Abstract: A method and apparatus for conducting a metallurgical process. In one form, iron oxides in the form of mill scale is placed in a container and subjected to heat thereby largely reducing the mill scale and largely converting it to metallic iron that can then be used in steel making processes, such as electric arc furnaces and the like. In one form, the container prevents volatile gases (such as gases given off when oily mill scale is heated) for a sufficient time so that the volatile gases heated to a high enough temperature to maximize pyrolysis and decomposition. In one form, vents are provided in the containers that are aligned with collection vents in the heating furnace so that any volatile gases may be easily removed without loss of large quantities of heat.
Pre-Processing Materials Using Encapsulation Technologies

[0001] Described herein are concepts concerning methods and apparatus for thermally pre-processing materials contained as cargoes within capsules and/or containers that, because of such pre-processing, become more advantageous, in and of themselves, or as feed stocks for further processing in existing systems devoted to, but not limited to, iron and steel-making, non-ferrous waste product recycling or re-use, remediation of hazardous substances, valuable substance recovery and the like. The present disclosure concerns certain novel aspects and features related, in part, to my other pending and provisional patent applications: provisional patent application 60/578,956 dated 12 June 2004; provisional patent application 60/604,364 dated 24 August 2004; provisional patent application 60/628,599 dated 17 November 2004; provisional patent application 60/633,614 dated 6 December 2004; provisional patent application 60/689,933 dated 12 June 2005; Non-Provisional patent application 11/151,041 dated 12 June 2005; and PCT application PCT/US05/020832 dated 12 June 2005; provisional patent application 60/689,866 dated 13 June 2005; and provisional patent application 60/725,716 dated 11 October 2005, all of which are incorporated herein by reference.

[0002] This Provisional Patent Application is also related, in part, to my provisional patent applications 60/811,003 filed on 5 June 2006 and 60/859,740, filed on 17 November 2006, which are both incorporated herein by reference. In many areas, the current submission amplifies inventions that are already disclosed in the aforementioned June 5 provisional application.

[0003] One important area of application of the present invention is in the iron and steel sector where large quantities of iron oxides in finely divided particulate form (such as mill scales) have been generated over many years and continue to be created in many parts of the world. Both the small particle sizes and frequently the contaminated state of such materials (by hydrocarbons, oils, and greases) complicate their re-cycling and re-processing for various technical reasons. The steel making process also creates other wastes such as flue dusts, ore fines, coke and coal fines and the like which normally present similar re-cycling problems but which now can be readily accommodated used the methods described here.

[0004] Additional applications of the concepts herein are in the pre-processing of materials containing non-ferrous inorganics, as well as hydrocarbons such as plastics, tires, and various bio-wastes including food processing wastes, animal wastes and excreta as well as crop components and other plant substances as well as combinations of any of the above. The disclosed concepts can also facilitate the processing of materials with one specific objective being recovering energy in the form of heat.
While much of what follows is couched in terms of applications to the iron and steel industry, it will hereinafter be readily understood by those skilled in the art that the methods and apparatus disclosed herein can be adapted to capsule cargoes with widely different combinations of substances and purposes. The methods taught here can be applied to other thermally driven processes involving non-ferrous materials or combinations of materials of many kinds. The reactions are arranged to take place in a cargo contained within a capsule that largely isolates the processes going on within the interior of the capsule from the environment external to the capsule (exceptions to such isolation can include for thermal input and the possible venting out of gaseous reaction products etc.) This isolation continues until the capsule cargo is harvested or the capsule is disassembled by melting or other causes.

At least some of my co-pending patent applications listed above describe, among other things, how cold iron oxide waste products, particularly in the form of mill scale, can be easily mixed with cold carbon-containing reductants such as coke fines, coal fines, and/or flue dusts to create a capsule cargo that without further treatment can be introduced (along with other more traditional burden components such as ores, pellets, metallurgical cokes, fluxes etc.) into a Blast Furnace and efficiently converted to metallic iron. As additions to traditional Blast Furnace burden, the capsules are specifically intended to thermally disassemble (open or melt) at appropriate depths in the furnace the first and (and most likely only) time they are exposed to processing heat or liquid metal pools. In addition to Blast Furnaces, as will hereinafter be obvious to those skilled in this art and possibly as stated in my co-pending applications, other types of thermal processors may be used with the innovations taught herein including but not limited to Electric Arc furnaces, Basic Oxygen Furnaces of all types, Rotary Hearth Furnaces, Linear Hearth Furnaces, Shaft furnaces, Cupolas and other similar or equivalent configurations.

**Pre-treatment of Encapsulated Materials Example: Iron Oxides**

In contrast to the methods and concepts of my previously disclosed patent applications, what is taught here are thermal pre-treatment processes which (when the objective is providing feed stocks for steel making processes) achieve efficient and economical conversion of cargoes comprised largely of unreduced iron oxides and reductants, into a highly reduced metallic iron state within still intact and un-melted capsules.

Pre-processing capsules can be designed to be either single use or re-useable. Both types can have various features in common. Single-use capsules need not be emptied after pre-processing but are used (even when largely intact) in downstream steel making. Following pre-processing treatment, re-useable capsules are intended to have their contents emptied (either while still hot or after cooling) and to be then re-filled to process another cargo. Because re-
useable capsules can be made of more expensive and thermally durable materials, they can typically tolerate higher pre-processing temperatures than single-use versions. This means re-useable capsules can sometimes offer an important further advantage of faster reaction rates and, of course, greater through-put if the requisite thermal energy can be provided.

[0009] Both single use and re-useable capsules can have particular features related to the manner in which they are transported to and moved through the heat source, extracted, unloaded or emptied, and in the case of re-useable units, refurbished as (or if) necessary, reloaded, and then re-closed.

[0010] Pre-treated capsules or their content can be used as a substitute for other metal sources such as scrap steel or Hot Briquetted Iron (HBI) in down-stream Electric Arc Furnaces (EAFs), Basic Oxygen Furnaces (BOFs) or the like. The material can also be used as a feed stock in Cupola furnaces or other casting operations that need hot or cold reduced metal. If such downstream facilities are nearby, the output of capsules from the pre-processing system can be delivered and used in EAFs etc. while still at a high temperature, thereby enabling recovery of substantial amounts of heat energy stored in the capsules.

[0011] Despite any contrast in intent described above between my previous disclosed pending patents and the present concepts, various combinations of design features and shapes etc that have been described in my co-pending patents can be combined with novel features specifically for use in carrying out a pre-processing mission rather than one involving destruction on application of first heat.

[0012] Figure 1 schematically represents a gross collection of three different substances often available in land fills used by iron and steel producers: relatively clean mill scale 2 or other relatively clean iron oxides, oily mill scale 4 or other oily iron oxides, and a carbon-containing reductant 6, such as coal fines, coke fines, flue dust or the like.

[0013] These can be combined (according to the desired thermo-chemistry) in various proportions to create mixtures (e.g. approximately 20% by weight carbon and 80% mill scales) can be homogenous mixtures. Other substances such as fluxes and chemicals can be added to the mixtures.

[0014] The disclosed methods and apparatus are not limited as to the number of substances in a given cargo. For example, if desired, it is possible to use virgin or prepared iron ores mixed with coal or coke fines and fluxes as a cargo. And unlike blast furnace processing requirements, strong (and costly) metallurgical coke need not be used.

[0015] In any event, whatever the material is, it is then loaded into a containment capsule that will be exposed to a heat-treatment preliminary to the actual steel-making process itself.
Some Basic Features of Single-Use Pre-processing Capsule Types

[0016] Single-use pre-processing capsules are intended to survive thermo-chemical pre-processing and then be transferred intact to a steel-making facility such as (but not limited to) an Electric Arc Furnace (EAF) in which the capsule and its content are subsequently consumed. An exemplar capsule 8 is illustrated in Figures 2 as inserted into an electrically heated (or other type of heated) space (about which more later) and in isometric view in Figure 3. It makes use of sheet steel wall material and has a shape with a large surface area that encourages very efficient heat transfer from hot external heat sources such as heaters 10 that can be adjacent to the capsule walls (or nested within the capsule walls as shown in Figure 3). The heaters can be, for example, electrically powered or can employ combustion heat. The capsule can include structural features which both confine the cargo and, to an appropriate degree, permit high temperature gases to escape. For example, the four-across multiple triangular ridge-like part of capsule 8 can be formed of one sheet of pre-formed steel 12 which is inverted for filling and the closure is simply a flat plate also of sheet steel which becomes the bottom 14 of the capsule during heat treatment. The height of the capsule is denoted 7, the length is designated as 9 and the width (less the crimped ends shown) is designated as 11 in Figure 3. The flat bottom can facilitate loading and mechanical movement through heat treatment furnaces. The capsule can be assembled after filling by any appropriate fastening means including rivets, crimping, spot or seam welding etc.

[0017] Some additional sample forms of capsules are shown in Figure 4 and a great many other variants are possible as those skilled in the art will hereinafter readily appreciate. It will be understood that there are numerous trade-offs between shapes, the amount of wall material required to contain a given volume of cargo, and the amount of surface area available for efficient and rapid heat transfer etc. A multiple diamond-like cross-sectional capsule similar to 16 could, for example, have twice the number of triangular cross-section cavities (e.g. eight) each with half the base width of the original design. If the height of the triangular cross-section of 8 was to be halved simultaneously, the time for completion of pre-processing would be substantially reduced because of the improved gross heat conduction to the core regions of each cavity. Such trade-offs include, among other factors, energy costs, furnace capital costs, capsule fabrication costs and consideration of the net cost of the wall materials required. Importantly, the sheet steel wall material in this example constitutes a source of high quality scrap for downstream steel-making whose market value effectively reduces the wall material net cost per capsule.

[0018] The shape of the cross-sections of other examples of multiple tubular cavity capsules
16, 18, 19 in Figures 4 and 5, offer various features of interest of which many variations are possible. For example, the diamond cross-section offers large areas for highly effective thermal coupling to the top and bottom faces. The flattening of bottom, 20, of the cylindrical cross-section (features are shown applied to only one cavity in an assembly but can also applicable to more than one or even all of them in other embodiments) can be useful for improving thermal properties such as better contact of the capsule to a hot refractory floor. Re-entrant wall groove, 22, can be provided for one or more portions of the capsule to afford an increased surface area for heat transfer purposes (again this feature is illustrated on only one cylinder but can be applied to all and to other shaped capsules). Notably, the cylindrical shape is inherently more resistant to bulging caused by pressure build-up during heat treatment which can increase the effective path-lengths that escaping gases 23 must traverse to get to equatorial or the vents 24 in the capsule (not shown in Figures 2-5, but can be provided similar to what is shown in Figures 6a, 6b, 7 or elsewhere) and help maintain higher integrity of thermally-activated binder shells and other features discussed below that relate to extending the containment time of volatiles and increasing the degree of decomposition of complex molecules as will be described below.

[0019] In any of the disclosed configurations, fasteners, crimps, spot welds, or other appropriate assembly methods and mechanisms can be placed in the valleys 3 between the ridges 5 or around the edges and spaced in such a way as to allow the opening of narrow gaps/vents 24 in the structure to allow for thermal expansion and/or the pressure of gases 23 generated during processing. As disclosed elsewhere in my referenced patent applications, other venting mechanisms such as weak points created by pre-cut slit lines or thermally operable (e.g. fusible) vent closures can be used at various places in the capsule structure. For example, vents of any type can be provided longitudinally on each cylinder of a multiple cylinder capsule and/or at the ends of each cylinder. Furthermore, closure base plates 14 or joint plates 15, shown schematically in Figures 3-5 and elsewhere herein, can include venting provisions. Closure can involve matching flanges or joint plates which can be emplaced after "open" capsule tubes (e.g. tubes cut open into two halves along their lengths or formed as two halves) are filled and packed with cargo. This can facilitate filling and/or momentary pressure compaction and volume reduction of the cargo in the open split-tubes (or other forms) before they are fully assembled and closed.

[0020] As will be discussed in more detail later, techniques and structures involved in venting vapors and gases from the capsules can be mechanically matched to collection channels or arranged to facilitate entrainment flows into exhaust channels which can tend to keep separate the general furnace atmosphere from gaseous products generated inside the capsules. This is
advantageous for avoiding dilution of valuable vapors by combustion off-gases or furnace atmospheres. It also minimizes the need to process large volumes of combustion gases containing admixtures of other substances originating in the capsule cargoes.

[0021] A capsule, comprised of multiple cargo-carrying tubular cavities (similar to those shown in figures 2-5), can be constructed as a set of sub-assemblies such that individual tubes can be filled and then assembled into multi-cavity structures for heating. After heat-processing, the assembly can be designed to be easily dis-assembled into individual tubes for introduction into down-stream processors such as EAFs and cupolas etc.

Some Basic Features of Re-useable Pre-processing Capsules

[0022] Re-useable capsules are intended for multiple cycles of cargo loading, heating and emptying. This can help avoid the repeated unit costs of materials and fabrication for single-use capsules. Such a capsule is preferably constructed of walls and materials that can sustain numerous cycles through the needed processing temperature profiles and repeated contact with hot cargos. They can have special mechanisms that allow them to be efficiently emptied (e.g. convenient attachments and/or handling points) and preferably include mechanisms and methods for minimizing adherence of interfering amounts of previously processed cargo such as shaking, inner wall coatings etc.).

[0023] Re-useable capsules also need mechanical mechanisms- allowing them to be readily re-assembled and/or closed after each loading including operability, maintenance, and/or re-setting of venting mechanisms and other features. Re-useable capsule vents can be based upon bi-metallic closures which open at pre-set temperatures, differential expansion or movement of two adjacent capsule components, effects caused by thermally-driven inflation of the capsules and the like. Those skilled in the art will hereinafter recognize there is wide latitude as to the details of mechanisms used to achieve venting in these and similar ways.

[0024] Many forms of single-use venting methods (such as fusible closures) can be incorporated in re-useable capsules by making them as separable components of a capsule wall. Novel labyrinthine capsule wall structures will be discussed later in this disclosure. Vent replacement can be part of the periodic refurbishment or re-packing of used labyrinthine wall sections that may be required.

Other Features of Capsules

[0025] Any, some, or all of the features and concepts pertaining to single-use capsules shown in Figures 6a, 6b and 7 can be incorporated in re-useable capsules on the specific application.
Wall Materials

[0026] Concerning wall materials for re-useable or if appropriate because of extreme processing conditions etc., in single-use capsules as well, there are a number of options and choices depending on the temperatures and lifetimes required. These can be used individually or in combinations and include, but are not limited to, the following:

[0027] **Steel and steel** alloys—if the pre-processing temperature is not too close to the melting point, steel walls can be satisfactory. Such capsules can be processed in furnaces while maintaining low oxygen availability through, for example, the use of nitrogen or argon sweep gases. If re-use or exposure to air/oxygen is contemplated during processing, while cooling, or while transporting hot capsules, protection against oxidation may be desirable. This can take the form of minimizing high temperature exposure to air via sealed transport or covers, by use of oxidation resistant stainless alloys, or by use of protective coatings. Such protective coatings can also provide anti-adherence characteristics and can be applied to both interior and exterior wall surfaces. Protective coatings can be metallic or formed of special materials (single substances or multi-layer combinations) that are permanent, semi-permanent, or routinely renewable. Anti-adherence can also be provided by removable/disposable thin metal foil liners.

[0028] **High temperature metals and alloys**—For example, Molybdenum (Melting Point >4000 °F vs. iron at 2600 °F), Hastalloy, MLR (Molybdenum Lanthanum Re-annealed Alloy), etc. Here again protective and/or anti-adherence coatings can be used.

[0029] **High temperature non-metallics**—Ceramics, refractories and forms of carbon. Some of these materials tend to be brittle and comparatively heavy and may not be well-suited to rough handling typical of steel mill processing but could be used in some situations.

[0030] **Composites and coatings**—NASA Glenn Center has developed a series of unique materials and techniques that can be used to form capsule components with very high service temperatures. These include direct fabrication of near-finished form high temperature SiC objects by conversion of wooden structures and means of making very strong joints between pieces of SiC and other composites including those involving carbon fibers. These form one basis for manufacturing re-useable capsules. In addition, a family of inexpensive NASA adhesives, based, in part, on a composition named GRABER (Glenn Refractory Adhesive for Bonding and External Repair) which has been recently also been developed under the direction of Dr. Mrityunjay Singh, for in-flight repair of damaged Space Shuttle thermal shielding and leading edge components prior to re-entry. These can be made in various viscosities and can be applied as protective coatings to either single-use
OR re-useable capsules. Furthermore, such coatings could be applied to the capsules
described in my co-pending applications if needed for oxidation resistance etc. See Figure
6a and 6b at 26, for examples of such heat resistant and/or oxidation resistant protective
coatings. Besides the above examples, protective coatings 26 of mullite and coatings based, for
example, on sprayed, dipped, or plasma-sprayed refractories can be used including but not
limited to those containing ZrSiO4 (Zirconium Silicate). Sodium Silicate compositions,
discussed in more detail below in the context of binders, can also be useful as low cost, easily
applied, and renewable protective coatings for capsule structures and can be used at service
temperatures exceeding 3000 °F. These can be resin-based or otherwise and are commercially
available.

[0026] Again referring to Figures 6a and 6b, shows a coating, 26, applied only to the outer
surface of a capsule wall, depending on the aggressiveness of substances contained within the
capsule or generated by the thermo-chemistry, an appropriate protective coating can also be
applied to the inner surface of the wall 28. This coating 30 can be the same or different than the
one used on the outer surface. This design feature can pertain equally to both iron-reduction pre-
processing and to any other purpose to which a re-useable OR a single-use consumable capsule
is to be put.

Membranes

[0027] Continuing now a discussion of the other novel concepts and features shown in
Figures 6a, 6b, and 7, 1 have previously disclosed simple sack-like capsules or sub-
capsules made of various materials including high temperature fabrics that can remain
intact to many hundreds of °F or more but which, in all cases, are designed to be consumed
on their first exposure to substantial heat as, for example, in Blast Furnaces.

[0028] In contrast to these, capsules made of membranes (which can be in bag or
"wrapped" form) which are designated 32 in Figures 6a and 6b can have several purposes
that can be utilized individually or in combination with one another, such as:

[0029] 1) Pre-bagging can be used to facilitate filling of cargo 34 into any form of
hard-walled multi-part capsules. For instance, multiple filled tubular bags 32 of appropriate
diameter containing cargo can be filled and closed, and then positioned in the open
longitudinally-split tubular shapes 33 shown in Figure 4 and the capsule itself assembled.
Cargo 34 can be any of the material discussed in this application, including clean mill
scale, oily mill scale, carbon containing reductants, various waste products, etc.

[0030] 2) In addition to simplifying clean or even sanitary capsule assembly, sacks of
this general character made of very inexpensive plastics can serve to minimize odors from

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cargoes (e.g. animal wastes) containing volatiles both during manufacture and/or during storage at normal ambient temperatures.

[0031] (3) If the membrane 32 material is chosen from among non-metallics or metals (e.g. thin aluminum foil) that can briefly withstand temperatures of hundreds of degrees before yielding, such membranes can be used to trap volatiles that might otherwise be released to the environment during at least early stages of exposure to the high heat of thermo-chemical processing. Until the membrane fails massively (note that such membranes are structurally supported by vapor pressure-driven expansion against the main capsule wall materials 40), vapors 23 are forced to take lengthy, circuitous, and diffusive routes to the capsule vents. Enroute to the vents 24, they can forced to come in contact with or move close to hot wall surfaces (which rapidly reach very high temperatures) and cargo regions close to the capsule walls that are at higher temperatures than the deeper cargo regions from which the gases are originating. This promotes pyrolysis and decomposition into more innocuous compounds. This is shown very schematically in Figure 8a and 8b for a somewhat generic single wall capsule 38 meant to represent the various types, sizes and variations discussed herein or in the provisional and pending patents included earlier by reference. Figure 8b shows dotted lines 42 which are meant to show possible expansion of wall materials 40 as the capsule and its contents heats up which can increase pressures cause by the formation of gases 23 from oily mill scale 4 or other contaminants and/or volatiles being present in cargo 34.

Re-entrant and Labyrinthine Designs

[0032] Shown in Figures 8c and 8d is a simple re-entrant double-walled capsule 39 design (see inner wall 44 and outer wall 46) that forces volatiles and/or other gases 23 to traverse even longer and hotter paths 42 before escaping out the capsule vents 24. A single capsule can include a multiplicity of such re-entrant routes to vents including "nested" re-entrant arrangements or other geometries making for very long and/or labyrinthine vapor escape paths. These re-entrant spaces and/or labyrinthine pathways (or structures that define them) can be packed with clean cargo 6 (e.g. non-oily mill scale) through which the vapors from the volatiles (say from oily mill scale 4) in the central cargo regions 34 must pass.

[0033] In the schematic example shown in Figure 9, the relative volume of the labyrinthine sections or paths 42, as compared to the main cargo volume, is greatly exaggerated for clarity. Not all the walls 44 and 46 and surfaces of a capsule need be equipped with labyrinthine features nor need all those that are used be part of the structural
wall themselves. Inserts of light-gauge labyrinths 48 can be installed as accessory parts (pre-loaded, if desired, with some of the packing types discussed herein) and can be supported by the heavier gauge walls of the capsule itself much like the replaceable filters and associated filter holders used commonly in home heating and air conditioning systems.

[0034] Clean packings 50 can also be made of re-useable or periodically replaced materials rather than clean versions of the main cargo as mentioned above. Such packing 50 could be materials that are sacrificed in the case of single-use capsules or which can be reused or sacrificed and replaced in the case of reusable capsules. Examples of these can include, but are not limited, to coarse Molybdenum wool especially if the vapors are reducing rather than oxidizing (or other forms of high temp alloys in various forms, such as crumpled foils), packed ceramic spheres, refractory and/or quartz wools, etc. which can be left in place in re-useable capsules and easily changed when necessary and others. In any case, the general concept is to place high surface area materials which are not themselves sources of troublesome volatiles in locations where they can, if so desired, achieve very high temperatures (up to 3000 °F or more) and to design the capsules so as to force volatiles 23 from deeper lying cargos to pass through the hot clean materials enroute to venting 24 thereby improving the likelihood of high volatile pyrolysis and decomposition. The packing materials can also be comprised of (or include) substances and/or coatings with catalytic properties that enhance desirable reactions in volatilizing or evaporating cargo. In one form, substances that can chemically combine with such undesired materials as sulfur can be used in the cargo itself or in the vent routes to minimize emission of such materials.

[0035] In some applications, it is possible to use the high degree of decomposition that can be achieved according to the aforesaid concepts to allow comparatively large percentages of heavy oils and other fuels and hydrocarbons etc to be present in capsule cargoes. Pyrolysis of these can add positively to the overall energy balance of the overall pre-processing and/or processing involved.

[0036] If, despite the high temperatures to which they will be subject, the products of cargo pyrolysis begin to clog passages of the labyrinth, these can be made as removable sub-sections that can be cleaned, refurbished, or replaced. During such servicing or as otherwise needed, venting mechanisms can be replaced or refurbished as well.

[0037] Note that when applying the concept of re-entrant volatile routing to capsules, it is not always necessary to also have membranes present. The two techniques can be applied independently as well as cooperatively.
Binders and In-situ Forming of Lowered Permeability Surface Layers

[0038] In the process of assembling the capsule and cargo, the outer layer of the cargo can be made to contain additional materials, such as binders, that can serve a variety of purposes including reduction of the rate of escape of volatiles during early stages of heating and/or promoting their pyrolysis and decomposition. For example, a small amount of a liquid sodium silicate-based material often used for binding agglomerates can be mixed with clean cargo. Although there are many types and compositions of suitable binding substances, examples include products made by PQ Corporation (see, for example, www.pqcorp.com/LITERATURE/bulletin_1_2-31.pdf) and a copy of their Brochure is appended to one of the provisional applications whose priority is relied upon and is incorporated herein by reference. The mixture can be pre-applied on the interior walls of capsules (or inside membrane 32) before the rest of cargo is loaded to create a surface region with some inter-particle bonding and initially low permeability. This is indicated schematically by 52 in Figures 6a and 6b for both a simple consumable and a pre-processing design. The clean and/or bonded layer 52 will less permeable to volatiles, such as gases 23, on their way from the main cargo 34 to the vents 24. If the capsule undergoes pre-processing, the heating profile can include a brief initial low temperature "set" exposure at a few hundred °F as is usually done with binding agents that set by drying. Alternatively, standard chemical catalyst setting accelerants mixed with appropriate binders can be used to form the bonded surface region. Furthermore, ultra-violet or flash heat lamp techniques to initiate setting are known to those skilled in the art and can be used to form the bonded, low-permeability shell-like region surrounding the main capsule cargo.

[0039] If the capsule is a consumable one intended for Blast Furnace use, a heat setting binder will quickly set in the uppermost regions of the burden.

[0040] In any event, the result need not be one that maintains strong bulk integrity (unlike the briquetting processes commonly used in the steel industry) because the capsule wall itself provides adequate structural strength.

[0041] Materials containing binders can also be used to fill escape routes in re-entrant and/or labyrinthine designs either alone or in combination with other techniques, as described above, to hold them in position and/or reduce their permeability until they reach temperatures high enough to destroy (at least partially) their integrity. A second use of binders or other additives in the outer layers or throughout a cargo is described below.

Mounding and Advantages of Compression Loading

[0042] The loading process for any capsule (for example capsule 60 in Figures 10a-b) can
optionally include a cargo compression step in which, for example, one part (such as bottom 62) of a capsule 60 is supported by a strong form-fitting backing, such as support 64, and an overfilling heap (or bag 66) of cargo 68 is forced into the available volume by pressure applied to the overfill, thus achieving a higher density than mere pour-filling would achieve. Such compression not only provides more weight of cargo per capsule but can enhances grain-to-grain contact among the cargo constituents resulting in higher heat conductivity and more opportunity for inter-grain chemical reactions at grain boundaries. It is also likely, for example with cargoes containing ferrous particles, that beneficial catalytic reduction reactions at micro-particles metallic iron within the cargo mass may be enhanced.

[0043] Figures 10a-c are schematics which illustrates one approach to an easily-automated potentially very high speed method for producing cargo compression while simultaneously simplifying the making of fully-assembled capsules.

[0044] These illustrations pertain to one portion of a multi-cavity cylindrical pre-processing capsule as seen in Figure 4, but the method can be applied to any capsule design including those intended to be consumed on first heat as described in my co-pending disclosures and patent applications.

[0045] In this concept, pistons with appropriately shaped faces 70 operate within confining walls that are mated to a capsule part 62 containing a metered heap (or bag 68) of cargo. For many powdered, granular or shredded cargoes, the angle of repose of the materials may inherently allow the formation of conveniently shaped heaps before compression. If necessary, the addition of very small amounts of oils (if not already present) or other liquid substances with good wetability can often be used to dramatically increase the angle of repose of many types of cargoes being metered into open capsule parts.

[0046] As a result of the compression, many types of cargo compositions can be rendered self-supporting and mechanically stable for a time sufficient to allow handling and/or the assembly and closure of a capsule (bottom 62 and top 72) around them. Those skilled in the art will understand many variations of these methods and the mechanical arrangements to achieve them are possible. For cargoes that do not inherently become self-supporting as result of the compression very small amounts of Sodium Silicates can also be used for this purpose.

[0047] Other means of facilitating fast, efficient, clean capsule loading include subjecting cargo (as it is being metered, shaped, or loaded) to spray-on application of dust-suppression fluids and/or substances that can serve as quick-acting surface binders by
undergoing physical or chemical changes due to evaporation or other changes that can be triggered by brief application of heat, UV light, surface sprays of catalytic agents and the like. Heat can be supplied by various means including but not limited to a transient flow of hot air, flash lamps, or by pulsed electric or fuel-driven heaters. The structures used to contain the compression step including the piston faces can also be heated.

**General Applicability**

[0048] Although illustrated for particular shapes of capsules, several in any combination or all of the aforementioned features and techniques can be applied, with variations, not only in pre-processing capsules, but also in any of the consumable, fusible seal, liquid metal seal or other capsule designs as disclosed in my pending patent applications referenced herein and incorporated herein by reference. Note that the schematic capsule shown in Figure 6b is a somewhat generic capsule representing any designed to be consumed during their first exposure to high temperatures for a sufficient period of time. It can have some, or all of the properties described for that figure. A case in point would be capsules intended to be loaded into a Blast Furnace rather than into a pre-processing furnace. In such instances, the coating 26 could be used as a rust inhibitor for long storage time or high humidity, salt-spray exposure conditions etc. such as encountered in ocean freight transport.

[0049] There can be situations in which no practical or economical coating is available that can withstand the internal thermo-chemical environment (in a re-useable capsule) for more than one or perhaps a relatively few cycles. In this case, sacrificial coatings that must be re-applied periodically can be employed and some of these can be based upon the substances described above.

**Pre-processing using Heat Treatment, such as Electric Furnaces**

[0050] In this section, the iron and steel sector will be used to illustrate one specific area of application of the technology and methods being disclosed herein. This is not meant to imply any limitations of the methods to that industry or the particular materials with which it routinely deals.

[0051] While certain types of furnace configurations will be discussed in some detail, it is not implied that such configurations are the only ones that are suitable according to the teachings herein. For example, so-called Car-kilns, Box furnaces, Shuttle Furnaces and any others known to those skilled in the art can be employed if desired. Furthermore, any form of furnace chosen can be heated with any desired form of energy.

[0052] After filling, closure, and final assembly, a capsule 8 containing ferrous 4 and 6 substances destined for pre-processing can be treated in any type of sufficiently powerful and
temperature-capable heat source driven by any type of fuel. Reduced iron produced by the means described herein can be a high quality, high value feedstock for many downstream steel-making processes including but not limited to Basic Oxygen Furnaces of any type, and Electric Arc Furnaces (EAFs) of various types and Cupolas. Rotary Hearth Furnaces and Linear Hearth Furnaces in a wide range of sizes can be used either as recipients of highly reduced iron made by these techniques or can be used as the heat sources applied to the capsules for doing the reduction. Fully or partially-reduced iron made by these techniques and with or without deliberate enrichment in certain element such as carbon or magnesium can be used as feed stocks to achieve certain economic or technical advantages.

[0053] Electric heat is felt to be a preferred energy source especially for installations already operating local EAFs such as Mini-mills. Strong electrical supply grids are already available in many of these facilities often capable of delivering over 100 MVA (megavolt-amperes). Any time when not delivering its absolute maximum power capability, such a plant grid could supply energy for pre-processing of capsules. In larger plants, with or even without EAFs, the overall plant power systems may have enough capacity margin to provide, say, 5-10 MVA of pre-processing power for economically useful intervals during a 24 hour period. It is also possible that adding, say, 10 MVA of new supplementary power in cases where the current system is at full demand 24/7 could be justified by the economic return offered by the present methods. For the above reasons, among others, simple electrically-powered furnaces built around conventional resistive heating elements can have particular virtues and can exploit novel design advantages which will now be discussed in some detail.

[0054] An overall conceptual representation of a dedicated pre-processing furnace system integrated into an EAF-equipped mill according to the teaching of this disclosure is presented in Figure 11. Since the objective of pre-processing is to bring the capsule 8 cargo to a highly reduced state or perhaps even a molten state, strong coupling between the electrical furnace heaters and the capsules is preferred. Because the capsules 8 are preferably of a fixed, uniform and relatively precisely known shape, optimized and comparatively economical furnace designs can be used that feature small, closely conformal refractory/insulating envelopes and customized loading ports. (Please refer also to item 10 in Figures 2, 3 and 5). The heating elements themselves can be fabricated of, e.g., molybdenum disilicide which can operate continuously at temperatures well above those required for our purposes (up to 3400 °F) for many years. Other heater designs known in the art have comparable performance. If desired, the heater elements can be placed in lines to fit within the "valleys" of the capsule structures (see Figure 3) whose locations are known and can be controlled thus tightening the radiative heat
coupling thereto and also providing shielding against some of the heat loss exposure to the furnace walls. The exact spacings and tolerable power maximums, etc. will depend on details of the furnace design and the capsules to which it is matched.

[0055] In particular, Figure 11 assumes the use of a group often identical modular furnaces operating in parallel and each driven by one megawatt of power, hence consuming IOMW although there is no uniqueness to this overall system size or the power level of the individual furnaces. Continuous processing electric furnaces of 1 MW capacity are readily available commercially and are used in annealing and powder metallurgy among other applications. These are generally equipped to deliver rather precise time-temperature profiles and to be very versatile in terms of the parts/processing handled and are used to heat-treat parts or sinter powdered metal parts and the like. See, for example, CM Furnaces at http://www.cmfurnaces.com/. None of these attributes are strong pre-requisites for present purposes and invite the design of much simplified versions suited to large scale duplication for use with the methods being discussed here.

[0056] In cases where endothermic reactions are taking place in the cargo of the capsules (for example, the reduction of iron oxides to metallic iron which is strongly endothermic), the furnace design can take advantage of the relative cooling of the capsule structures produced by the internal reactions to allow increased power-to-heater surface ratio loading limits. This can be done by insuring that the heaters "see" as much capsule wall as possible and as little as possible of other heaters. The upper heater array in example drawing Figure 5 shows an implementation of this concept using heaters 10.

[0057] Although complete unitary structures are possible, furnaces for our purposes can be made in modular form with individual open-ended modules produced in quantity in a convenient size, e.g. hot volumes of 24 to 48 inches long by 11 inches high by 26 inches width (roughly compatible with the dimensions of a capsule 8 example to be described below). Each module could be equipped with pre-mounted heaters and bus-bar connections for power distribution 110 to facilitate series/parallel connections in arrays matched to the Mill power grid 112 and the transformers used. Each open-ended module can be designed to bolt end-to-end to another to create long heat zones of any desired total length such as the 20 or 40 foot long units of the illustrative example to follow. Such a modular design also makes for convenient repair or replacement of components.

[0058] A lower temperature or a pre-heat section or cycle can be provided when capsules first enter a pre-processing furnace. A cooling section or cycle 114 can also be employed at the end of the reduction. Some reasons for a pre-heat section (or a pre-heat cycle in the case of batch
processing) such as activating/setting anti-oxidation coatings and/or means of volatile component control/decomposition by thin binder layers near the interior walls of the capsules have already been mentioned.

[0059] It is also worthy of note that, compared to the volumes of off-gases generated by, say, natural gas or coal-fired furnaces, only relatively small amounts of vaporized and gaseous compounds which escape the capsule vents (if any, because the capsules may have none in some forms) must be handled by an electrically heated installation. Furnace complexity, capital costs and many operational aspects are all benefited thereby. For example, only modest amounts of (e.g. nitrogen) sweep gas need flow through the furnace and therefore transports only modest energy out of it (especially compared to combustion fired systems). The sweep gas can also be used to minimize capsule wall oxidation.

[0060] As Figure 11 suggests, the output of capsules 8 from the furnaces 100 can be delivered 116 in hot form to any transporter, insulated bucket 118 or other conveyance used in the industry and the sensible heat energy recaptured in down-stream processing. The anti-oxidation coatings described earlier can be especially useful in processing schemes where highly reduced cargo-bearing capsules are introduced while hot into a subsequent steel-making device.

[0061] Over and above an ability to generate a hot replacement for traditional purchased high quality replacements for scrap, thermal energy recapture can be a not-insignificant economic benefit to EAF operators. Alternatively, the capsule output can be sent through a cooling cycle and to stock-piling or other destinations.

[0062] Either continuous processing or batch processing is possible with these types of electric-heater driven furnaces. Continuous processing can offer various advantages including less thermal cycling of the furnace components. These pre-processing furnaces can feed either batch-processing EAFs 120 or can be set up to feed continuously operating EAFs of which there are a small number in operation, such as CONSTEEL and the Fuchs Shaft Furnaces etc.

[0063] EAF operators strive for maximum "Arc ON" performance to produce the greatest steel output possible. Nevertheless, there are "Arc OFF" times for various operational and other reasons. Furthermore, EAFs 120 do not always operate at maximum arc power nor do they necessarily always use 100% of the power available to the entire Mill facility. For these reasons, combining electrical heater driven pre-processing furnaces 100 with electrical energy storage 122 on-site or otherwise can be useful. The state of the art of large-scale electrical storage 122 for "peak-shaving" and other purposes is being advanced by the electrical power industry and others. There are several technologies on the cusp of being readily commercially available. One example is the Flow Battery 122 which uses electrochemical storage and can store perhaps 10
MWH or more. The economics of energy supply and the requisite capital costs of these storage mechanisms have to be determined but having local storage capabilities may soon cross into practicality and allow the topping energy they could provide to be well-used in the pre-processing furnaces discussed herein.

[0064] Figure 12 shows a schematic side view of one type of pre-processing furnace 200 and its support gear. A moving molybdenum belt 202 (equipped with spacers, attachments that mate to the capsules, anchored open boxes, or similar devices 204) picks up capsules (such as capsules 8) which are mechanically off-loaded from an elevator rack 206 or other device. The furnace is slanted to use gravity to reduce the tension load on the hot moving moly belt. A local, mobile, or remote capsule filling system 208 is used to load capsules 8 on elevator rack 206. Sweep gas 210 is supplied to the hot volume of furnace 200 if necessary and exits 212 to a scrubber (not shown), if necessary, after clearing air out of the exit shroud 214. Capsules 8 exit furnace 200 to be used for used for hot or cooled preprocessed product or charges for a steel making process 216.

[0065] Alternatives to moving belt systems which can also be used in long heat treating furnaces include the use of "pusher" mechanisms applying translational forces against a column of open boxes carrying the objects to slid along through the furnace on its flat floor. Capsules can be readily designed to facilitate this technique and others.

[0066] Figures 13a-b show a "down-the-belt" view of a re-usable, for example capsule 304, in a pre-processing furnace 200. The capsule 304 can be fabricated of molybdenum sheet 300 and clamps 302 which keep the bottom plate in place to contain the cargo and other hardware are re-usable. It is emphasized again that these concepts are not restricted to the use of metal capsules—alumina or many other refractory materials can be employed. Combination designs, combining materials with complementary characteristics can be used such as in the example shown in Figure 14 or the other figures. Regardless of the specific details, such capsules 304 can be moved through the furnace by various methods, for example, riding on the previously described moly belt mechanism or other version thereof, by using a towing attachment 306 which engages a towing cable outside of the hot zone through a slit in the furnace floor 308, or by being placed in and being pushed along in a box 310 made of high-temperature-capable materials. Furnaces 200 can be designed to keep the belt itself out of the maximum heat zones and/or to protect it with a localized inert or a relatively non-reactive gas such as nitrogen. Other methods of loading/handling/extracting the capsules for processing are possible, and will be hereinafter be apparent to those skilled in the art, hence will not be detailed further here. Vents 24 can be provided through moly flanges and cover 312 to allow for the venting of volatiles.
A single-use capsule would typically have no re-usable components and could be translated by any of these various means. If the treatment temperatures are in the 2250-2300 °F range, the simple moving belt or the "box and pusher" methods can be adequate and may be preferred because of their simplicity.

Since one can make capsules that are capable of withstanding temperatures well in excess of the melting point of many materials that can benefit from processing by the methods taught here, it is possible, in properly designed capsules, to take cargoes such as highly reduced Mill-Scales to the completely molten metallic state. In such circumstances, there will typically be a layer of slags and other substances floating atop the molten mass.

The furnace system can include mechanisms for de-slagging the cargo before passing it to downstream processing. This can increase the value of the recycled cargo. De-slagging can be accomplished near the output end of the furnace by skimming, raking, or tilting the capsules so slag is decanted through properly arranged openings or channels etc. or any equivalent technique. For example, a tilt mechanism (e.g. a tilt in a direction orthogonal to the line of advance of the capsule) can be activated near the output region of the furnace that allows escape of floating slags through ports that would normally be above the level of the heavier molten metal capsule cargo. De-slagging openings can also be kept closed until the proper time by various mechanical methods and or by fusible elements (replaceable if desired) that melt during processing when the cargo also fully melts.

Reagents such as Mg compounds can be mixed in the cargo or packaged to release into the cargo for purposes of de-sulfurizing the capsule content either as the liquid phase is achieved or as it is approached. Materials specifically intended to be sources of additional exothermic reaction heat can also be accommodated in many forms within the cargo.

In some processing systems, it may be desirable to equip capsules with partitions so that the agglomerated or melted cargo does not form a single mass. Another approach is to longitudinally partition the channels into which the finished pre-processed cargoes are discharged so there is a natural formation of sub-masses of the original total cargo.

System and Capsule Design parameters —An Example

The teachings of this disclosure can be used with a very wide range of capsule sizes and shapes. For illustrative purposes we will assume a capsule with the form-factor shown in Figure 3 and with the following dimensions: width 11 = 24 inches, length 9 = 48 inches, and height 7 = 9 inches. Each such capsule can contain a volume of roughly 5000 cubic inches (~3 cubic feet). At a cargo density of 2.3, corresponding to a typical mix of mill scale and an appropriate amount of a carbon source such as flue dust, the cargo weight is about 430
pounds/capsule. This assumes some densification by compression, as has already been discussed. Uncompressed mill scale has about this density and adding reductants would reduce the overall effective density somewhat. On the other hand, it is perfectly possible to use a somewhat longer capsule design for this merely illustrative example. For purposes of further order-of-magnitude discussion, a rough figure of about 5 capsules per ton of cargo will be used. To reduce one ton of 70% Fe cargo at 1500°F to about 1440 pounds of metallic Fe requires about 1000KWH (allowing for various inefficiencies and not taking precise account of the heat contribution of any added carbon combustion or catalytic Fe effects within the capsules).

[0073] A pre-processing furnace with a minimum hot length of 20 feet would be needed to house 5 capsules in a batch processing scheme. If the furnace energy input averaged 1 megawatt then roughly one hour of processing would be required and would produce 0.7 tons of hot metal per hour. An array of 10 one megawatt furnaces would make 7 tons/hr or 170 tons per day. In practice, the pre-processing energy input will be limited by the maximum tolerable heat flux to the capsule walls. Certain forms of single-use steel capsules could be limited to maximum surface temperatures up to about 2300°F, or so. The processing time to a high state of reduction is also a function of the (varying) thermal conductivity and the effective thickness of the cargo. The effective thickness used in this example has been estimated but can be readily adjusted. If one assumes a two hour cycle time might be needed, a 40 foot long furnace (still a quite practical length) would be more appropriate.

[0074] Re-usable capsules made of Molybdenum or other high temperature materials can withstand much higher maximum temperatures and the reduction reactions will accordingly be much faster. One particularly attractive material from a properties standpoint is a relatively new molybdenum alloy known as MLR which is useable above 1400°C (above 2600°F).

Opportunity for Closed Loop Control of Melt Chemistry

[0075] The basic metallurgical goal of pre-processing is to take the cargo through a temperature/time profile sufficient to cause a high percentage (preferably 65% or more) of the ferrous oxides to be reduced to metallic iron by interaction with the contained reductants. That being said it can be useful to the reductant loading to somewhat "under-saturate" or "super-saturate" the cargo with available carbon according to the chemistry of the other raw materials that will also be going into subsequent steel-making steps. An ability to independently control carbon levels in the pre-processed reduced iron may be advantageously used to optimize the final product from down-stream processing devices such as EAFs and BOFs. Furthermore, together with available real-time sensor technologies for measuring the degree of carburization in an EAF (for example) melt, having an ability to select various carbon contents from a
"library" of pre-processed capsules offers opportunities for real-time closed-loop control of individual steel-making heats.

Other Sources of Pre-processing Heat
[0076] As mentioned earlier, Electric heating is, of course, not the only source of energy that can be applied. The disclosed concepts, encapsulation designs, and processes are also applicable to oxide-to-iron reduction technologies that do not employ electric heat. Various sources of heat energy (including but not limited to gas-fired, coal-fired, oil-fired and/or combinations thereof such as powdered coal + gas) and various devices can be used to deliver the requisite heat for the pre-processing of filled capsules. In addition to the usually smaller types of furnaces listed previously, large furnace systems can also make use of the teachings herein described. Examples of large installations include Rotating Hearth Furnaces (RHFs) and similar systems such as the ITmk3™ process developed by Kobe Steel. In such instances, the capsules can be treated with temperature profiles that leave them intact for further processing elsewhere or the capsules and their contents can be brought to a fully melted state and the resulting hot iron delivered downstream for further processing or cooled and transported elsewhere.

[0077] In addition, capsules can be introduced into various furnaces already operating in iron and steel mills but which are used in the steps necessary for product finishing purposes rather than bulk iron making or refining. As a specific case in point, one could arrange to do batch or continuous processing of capsules in gas-fired Hot Strip Reheat Furnaces by providing existing small and/or marginal and head-space regions not occupied by materials coming from the Slab Caster with mechanical means such as non-interfering high temperature (MoLy) belt conveyors equipped with re-useable capsule carriers. Another possible method for exploiting unoccupied spaces in existing thermal processing facilities to be found in Mills, such as slab reheat furnaces and the like that soak or move large hot masses of steel, is to arrange to place filled capsules of the types described herein on the surfaces of the hot steel product. To reduce thermal shock to the capsules, the exterior and/or the bottom of the capsules can be provided with a comparatively thin insulating buffer materials between the capsule exterior and the hot metal. Such buffers can be composed of substances or combinations of substances with good shock resistance that will temporarily slow the conductive and radiative heat input to the capsule structure and its cargo.

[0078] A typical slab strip might be 10" thick, 30" wide and 360" long with a weight of roughly 15 Tons and is exposed to temperatures up to about 2300 °F for times of, say, 3 hours, hence 6-8 heats per day. Also taking advantage of pre-processing opportunities when the furnace is being held at 1700-1750 °F during waiting time suggests pre-processing of perhaps 10 to 20
tons per day of capsules with mill scale cargoes could be carried out concurrently with slab reheating without significantly affecting the primary mission of the furnace or its heat-balance. Indeed, because of possible combustion of excess carbon in the cargoes and perhaps some shielding against radiative losses to walls, the heat balance could be benefited. Assuming highly reduced Mill Scale cargo is roughly comparable to HBI as an iron source suggests a gross annual production worth about $1 million could be achieved by suitably outfitting one Hot Strip Reheat Furnace. Another evident area of applicability is in feeding reduced (hot or cold) iron into Cupola Furnaces used in the casting industry.

[0079] Nor are the innovations taught herein restricted to the ferrous metal sector alone. Other metals and alloys can benefit from similar pre-processing in capsules as well as can non-metallic substances. The methods can also assist in controlling and making more economical the harvesting volatilized substances generated during processing, such as zinc. For example, in the following section are disclosed advantageous ways of keeping vented vapors and gases originating within a capsule under-going thermal pre-processing largely separate from off-gases produced by combustion-driven energy sources. This, in turn, means that potentially valuable (or hazardous) volatiles originating within the capsules will be much more concentrated and hence easier and more economical to control than if they were mixed with large volumes of hot combustion off-gases.

**Furnace and Capsule Considerations**

**Multi-component Wall Material Capsule Structures**

[0080] **Figure 14a-b** schematically represents a compound structural material 400 out of which capsule components can be fabricated when conditions require. **Figures 14a-b** are a representation of the concept in cross-sectional view through the wall itself. The refractory layers 402 can have high hot strength and other desirable properties but may have to be relatively thick in order to achieve these advantages. However, such thick sections may then impede fast and efficient heat flow into the capsule cargo because they may have a relatively low thermal conductivity refractory. By mechanically supporting a high thermal conductivity layer 404 (but which might sag or creep excessively under repeated loads and thermal cycles, e.g. a moly sheet) with one (or as shown two) refractory layers that have multiple apertures (of any appropriate shape, cross-section, size and array spacing) and allowing thermal energy to impinge on the high conductivity layer 404 through the array openings, one can achieve improved overall performance and robustness of the capsules. In one of many possible embodiments the schematic in Figures 14a-b show thin disks of material, e.g molybdenum, supported by partially surrounding thick strong refractory. The surface regions of the disks (this
shape is merely an illustrative example of the principles being taught) can also be covered by thin protective refractory 406 or other substances to protect the underlying high conductivity material from deleterious effects of the interior and/or exterior environment of the assembled capsule. The differential thermal expansion between the materials is accommodated by distortion of the trapped disks. The trapping can be relatively loose prior to reaching temperatures at which gas escape begins to become significant. The design can also feature long escape paths combined with thermal expansion accommodation.

Segregation of Off gases and Vapors

Figures 15a-d disclose novel features whereby capsules, such as capsule 502, and the processing furnace 500 are equipped with structures that facilitate the segregation of gases and vapors 23 exiting the capsules from any other gases and/or particulates associated with processing. The latter can include sweep gases 510 used to maintain desired atmospheres outside the capsules and/or gas phase or particles generated from the fuels used to heat the furnace. The former may include substances with high vapor pressures at pre-processing temperatures. One such example, among many, would be zinc vapor. In this case, the zinc vapors would not be diluted by the combustion products of the heating source making recovery of the more highly concentrated metallic zinc as a valuable by-product significantly simpler and more economical. Other capsules discussed herein can be substituted for capsule 502.

In Figure 15a, a furnace is shown schematically in which the capsules 502 have off-gas venting port structures 504 through which internally generated gases and/or vapors can exit the capsules and remain segregated from the main furnace atmosphere. The port structures are designed to "mate" with collection channels 506 in the furnace as shown schematically in Figures 15b and 15c. The mating need not be gas tight. A modest negative pressure, venture effects, or air-curtain techniques and the like can be used to minimize escape of the capsule off-gases and vapors into the main furnace volume. The mating ports can be designed to merely be close-fit to openings in the furnace collection channel 506 at known locations along its length, can intrude into the collection channel 506 which is curtailed elsewhere or can be otherwise restricted. As shown in Figure 15d, the venting structures 504 and/or 506 can include any or all of the features already discussed in this disclosure such as thermally activated vents seals and the capsule itself can include any or all features described earlier such as labyrinthine paths to the vent ports etc. A pusher 508 can be used to push trays 310 containing capsules 502 through heater 500. A preheat section 512 and/or cool-down section 514 can be provided.

Production of Powdered Substances

Processing in capsules offers an ability to thermally facilitate controlled reactions
between intimately mixed small particles of various types while avoiding many handling and dispersal issues encountered with such materials. Furthermore capsule processing offers opportunities to use starting materials not traditionally employed for such purposes as the manufacture of particles for use in powder metallurgy. For example, iron powders powder metallurgy are usually prepared by various methods involving creation of fine particles from significantly large masses elemental iron via atomization of molten iron, centrifugal disintegration of arc-melted iron rod electrodes, plasma processing or other comparatively costly procedures. Here is disclosed a process that does not begin with a large mass having the desired chemical composition or element (in this illustrative example iron) followed by some form of disintegration into powder. The new process starts with sand-like mill scale which is a very friable and brittle material derived from the oxidation of refined from steels and irons. Mill scales contain very low levels of gangue and tramp elements etc. The starting mean particle size in the scale can be substantially reduced by low energy means such as compression or grinding etc. The resulting small Fe oxide particles are then mixed with appropriate additives (usually also in small particle form) and including finely divided carbon. The prepared cargo is then loaded into capsules (preferably re-useable) and subjected to a heating profile that results in the reduction of the iron oxide into iron. Capsule dimensions and time temperature profiles can be chosen to insure good uniformity of heating throughout the mixed mass of scale and additives.

Other particulate additives in the cargo can include such substances as copper (particles of which can attach themselves to the iron-containing powders during the subsequent thermal treatment) or so-called "partial-alloy" particles as used in the powder metallurgy art to improve the resulting powder metal manufactured part as a cargo in a suitable capsule. Special requirements such as the late release of lower melting and vaporization of materials that can diffuse through the heated and pre-reduced mass of powder can be achieved by placing reservoirs of such substances at the "core" of the main mass of cargo. This "core" payload can be partially thermally isolated for some time using low conductivity thermal insulator containment formed of such as glass or ceramic foams, fabrics etc. Longer exposure at lower heat levels then releases the core cargo to permeate the outer (and now reduced) iron powder.

The concepts described herein are not limited to the Fe oxide to reduced Fe process. Any readily size-reduced substance can be used which, in a thermally driven process, can be transformed into a desirable material for forming shaped products using the wide gamut of modern manufacturing technologies requiring powder as a starting form can benefit from the teachings herein. Additionally, the various forms of capsules can be utilized, as appropriate, in each of the various systems described herein.
What is claimed is:

1. A process for reducing mill scale, the process comprising:
   providing an ingredient enclosure that contains mill scale and a reducing agent;
   applying heat to the container until at least 50% of the mill scale is reduced to metallic iron.

2. A metallurgical process comprising:
   providing an ingredient enclosure having a plurality of vents;
   placing mill scale in the ingredient enclosure, wherein the mill scale contains a ingredients that when heated gives off volatile gases;
   placing a reducing agent in the enclosure;
   heating the enclosure;
   opening the enclosure vents by the application of heat after a period of time sufficient so that the heat has pyrolysis and decomposition of the volatile gases and at least some portion of the mill scale is reduced to metallic iron.

3. A raw material ingredient used in a metallurgical process for making steel; the raw material ingredient comprising an enclosure and mill scale and a reducing agent in the enclosure, wherein the enclosure includes a vent, the vent opening after a period of time of exposure to sufficient heat so that pyrolysis and decomposition of volatile gases occurs.

4. The process of claim 2 further comprising providing a furnace to heat the enclosure and providing furnace vents that are cooperative with the enclosure vents for the venting of any volatile gases from the enclosure.