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(54) **RENEWABLE BIOMASS DERIVED CARBON MATERIAL FOR METALLURGICAL PROCESSES AND METHOD OF MAKING THE SAME**

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(57) **ABSTRACT**

A method for the production of a carbon material entirely from raw biomass feedstock for use in connection with a metallurgical production and refining process such as the production of steel, aluminum or silicon. The carbon material has a carbon content of greater than 50% by volume of non-volatile, high purity fixed elemental carbon and includes physical properties such as coking strength, conductivity, density, porosity, surface area and particle size which may be individually modified to meet the requirements of a specific metallurgical application.

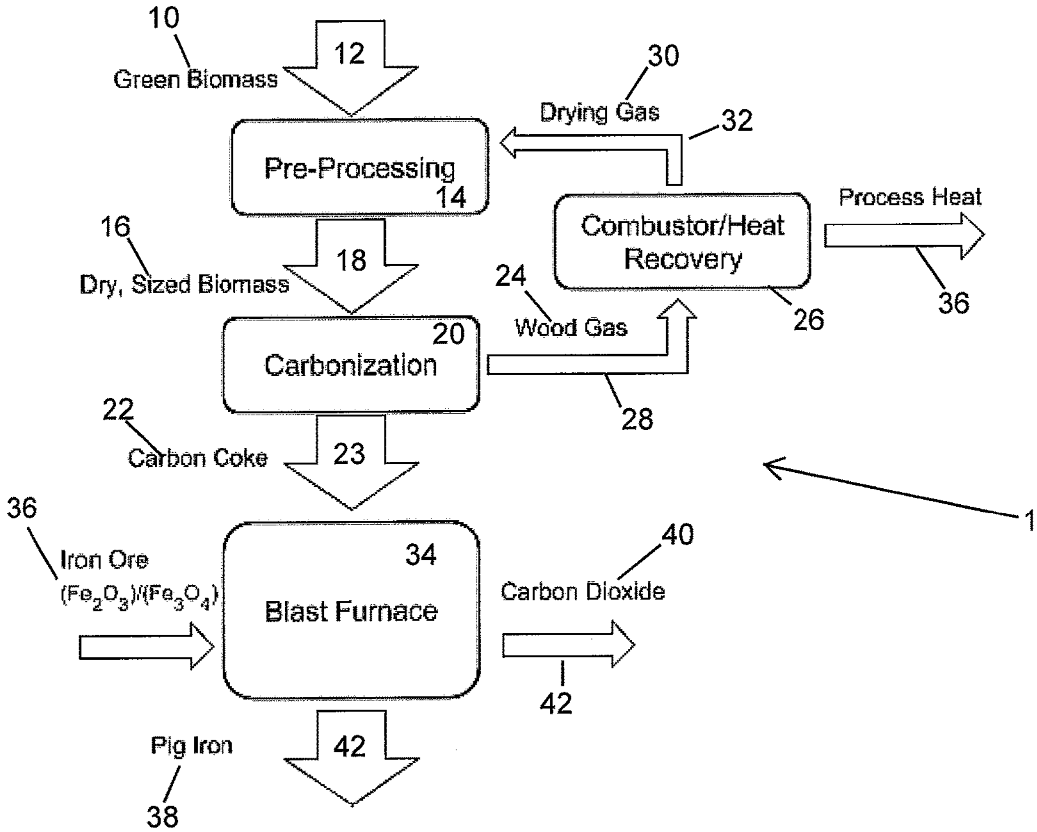
10
Green Biomass
12
Pre-Processing
14
30
Drying Gas
32
Combustor/Heat Recovery
Process Heat
16
Dry, Sized Biomass
18
24
26
36
Carbonization
20
Wood Gas
28
22
Carbon Coke
23
1
36
Iron Ore
$(Fe_2O_3)/(Fe_3O_4)$
34
Blast Furnace
40
Carbon Dioxide
42
Pig Iron
42
38

Figure 1

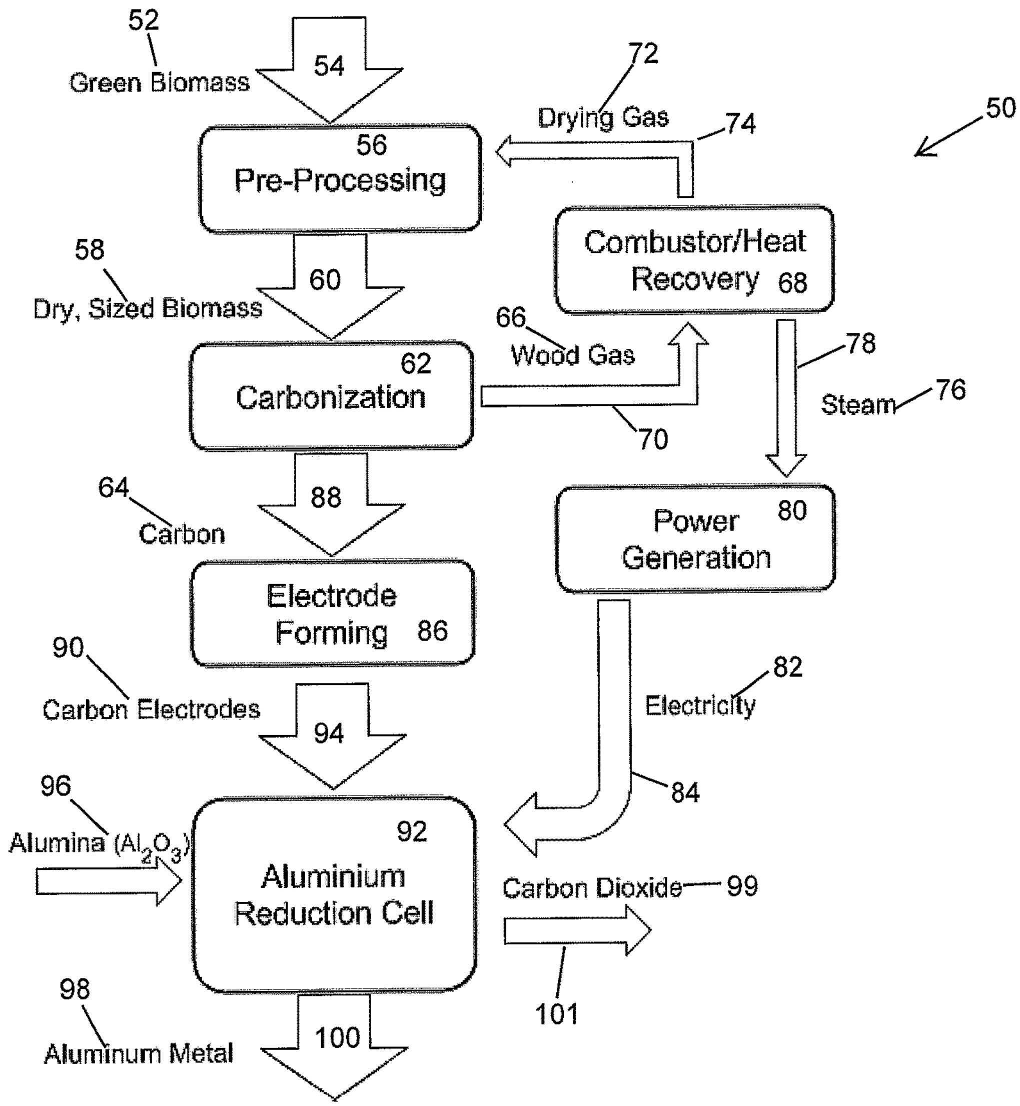
52
Green Biomass
54
72
Drying Gas
74
50
56
Pre-Processing
Combustor/Heat
Recovery 68
58
60
Dry, Sized Biomass
66
Wood Gas
78
62
Carbonization
Steam
76
70
64
88
Carbon
Power
Generation
80
Electrode
Forming 86
90
Carbon Electrodes
94
82
Electricity
84
96
Alumina (Al_2O_3)
92
Aluminium
Reduction Cell
Carbon Dioxide
99
101
98
Aluminum Metal
100

Figure 2

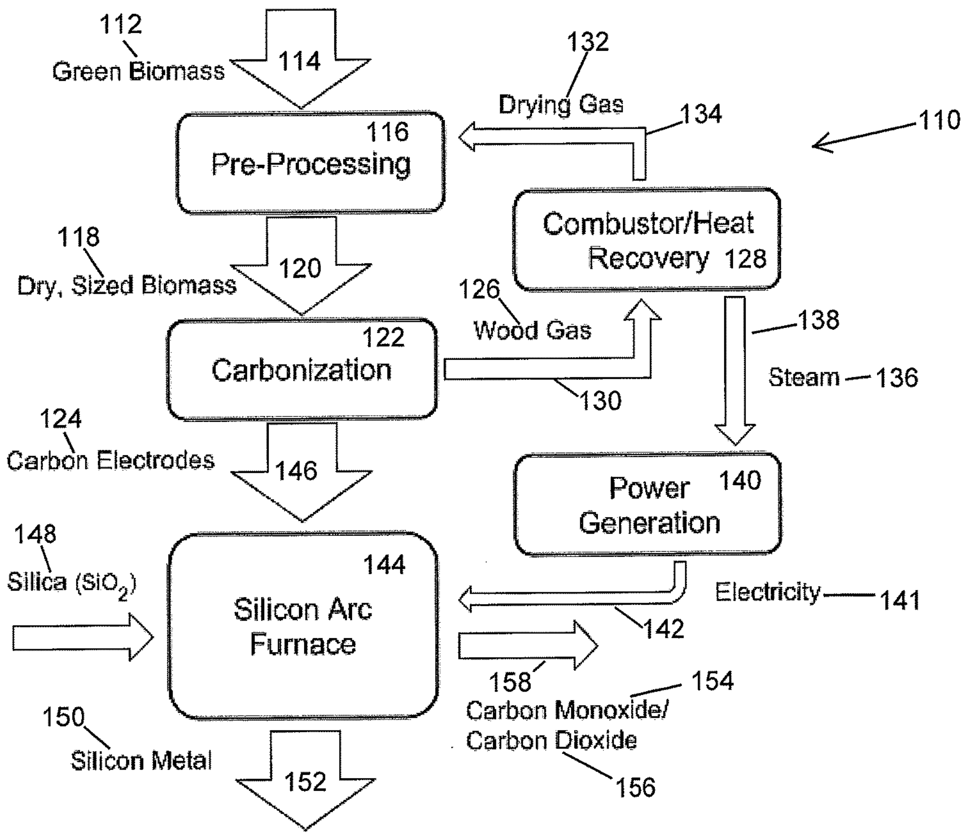
112
Green Biomass
114
132
Drying Gas
134
110
116
Pre-Processing
Combustor/Heat
Recovery 128
118
Dry, Sized Biomass
120
126
Wood Gas
138
122
Carbonization
Steam
136
130
124
Carbon Electrodes
146
Power
Generation
140
148
Silica (SiO_2)
144
Silicon Arc
Furnace
Electricity
141
142
158
154
Carbon Monoxide/
Carbon Dioxide
156
150
Silicon Metal
152

Figure 3

RENEWABLE BIOMASS DERIVED CARBON MATERIAL FOR METALLURGICAL PROCESSES AND METHOD OF MAKING THE SAME

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Ser. No. 62/438,633, filed Dec. 23, 2016, which is incorporated herein by reference in its entirety as if fully set forth herein.

FIELD OF THE INVENTION

[0002] The present invention relates to a novel composition of matter having application for use as an electrode, reducing agent, and carbon source in metallurgical processes and the method for its manufacture.

BACKGROUND OF THE INVENTION

[0003] Carbon serves an important role in the refining and manufacturing of several metals including aluminum, silicon, and carbon steel.

[0004] Aluminum metal is produced from aluminum oxide in the Hall-Héroult process, in which the aluminum oxide is electrolyzed in a molten mixture of cryolite with calcium fluoride. A consumable carbon anode serves the dual role of an electric current source for the process and a source of carbon to react with oxygen produced in the process to form carbon dioxide.

[0005] Silicon metal is produced in a similar fashion from silicon dioxide in an electric arc furnace using carbon electrodes. The carbon electrodes are oxidized by the oxygen in the silicon dioxide, reducing the silicon and leaving pure silicon metal.

[0006] In steel production, the carbon is utilized in the form of coke, which is burned as fuel and used as a reducing agent for the conversion of iron into steel. Coke is produced from metallurgical coals using a process which requires low levels of sulfur, phosphorous, and ash to prevent the addition of impurities in the coal to the coke product. Petroleum coke is a solid residue produced in oil refining which is resembles coke. However, it contains too many impurities to be useful in metallurgical manufacturing process.

[0007] Although only three examples are listed, carbon is used in a broad range of metallurgical applications including, but not limited to the production of titanium, zinc, copper, silver, gold, and many other applications. All of these applications utilize carbon as a fuel or reducing agent and produce CO_2 as a byproduct. If the carbon is derived from coal, or other fossil sources, the released CO_2 represents an increase in atmospheric CO_2 levels.

[0008] U.S. Pat. No. 3,215,522 A, "Silicon Metal Production" issued to August M. Kuhlmann on Nov. 2, 1965, describes a method of silicon metal production which uses electrodes made from coke, coal, and wood chips in an electric arc furnace. However, carbonaceous materials with fewer fines and low iron content are preferred over the materials disclosed by Kuhlmann.

[0009] US Patent Application Publication No. 20110150741 A1, published Jan. 23, 2011, now abandoned, by Lang et al. for "Production of Silicon by Reacting Silicon Oxide and Silicon Carbide, Optionally in the Presence of a Second Carbon Source" describes an improved method of silicon production utilizing a mixture of silicon oxide and silicon carbide with a secondary carbon source. The carbon source can include wood, or plant matter and charcoal, preferable low in boron and phosphorous.

[0010] U.S. Pat. No. 1,996,643 A, for "Improved Electrode and Method of Making Same" issued to De Pree, on Apr. 2, 1935, discloses a method for producing electrodes for a steel making process. In De Pree's process, carbon, graphite, or graphitized carbon are bound with rosin and oil to produce an electrode which will withstand oxidation at high temperatures.

[0011] Kuhlmann and Lang both focus on methods of silicon production and list preferred properties of carbonaceous electrode material. De Pree shows a method for producing resistant electrodes from a combination of a carbon material and pitch binders. None of the above patents describe a method for producing a carbon material with targeted properties for metallurgical processing; although, they do explain the properties of the used carbon being of significant importance. They also do not address a need for renewable materials or materials which have a negligible impact on atmospheric CO_2 levels.

[0012] In view of the foregoing, it is apparent that a need exists for a new and useful material which has properties similar to existing electrodes and cokes, but with targeted physical properties and which can be produced renewably and without the emission of fossil carbon dioxide or other pollutants into the environment.

SUMMARY OF THE INVENTION

[0013] The novel material and manufacturing processes herein described are complementary to the prior art and represent significant improvements thereto. In an embodiment, the present invention provides a method for the creation of a novel composition of carbon to be used in metallurgical processes through the pyrolysis of biomass particles under special treatment conditions to create specific properties targeted for use as a metallurgical carbon.

[0014] In another embodiment, a system is disclosed for carbon production which is integrated with the metallurgical process to provide increased efficiency and manufacturing costs reductions.

[0015] These and other advantages and novel features of the present invention will become apparent from the following description of the invention and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. **1** is a flow diagram of a process for producing a carbon coke for steel production in which green biomass is first dehydrated and then introduced into a carbonization reactor where it is thermally decomposed into solid carbon coke and wood gas, useful as a fuel for biomass drying and for adding heat to a steelmaking process;

[0017] FIG. **2** is a flow diagram of a process for producing carbon electrodes for aluminum refining in which green biomass is first dehydrated and sized according to particle size and introduced into a carbonization reactor where it is thermally decomposed into solid carbon and wood gas, the solid carbon being used to form anodic and cathodic electrodes of an aluminum reduction cell; the wood gas being used as a fuel for biomass drying and steam production for process power generation; and

[0018] FIG. **3** is a flow diagram of a process for producing carbon electrodes for silicon refining in which green biomass is first dehydrated and sized according to particle size, introduced into a carbonization reactor where it is thermally decomposed into solid carbon and wood gas, the solid carbon being used to form electrodes of a silicon arc furnace and the wood gas being used as a fuel for biomass drying and steam production for process power generation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0019] It should be noted that the present description is by way of instructional examples, and the concepts presented herein are not limited to use or application with any single method and/or apparatus for the production of a metallurgical carbon material. Hence, while the method of producing a novel carbon material of the present invention may be used in connection with a selected metallurgical precursor in the manufacturing of a preselected metal in a metallurgical refining unit such as a furnace. the details of the innovation described herein are for the convenience of illustration and explanation with respect to exemplary embodiments, and the principles disclosed may be applied to other types and applications of the production of metallurgical carbons from biomass feedstocks without departing from the scope hereof.

The Method:

[0020] Referring now to FIG. **1**, by way of example and not of limitation, a flow diagram for a process **1** for the production of carbon coke which may be used in steel production illustrates the process steps of an exemplary embodiment of the present invention. Depending on the specific intended application, the novel final carbon product of the present invention, pre-processing of green biomass feedstock **10** may or may not be necessary. The pre-process step **12** includes the introduction or feeding of green biomass feedstock into pre-processing equipment which may include drying, sizing, and/or densification apparatus shown generally at block **14** to produce biomass feedstock **16** of a selected size and/or shape (for example, by pelletizing), moisture content and density. The sizing operation may be performed by chipping, cutting, screening, or similar processing to achieve the desired size for the metallurgical reaction, and the physical structure may be modified via chemical reaction, by way of example, by exposing the biomass to an acid, a base or another chemical agent adapted to modify the feedstock structure for the intended application.

[0021] Once the feedstock had been dried, sized, and otherwise prepared, at step **18**, it is introduced to a carbonization reactor **20** where it is thermally decomposed or pyrolyzed at a sufficiently high temperature to drive off volatile carbon and create the high purity, highly fixed solid carbon structure or carbon coke **22**. The carbonization or pyrolysis of the biomass at a preselected temperature of between approximately 350° C. and approximately 750° C. under atmospheric pressure for a preselected time of between one and twenty minutes will yield a carbon material which has a predetermined structure, size and density for the specific application. This structure may be created via any number of pyrolysis processes known in the art, including external heating, steam pyrolysis, or staged pyrolysis as described in Applicant's U.S. Pat. No. 9,505,984 B2 (the "'984 patent"). Any cost effective method for the carbonization would be suitable for this process. The carbon material may then be added directly to the steelmaking process at step **23** or processed further as will be discussed in greater detail below.

[0022] By way of example and not of limitation, the pyrolysis process as described in the '984 patent, produces the desired carbonized structure without the need for external fuel beyond the chemical energy in the biomass feedstock. Additional carbonization by-products such as wood gas **24** are also produced in the pyrolysis process which may have a number of uses, all of which create significant economic advantages and enhanced efficiencies over prior art systems and manufacturing processes.

[0023] First, it reduces operating costs since the wood gas may be directed to a combustor **26** as shown at step **28** where it is burned for heat recovery, producing hot gas for biomass drying **30**, step **32**, a portion of which may be directed to a blast furnace **34** at step **36** for adding heat to the steelmaking process. The need for fuel from extraneous fuel sources, which would otherwise be required to be burned for process heating, is eliminated. Moreover, the excess wood gas produced by carbonization, which does not drive the carbonization process, can be used to produce steam and/or electricity to offset the electrical needs of many metallurgical production and refining processes, to provide heat for biomass drying, and/or to fire a furnace. Hence, a synergistic integration of carbonization and electricity production with a metal refining facility is created.

[0024] Second, a substantial environmental benefit is realized by not utilizing fossil carbons for fuel or feedstock in metallurgical processing. No fossil CO_2 emissions from the reduction reaction are present; the emissions being substantially if not completely free of any environmentally hazardous compounds or chemicals. Moreover, other heat and/or electrical requirements can be offset using produced wood gas, as noted above.

[0025] Referring again to FIG. **1**, once a carbon with the desired properties and dimensions has been created, it may be densified or agglomerated into a larger electrode. Otherwise the produced carbon can be used directly in the refining process of iron ore **36** (Fe_2O_3 and Fe_3O_4), as an electrode, fuel, or strictly as a reducing agent creating pig iron **38** and carbon dioxide gas **40** as depicted at step **42**. Carbons described herein can also be used as a re-carburizing carbon to adjust to total carbon content in steel.

[0026] FIG. **2** is a process flow diagram of a process **50** for producing carbon electrodes for use in aluminum refining in accordance with an embodiment of the present invention. As described above with respect to the process for making carbon electrodes for steel making applications and in a similar manner, green biomass **52** may be introduced via step **54** to preprocessing equipment apparatus shown generally at block **56** to produce biomass feedstock **58** of a selected size, moisture content and density.

[0027] The dried and sized biomass **58** is introduced via step **60** to a carbonization reactor **62** where it is decomposed at high temperature (between approximately 350° C. and approximately 750° C.) under atmospheric temperature into solid carbon **64** and wood gas **66**. The wood gas may be directed to a combustor **68** as shown at step **70** where it is burned for heat recovery, producing hot gas for biomass drying **72**, step **74**. A portion of the wood gas produced during the carbonization process may also be used to produce steam **76** at step **78** which is directed to an electrical power generator **80** to provide electricity for the aluminum making process at step **84**.

[0028] The solid carbon **64** produced in the carbonization process at **62** is then introduced into an electrode forming apparatus **86** where it is mixed with a binding material and formed into one or more solid electrodes **90**. The electrodes are installed in an aluminum reduction cell at step **94** to provide a reducing agent and an electron sink to process alumina **96** ($A1_2O_3$) into molten aluminum **98** and carbon dioxide **99** at steps **100** and **101**, respectively.

[0029] FIG. **3** is a process flow diagram of a process **110** for producing carbon electrodes for use in silicon refining in accordance with another embodiment of the present invention. As described above with respect to the processes for making carbon electrodes for steel and aluminum making applications and in a similar manner, green biomass **112** may be introduced via step **114** to preprocessing equipment apparatus shown generally at block **116** to produce biomass feedstock **118** of a selected size, moisture content and density.

[0030] The dried and sized biomass **118** is introduced via step **120** to a carbonization reactor **122** where it is decomposed at high temperature (between approximately 350° C. and approximately 750° C.) under atmospheric temperature into solid carbon as above which is formed into carbon electrodes **124**. Wood gas **126** is a by-product of the carbonization process which may be directed to a combustor **128** as shown at step **130** where it is burned for heat recovery, producing hot gas for biomass drying **132**, step **134**. A portion of the wood gas produced during the carbonization process may also be used to produce steam **136** at step **138** which is directed to an electrical power generator **140** to provide electricity **141** for the silicon making process at step **142**.

[0031] One or more of the electrodes **124** formed of the carbon are installed in a silicon arc furnace **144** at step **146** to provide a reducing agent and an electron sink to process silica **148** into molten silicon **150**, at step **152** and carbon monoxide **154** and carbon dioxide **156** at step **158**.

The Product:

[0032] The end product material of the manufacturing processes described above with respect to the embodiments of the processes of the present invention possesses a number of properties and characteristics which overcome the shortcomings of the prior art and make it ideal for use as a metallurgical processing or refining material, a reducing agent, and as a source of metallurgical carbon. The material may be formed into an electrode by incorporating a binder and by submitting the material to a densification process. The material's properties and characteristics include by way of example:

[0033] 1. a composition of matter, particulate or pelletized material created entirely through the pyrolysis of biomass which has greater than 50% by mass of non-volatile, high purity fixed elemental carbon, the composition of which material may be adjusted for a specific metallurgical application;

[0034] 2. a sulfur content less than or equal to approximately 1% by mass;

[0035] 3. an ash content less than or equal to approximately 10% by mass;

[0036] 4. a content of less than approximately 10 mg/kg of each of the following: antimony, arsenic, barium, cadmium, chromium, cobalt, copper, lead, nickel, mercury phosphorous, boron and selenium;

[0037] 5. a content of less than approximately 5 μg/kg of any polycyclic aromatic compound;

[0038] 6. a surface area of between approximately 10 m^2/g to approximately 600 m^2/g as measured by nitrogen absorption techniques.

[0039] 7. substantially free of any environmentally hazardous chemicals or components; and

[0040] 8. the following physical properties which may be adjusted to meet the requirements of a specific metallurgical application, including but not limited to, coking strength, conductivity, density, porosity, surface area and particle size.

[0041] Changes may be made to the foregoing methods, devices and systems without departing from the scope of the present invention. It should be noted that the matter contained in the above description should be interpreted as illustrative and not in a limiting sense. The following claim(s) are intended to cover all generic and specific features described herein as well as statement of the scope of the present invention, which, as a matter of language, might be said to fall therebetween.

What is claimed is:

1. A method for the production of a carbon material from raw biomass feedstock for use in connection with a metallurgical production and refining process, the method comprising:

introducing raw biomass feedstock to a carbonization reactor;

carbonizing the biomass feedstock at a preselected temperature at atmospheric pressure for a preselected period of time, thereby creating a carbon material having predetermined carbonized structure, properties and dimensions and carbonization by-products;

introducing the carbon material and a metallurgical precursor into a metallurgical refining unit;

heating the carbon material and metallurgical precursor to produce a preselected metal.

2. The method of claim **1** further including preprocessing the biomass feedstock prior to carbonizing it.

3. The method of claim **2** wherein preprocessing the biomass feedstock includes drying the biomass feedstock to a preselected moisture content.

4. The method of claim **2** wherein preprocessing the feedstock includes densifying the feedstock and forming or sizing it into a preselected size and/or shape.

5. The method of claim **2** wherein preprocessing the biomass feedstock includes chemical modification of the biomass feedstock through exposure to an acid, a base or another chemical agent adapted to modify the biomass feedstock's physical structure.

6. The method of claim **1** including processing the carbonization by-products to provide fuel for the generation of heat, steam, electricity or other energy for biomass feedstock processing.

7. The method of claim **6** wherein processing the carbonization by-products further includes utilizing a portion of the carbonization by-products to generate heat, steam, electricity or other energy for the metallurgical production and refining process.

8. The method of claim **1** wherein the metallurgical precursor comprises iron ore and wherein the preselected metal end product comprises iron.

9. The method of claim **1** including introducing the carbon material having a predetermined carbonized structure into an electrode forming apparatus, mixing the carbon material with a binding material and forming the mixed carbon and binding material into one or more carbon electrodes.

10. The method of claim **9** including installing the one or more carbon electrodes in a metallurgical refining unit.

11. The method of claim **10** wherein the metallurgical precursor comprises alumina and wherein the preselected metal end product comprises aluminum.

12. The method of claim **1** wherein the metallurgical precursor comprises silica and wherein the preselected metal end product comprises silicon.

13. A metallurgical processing and refining material comprising greater than 50% by volume of non-volatile, high purity fixed elemental carbon.

14. The metallurgical processing and refining material of claim **13** further comprising a sulfur content of less than or equal to approximately 1% by mass.

15. The metallurgical processing and refining material of claim **14** further comprising an ash content of less than or equal to approximately 10% by mass.

16. The metallurgical processing and refining material of claim **15** further comprising less than or equal to approximately 10 mg/kg of each of the following components: antimony, arsenic, barium, cadmium, chromium, cobalt, copper, lead, nickel, mercury, phosphorous, boron and selenium.

17. The metallurgical processing and refining material of claim **16** having a surface are of between approximately 10 m^2/g to approximately 600 m^2/g.

18. The metallurgical processing and refining material of claim **17** which is substantially free of environmental hazardous chemicals or components.

19. The metallurgical processing and refining material of claim **18** wherein the material is produced entirely from raw biomass feedstock.

20. The metallurgical processing and refining material of claim **19** further including the following physical properties which may be individually modified or adjusted to meet the requirements of a specific metallurgical application: coking strength, conductivity, density, porosity, surface area and particle size.

* * * * *