to heat gas ducts to avoid tar condensation and reducing maintenance problems.

[0075] Further yield improvements are possible and this is one of the driving forces of our invention.

DETAILED DESCRIPTION OF THE INVENTION

The Present Invention

An Integrated Process

[0076] The present invention relates to the design of interactions among the above mentioned four industrial processes to integrate them into one system for the co-generation of pig iron and electric energy in the most effective and efficient way (FIGS. 1 and 2). The objective is to optimize the new system in order to solve the above mentioned problems that confront the steel industry, instead of optimizing each of the four production subsystems independently of each other. By optimizing sub-systems in an independent way, we will continue to drag into the future the same problems that we face today because these problems are neither fragmented nor isolated. They are systemic, interdependent and interconnected and therefore, they must be solved as a system.

[0077] We propose the elimination of the traditional independent charcoal production process and to charge the wood (better high energy density hardwoods) directly into the blast furnace, after being dried to less than 10% moisture content (better 0% MC and hot from the dryer), heat treated to about 150° C. and classified by size. Wood is transformed into charcoal at the top of the furnace where the oxygen content is very low. The charcoal so produced is heated as it descends while performing its role as reducing agent. It is finally burned at the lowest part of the charge in front of the tuyeres where it finds the highest oxygen concentration. The heat generated by the combustion of carbon at the bottom of the charge rises through the burden and contributes to maintain, together with the “hot loop”, a hot top temperature around the optimum level for that particular wood specie and particle size, in order to produce charcoal with the pre-determined optimum Fixed Carbon content. This high top temperature promotes the start of reducing reactions at a higher point inside the blast furnace thus increasing furnace efficiency and offsetting the transitory reduction of its working volume caused by the larger wood charge.

[0078] The large amount of wood charged into the furnace acts as a filter that increases the residence time of the fine particles produced during the carbonization process and increases the probability of being burned inside the furnace. Therefore, mainly ashes that are not trapped by the slag will be blown out of the furnace. All of the distilled products (volatiles) from the wood carbonization process are available to be burned outside the blast furnace in order to generate heat energy. Under these operating conditions, burning heat treated wood is more efficient than burning charcoal because the permeability of the charge to the passage of gases is maintained at optimum levels and the process yield is increased.

[0079] As indicated before, storage of charcoal contaminates the ground, the atmosphere and eventually the surrounding water, whereas storage of wood in the form of logs or chips or other shapes does not produce contamination or degradation by rain since the product will be dried before charging it inside the blast furnace. The development of a continuous drying apparatus and method to dry solid wood particles (U.S. Pat. No. 8,161,661B2) has efficiently resolved a technical problem thus making possible the production of new sources of clean and renewable energy.

[0080] The following tables based on operating parameters from the Brazilian steel and steel foundry industries provide information about a broad number of variables for a blast furnace producing, as an example 1,000 tpd of pig iron, using green wood with 50% M.C., drying it to 10% M.C. and having an average of 20% Fixed carbon. These Tables will be a helpful aid to understand the preceding process description:

TABLE 1

EXAMPLE OF FUEL CHARACTERISTICS		
	Charcoal 0% M.C.	Dry Wood 0% M.C.
Elemental Analysis		
Carbon	84%	49%
Hydrogen	3%	6%
Oxygen	0%	44%
Sulphur	0.10%	0%
Others	13%	1%
	100%	100%

TABLE 1-continued

EXAMPLE OF FUEL CHARACTERISTICS		
	Charcoal 0% M.C.	Dry Wood 0% M.C.
Proximate Analysis		
Fixed Carbon	75%	20%
Volatiles	22%	79%
Ash	3%	1%
	100%	100%
Fuel Consumption		
Fixed Carbon - kilos per ton of pig iron	450	450
Charcoal and wood - kilos per ton of pig iron	600	2,250

TABLE 2

EXAMPLE OF ENERGY VALUES		
Heat of Combustion		
Carbon	34,157	kJoules/kilo
Hydrogen	138,135	kJoules/kilo
Latent Heat of Water	2,512	kJoules/kilo

TABLE 3

EXAMPLE OF CHARCOAL AND WOOD ENERGY VALUES AT INDICATED % M.C.			
% Moisture Content	% M.C.	Charcoal 8%	Wood 10%
Lower Heating Value	KJoules/Kilo	29,967	16,325
Fixed Carbon	KJoules/Kilo	25,417	6,580
Volatiles	KJoules/Kilo	4,550	9,745

TABLE 4

EXAMPLE OF WOOD CHARACTERISTICS		
Humidity of Dry Wood	% M.C.	10%
Dry Wood Consumption - Kilos of Dry Wood/Ton of Pig Iron		2,500
Lower Heating Value	KJoules/kilo	16,325
Humidity of Incoming Green Wood	% M.C.	50%
Green Wood Consumption - Kilos of Green Wood/Ton of Pig Iron		4,500
Lower Heating Value	KJoules/kilo	7,953

TABLE 5

EXAMPLE OF BIOMASS AND WATER		
Pig Iron Production	tons/day	1,000
Dry Wood Consumption 10% M.C.	tons/day	2,500
Green Wood Consumption 50% M.C.	tons/day	4,500
Water Evaporation	tons/day	2,000
Green Wood Consumption	tons/yr	1,642,500
Process loss (debarking, cut-to size, . . .)	15%	246,375
Green Wood - Annual Consumption	tons/yr	1,888,875

Energy from Wood

[0081] The heat from charcoal combustion and the heat supplied by the “hot loop” maintain the gasification process at

the top part of the furnace where the volatiles contained in the wood are distilled. These volatiles hold potential heat energy that can be recuperated by burning them with air in a combustion chamber (FIG. 1), outside the blast furnace. As indicated in Table 1, if 450 kilos of fixed carbon are required to produce one ton of pig iron then, 600 kilos of charcoal containing 75% fixed carbon and 2,250 kilos of dry wood with 20% fixed carbon are required to produce one ton of pig iron. The weight of wood is 3.75 larger than the weight of charcoal and contains a large amount of volatiles that, when burned in the combustion chamber, generate an amount of heat energy that is above the energy required for the blast furnace process. As indicated in the following table, a simple theoretical calculation for a blast furnace producing 1,000 tons per day of pig iron, burning dry wood with 10% M.C. and 20% fixed carbon indicates that the excess heat energy can generate over 60 MW of continuous power.

TABLE 6

EXAMPLE OF ENERGY BALANCE		
Pig Iron Production	tons/day	1,000
	kilos/hour	41,667
Dry Wood Consumption 10% M.C.	kilos/kilo pig	2,50
Lower Heating Value	KJoules/kilo	16,325
Energy Generated with Dry Wood	KJoules/k pig	40,813
10% M.C.	MJoules/hr	1,700,522
Energy Consumed in Burning Fixed Carbon	KJoules/k pig	15,371
	MJoules/hr	640,443
Available Thermal Energy	KJoules/k pig	25,442
	MJoules/hr	1,060,079
% of Available Thermal Energy used to generate Power	%	100%
Efficiency of the Power Generating Process	%	22%
Thermal Energy Transformed into Power	MJoules/hr	233,217
Example of Continuous Power Generation	MW	64.8
Blast Furnace - Annual Operating Time 98%	Hours/year	8,585
Annual Power Generation	MWh/year	556,165

[0082] Power generation is a function of pig iron production as well as the amount of wood charged in the furnace, its % M.C. and its % fixed carbon content. Therefore, economic business performance will depend, among other items, on the market value of pig iron, wood and electric energy. Tables 7 and 8 provide guidance to an operator in deciding the best combination of these three variables in order to optimize the economic results of the business.

TABLE 7

Example of Continuous Power Generation (in MW) (Based on Pig Iron Production and % Fixed Carbon of Dry Wood)						
		Pig Iron Production in Tons/Day				
		64.8 MW	800	900	1,000	1,100
% Fixed Carbon	10%	135.0	151.8	168.7	185.6	
	15%	79.5	89.5	99.4	109.4	
	20%	51.8	58.3	64.8	71.3	
	25%	35.2	39.6	44.0	48.4	
	30%	24.1	27.1	30.1	33.2	

TABLE 8

Example of Green (50% M.C.) Wood Required (in 1,000 tons/year) (Based on Pig Iron Production and % Fixed Carbon of Dry Wood)						
		Pig Iron Production in Tons/Day				
		1,889 tpy	800	900	1,000	1,100
% Fixed Carbon	10%	3,022	3,400	3,778	4,156	
	15%	2,015	2,267	2,519	2,770	
	20%	1,511	1,700	1,889	2,078	
	25%	1,209	1,360	1,511	1,662	
	30%	1,007	1,133	1,259	1,385	

Burden Calculations

[0083] Most Blast furnace operators have developed or acquired mathematical computer models to calculate the burden, burden distribution at different heights inside the furnace, temperature and pressure profiles, mass and heat transfer, air ratios, etc. which cover most aspects of the furnace operation. These models can take into consideration the different characteristics of wood vs. charcoal such as % fixed carbon, density, heating value, oxygen content, working volume of the furnace, etc. Therefore, we will not concern ourselves with these calculations because they can be easily performed using these readily available mathematical models.

Quality of the Pig Iron Produced with Wood

[0084] The pig iron facility may specify species of trees (better one or two species of high energy density wood) from renewable plantations to be purchased as fuel and may be produced at several locations (better within a short distance from the blast furnace site). The quality variations among wood shipments of the same species will be minimal and as a consequence, the quality of pig iron will be practically a constant. Furthermore, the administrative costs of purchasing from a few wood sources are irrelevant when compared to the purchase of charcoal from hundreds of different small producers who may use many different species of wood thus introducing additional variables to the blast furnace process. Wood processing does not generate pollution whereas the transport, storage and handling of charcoal are highly pollutant.

Water Recuperation

[0085] The wood drying operation allows the recuperation of the evaporated water since it is trapped in the moist hot air exiting the drying station. Wood with 50% MC dried to 10% MC evaporates water which represents approximately 45% of the weight of the moist wood. This is a relevant amount of water that is totally lost in the charcoal production process and can be recuperated adopting the present invention thus minimizing the use of water in the industrial process.

[0086] The co-generation process operates as follows:

[0087] a) Wood (better high energy density hardwood), with or without bark (better without bark to avoid fines, to have uniform combustion and to avoid refractory deterioration) is sent to the blast furnace site to produce, as an example, a certain particle size such as chips (but not only this shape), to be dried and heat treated at the wood drying station and classified with cyclones. Only coarse dry particles are charged into the blast furnace to be used as the fuel, as the reducing and as the carburizing

agent while the fine dry particles are fed into the combustion chamber as additional fuel.

[0088] b) Assuming the fixed carbon content of wood is 20% and the fixed carbon content of charcoal is approximately 75%, the amount of wood charged into the blast furnace must be approximately 3.75 (75%/20%) times greater than the amount of charcoal to have similar operating conditions as with charcoal. The fixed carbon assures the melting of the charge, the reduction of the iron ore, and the contribution of the element carbon to the composition of the pig iron produced.

[0089] c) Pig iron and slag produced are managed in a similar fashion as with a conventional charcoal charge. However, the proposed process generates an excess of electric energy, a part of which can be used to grind the slag and sell it to cement plants.

[0090] d) Wood has approximately 49% carbon content and the excess over the assumed 20% fixed carbon or 29% is combined with hydrogen and oxygen to form volatiles that are distilled before the carbonization process takes place. These volatiles, which are normally lost in the traditional charcoal production process, are recuperated and sent together with the combustion gases to the dust catcher. The dust catcher separates the solid particles (mainly wood ash and fine iron ore particles) from the gaseous stream that is sent to the combustion chamber to be burned with fresh air and generate heat energy.

[0091] e) A fraction of the hot gases exiting the combustion chamber is sent to heat exchanger "A" to heat the air coming from heat exchanger "B" to the predetermined temperature of the combustion air ("Hot Blast"). The balance of hot gases is divided so that a part goes to generate, for example, steam and electric energy and another part becomes the "hot loop" that is fed at the top part of the blast furnace to maintain the ideal carbonization temperature and, in case of need, to heat gas ducts to prevent hydrocarbon condensation.

[0092] f) In this example, the steam generator heats water coming from both heat exchangers "C" and the condenser and produces super-heated steam that is sent to the turbine. The bulk of the super-heated steam produced by the steam generator is used to generate electric energy in a conventional line. A small fraction of the lower pressure super-heated steam from the turbine may be sent to the condenser to heat fresh air that may be sent to the mixing chamber. The mixing chamber receives, in addition, in this example, exhaust gases from the bank of cyclones after heat exchanger "B" that contribute gas volume, temperature and a low oxygen composition to minimize fire hazards inside the dryer. In case of need, fresh air may be also sent to the mixing chamber to obtain the required volume of gases at a temperature of about 150° C. to dry and heat treat the wood inside the drying apparatus.

[0093] g) The water contained in the hot moist air leaving the drying process, may be recuperated (not shown in FIG. 1) and sent, in this example, to the steam generator or cooling towers in order to reduce the need for fresh water in the system.

[0094] h) Exhaust gases from the steam generator, together with hot gases from heat exchanger "A" are passed through heat exchanger "B" to heat fresh air that becomes preheated air that is heated in heat exchanger

"A" to the predetermined temperature that is fed into the blast furnace as the "hot blast".

[0095] i) Hot gases from heat exchanger "B" are passed through a battery of cyclones to remove the "ashes" and then, they are sent to the wood drying station as indicated above and/or vented to the atmosphere and/or sent to a gas processing plant (not shown in FIG. 1).

Main Invention Benefits

[0096] The invention generates many benefits for the operation of a blast furnace and some of them solve the main problems confronting the steel industry as shown in the following list:

[0097] 1) It is now possible to add value to iron ore and convert it to pig iron in countries that do not possess coal mines and have low availability of electric energy.

[0098] 2) Dry wood, instead of charcoal, is a better fuel for a blast furnace operation because it minimizes pollution and generates energy in excess of what is required to operate the blast furnace equipment.

[0099] 3) The energy generated by burning dry wood inside the blast furnace is recuperated and not lost as in the traditional charcoal manufacturing process. The energy from the combustion of wood volatiles may be transformed into electric energy, the amount of which is in indirect proportion of the Fixed Carbon content of the wood (the higher the Fixed Carbon, the lower the amount of energy produced).

[0100] 4) Wood consumption per ton of pig iron produced is lower using heat treated wood as fuel than the amount of wood consumed in the traditional independent charcoal process since it is consumed dry inside the furnace with minimum mass loss.

[0101] 5) The quality of the pig iron produced is improved since the fuel, the reducing agent and the carburizing agent are basically a constant

[0102] 6) Water may be recuperated from the moist hot air as it exits the wood drying station thus diminishing the use of fresh water for the process.

[0103] 7) The material efficiency or total yield of the system is increased due to minimum material losses.

[0104] 8) There are no carbon losses since the carbonization process occurs inside the blast furnace and there are no carbon emissions that pollute the air, the grounds and eventually, the water.

[0105] 9) Atmospheric contamination is reduced to a minimum since practically all emissions are contained inside the furnace and can be managed at will.

[0106] 10) Atmospheric and ground contamination (and eventually, water contamination) caused by transportation is reduced by avoiding the production and handling of charcoal.

[0107] 11) A clean environment reduces health hazards and improves the quality of life of workers and of the surrounding community.

[0108] 12) Increased efficiency of the combustion chamber and the steam generator as a result of the use of dry gases generated by the combustion of dry wood.

[0109] 13) Generation of own electric energy reduces the need for purchased power that may be another source of contamination.

[0110] 14) Economic performance of the system is improved:

[0111] a. The lower cost of the blast furnace fuel (dry wood vs. charcoal).

[0112] b. The constant quality of the pig iron produced resulting from burning a unique source of fuel (one or two similar wood species).

[0113] c. The decrease in inventory and administrative costs related to the purchase of wood from few sources vs. the purchase of charcoal from hundreds of small producers.

[0114] d. The generation of electric energy for own consumption and substitution of purchased energy and/or eventual income resulting from the sale of the excess energy to the local power company.

[0115] e. The improved yield of the new integrated process.

groups oppose this idea due to potential pollution problems. Since pig iron cannot be produced in the country with current technology, the owners proposed the installation of a pipeline to move the crushed iron ore concentrate (69% Fe) from the mine to an ocean port, some 125 miles away that would be built as part of the project. Iron ore concentrate would then be exported to world markets and the water returned to the mine site. Opposition to the pipeline continues on many fronts and in particular, due to the lack of electric energy to move the iron ore to port, the lack of added value to the iron ore concentrate and the potential environmental damage caused by contaminated water from the pipeline and from open pit mining. As a consequence, the project is at a standstill. Ample information backing our assertions is found in the press and a cursory Internet search would immediately produce the desired results.

TABLE 9

PROJECT ARATIRI - ADDING VALUE TO IRON ORE CONCENTRATE						
		IRON ORE	CONCENTRATE	PIG IRON	WIRE ROD	WIRE
PRICE	US\$/ton		77.78	400	800	1,200
INVOICED SALES	1,000 tons/yr		18,000	3,500	1,750	1,166
	1,000 US\$/yr		1,400,000	1,400,000	1,400,000	1,400,000
Fe Content	%	27%	69%	94%	99%	99%
	1,000 tons Fe/yr	13,800	12,420	3,290	1,732	1,155
Assumed % Process Loss		10%	10%	10%	6%	4%
CONCENTRATE	1,000 tons/yr		18,000	5,297	2,967	2,061
IRON ORE	1,000 tons/yr		51,111	15,043	8,427	5,852
PROJECT LIFE	years		25	85	152	218

Note:

Constant annual \$ sales and higher value-added products extend the project life

[0116] f. The recuperation of water evaporated in the drying of wood, and

[0117] g. A drastic reduction in the cost of pollution equipment and control systems.

[0118] h. The potential sale of ground slag to the cement industry.

[0119] i. The generation and sale of Certified Emissions Reduction (CER's)

Proof of the Non-Existence of Prior Knowledge

[0120] The real world is the litmus test of theories. There are many iron ore projects around the world that have been stopped due to the lack of a local source of coking coal and/or insufficient supply of electric energy. In this case, we will describe a 3 billion dollars project that was not advanced due to the lack of coking coal and energy in its vicinity. Such a problem would not have existed if our invention had been implemented. Furthermore, our invention would have provided enough energy not only for the iron smelting plant, but also for other plant facilities and/or for sale to the local power company for distribution.

[0121] Project "Aratiri", in the country of Uruguay in South America, is a perfect example of the non-existence of prior knowledge on the subject addressed by this invention. In effect, vast iron ore deposits have been identified in the North-eastern part of the country but cannot be converted into pig iron because there are no known coking coal deposits in Uruguay and there is not sufficient power generation in the country to satisfy the needs of a blast furnace installation. Investors propose to import coal or coke but local social

[0122] This invention would solve all of these problems and the project could move forward as the first step to develop an integrated steel industry in the country. In effect, there is a growing forestry industry in Uruguay that is capable of supplying wood to an existing paper pulp plant, a second pulp plant that is being built, and to serve the needs of the local wood industry as well as export markets. The forested area represents less than 10% of the country's area and there is plenty of room for growth to support a project such as Aratiri. Selected species of *Eucalyptus* or other high energy density species would be acquired locally and/or be planted in the vicinity of the iron ore deposits and processed as indicated in this document to replace imported mineral coal or coke. A portion of the excess of heat energy generated by the wood fuel would be converted into electric energy to run the blast furnace and other plant facilities. The balance, if any, would be distributed to the local power company to generate additional income and to alleviate the increased demand for electricity in the country. Opposition to open pit mining could be resolved by showing and implementing the best practices developed in other countries to improve the environment that is negatively impacted by the mining operation. This sustainable co-generation process for the production of pig iron and electric energy with local raw materials would be the foundation to build, at a later date, an integrated steel mill to supply the needs of the local market, of neighbor countries (Argentina, Brazil, and Paraguay), and of selected countries of the world. Adding value to the iron ore and maintaining the same projected annual invoice value would extend the project life from some 20-25 years selling a 69% Fe concentrate to

152-218 years in case wire products were produced. The country could export technology, steel and electric energy instead of wood and iron ore. The country would make rational use of a non-renewable resource and social development would be enhanced.

[0123] Furthermore, none of the known research projects funded by the steel industry on a worldwide basis, such as the "Green Pig iron", "Green Steel Industry", or "Ultralow CO₂ Steelmaking" considers the use of wood as the fuel for the blast furnace. Most propose the use of low-volatile coal that eliminates the need for coking and sintering. They claim that emissions can be reduced by 20% compared to a standard blast furnace. Further improvements aim at carbon capture and storage to eventually reduce a further 60% in emissions.

[0124] Our project, that uses wood, would be much less polluting than any one of these projects. In effect: a) CO₂ emissions are equal to those of a charcoal furnace, however, since our invention consumes less wood, CO₂ emissions are proportionally reduced, b) Wood is totally consumed inside the furnace and its volatiles are totally burned inside a combustion chamber thus minimizing CO emissions, c) Wood generates less than 1% of ashes which contain nutrients for the soil and could be used as a fertilizer for the tree plantations.

[0125] This invention allows the development of a truly sustainable and vertically integrated "green" steel industry in countries having abundant iron ore reserves and a suitable climate and abundant land for the development of a forestry industry with efficient wood species to be used as blast furnace fuel. This project could entail, in itself, its own energy plantations development program with consequent development over a wide rural area and with a minimum of environmental impact.

[0126] This forestry development, already present in some cases, would be enhanced and it can even be considered as integral part of a smelting/steel plant, with notorious advantages in rural development up to 150-200 km from the plant (s), being these distances the average ones considered for the pulp industry, already burgeoning due to the speed of *Eucalyptus* growth in some areas as well as the ease of transportation in flat or undulating countries, many times also having abundant waterways. This is precisely the case in the area of the Aratiri project already described, where the lack of this technology means a tremendous waste.

Additional Investments Required for the Proposed Invention

Wood Preparation:

[0127] a) As results from our pilot plant experiments, wood (better high energy density hardwoods) should normally be debarked and sized to improve the efficiency of the combustion, reduction and carburizing processes as well as the life of the blast furnace top refractory lining. Successful melting of a steel products charge, in the prototype built for this purpose, was attained with small as well as large pieces of hardwood (*eucalyptus Camaldulensis*), up to 10" long, with and without bark. Combustion is a surface process; therefore, it is best to define in laboratory tests the right size of the wood pieces in combination with the iron containing material (lump ore, sinter, iron ore pellets, or others) used in order to enhance the efficiency of the melting process. Small pieces of metallic scrap (turnings, bolts, nuts, short bars, etc.) can also be added to the mineral

charge, even though they have a melting temperature which is higher than that of iron ore because the flame temperature of dry wood is capable of melting carbon steels.

[0128] b) Wood needs to be dried and heat treated prior to charging into the blast furnace. A "Continuous Drying Apparatus" (our U.S. Pat. No. 8,161,661B2) has proven to be an efficient piece of equipment to dry wood particles and requires minimum supervision and maintenance.

[0129] c) Cyclones will be required to separate the fine particles of dry wood which are sent to the combustion chamber to be used as additional fuel. Only coarse dry wood pieces (better hardwood to support the weight of the burden without collapsing and to occupy less furnace volume) are sent to the blast furnace to preserve optimum permeability conditions to enhance gas passage through the burden to accelerate chemical reactions and increase the efficiency of pig iron production.

[0130] d) Wood storage and handling equipment will be required to efficiently move the wood from storage through the different stages of the process.

[0131] e) A mixing chamber that may receive a combination of fresh air, hot air, and exhaust gases in different proportions to deliver drying gases to the dryer in the specified volume, temperature, moisture and oxygen content.

Energy Generation:

[0132] a) A separate combustion chamber is required to burn the volatiles distilled at the top of the blast furnace.

[0133] b) As an example, a steam generator and a complete energy generation plant with heat exchanger "C" to preheat water to feed the steam generator are required to generate electric energy and distribute it to the plant and to the grid.

[0134] c) The example includes a condenser that takes a portion of steam from the turbine to preheat fresh air and send it to the mixing chamber as part of the drying gases.

[0135] d) The example also includes heat exchangers "A" and "B" to preheat the air blast with hot gases from the combustion chamber and the steam generator.

[0136] e) A battery of cyclones to separate ashes from the exhaust gases from heat exchanger "B" and

[0137] f) Gas processing equipment in case local management decides to recuperate heat and/or valuable chemicals contained in the gases.

Water Recuperation:

[0138] a) Water can be recuperated by condensing the moist hot air leaving the cyclones of the wood drying station and sending it, as in the example, to the cooling towers or to heat exchanger "C" to reduce the amount of fresh water used in the system. This process is not included in FIG. 1.

Air and Gas Handling Equipment:

[0139] a) Numerous fans, dampers and auxiliary equipment will be required to manage the flow of air and gases for the system

1. A sustainable joint smelting and energy producing process where wood is used as the only fuel, reducing agent and carburizing agent and where all the wood used is put inside the blast furnace.

2. The process of claim 1, where various additional plant facilities may be included, such as for example—but not only—a steel mill or a wood drying plant, that use—partially or totally—the surplus energy from the smelting plant.

3. A sustainable smelting process according to claim 1 where wood is used as the only fuel, reducing agent and carburizing agent and where all the wood used (being it the only fuel, reducing agent and carburizing agent) is put inside the blast furnace.

4. A sustainable joint smelting-energy producing process where wood is used as the only fuel, reducing agent and carburizing agent, and where the excess energy produced is an indirect function of the % fixed carbon content of the dry wood.

5. A sustainable smelting process where wood is used as the only source of both carbon and energy

6. A sustainable joint smelting-energy producing process whose flow-sheet is substantially similar, from the conceptual point of view—in all or some of its tables/equations—to the one depicted in FIGS. 1 and/or 2, and/or where the quantitative and qualitative relations (ratios) are substantially as shown in the tables and equations shown.

7. A sustainable smelting process where wood is the only fuel, reducing agent and carburizing agent, and where only part of the wood is put inside the blast furnace.

8. A sustainable co-generation process where energy and pig iron are its main products, being any cellulosic material its only energy source, as well as reducing and carburizing agent, and being all or part of such cellulosic material put inside the blast furnace.

9. A sustainable co-generation process as in claim 1 where the amount of excess energy produced may be used as electric energy, thermal energy, or any other type of energy.

10. A sustainable co-generation process where energy and pig iron are its main but not necessarily its only products, being any cellulosic material its only energy source, and being that this cellulosic material may be put completely or partially inside the blast furnace.

11. Any smelting process where the amount of wood or any other cellulosic material is charged into the Blast furnace in direct proportion to the % fixed carbon content of the charcoal that would have been used in the current smelting processes where such charcoal is the only reducing and carburizing agent.

12. The process of claim 1 where wood or any other cellulosic material is the only source for any of the following concepts: energy, reducing agent or carburizing agent, being these considered either together or in a separate way.

13. The process of claim 1 where the iron smelting facility has a nearby situated wood drying plant and where the energy necessary for its drying comes, partially or completely, from the smelting process.

14. The process of claim 1 where all or part of the dried wood necessary in the smelting process as described comes from the wood drying facility, and where all or part of the energy needed for wood drying comes from the smelting plant.

15. The process of claim 1, where a steel producing plant receives all or part of the pig iron from the smelting plant and works, partially or completely, with the energy produced by the smelting plant.

16. The process of claim 1 where both the wood drying plant and the steel making plant work partially or completely with the energy from the smelting plant.

17. The process of claim 1 where a portion or all of the excess energy from the smelting plant is sold into the network.

18. A smelting process according to claim 1 whose energy generating capacity is in indirect relation to the % fixed carbon content of the cellulosic material used as fuel.

19. A co-generation plant, or a smelting only plant according to claim 1, where combustion chambers have their efficiencies enhanced by the use of dry and/or distilled gases generated by the combustion of charcoal produced with dry wood.

20. A process according to claim 1 which produces pig iron of improved quality with to the use of dry wood, heat treated wood, or any combination of them as the only fuel, reducing agent and carburizing agent, since the characteristics of such wood are practically constant.

* * * * *